Günther Seliger *Editor*

Sustainable Manufacturing

Shaping Global Value Creation

CIRP

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Preface

The annual series of Global Conferences on Sustainable Manufacturing (GCSM) sponsored by the International Academy for Production Engineering (CIRP) is committed to excellence in the creation of sustainable products and processes, which conserve energy and natural resources, have minimal negative impact upon the natural environment and society, and adhere to the core principle of sustainability by considering the needs of the present without compromising the ability of future generations to meet their own needs. To promote this noble goal, there is a strong need for greater awareness in education and training, including dissemination of new knowledge on principles and practices of sustainability applied to manufacturing. The series of Global Conferences on Sustainable Manufacturing offers international colleagues opportunity to build effective relationships, expand knowledge, and improve practice globally.

Every year, a country is selected to host the Global Conference on Sustainable Manufacturing, building effective links among the international colleagues, expanding their knowledge, and improving their practice globally. Conferences in this series have previously been held at different countries and locations: At Masdar Institute of Science and Technology, Abu Dhabi University, United Arab Emirates in November 2010, at the Indian Institute of Technology Madras, India in December 2009, at the Pusan National University, Korea in October 2008, at the Rochester Institute of Technology, Rochester, USA in September 2007, at the University of Sao Paulo, Brazil in October 2006, at the Jiao Tong University, Shanghai, China in October 2005, at the Technische Universität Berlin, Germany in September 2004, and in the form of a workshop on Environmentally Benign Manufacturing held in Birmingham, Alabama, USA, in January 2003.

In September 28th – 30th, 2011, St. Petersburg State University of Economics and Finance, and St. Petersburg State Polytechnical University, Russia in cooperation with Vodokanal of St. Petersburg, Russia host the 9th Global Conference on Sustainable Manufacturing under the patronage of Prof. D.Sc. (Phys., Math.) Zhores I. Alferov Vice-President of the Russian Academy of Sciences, Inventor of the heterotransistor and the winner of 2000 Nobel Prize in Physics.

Modern Russia is a strong and rapidly developing state implementing the best of international practices on the fundament of its own rich historical experience. Russian economy aspires for sustainable and innovative advance together with its continental and overseas partners. St. Petersburg being a significant metropolis and business center of Russia welcomes international partners for work and for fruitful exchange of ideas.

Participants from all over the world come together for presenting their research results in sustainable engineering. Contributions are clustered in value creation by sustainable manufacturing, manufacturing processes and equipment, remanufacturing, reuse and recycling, product design for resource efficiency and effectiveness, innovative energy conversion, green supply chain and transportation, adequate environments for entrepreneurial initiative, education for sustainability engineering, and economics for sustainability and development. Tours to industrial companies in the region of St. Petersburg have been arranged to give an impression of the Russian approaches in value creation.

The 9th Global Conference on Sustainable Manufacturing (9GCSM) is geared towards representatives of science and industry from different continents. The conference serves as a forum for international research institutes and industrial companies related to the area of sustainable manufacturing. The conference offers keynote speeches, panel discussions, expert sessions and a poster forum. Discussions and exchange of ideas between the participants are an integral part of the meeting.

This book includes the research papers, which have been accepted at the 9th Global Conference on Sustainable Manufacturing. These contributions are structured in nine chapters covering areas: Value Creation by Sustainable Manufacturing; Manufacturing Processes and Equipment; Remanufacturing, Reuse and Recycling; Product Design for Resource Efficiency and Effectiveness; Innovative Energy Conversion; Green Supply Chain and Transportation; Adequate Environments for Entrepreneurial; Engineering Education for Sustainability; and Economics for Sustainability Development.

My special thanks go to Prof. Dr. Felix V. Karmazinov, Director General Vodokanal of St. Petersburg, Russia and Prof. Alexander Karlik for their support and hospitality in preparation and execution of the conference. In addition, I want to thank Prof. D.Sc. (Econ.) Igor A. Maksimtsev, Rector of St. Petersburg State University of Economics and Finance, Russia; and Prof. D. Sc. (Eng.) Andrey I. Rudskoy, Rector of St. Petersburg State Polytechnical University, Russia for their continuous support in organizing the conference. Finally, I thank MSc. BEng. Sadiq AbdElall, M.LL.P Julia Melikova, Dr. Irina Vostrikova, and Prof. Olga Borozdina for their never-ending patience and persistence in letting the conference become reality.

September 27th 2011

Günther Seliger, Technische Universität Berlin, Berlin, Germany

Contents

Chapter 1:

Value Creation by Sustainable Manufacturing

1.1 Sustainable Manufacturing for Global Value Creation

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Abstract
Sustainability in the three dimensions of economic competitiveness in market environment, of ecological resource efficiency and effectiveness and of social development in education, health and wealth for humans in the global village has become a guideline for mankind`s future existence on earth. An architecture of sustainable manufacturing for global value creation is specified in challenges and approaches to cope with them. Activities at Technische Universität Berlin with respect to a major integrated interdisciplinary research project are presented.

Keywords:
Collaboration, Competition, Strategies, Production equipment

1 Introduction

Engineering is exploiting potentials for useful applications. Manufacturing, as a specific discipline in engineering, starts from human thinking and imagination, from knowledge about natural scientific phenomena, from physical materials and shapes value creation via processes in management and technology, objectified in tangible and intangible products, in physical artefacts and services. This research intends to demonstrate how sustainable manufacturing embedded in global value creation proves to be superior to traditional paradigms of management and technology.

Sustainability has become an urgent requirement and challenge for mankind's survival on earth and for their future development, considering the limits of resources and growth and the unequal distribution of wealth. Sustainability here is interpreted in ecological, economic and social dimensions. Ecologically, non-renewable resources must not be disposed anymore but regained in product and material cycles. Chances of substituting them by renewables must be exploited, but only to the extent that renewables can be regained. Economically, wealth can be achieved in the different areas of human living without increasing physical resource consumption by selling functionality rather than tangible products. In the social dimension, a global village with less than one billion out of currently close to seven billion people consuming more than four fifths of global resources is hardly acceptable for living peacefully together. Teaching and learning for a global culture, wealth and health become vital tasks for the global human community. If the lifestyles of upcoming and also developed communities will be shaped in the future by the existing, actually predominating technologies, then the resource consumption will exceed every accountable ecological, economic and social bound.

2 Sustainability Engineering

Sustainable engineering represents a new scientific approach to cope with this challenge. The dynamics of global competition and cooperation shall be utilized for lending wings to processes of innovation and mediation towards the reasonably demanded sustainability on our globe. A special focus lies on condensing engineering to sustainable manufacturing, thus specifically addressing artefact generation for shaping human living.

The current research combines the breadth of systemic reference in pathways for sustainable technology, their assessment, valuation and mathematical modelling with exemplary in depth realization of manufacturing processes and equipment, virtual systems for product development and organization of sustainable value creation in product and material cycles on different levels of aggregation. These two perspectives are merged for methods and tools creating social capital enabling humans for learning and teaching help for self-help (Fig. 1.1.1).

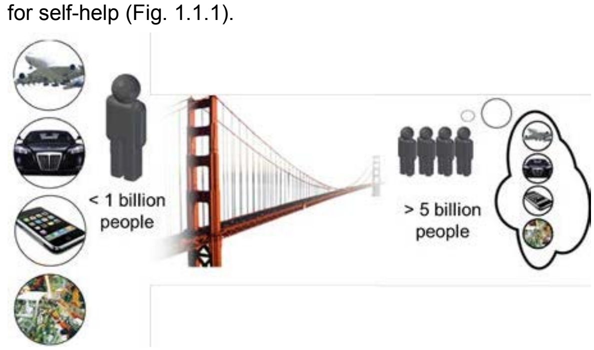

Fig. 1.1.1 From saturated markets bridging the gap to hungry markets

Although there are differences in the single items of the research area, the overall focus is on identifying potentials in Germany and Europe for initiatives in driving the global village to awareness and activity for sustainable development. Contributions from emerging communities shall be identified for exchange in a cooperative environment with continuous innovation empowered by fair trade and competition. Further cases may specify the implementation of global sustainable value creation in mutual exchange of knowledge between partners from different communities. As knowledge is the only resource not being reduced but expanding by utilization a strong leverage can be expected from the manifold contents of knowledge management. Consequently services on information infrastructure or on public awareness for mutual exchange of ideas with societal

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stakeholders, and an integrated research training group for doctoral students from different continents becoming ambassadors of sustainable manufacturing in their native countries and universities are possible.

Value creation dependent on the perspective of consideration is represented by modules and networks respectively. Modules in a bottom up perspective constitute networks by dynamics of cooperation and competition within the different levels of aggregation from manufacturing cells via lines, factories, enterprises, local, regional, global consortia in value creation for tangible and intangible products. On the other hand in a top down perspective networks integrate modules horizontally and vertically again on different levels of aggregation. E.g. original equipment manufacturers look for innovative suppliers of physical components or services thus improving their competitiveness. Or communities look for educational partners to improve their social capital and thus their level of wealth. Modules consist of humans, processes, equipment, organization and product as so called factors of value creation. They can be created or adapted in consecutive usage phases within product life cycles along setting up or modifying these factors. Modules are to be modelled and valuated on different levels of aggregation e.g. from a single workplace for component manufacturing to regional value adding in production equipment for mobility or energy as areas of human living. Valuation of modules in the sustainability perspective is no longer limited to economical but also includes ecological and social criteria.

3 Complex Challenge of Sustainability

Mankind is confronted with the complex challenge of sustainability. The concept of a sustainable development is mentioned in the Brundtland-Report in 1987: Making development sustainable means that the present generation meets its needs without compromising the ability of future generations to meet their needs [1]. In 1998 the Enquete Commission of the German Parliament expressed this explanation in its three-pillar-system of sustainability as a conception of a permanent sustainable development of the economic, ecologic and social dimension of human being [2]. In a sustainability study of the Boston Consulting Group, 92% of the companies surveyed already stated sustainability as a part of their corporate strategy [3].

Mankind is increasingly aware of how dependent they are on natural regeneration and on conscious saving non-renewable resources. At the beginning of the 1970s, a report by the Club of Rome "The Limits of Growth" [4] caused international attention on effectiveness and efficiency of resource utilization.

Today sinister scenarios like an ecological collapse caused by proceeding population growth, exhausted resources and risks of pollution are controversially discussed. Unevenly distributed wealth and violent conflicts are global challenges to be addressed. Current concrete actions of the globalised mankind to manage these challenges are however still insufficient. They demand an integrated understanding of these factors as a part of an interaction system [5].

According to estimations the temperature will raise 1–6°C in this century [6, 7]. Effects of this phenomenon are the already melting polar caps, the thawing of the permafrost soils and the acidification of seawater. Consequences of this development could prove to be disastrous [8]. In 2005, 250 million people were affected by weather catastrophes with estimated costs of more than 200 billion US dollar [9].

Mankind may face projected costs of about 5.5 trillion euros if nothing is undertaken to combat progressing climate change [Ste-07]. The poorest regions of Africa, Asia and Latin America will be affected the hardest. They will suffer under desertification, changing precipitation patterns, declining agricultural production and shortage of water [7].

The Human Development Index measures (HDI) the living standard of people in terms of health, freedom, education and other aspects of life not measured by gross GDP [10]. By contrasting the consumption of resources on different levels of development with the quality of life, measured in terms of the HDI, a worldwide increase in wealth based on current technologies with their consumption of resources would be fatal (see Fig. 1.1.2).

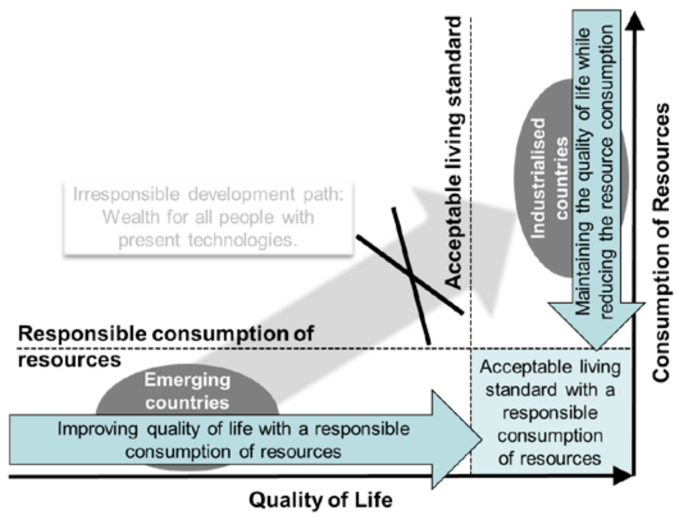

Fig. 1.1.2 Required directions of responsible development

The present consumption of natural resources exceeds the current regeneration capacity of the earth by more than 25 percent. If this development persists a second earth would be needed to meet the resource demands in 2050 [11]. The increasing scarcity of non-renewable resources already causes drastic price increases. In the future we need to adjust our production technologies to a closed loop economy. Not only for Germany waste represents the only long-term source of materials [12]. Thus it is imperative to rapidly adjust our lifestyle as well as respective technologies to the availability of resources. Further challenges are a fair distribution and the access to resources, wealth, rights, duties, political influence.

Today about one half of the world population is forced to live without telephone and electricity and with less than two US dollars per day. While 140 million children must starve one fifth of mankind owns four fifths of global prosperity. Even in the industrialised countries of the OECD inequalities in terms of payment between women and men can be observed. Climate change, uneven distributed wealth and damages caused by consumption of resources are often the direct, but also indirect reason for social unrest and violent conflicts. Beside the unknown and hidden violence e.g. by discrimination, presently there are 25 wars, more than 16 violent conflicts as well as terrorism all over the world [7].

In case of improving people's ability to meet their primary needs as food, clothes, living and mobility by own competence and initiative while complying with sustainability standards, good opportunities to essentially balance the uneven global distribution of wealth can be exploited. Production technologies in the broadest sense determine the relation between benefit and the required use of resources. For this purpose new production processes and products, a decreasing intensity of resource consumption and a closed loop economy are required [13]. In 1995, von Weizsäcker and Lovins already outlined ways to double wealth with half of the consumption of natural resources [14].

Thus, there are many possibilities to tremendously reduce the consumption of resources in the first world without decrease of quality of life and also to depart from the well-trodden paths of our technological habits of thought. With his micro credit program the Nobel Peace Prize winner Muhammad Yunus has demonstrated how wealth can be sustainably increased due to entrepreneurship in connection with technology. Micro credit programs have financed projects for solar home systems to substitute diesel generators and less efficient electrical appliances by photovoltaic solar collectors in connection with batteries, energy saving lamps and television sets [15]. They also support initiative and make learning easier via telecommunication [16].

There exist big opportunities even for the poorest of the poor, if potentials of human initiative are used in a smart way. There are projects on mini-factories for the Amazonas region that enable the inhabitants of this region to create added value and to increase their wealth without destroying the rainforest [17]. Relatively large strides to sustainable development in structurally fragile regions can be financed by relatively few financial resources of the industrialised world. This results in great opportunities to manage the global challenges of a sustainable development. Therefore people all over the world need to learn about how wealth for anyone can be realized with resource-efficient technologies. Fair processes in research and education, value creation and exchange of goods and services have to be established.

In the long-term perspective a methodical frame how to set up more value creation with less resource consumption, "substituting something by nothing" [18], to be achieved by innovative management and technology in manufacturing shall be specified.

Sustainable manufacturing embedded in global value creation shall be proved to be superior to traditional productivity paradigms. Value creation is interpreted not only in economical but also in ecological and social dimension [19]. The vision of the Blue Economy as specified in Gunter Pauli's report to the Club of Rome [20] opens a kernel perspective of entrepreneurial initiative driving technological innovation thus creating millions of jobs inspired by imagination and creativity. The dramatic increase in global resource consumption exceeding ecological limits has expanded traditional manufacturing research into the reference frame of sustainability. Consequently increasing the use productivity of resources and the equity of wealth distribution among mankind as a global community have been identified as challenges for engineering to cope with by sustainability in manufacturing [13].

The guiding question is how the dynamics of competition and cooperation in globalized markets can be utilized by innovative technology to cope with the challenge of rationally required mankind`s sustainable development on earth.

3.1 Approach to Cope with the Challenge

Figure 1.1.3 describes an approach how to cope with the challenge. Value creation factors shape value creation modules to be evaluated in ecological, economical and social sustainability dimensions. The dynamics of cooperation and competition drive for horizontally or vertically integrating modules to networks. Producing enterprises are confronted with an increasing complexity and a growing number of products and variants.

In order to survive in global competition, companies focus more and more on their core competencies. They increasingly divide the value creation among numerous enterprises and organize themselves in global value creation networks [21]. The management challenge arises how to keep the balance between breadth of knowledge about an increasing manifold of potentials in different technological disciplines without frittering away and the economically required concentration on core competencies without losing innovation chances by lack of understanding. How to differentiate between conditions to be accepted and parameters of value creation to be shaped by own activity? How to negotiate about own and partners` activities in value creating networks? And how to exploit the dynamics of cooperation and competition as a tool for sustainable value creation? The Blue Economy Paradigm [20] specifies the risks of competence losses for sustainable development caused by division of labour and concentrating on core competencies. Also the chances of overcoming the risks by modern means of communication, by tools for learning and teaching and by conveying entrepreneurial spirit are addressed. Areas of human living are interpreted not only in the sense of tangible and intangible artefacts shaping human life but also in the sense of surrounding fields of useful technology coming into existence and consequences of applications in respective fields [22]. The research intends to instantiate this general pattern of areas of human living in the concrete cases of energy, production and mobility including their interrelations. How can sustainable value creation be implemented in fair relations of exchange between developing, emerging and industrialized communities in the global village?

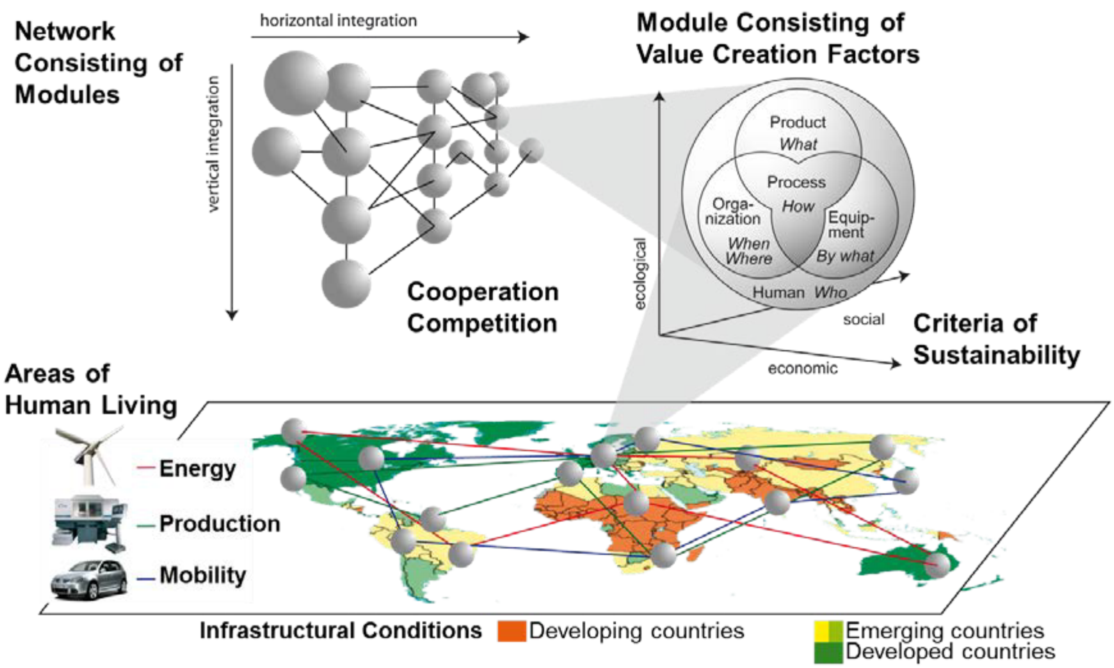

Fig. 1.1.3 Approach to cope with the challenge

3.2 Ability of the Local Scientific Environment

The TU Berlin is a research university with a predominantly engineering science approach that emphasises applied sciences. It has developed a pioneering institutional strategy in order to meet future social requirements and technical issues. Based on this concept the profile of teaching and research activities at the TU Berlin shall be developed and consolidated through an orientation towards the identified future areas of research and education. Besides basic research the TU Berlin will focus on the interdisciplinary fields of energy, design of living spaces, health and food, information and communication, mobility and traffic and water as well as knowledge management. These fields are set up across all schools to meet the required interdisciplinary problem solving competence. The composition of future research and education as well as the strengthening of interdisciplinary cooperation at the TU Berlin will create suitable conditions for research activities in the framework of sustainability. To promote the development of innovative technological solutions, the further research shall closely be related to the research and teaching modules of the TU Berlin and its researchers promote development of technological solutions.

The school V for “Mechanical Engineering and Transport Systems” acts in accordance with the principle of “humans in the centre of technical systems”. This idea represents the specific direction of the school’s focus on mechanical engineering systems. Focus of chairs within this school in products varies from stationary machines, medical equipment, automotive, railway, ships, air- and spacecrafts. Different engineering science skills, e.g. mechanics, acoustics, design, micro system techniques or manufacturing technology are necessary to create these technical objects and systems. The school also considers other engineering sciences as well as natural, social sciences and economics, for its educational, scientific and industrial activities. This principle also enforces the school’s claim to meet the societal needs already in the early product development and manufacturing planning phases. This, as well as consideration of aspects like ecological efficiency, affects the users, operators, suppliers and developers of useful systems.

Project oriented teaching plays a key role here. Many new and future oriented courses have been developed in the TU Berlin as a result of the Bologna process. In order to keep the high education standard for bachelor and master programs a comprehensive quality control has been established. Numerous internal university programs of the TU Berlin support the reduction of study duration and the improvement of student supervision. Among other things, the range of study programmes for doctoral students at the TU Berlin shall be extended. The international orientation further supports the exchange of guest researchers who will be actively involved in courses at the guest universities. More opportunities for international and project oriented courses will therefore be established to support intercultural competences.

In the context of these recent reforms the paradigm shift from conventional frontal teaching to more project oriented teaching methods with consideration of sustainability aspects is essential. Students already obtain experience in scientific working methods during their study. A close collaboration between supervising research engineers and students is established by industry oriented projects.

Due to this knowledge transfer, students are enabled to enhance their knowledge and to access research results. In this context the project oriented courses mentioned in the next chapter, e.g. “Global Engineering Teams”, “Global Product Development” as well as “Courses in Assembly Technology and Factory Management” (MF, German: Montagetechnik und Fabrikbetrieb) have already proven to be successful.

The course “Global Engineering Teams” has been offered at the chair for MF (Seliger) since 2004. In this course, students from industrialised and emerging countries work together in international working groups (e.g. with students from the Stellenbosch University South Africa, the University of Botswana, the University of Chile as well as the SOSIESC Joinville, the Federal University of Rio Grande do Norte and the University of Sao Paolo Campos Sao Carlos in Brazil) to prepare solutions for industrial partners and obtain competence in independent problem solving and intercultural communication abilities. Resulting from this, acting and decision-making competences follow [23].

Between 2002 and 2007 students could also join the course “Global Product Development”. With these courses the chair for MF aims to systematically transfer methodical and social competences with the application of technical expert knowledge in practical projects simultaneously. Therefore the TU Berlin cooperates with the University of Michigan, Ann Arbor, USA and the Seoul National University, South Korea.

The English master course “Global Production Engineering” (GPE) with its specialisations in manufacturing and solar technology is coordinated. The diffusion of knowledge among scientists, teachers, students and pupils shall be further improved. Due to an increase in the teaching and learning productivity the transfer of sustainability related knowledge in the area of manufacturing technologies shall be substantially advanced. Therefore physical and virtual so called instruments suitable for teaching courses need to be developed [24].

In addition to educational efforts, scientific research is also becoming a successful proponent of technology specialization in the local scientific environment and actively participates in the implementation of scientific, economic and innovation policies which can be shown by the following examples of current research projects and events at the TU Berlin. The collective goal of the TU Berlin is to strengthen the role of research and development outcomes in value creation.

The Collaborative Research Centre/Transregio (TR) 29 “Industrial Product-Service Systems - Dynamic Interdependency of Product and Service in Production Area” (Ruhr-University Bochum and Technische Universität Berlin, since 2006) aims to find potentials, boundaries and deployment options of an extended product. It also aims to examine ways to reach the integration of products and services in the form of a customer oriented total solution; the hybrid performance bundle. New business models are researched exemplarily for micro production, which can be classified as functionality, availability or event driven.

The goal of the CRC 281 “Disassembly factories for the recovery of resources in production material cycles” (Technische Universität Berlin, 1995–2006) was the development of new methods and tools for disassembly, the provision of integrated, computer aided support for its design and remanufacturing planning as well as an improved logistical integration as a basis for economical disassembly.

The project “Integration of Sustainability Innovations in Catching-Up Processes” (ISI-CUP, Tech-nische Universität Berlin, since 2006–2010) dealt with sustainability innovations and the process of closing the gap between developing and industrialised nations. The project examined the design potentials of sustainability innovations both conceptually and empirically in order to contribute suggestions for courses of action in technology and environmental policies as well as for the design of reglementing instruments.

In October 2010 also the “Produktionstechnisches Kolloquium” (PTK, English: Production Technology Colloquium)—sustainability in production economies—was inspired by the research aims of the TU Berlin. In the “Produktionstechnisches Zentrum Berlin” scientific and industrial partners discussed ways to survive in globalised markets with consideration of sustainability in engineering and manufacturing. Development paths for innovative resource management, quality and cost leadership strengthen the sustainable value creation of the industrial sector. Thus specific management of intellectual capital, the improvement of product and process development in value creation networks and the organisation of competitive collaboration in networks have been detected as key factors for a sustainable engineering.

4 Conclusion

In their different disciplinary directions of tools and application, specifying generic guidelines of management and design, exploiting potentials of sciences for developing materials, processes, products and services, information and communication technology, a huge space for practical implementations is revealed. Mathematical calculus further developed for multi-criteria valuation and complex influence networking helps for orientation in the wide area of paths to sustainable solutions. Economical science contributes by micro- and macro-economic modelling and game theoretically based modelling of strategic interactions and incentives for sustainable activity. The orientation in the different ecological, economic and social criteria for technological innovation is fundamentally provided by environmental engineering. The collaboration of the four disciplinary science clusters of manufacturing and environmental engineering, economics and mathematics shall considerably be inspired by the respective global science networks and close relations to practical implementation in science and industry in different regions of the globe.

5 Acknowledgments

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1.2 Modelling and Tactics for Sustainable Manufacturing: an Improvement Methodology

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Abstract
Sustainable manufacturing practices demonstrated by companies are a key ingredient to increasing business performance and competitiveness. Whilst reported practices are good examples of what has been achieved, they are often company specific and difficult for others to reproduce since they provide few, if any, details on how improvements were achieved. Sustainable manufacturing strategies offer insight to the overall approach taken by companies but they can lack practical support for implementation. This paper examines the gap between strategic direction and practices to extract the mechanisms behind the practices and formulate sustainable manufacturing tactics (which provide information on how specific improvements can be implemented). The research is based on extensive collection and analysis of available case studies in published literature and interaction with industry. The combined use of resource flow (material, energy and waste) modelling and the tactics can support manufacturers in their journey towards sustainability by providing generic solutions on how to adapt their operations. An improvement methodology is developed by combining the manufacturing ecosystem model and tactics to guide manufacturers in a structured and systematic way to identify improvement opportunities. The paper explores the design challenge of developing such an improvement methodology to assist users in identifying which tactics might apply in their specific context.

Keywords:
Improvement methodology, Modelling, Sustainable manufacturing practices, Resource productivity, Tactic

1 Introduction

Manufacturing has traditionally been associated with undesirable environmental side effects [1] as manufacturers are responsible for the transformation of resource inputs into useful outputs (i.e. products with economic value) with limits on efficiency due to the laws of thermodynamics [2]. Over the last four decades, the environmental burden linked to industrial activities has become an increasingly important global issue [3–5] and a great challenge for society [6, 7].

Awareness about the impact of human activities on the global environment has promoted the implementation of environmental degradation prevention practices. These practices can be found under various labels and fields such as Industrial Ecology [8], Green Supply-Chain Management [9], Product Life-Cycle Management [10], Corporate Environmental Management [11], Design for Environment [12], Product-Service Systems [13], and many others [14, 15]. There are numerous factors playing a significant role in defining the requirements for a next-generation manufacturing paradigm, such as increased product and systems complexity, environmental concerns, lack of knowledge integration, technology advances in modelling and simulation techniques [16].

More recently, the concept of a Sustainable Manufacturing (SM) has been developed under various labels (e.g. Environmentally Conscious Manufacturing [17, 18] or Green Manufacturing [19]) as a sub-concept of Pollution Prevention (P2) [20]. The main objective of SM is to lower the environmental impact linked to manufacturing. Environmental activities have long been associated with a negative impact on business performance but this assumption has been proved wrong by many researchers [19, 21]. An illustration of both the economic and environmental benefits of SM is apparent in the cost savings due to energy reduction and waste minimisation. Research is rapidly developing and there are no established definitions or boundaries for studying sustainability performance of manufacturing systems. Throughout literature the flows of resources in the form of material, energy and associated wastes (MEW) reoccur [22]. The MEW flows must be interpreted in the widest forms to include not just primary material conversion but others inputs and wastes such as water, consumables and packaging.

SM can be thought of as a manufacturing strategy that integrates environmental and social considerations in addition to the technological and economic ones. The work presented in this paper focuses on the environmental aspects and emphasises on-site solutions rather than ‘product life cycle’ or ‘supply chain’. In particular the work focuses on generic tactics to improve the MEW flows within a manufacturing system and proposes an approach by which it can be examined. The tactics are created by extracting the mechanism of the SM practices and formulated so that they can be widely applied to multiple technologies and resources. It means that tactics must be generic to capture the principles of improvement, but sufficiently detailed to be adapted to the specificity of the system studied.

Using a manufacturing ecosystem model, modelling techniques can capture the MEW flows through a manufacturing system. It takes the user through the improvement methodology to identify improvement opportunities in resource productivity using the generic tactics to move towards sustainable manufacturing.

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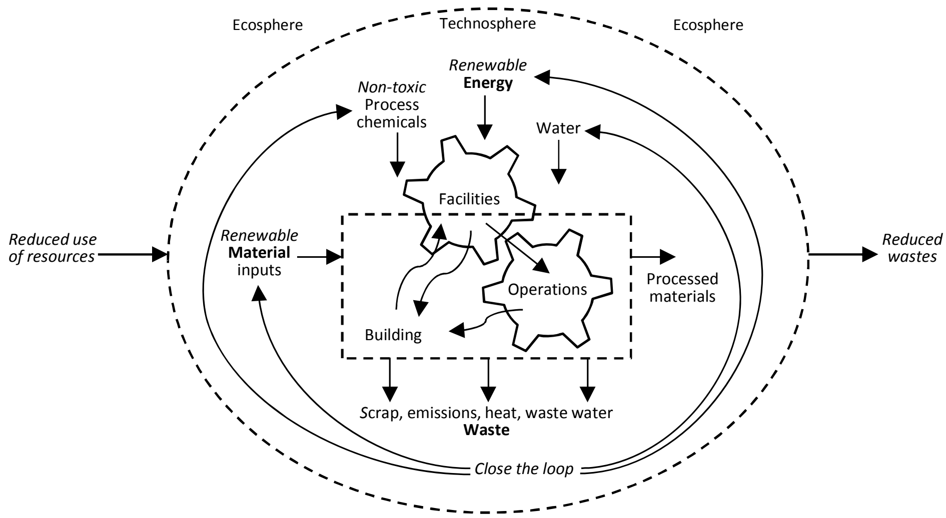

Fig. 1.2.1 Manufacturing (eco)system model with the sub-systems and resource flows (from [24])

2 Research Methods

This research is part of a larger project developing a modelling and simulation tool [23, 24]. It aims to provide support for manufacturers to identify improvement opportunities in their MEW resource flow using generic tactics, an improvement methodology and modelling of MEW flows. It seeks to address the research questions "How can generic tactics support the identification of improvement opportunities in a systematic way?"

This research was conducted in two main phases: (1) theory building using Sustainable Manufacturing strategies and case study collection from the literature and (2) theory testing through the THERM project industrial partners.

In the first phase, case studies of sustainable practice in industry were collected from peer-reviewed and trade literature. Although the case collection showed there are many cases of sustainable manufacturing practices, there are few detailed reports on how to improve the sustainability performance as opposed to the benefits of implementing improvement measures [25]. The cases collected and analysed were classified to understand the breadth of practices in industry and understand how other manufacturers could implement similar improvements in their own factories. Practices were examined under the lens of the conceptual model of manufacturing ecosystem shown in Fig. 1.2.1 by focusing on the MEW flows linking the three system components (manufacturing operations, facilities and buildings). The generic tactics were then formulated to extract of mechanism of change and support the wide dissemination of these practices in the manufacturing industry [26]. A library of tactics was created to make them available in a format readily exploitable via the modelling tool being developed in THERM. The collection of practice is currently being extended to widen the range of best practices available in the database [25].

The second phase consisted of prototype applications of the manufacturing ecosystem model. The application includes testing of the library structure (classification based on how the tactics affect the MEW flows through the manufacturing system) and development of the associated improvement methodology for accessing tactics using process data.

The contribution to knowledge is the creation of a structured library of tactics that identifies the mechanism of improvements and allows generalisation of Sustainable Manufacturing practices. The contribution to practice is making tactics available to support manufacturers identifying improvement opportunities in a structured and systematic way.

3 Manufacturing System Modelling

The conceptual manufacturing ecosystem model [27] shown in Fig. 1.2.1 is based on the Industrial Ecology model type II [28]: the system's input (overall resource intake) and output (waste and pollutant emissions, product output being kept in the technosphere) are limited, and the resource flow within the system has a certain degree of cyclicity. It means that the sum of all flows within the system is higher than the total inputs and outputs to the system, therefore reducing the dependency of the system on external resources and sinks and its environmental impact.

The model shows the three main components of the manufacturing system: manufacturing operations, supporting facilities and surrounding buildings. All three components are linked by resource (material, energy and waste) flows. Various strategies (or themes or principles) for sustainable manufacturing were collected from literature [29–31] and can be summarised as follow:

1. Avoid resource usage and improve conversion efficiency: use and waste less by dramatically increasing the productivity of natural resources (material and energy);
2. Close the loop of resource flow: shift to biologically inspired production models such as reduction of unwanted outputs and conversion of outputs to inputs (including waste energy): recycling and all its variants;
3. Change supply or replace technology: reinvest in natural capital through substitution of input materials: non-toxic for toxic, renewable for non-renewable;
4. Shift paradigm: move to solution-based business models including changed structures of ownership and production: product service systems, supply chain structure.

This ecosystem model is used to define the direction of change needed and objectives to move towards sustainability. Boundaries are drawn following the factory gate. The work focuses on factory-wide improvements to retain the value of resource and avoid environmental degradation. The four strategies mentioned above are usually applied at supply-chain level beyond the control of a single company. This work takes a narrower view and applies the three first strategies at factory level.

The elements modelled are the buildings, the technology components (equipment and processes) placed in and near the buildings, and the resource flows linking all elements of the model (inputs: energy and material including water and chemical; outputs: product and wastes including physical waste accumulating in bins as well as energy waste mostly in the form of heat). All elements of the system are characterised by process data. Table 1.2.1 shows the list of process data and the corresponding real-world information collected by the user (right-hand column).

Some of the process data and profiles can be defined as constraints to determine the minimum requirements (inputs quantity and quality) for the manufacturing processes to achieve their function correctly (product output quantity and quality): mainly production schedule and set points. The other process data and profiles can be functions of these constraints or metered data. Other variables must be defined to characterise the technology elements (equipment and processes, or the transformation processes): capacity or equipment rating, running load (including the minimum/base load and maximum/peak load), the performance/efficiency curve (ratio output/input as function of running load), etc. Other optional information can be added to increase the quality of the analysis, such as equipment age (depreciation time), operating cost, etc.

4 Sustainable Manufacturing Tactics

Sustainable manufacturing practices were collected and analysed to formulate generic tactics. The aim was to abstract the principles/mechanism of the practices in order to apply them to other types of technology and resource. In turn this supports the generalisation of practices.

Sustainable manufacturing practices were collected from two types of sources:

- Research papers with principles and approaches for sustainable manufacturing, sometimes based on a survey of industrial practices, or on analysis of current practices. These sources provided a wide range of practices but few details on the application of the practice or on the technical content of the activities.
- Internet website on best practices, examples from companies. These sources provided more details on the activities and the results from the implementation, but few details on how the improvements where identified or what were the difficulties encountered.

These two types of source gave different information about the activities: some cases provided full reports of initial investment cost, operational and maintenance costs, and annual savings in terms of water, material, energy and cost, while other cases gave insufficient or no information at all on benefits of implementation. Therefore, it is difficult to draw conclusion on trends in the scale of change, the amount of efforts required or the magnitude of the savings. Moreover, all collected cases reported success stories with no mention of challenges, difficulties or barriers to implementation, and no reported case of failure.

Three categorisations were used to analyse the practices and to compare the mechanism for identifying sustainable manufacturing improvement opportunities. The structure chosen for the library of SM tactics has been designed in

Table 1.2.1 List of process data for modelling and their sources

Building model: drawing the infrastructure	
Building geometry / thermal zones	Factory layout (technical drawings)
Construction data	Building construction materials
HVAC systems	Building service system documentation
Qualitative process model: mapping manufacturing operations & facilities	
Technology (process/equipment) geometry	Pictures of equipment/processes (optional)
Technology layout	Factory layout (technical drawings)
Technology attributes/characteristics	Process/equipment specifications
Resource layout	Energy and material path/network layout
Resource characteristics	Energy and material characteristics
List of processes (qualitative product flow)	Manufacturing routings
Quantitative process model: modelling manufacturing operations & facilities	
Production profile (factory-wide),equipment/process operations profile (local), product profile (quantitative product flow)	Production schedules
Technology set point/demand profiles	Equipment and process set points, demand, running load
Technology control profiles	Controls (controllers, valves, etc.)
Resource usage profiles	Facility equipment & manuf. process cons. (metered data)
Resource supply profiles	Facility equipment generation (metered data)
Waste profiles	Facility equipment & manuf. process waste generation
Total inputs to the system (check model completeness)	Total inputs to the system (energy/water bills and BOM)
Energy and mass balance (for missing data)	Thermodynamics for resource transformation process
Link technology to HVAC system	Thermal transfer to space/building
Link technology to bins (waste profile, energy and mass balance)	Waste data (if available)
Optimised process model: improvements implementation	
Controller functions (for simulation purpose)	Control strategy
Bins/recycling repositories	Recover, sort, collect, reuse, recycle
Modification to technology (process/equipment)	Equipment/process management or change
Modification to resource flow	Resource management or change

order to ease the implementation of the library directly into the simulation software (THERM tool). The objective is to identify Sustainable Manufacturing improvement opportunities in a structured and systematic way.

The first categorisation is based on the type of modification (organisational or operational **Manage**; technical or physical **Change**) and the elements targeted (focus on **Resource** or **Technology**). Tactics were listed against these four labels in the first categorisation system as shown in Table 1.2.3. The second categorisation distinguishes the nature of the flow affected by the practices (inputs: energy, water, material; or outputs: air emissions, wastewater, solid waste) and allows to filter practices based the flow type and targeted benefits (energy reduction, CO_2 emissions abatement, water conservation, toxicity, "zero waste", etc.). Finally, the third categorisation identifies the functional responsibility to implement the improvements in the factory. Similarly to the second categorisation, it is used to narrow down the search of practices to specific functional areas of the company according to the responsibility of the people involved in the improvement activities.

By attempting to classify all the cases, the type of activities in some cases appeared be out of the scope of this study (off-site activities or changes in the way of thinking/managing the production rather than physical changes in the factory). Therefore some practices were excluded from the final database for formulating generic tactics. Table 1.2.2 summarises the distribution of practices across strategies and the nature of the flow targeted by the improvement activity (note that one practice can fit under multiple labels at once). The tactics were identified by classifying the cases based on their commonalities, the drivers of change and the mechanisms for implementing the practices. As the tactics are generic and cover various technological solutions and MEW flows, the number of tactics formulated was as low as 20 (Table 1.2.3). In other words, it means that a large number of practices can be identified by looking at few variables and using simple rules.

This first categorisation helped to check the completeness of the tactics library. Each generic tactic was then analysed using the manufacturing ecosystem model (Fig. 1.2.1) and energy/waste hierarchy (strategies adapted from [29–31]) to prioritise the tactics by identifying at which stage the tactics would be implemented.

The material waste hierarchy is well-established and is typically represented by a pyramid with disposal at the bottom rising up though the 'R' levels of recovery, recycling, reuse, reduction and finally prevention at the top. Prevention is the preferred option with disposal the least favoured.

Table 1.2.2 Distribution of practices

	1 Manage resource	2 Change resource	3 Manage technology	4 Change technology	Energy	Air emissions	Water	Wastewater	Material	Solid waste	Total no. of practices
1 Prevent	1	0	2	4	2	0	0	2	2	0	**6**
2 Reduce wg[a]	10	25	34	6	18	2	9	6	23	20	**62**
3 Reduce ru[b]	10	6	24	6	11	3	5	2	13	7	**36**
4 Reuse	17	29	0	8	9	2	8	13	9	17	**37**
5 Substitute	5	30	6	50	30	7	10	13	26	15	**72**
Total	**43**	**90**	**66**	**74**	**70**	**14**	**32**	**36**	**73**	**59**	**213**

[a]waste generation; [b]resource usage

Analogous energy hierarchies also exist to prioritise improvements in energy resource use, again with prevention at the top and going down through the levels of reducing, reusing, etc. [32, 33]. Such hierarchies are distinct from the source of energy supply, e.g. prioritising renewable over fossil fuel to decarbonise through substitution.

It is appropriate therefore to base the prioritisation of MEW flow improvement options on these hierarchies.

- Prevention by avoiding resource use: eliminate unnecessary elements to avoid usage at the source, stop or stand-by equipment when not in use.
- Reduction of waste generation: good housekeeping practice, repair and maintain equipment.
- Reduction of resource use by improving efficiency: optimise production schedule and start-up procedures, match demand and supply level to reach best efficiency point of use of equipment or improve overall efficiency of the system, replace technology and resource for less polluting or more efficient ones.
- Reuse of waste as resource: look for compatible waste output and demand, understand where and when waste are generated and whether it can be used as resource input elsewhere considering the complexity of the system.
- Substitution by changing supply or process: renewable and non-toxic inputs, change the way the function is achieved to allow larger scale improvements.

Table 1.2.3 List of generic tactics

1 Manageresource	**2 Changeresource**
1a Align resource input profile with production schedule	2a Remove unnecessary resoure usage
1b Optimise productio schedule to improve efficiency	2b Replace resource input for better one
1c Optimise resource input profile to improve efficiency	2c Add high efficiency resource
1d Synchronise waste generation and resource demand to allow reuse	2d Reuse waste output as resource input
1e Waste collection, sorting, recovery and treatment	2e Change resource flow layout
3 Managetechnology	**4 Changetechnology**
3a Repair and maintain	4a Remove unnecessary technology
3b Change set points/running load, reduce demand	4b Replace technology for better one
3c Switchoff/standby mode when not in use	4c Add high efficiency technology
3d Monitor performance	4d Change the way the function is accomplished
3e Control performance	4e Change technology layout

Table 1.2.4 Strategies and tactics

1 Prevention
1a Align resource input profile with production schedule
2a Remove unnecessary resource usage
3c Switch off/standby mode when not in use
4a Remove unnecessary technology
2 Reduction (waste generation)
1e Waste collection, sorting, recovery and treatment
3a Repair and maintain
3 Reduction (resource use)
1b Optimise production schedule to improve efficiency
1c Optimise resource input profile to improve efficiency
3b Change set points/running load, reduce demand
3d Monitor performance
3e Control performance
2e Change resource flow layout
4e Change technology layout
4 Reuse
1d Synchronise waste generation and resource demand to allow reuse
2d Reuse waste output as resource input
5 Substitution
2b Replace resource input for better one
2c Add high efficiency resource
4b Replace technology for better one
4c Add high efficiency technology
4d Change the way the function is accomplished

5 Improvement Methodology

The improvement methodology must follow a sequence that links the tactics to the process data used to model the manufacturing system. Interestingly, the order in which improvements can be identified does not follow the prioritisation order presented earlier. This presented a major challenge for developing the tool and the improvement methodology. The difficulty for identifying an improvement is not reflecting the difficulty for implementing it. On the contrary, in some cases bigger efforts in data collection are required to identify “low-hanging fruits” (e.g. stop and repair equipment) whereas replacing elements of the system at high cost can be identified quickly (e.g. black-listed resources or old inefficient equipment). Keeping this challenge in mind, this section presents the improvement opportunities following the prioritisation order rather than the first possibility identified.

To access the **prevention** types of improvement, it is important to note that the “change” tactics (2a and 4a) can be difficult to identify as they require expert knowledge about the process to identify the resources or process being used unnecessarily and therefore can be removed. The “manage” tactics (1a and 3c) are comparing patterns between data defining the constraints (production schedule or product profile) and the resource usage or equipment controls to identify when they can be stopped or put in stand-by mode.

The **waste reduction** improvements focus on waste outputs to find a way to reduce losses or maintain the value of the output, even when it is a waste (residues, unwanted by-product, etc.). These improvements are considered as relatively easy since they allow quick savings in resource and cost with limited efforts. But manufacturers’ knowledge about their waste is often limited and for the waste patterns to be identified, a thorough data collection must be conducted. The focus is on processes which are the largest resource consumers and waste generators.

The **resource use reduction through efficiency** improvements focuses on the resource inputs to find a way to increase the use productivity. The most difficult improvements can be to challenge the set points or modify the production schedule as these can only be done with deep knowledge of the processes and production system. The other types of improvement are comparing patterns in demand and supply profiles both in a static (logic tests) and dynamic (simulation) way. The logic tests are comparing the magnitude of supply to the minimum requirements to better match the demand-side (e.g. pressure of compressed air, temperature or cooling water, etc.). Simulation is also used to optimise the timing of the resource flow which can result in overall efficiency improvements (avoid peak consumption or reach the optimum demand level to match equipment high efficiency point of use). The simulations requires a large amount of data, thus those improvements can be identified only based on advanced analysis of the system.

The **reuse** types of improvements are focusing primarily on the waste flows and look for opportunities to reuse waste output as a resource input. The use of a simulation tool is an important asset to allow systematic search for compatible waste and demand in the system taking into account the complexity of the system modelled, the timing of the flows and the spatial dimension. These improvements are done last as wastes must be eliminated or reduced before looking for reuse opportunities.

The **substitution** improvements can be identified at early stage of the modelling by recognising inefficient components (the basic information about component capacity, efficiency and age of equipment) or black-listed resource being used (toxic, non-renewable, non-reusable, etc.). This type of improvement was the most commonly found in the case collection: replacing a piece of equipment or a process by a more efficient one or a less environmentally damaging one is a quick way to increase the sustainability performance but likely at high cost. They involve large scale changes by improving the source of supply and using high efficiency technology but they also reduce more dramatically the environmental impact of the manufacturing activities. The tactics are linked with the database of best practices to suggest alternative resources or technological solutions.

6 Application Example

Prototype applications were conducted with industrial partners to model the manufacturing operations and facility performance before improvements to test how the tactics would identify them. Fig. 1.2.2 shows a graphical example of an air supply system modelling based on the manufacturing ecosystem model. The diagram shows the MEW flows across the system as resources are being consumed to draw air through the processes by fans to achieve the manufacturing process set points (air temperature and humidity). The MEW flows are modelled from supply source to treatment (shaded boxes), to the equipment and process being investigated (clear boxes). The process data collected were used to characterise each element of the system: input and output profiles, air and water properties before and after each process, equipment capacity and actual running loads, process demand profiles and set points.

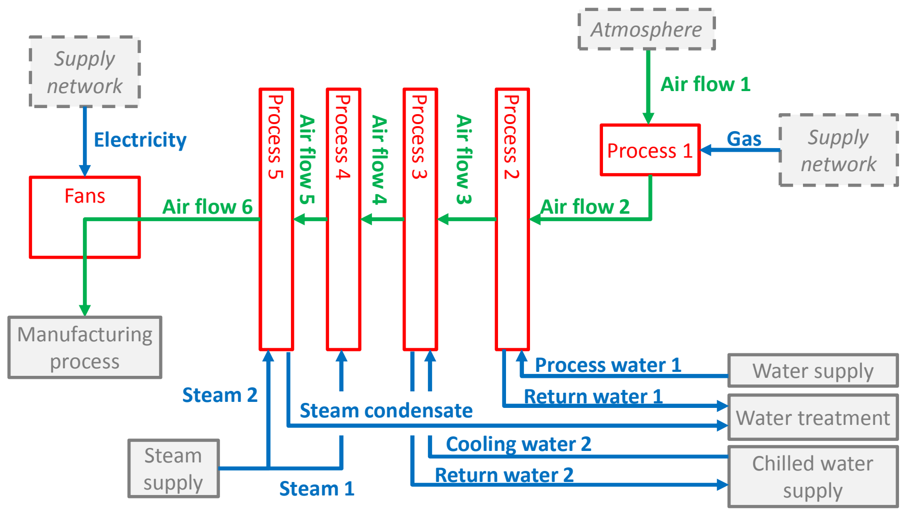

Fig. 1.2.2 Modelling of an air supply system

Each process can be further detailed by creaking down a box of the diagram into a new diagram to show more details. For instance, Fig. 1.2.3a shows a more detailed view of the chilled water supply. Depending on the data available—and therefore the process data used to characterise the system's components—different tactics are used to compare profiles, identify mismatch and inefficiencies, and suggest improvement options.

Following the sequence for improvement strategies and tactics as listed in Table 1.2.4, the prevention tactics were used to compare resource usage profile and production schedule, i.e. check whether resources were consumed during non-production hours. Then a comparison of total supply and sum of all usage allowed a check on completeness of the model and identify excessive losses occurring between supply and usage. In this particular example, the prevention and waste reduction activities were already applied.

The next group of tactics in the sequence is the resource use reduction. Tactics 3b and 3e identified an improvement opportunity by comparing the cooling water system performance (water temperature and pump running load, and therefore cooling water supply) to the cooling demand profile of process 3. As illustrated in Fig. 1.2.3a the pump was running full load all the time when the demand was significantly varying. A first improvement opportunity was identified by comparing the temperature of the cooling water input and the process set points (or cooling requirements). After performance assessment, the water tank temperature

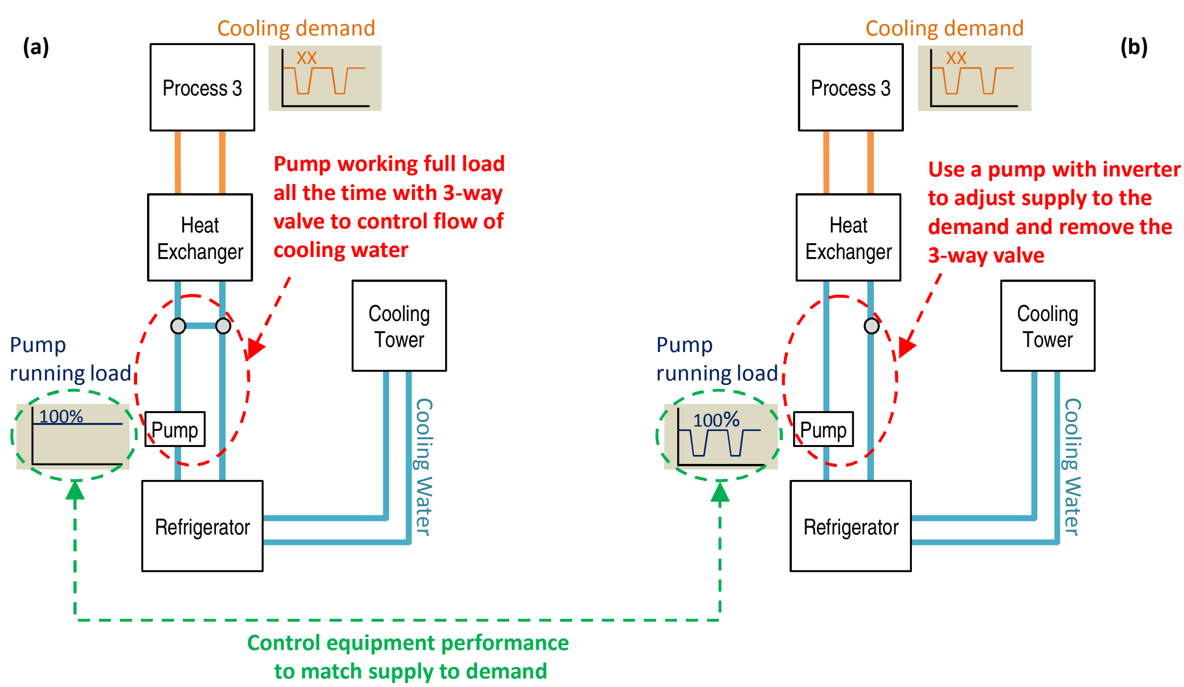

Fig. 1.2.3 Chilled water system. **a** Before improvement, **b** after improvement

was increased resulting in significant energy savings to maintain the cooling water temperature. Additional improvements were implemented on the chiller sequence control as well as inter-shift and weekend switch-off, resulting in a total saving of 40% energy for the chilled water system.

An energy and water reduction opportunity was also suggested as illustrated in Fig.1.2.3b: improve the equipment control to better match the supply to the demand. In this particular case, using an inverter with the pump allowed the water input to match the demand for cooling water by reducing from oversized and continuous supply flow to variable adjusted supply level, resulting in a total of 75% water savings and additional energy savings on the pumping system.

The same system was modelled in two different ways to test the access to more tactics using other process data. In a second variant, the pump characteristics (running capacity and performance curve) were used to identify a substitution improvement (tactic 4b) were the pump would be replaced with variable speed one and adequately sized for the process demand as the current one was oversized in anticipation of production expansion, overlooking the energy savings accomplished over the years which decreased the energy demand while increasing production level.

This application example demonstrates that it is possible to identify improvements in a structured way using modelling of MEW flows to connect the manufacturing facilities and operations and gain a better understanding of the interactions between them. The modelling tool developed can assist manufacturers in assessing the resource productivity with a systems perspective and help to manage resource flows more sustainably.

7 Concluding Remarks

This paper introduced sustainable manufacturing tactics which can support manufacturers in undertaking the journey towards sustainable manufacturing. Cases were collected from literature and the practices classified using various categorisation systems and hierarchies. Generic tactics were formulated to cover a wide range of sustainable manufacturing practices and dictates the rules for identifying improvements in a structured and systematic way. The practices can be formulated with only 20 generic tactics and therefore be identified using few simple rules.

An application example showed that tactics enable the how question to be answered and help identify improvements opportunities. Improvements can be prioritised using the waste and energy hierarchies: high efficiency technology or renewable resources are not necessarily the ultimate answer or “sustainability silver bullets” as there are many options to consider before coming to substitution of technology and resources.

Modelling is used to guide the user through the steps of collecting data and understanding their manufacturing system before undertaking improvement activities. The manufacturing ecosystem model captures the resource flows through the factory using the manufacturing ecosystem model developed by the authors. The work focuses its analysis to what happens within a factory or a part of it (gate-to-gate). The authors recognise the need for a more holistic perspective on industrial systems and on society if sustainability is to be achieved. The boundaries have been set so that the manufacturer has full control on all elements in the studied system. The work excludes certain aspects of sustainability such as social and economic impact, since they are considered as positive side-effects of the work conducted rather than objectives. Also, the resources here are only energy, material, water, chemicals, etc. and not capital, employees, etc.

The improvement methodology was developed to guide the user to opportunities using the energy and waste hierarchies, and help selecting the most appropriate options based on defined targets. Disposal, which is at the bottom of the hierarchy, was not used as it is not considered as an improvement, but rather the least desirable option obtained once the higher levels of the hierarchy have been exhausted. The work showed at it is possible to identify sustainable manufacturing improvement opportunities in a systematic way using modelling of manufacturing system.

Future work includes an extension of the practices database and software development [23] for integrated modelling of MEW resource flows to identify improvement opportunities towards sustainable manufacturing through combined analysis of manufacturing operations, supporting facility systems and production buildings.

8 Acknowledgments

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1.3 Lean Production Systems as a Framework for Sustainable Manufacturing

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Abstract

The constantly rising consumption of resources, global warming and a growing population force the society towards more sustainability regarding ecologic, economic and social aspects. Especially manufacturing industries are challenged to adapt their processes since they play a major role in resource consumption and green house gas emission. Besides more sustainable products, principles of shop floor management have to be redesigned towards more sustainable processes. State of the art manufacturing is usually designed according to enterprise-specific Lean Production Systems. These systems are considered to ensure a comprehensive and sustainable design of production. However, the general goals of an LPS focus on economic aspects. Ecological and social sustainability are rarely considered. Therefore, this paper analyzes Lean Production Systems concerning sustainable aspects. Furthermore, the given structure of these systems provides a framework, where goals and principles of ecological and social sustainability can be incorporated.

Keywords:

Lean production, Framework, Sustainable production management

1 Introduction

Manufacturing has a major impact on society in industrial economies [1–3]. In the European Union about 2.3 Million manufacturing enterprises employ more than 34 Million people and generate 7.3 Trillion Euro turnover [4]. They cause a considerable part of greenhouse gas emissions. European industry has a share of 27% in final energy consumption [5]. Sustainability in manufacturing is therefore an important point of research for science and industry. In this connection sustainability is described by the United Nations as “meeting the needs of the present without compromising the ability of future generations to meet their own needs” [6].

However, sustainability in manufacturing is still not as widespread as it should be. Of course, especially larger enterprises aspire toward sustainability in their corporate visions and strategies. But often sustainability does not arrive in daily tasks of manufacturing facilities. Managers in manufacturing are rarely rated on how many positive changes they achieved in terms of environment or towards society. In general, key performance indicators concerning productivity and quality are prevailing. The sustainability contained in the enterprise’s vision is an abstract term in daily work, which is not put into practice yet. Often, sustainability is seen as long term thinking which is rather unclear.

Manufacturing is a highly competitive field and processes became more and more complex. On the one hand, advanced machines and technologies replaced old-fashioned simple machines. On the other hand, globalization as well as the ambitious requirements of customers forced enterprises to optimize their processes in production. Therefore, manufacturing processes of today’s state of the art factories are organized in compliance with lean principles. Those principles are part of Lean Production Systems (LPS) which are an “enterprise-specific compilation of rules, standards, methods and tools, as well as the appropriate underlying philosophy and culture for the comprehensive and sustainable design of production” [7]. Summarized, LPS are a framework for comprehensive and sustainable design of production. According to the definition, LPS already focus on sustainability. Generally, the intended sustainability of LPS does not match the common thinking towards social, ecological and economic sustainability [8].

2 Lean Production Systems

Lean Production Systems have their origin in the Toyota production system, which was developed after World War II. Japan had a small market with high product variety, new employee-friendly laws and missing financial means. These circumstances prevented the imitation of mass production like in western automobile industry. Therefore Toyota developed innovative methods to optimize production and to avoid waste in each form [9].

2.1 Basics of Lean Production Systems

The elementary principle is the focus of all activities on creating value for the customer. Every activity in the enterprise should create this value-thus be value-adding. All activities which do not increase the value of the product and also are not essential for the production process are considered as waste. It is necessary to continually eliminate waste and to optimize value-adding activities [10].

LPS demand for the holistic consideration of human, organization and technology and thereby sustainably optimize the production system. An LPS can unfold its full effectiveness only if workers support the underlying philosophy and want to contribute to the success of the enterprise [11].

The advantages of the Toyota production system became clear with the globalization and the individualization of customer's requests and the accompanying increasing variant diversity. The main advantages were a high profitability, high customer satisfaction and a very good quality of goods.

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2.2 Continuous Improvement Process

One main aspect of Lean Production Systems is the continuous improvement process (CIP), Japanese “Kaizen”. All employees are encouraged to permanently question all processes, methods and existing standards. Main assumption is that employees executing an activity on a daily basis should know best how to improve the respective process. The continuous improvement process aims at small, but many improvements. The team leader encourages the workers to think about improvements which are often developed in teamwork during regular working hours. Team leaders are responsible for the personal development of their employees and have to tap the employees’ capabilities for the enterprise’s benefit [12]. They are educated in questioning techniques and observance. Furthermore, they have a profound knowledge about the relevant processes in their team.

Most of the ideas are implemented at once without a long and expensive evaluation process. The success of each measure will be evaluated and it will be decided if the formulated objectives are fulfilled. All improvement activities are conform to the Plan-Do-Check-Act cycle. Changes that turn out to be effective will be applied on other processes throughout the enterprise.

2.3 Seven Types of Waste

The seven types of waste, in Japanese “Muda”, were defined by Ohno as follows [10]:

- Transportation: Every time a product is moved there is a risk of delay or damage. Furthermore, the value of the product is not increased by a transport.
- Inventory: Inventory, either raw materials, work-in-progress or finished products ties up capital without value for the customer.
- Motion: Motions of workers should be minimized because they do not add to the value of the product. If an assembly worker has to walk a few meters to the supplied goods, he is not adding value at this time. In the summation over a whole day even small motions will add up to a relevant amount.
- Waiting: Goods that are not processed or workers that are waiting for orders are waste.
- Over-processing: If a product is in some details better than the customer required (e.g. smaller tolerances than needed), the customer will not pay for this additional work.
- Over-production: Production without an assigned demand of a customer is waste. It will lead to inventory and needs resources during storage. Furthermore, customer requirements will change and the surplus production may not be sold anymore.
- Defects: A defect will generate extra costs for rework or for the scheduling and production of a new part.

In the continuous improvement process every worker knows these seven types of waste and has therefore a clear direction for his improvement efforts. The types of waste are easy to understand and can be applied to nearly every process.

2.4 Framework

The framework of an LPS is a hierarchical structure of different elements as shown in Fig. 1.3.1. First step in the configuration of an LPS is the determination of the enterprise’s superior goals [13]. These goals interfere with the organizational structure and consequently with the business processes of an enterprise. The processes are designed according to achieve these goals. In an LPS, principles like standardization, zero-defects or pull bundle methods and tools with similar contents [14]. The enterprise-specific selection of these principles ensures that methods and tools are restricted and a coherent integral system is built [13]. Due to the complex structure an LPS implementation is far more than a regular rationalization project. It is a fundamental change in the organization and culture of an enterprise. Furthermore, the continuous improvement will never end [14]. In addition to the tangible elements, a common vision of the ideal state as well as a philosophy and corporate culture that also reflect the lean ideas are crucial parts for a successful implementation of the LPS [15].

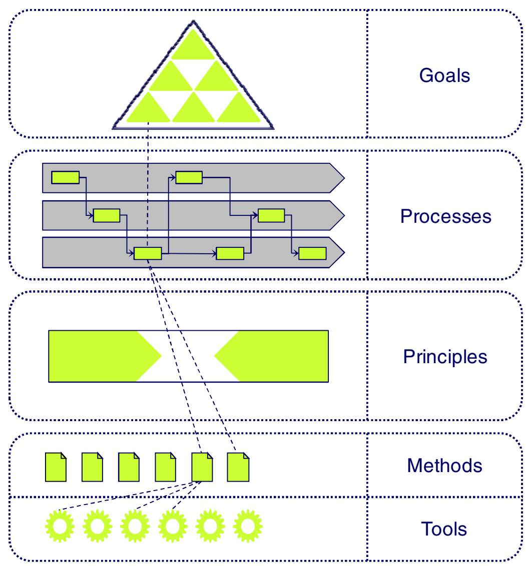

Fig. 1.3.1 General structure of an LPS [13]

3 Sustainable Manufacturing

3.1 Dimensions of Sustainability

The above mentioned universal definition of sustainable development laid the foundations for further application in specific fields as the industry sector. The Lowell Center for Sustainable Production describes sustainable production as “the creation of goods and services using processes and systems that are non-polluting; conserving of energy and natural resources; economically viable; safe and healthful for employees, communities and consumers; and socially and creatively rewarding for all working people” [16].

According to the Rio Declaration on Environment and Development, three dimensions of sustainable development have to be regarded (Fig. 1.3.2) [17]. Today’s common understanding recommends an equal consideration of all three dimensions [2,16].

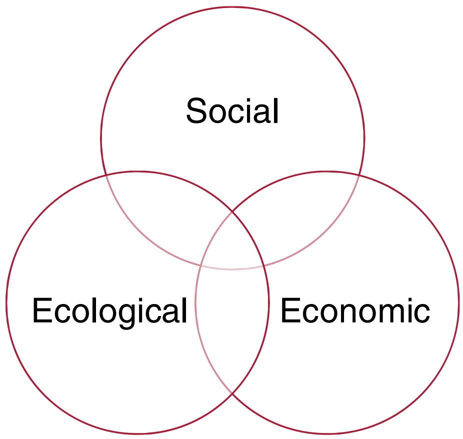

Fig. 1.3.2 Three dimensions of sustainability

This concept emerged in the last decades [18] and is also known as triple bottom line [1, 19] or tripartite goals [22] of sustainability. At the beginning of the sustainable development evolution, the ecological sustainability was focused [18, 20]. The term sustainability was linked to the environment and it took decades to establish the consensus that sustainability in economy and society is equally important. Relating to the field of manufacturing, the three dimensions must be interpreted from macro to meso level. In sustainable manufacturing, the economic dimension has to be addressed by creating value and development in order to ensure long-term competitiveness [1]. Economic success is a necessary precondition for enterprises in market economy. But only long-term success cultivates sustainable development and assures a continuous growth. The second dimension is pursued in having minimal use of natural resources [1]. Since natural resources are a necessary input as well for products as for power generation, the impact on the environment should be minimal. The social dimension requires to support social development and to enhance quality of life for the employees but also for society [1].

3.2 Integration in Existing Frameworks

In the last decades, a variety of authors have presented concepts and approaches to enhance sustainable production [1, 3, 16]. However, sustainability is still not embedded in daily processes. According to this, it seems reasonable to focus on practical approaches for implementation in daily operations. But these approaches need to be aligned with established processes in production in order to be accepted by production employees. The integration in existing systems reduces the effort and improves the long-term application of the approach.

The prevailing approach for organizing manufacturing processes is Lean Production. After several years of experience, enterprises realized that implementing single methods of lean does not promote lasting success. Over the years, enterprises started to implement holistic systems addressing the lean principles and methods. Those Lean Production Systems now present a highly structured and well organized framework for manufacturing. As described above, the structure of LPS is aligned to the general goals of the enterprise. As goals are derived from enterprise strategy, LPS provide a consistent framework from strategy to shop floor level. LPS still are described as holistic production systems, they are limited on economic objectives. Increasing customer value and quality are main objectives in each LPS, but they focus on long-term economic growth by satisfying customers' needs. Hence, the integration of the social and ecological dimensions requires a supplementation of LPS structure. As shown in Fig. 1.3.3, the integrated LPS structure could be displayed as a three-sided pyramid. Thereby, each side represents a dimension of sustainability.

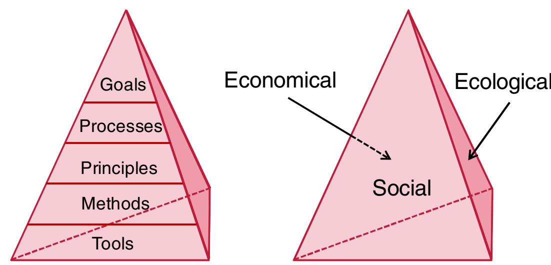

Fig. 1.3.3 Integration in LPS framework

4 Integration of Sustainability in Lean Production Systems

Theoretical approaches often fail in practical implementation because they fail to achieve sustainable application. Sustainable manufacturing runs the risk of being a worthwhile approach but never being applied on shop floor level. Lean Production Systems have come up against this challenge by formulating simple rules for every day work.

In LPS every employee consequently and thoroughly tries to eliminate waste in all processes [10]. Everything that is not adding value to the product from customer's perspective is considered being waste. As described above, waste is categorized in seven types. These types of waste on their own might seem trivial but work very effective in everyday problem solving. The elimination of waste is the core principle of LPS and helps workers to focus their activities.

However, LPS focus on economic aspects and the seven types of waste are the guideline for daily operations. In order to achieve sustainable manufacturing, social and ecological aspects have to be similarly integrated in the LPS. Therefore, simple rules have to be described that provide a guideline for everyday operations.

4.1 Ecological Dimension

Main goal for the ecological sustainability is the creation of a closed loop. That means that the enterprises act autarkic from environment, do not use any inputs from the environment and have no output. For a closed loop the complete reuse of the primary products would be necessary. In reality, this would be a perpetuum mobile which is an inaccessible goal. Even so, there are several measurement methods for the life cycle assessment of a product or a facility, e.g. the ecological footprint. These methods measure the environmental impact and help to identify improvement potentials [21]. But the measurement of such complex interrelations is complicated and hard to teach to a shop floor worker. It is therefore necessary to establish a simple and catchy compilation of ecological impact factors. The optimization of the ecological sustainability should not just take place focusing on the internal processes of the enterprise but also in regard to suppliers and to product life cycle. Seven main ecological impact factors could be identified.

Industry has a high consumption of *energy* in form of oil, gas, coal or other energy sources. Although the usage of renewable resources may reduce the emission of greenhouse gas,it has to be considered,that there might also be negative impacts. For example, the generation of hydro power needs storage lakes or will change the river in terms of course and speed. Therefore also the usage of renewable energy has influence on the ecological footprint of a product [21].

The availability of *resources* like iron or copper ore is finite. Their usage is therefore qua definition not sustainable. The share of recycled materials should be increased. Renewable resources like wood or cotton may be used, when their cultivation goes along with the other criteria, especially in terms of land consumption and water usage.

Industry has a high usage of *water*, e.g. for cooling in power houses or in chemical industry. In a closed loop the withdrawn water from rivers or lakes should be returned in the same condition, i.e. also in the same temperature.

The *emission of toxic or harmful substances* to the air, soil or water should be minimized. Furthermore also the products should not include any of these substances.

Waste is, beside the desired primary product, output of many industrial processes. Main goal should be to reuse or recycle these outputs. Landfill or refuse incineration have negative impact.

The emission of *noise* will affect especially the direct neighborhood, but e.g. in case of an airplane manufacturer also the emissions of the product itself are in the responsibility of the enterprise.

Land consumption, i.e. the sealing of soil for roads, factories and storage buildings or land for the cultivation of renewable resources, has a high impact on the environment. Especially in rain forests large areas are cleared every day. Even so the producing enterprises in the industrialized countries are not directly responsible, they have to take account for the production conditions of their raw material.

4.2 Social Dimension

A socially sustainable system must achieve distributional equity, adequate provision of social services including health and education, gender equity, and political accountability and participation [22]. In contrast to the ecological and economic dimension of sustainability there is no simple guideline such as customer value or closed loop. The social dimension is far more complex and involves a variety of stakeholders. The social impact factors were classified in Fig. 1.3.4 in a coordinate system. On one coordinate axis the type of impact is determined, whether the impact is physical or psychological. On the other axis is detected whether the individual, especially the affected workers, or society are in the focus of the social impact factor.

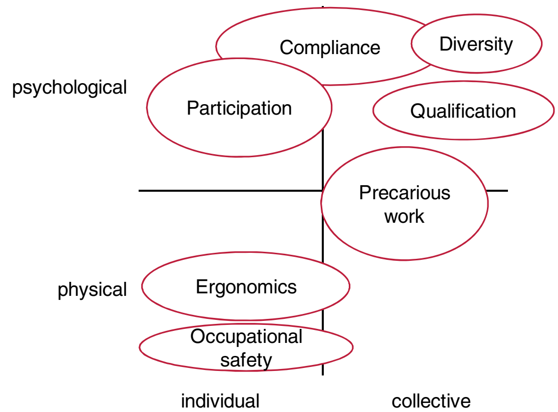

Fig. 1.3.4 Social impact matrix

Occupational safety comprises the identification of risks at the workplace which may lead to accidents. Furthermore, preventive measures to reduce or eliminate these risks are part of the occupational safety. The goal is to prevent any physical damage of the employees and thus raise their morale. It focuses on the individual worker.

Ergonomics helps to evaluate whether the workload is adequate and does not lead to any physical or psychological damage over the entire working life. The derivation of measures to decrease harmful effects is also part of ergonomics. Like the occupational safety it focuses mainly on the individual worker and on physical damage.

Compliance means to be in adherence with legislative but also internal and informal regulations. It is a management's task to be proactive and to secure the adherence in all departments. Compliance has psychological impact and is important for the single worker but also for society.

Enterprises are responsible for the adequate *qualification* of their employees. Not just the necessary qualifications from the enterprise's perspective but also the requirements of the employees have to be regarded. Furthermore, the vocational training of young people is a responsibility towards society.

Diversity means, that nobody is discriminated against based on race, color, religion, sex, national origin, age or disability [23]. Diversity has as well positive effects for the enterprise. A more diverse workforce will increase organizational effectiveness and help to understand the special needs of the diverse customers. One main point for focusing on diversity is demographic change with an increasing number of retiring people and a decreasing workforce e.g. in many countries in Western Europe or Japan. That will lead inevitably to a lack of qualified personnel in some branches of industry [23]. Therefore, many initiatives to develop new talents are necessary. E.g. in Germany the share of women in engineering courses is still lower than 20% [24].

Precarious work conditions are different forms of employment established below normative standards, which results from an unbalanced distribution of insecurity and risks between workers and employer [25]. Signs for precarious work are for example low wages, temporary and short labor contracts, no social security and working hours by acclamation. Precarious work has a high psychological impact but due to stress it can also result in physical impact.

Besides the directly concerned people, precarious work also affects the society, which has to support the people with social security. Enterprises are not only responsible for their own workforces but have to use their influence on their suppliers in order to improve their labor conditions.

Direct participation in change processes is the appropriate and targeted direct involvement of employees in solution finding and decision making. This takes place with the aim to use tacit knowledge, to qualify employees, to increase the acceptance of project results and to consider the needs of employees comprehensively [26]. Participation has mainly a psychological effect. Furthermore, it focuses on the individual worker.

4.3 Interferences

The three dimensions of sustainability are not isolated, but have a variety of interferences. Some of them are conflictive, but often with one measure several goals can be accomplished. Contrasts can be seen for example in the ecological and economic sustainability. While additional cost for an environmentally friendly production process are justified from an ecological point of view, from an economic perspective the main question is whether this measure will add value for the customers and if they are willing to pay for it. If this is denied, this measure will not be implemented. Precarious work can also be reasonable for the enterprise from a strict economic perspective, especially if it takes place at a supplier's factory. However, this behavior is socially not sustainable.

Nevertheless the synergies outweigh the conflicts by far. Thus, the social sustainability for example, helps to increase the motivation of employees due to a hazard-free workplace and an active participation. The increased motivation will result in a lower fluctuation and therefore lower recruitment costs, lower absenteeism due to illness and an innovative work environment. These positive effects will pay back also in economic terms for the enterprise. The social impact factors, which have a collective impact, will improve the image of the enterprise. Thus the enterprise will become more attractive to applicants and especially the customers.

Interdependencies between the environmental and economic sustainability also exist through the efficient use of resources, energy and water. In addition, significant economic and environmental benefits are achieved. This harmonizes with the overarching theme of avoiding waste.

5 Conclusion

In many companies, sustainability is seen as an important part of corporate strategy. State of the art factories have implemented Lean Production Systems which focus on long-term customer value and the avoidance of waste in all processes. Using a catchy classification it became clear to all employees, how waste is defined. Furthermore, all employees try constantly to eliminate waste in business processes and create value in a continuous improvement process. However, despite the definition of an LPS mentions the sustainability of production, the focus is solely on the economic dimension. This is partly due to the measurable success with key performance indicators like inventory, lead time or productivity. Secondly, the ecological and economic dimensions of sustainability are harder to understand by the operational staff due to their complex interrelationships. The integration of social and ecological sustainability into the structure of LPS provides a possibility to bring sustainability to the shop floor level. As in LPS, simple and catchy rules have to be formulated to receive a sustainable development in every day manufacturing processes. Furthermore, the holistic view of the three dimensions of sustainability often causes conflicts. The definition of a nomenclature, which can be easily understood by the operational staff, will help to change the emphasis on profitability.

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1.4 Cleaner Production as a Corporate Sustainable Tool: a Study of Companies from Rio Grande do Norte state, Brazil

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Abstract

This study aimed to assess the Cleaner Production—CP as a corporate sustainability tool, through the study of multiple case studies within companies from Rio Grande do Norte State. In order to achieve this goal our research methodology approach used the CP methodology from SEBRAE (2005) (based on CP programme of UNEP/UNIDO and applied it within the food industry (Company 1), the textile industry (Company 2) and in a car dealer (Company 3). The results highlighted (among other variables) the specific sustainability focus of any observed Cleaner Production activities. In the Company 1, raw material substitution and the optimization of water and energy usage were the main foci. In Company 2, the foci were the optimization of fabric usage and the technological modification (installation of washing equipment for the printing plates, before of this, there was not control of water usage in this process, resulting in increased water consumption and disposal of waste). Company 3 was focused on source segregation and external recycling. Thus, it was possible the implement within three companies a prevent control of significant environmental aspects, providing evidence to the incorporation of environmental issues in the corporate management process, as well as decreasing the operational risks among employees, community and environment. On the other hand, the continuity of the CP program depends on the total commitment from the top management. In addition to understanding the specific Cleaner Production foci chosen by each case company, the paper reflects on the reasons why the company may has chosen that focus, and implications for the adoption of Cleaner Production.

Keywords:

Cleaner production, Corporate sustainable, Environmental impacts, Environmental management, Waste

1 Introduction

In order to achieve a sustainable development, businesses need to adopt a socio-environmental protection policy aligned with economic development. In this context, companies are required to make fundamental changes towards new goals in order to increase their quality while lowering costs. In addition, organizations want to avoid possible penalties and heavy fines as well as indicate that the company is social and environmental responsible. Also, this can be a competitive advantage on global market.

It has to be stressed that government (environmental legislation and policy control), market (competitors, investors and consumers) and socio-environmental responsibility are inducing the need to implement tools that aim at corporate sustainability. Therefore, Cleaner Production (CP) can be one alternative to be implemented in response to these pressures, once it can reduce the risk of operations on the environment and society, and encourage companies to adopt self assessment procedures.

Based on this scenario, CP aims to improve the efficiency of production processes and services and it is considered a favorable approach to the companies operate in a preventive manner in relation to its environmental aspects as well as reduction of their risks on staff and community and the pursuit of sustainability. This occurs through the minimization of impacts associated with minimization of cost and optimization of process, raw materials and energy.

Thus, CP can be regarded as a modern solution to the environmental issues, since involving the concepts of reducing losses and increasing competitiveness, changing production processes [1].

As a consequence, this study aims to identify the environmental, social and financial benefits from the implementation of CP within Brazilian Small and Medium Enterprises (SME). In order to achieve this goal, a series of multiple case studies is carried out within companies located at Rio Grande do Norte State (northeast part of Brazil). More specifically, the research seeks to provide elements of discussion for each company studied in order to identify and incorporate environmental aspects in their daily management process.

2 Cleaner Production: A Tool for Corporate Sustainability

2.1 Brief History of CP

In 1994, United Nations Industrial Development Organization—UNIDO and United Nations Environment Programme—UNEP jointly initiated the Global Programme of Cleaner Production Centres, aiming to promote, coordinate and facilitate the activities of the Cleaner Production in each

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country by building local capacity to implement CP and to train of professionals who could apply the concepts or even building local capacity to implement CP and (to) train professionals who could apply the concepts or even adjust them to local conditions [2, 3].

A total of 25 centers was established in the following countries since 1995: Brazil, China, Costa Rica, Czech Republic, El Salvador, Ethiopia, Guatemala, Hungary, Korea, Lebanon, Mexico, Morocco, Mozambique, Nicaragua, Slovak Republic , South Africa, Tanzania, Tunisia, Uganda, Vietnam and Zimbabwe. According to Navratil and Luken [4], over US$ 17 million has been invested for training centers, with a turnover of 4 million annually.

In Brazil, the National Center for Clean Technology—CNTL, was installed in July 1995 at the National Service of Industrial Learning (SENAI) of Rio Grande do Sul [5]. In 1999, it was implemented the Brazilian Network for Cleaner Production in order to promote sustainable development in small and medium enterprises in Brazil. Currently, the Network is comprised of seven states centers and eleven regional centers (CNTL's). This network has completed a decade of operations in Brazil and CP has been implemented in more than 300 companies, providing improvements in environmental performance and economic gains.

At the Rio Grande do Norte State, in 2003, CNTL/SENAI-RS in partnership with SEBRAE-RN have formed the first group of consultants in CP. The final result was the implementation of CP methodology in six companies. According to the "Nucleo Potiguar de Econegocios" the investment required to implement the CP program was just over US$ 13,378.8 and the return exceeded US$ 95,541.4 in a one-year horizon. The environmental benefits translate to optimize the use of materials, reduced water consumption and minimize the risk of contamination.

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2.2 Concepts, Levels of Opportunity and Roadblocks to CP

According to UNIDO [6], CP consists of a preventative and integrative strategy which can be applied to the entire production cycle in order to: (a) Increase productivity, ensuring more efficient use of raw materials, energy and water, (b) Promote better environmental performance by reducing source of waste and emissions; (c) reduce environmental impact throughout the life cycle of a product.

In addition, CP can be adopted in any sector of activity and size based on a technical, economic and environmental detailed analysis of the production process, aiming to identify opportunities that provide improved efficiency rate without additional cost to the company [7, 8].

Glavic and Lukman [9] mention that CP includes either a condition for achieving environmental improvements in process and product development as well as a contribution to a more sustainable world.

Opportunities for improvement based on CP can be developed on three levels (Please, see Fig. 1.4.1), namely: Level 1—Source reduction; Level 2—Internal Recycling and Level 3—External Recycling as shown in the Fig. 1.4.1 [10, 11]. The first level aims to optimize the use of natural resources while preventing the generation of pollutants by promoting modification in the product (Housekeeping, changes in raw materials and Technological Change). Pollutants which can not be avoided should be reintegrated into the production process of the company (Level 2—internal recycling). Only after considering Level 1 and 2 that one should opt for measures of external recycling (Level 3).

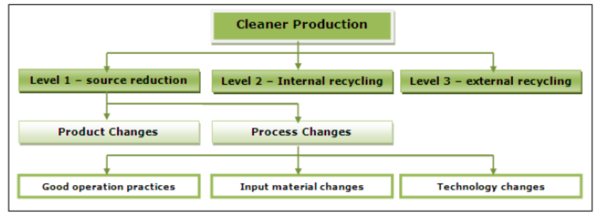

Fig. 1.4.1 Opportunity levels of CP

It is essential that in the process of implementing a CP program, possible barriers that arise will be overcome. The main roadblocks are due to resistance to change such as: misconception (lack of information about the technique and the importance given to the natural environment); absence of national policies that support the activities of CP beyond a little interaction between the private and universities and research centers; economic barriers (incorrect evaluation of environmental costs and investments as well as low investment capacity) and barriers related to the role of the deployment team [12–18].

2.3 Cleaner Production as a Corporate Sustainability Tool

This section shows some initial perspectives of the framework of CP as a corporate sustainability tool. Initially it is worth remembering the three aspects of corporate sustainability, corporate social responsibility (improving quality of life), eco-efficiency (optimizing natural resources usage and reduction of pollutant burden considering the life cycle of products) and competitive position [19–22].

Thus, it is possible to associate CP as a tool to assist the promotion of corporate sustainability, hence this tool allows continuously search for the environmental efficiency of operations through optimizing of natural resources usage and eliminating waste, improving the workplace by the elimination or minimization of risk to employees and community, and change the consciousness of employees facing the environmental problem, while allowing economic gains with the elimination of waste and risks, as well as increased productivity.

UNIDO [23] CP is still considered a management, economic, and environmental and quality tool as can be seen in Table 1.4.1:

According to UNIDO and The Danish Environmental Protection Agency [24] there are some reasons to invest in Cleaner Production, named: improvements to product and processes; savings on raw materials and energy, thus reducing production costs; increased competitiveness through the use of new and improved technologies; reduced concerns over environmental legislation; reduced liability associated with the treatment, storage and disposal of hazardous wastes; improved health, safety and morale of employees; improved company image and reduced costs of end-of-pipe solutions. In addition they claims that Cleaner Production can reduce or eliminate the need to trade off environmental protection against economic growth, occupational safety against productivity, and consumer safety against competition in international markets. Setting goals across a range of sustainability issues leads to 'win–win' situations that benefit everyone.

Table 1.4.1 Some characteristics of the CP

Tool	Description
Management	It involves rethinking and reorganizing the way activities are carried out inside an enterprise. In order to CP to be implemented successfully the concept must have the support of middle and top management; this reinforces its function as a management tool.
Economic	Waste is considered a product with negative economic value. Each step to reduce the consumption of raw materials and energy and prevent or reduce the generation of waste, can increase productivity and bring financial benefits to an enterprise.
Environmental	It solves the waste problem at its source.
Quality	The systematic avoidance of waste and pollutants reduces process losses and increases process efficiency and product quality. The continuous attention and focus on the organization and management of activities in an enterprise brings the added benefit of an improvement in the quality of products, and a reduction in the rate of rejects.

Thus, Cleaner Production can be considered a 'win–win' strategy. It can also protect the environment, the consumer and the worker while also improving industrial efficiency, profitability and competitiveness.

3 Methodology

The study is based on a quantitative approach and explanation from multiple case studies, once the analysis was carried out within two or more companies [25]. These companies were selected based on the criteria of easy accessibility and company's interest to participate in the study. Therefore, a bakery, a textile (garment and printing) and a car dealer, respectively, Company 1, 2 and 3.

3.1 Brief Description of Natal

Natal (Fig. 1.4.2), which is located in northeastern Brazil, in Rio Grande do Norte, has an area of 170.30 square kilometers and a population of approximately 7,98,065 residents. The city has a diversified economic sector, focusing especially on tourism, trade, construction and industry. The city's GDP in 2008 was US$ 4,782,462,420. Currently the city of destination for Christmas is some 1,351,127 tourists (2007), mostly nationals who hold annual spending in the order of US$ 473,810,091 (year 2007) [26].

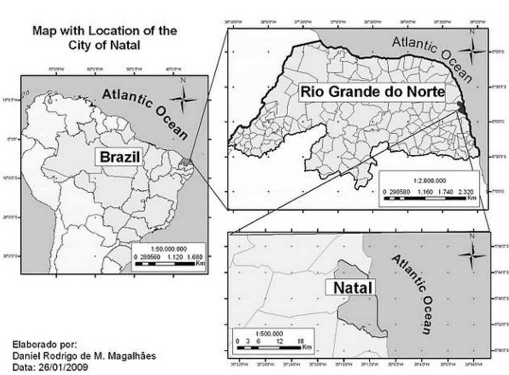

Fig. 1.4.2 Localization of Natal

3.2 Research Study

The research study was carried out from June/2005 to December/2008 using the CP model as proposed by SEBRAE [27]. The methodological procedures follow below:

3.2.1 Planning

The planning phase aimed to obtain top management commitment based on an initial meeting when the methodology was presented as well as possible advantages and some successful cases of implementation of CP.

In addition, it was established the internal team of the CP implementation—ecoteam. As a consequence, a training program of 10 hours including quality management, health and safety work and CP was carried out.

After a short visit to the company in order to get to know company's products and procedures a preliminary scope of work was discussed with top management and the ecoteam. Therefore, it was decided by which sector/process the CP process should be initially carried out.

3.2.2 Operational and Environmental Diagnosis

The second step was based on gathering operational (e.g. equipment, materials, labour, costs associated with environmental aspects etc.) and environmental (e.g. environmental permit, there are programs, procedures or mechanisms for environmental control etc.) information.

Then, a qualitative flow chart was developed for each sector/process/product followed by its environmental evaluation according to methodology. This step aimed to point out the significant aspects of each process.

Finally, it was selected which steps/operations/industry that would have its inputs and outputs quantified in order to identify the causes of the generation of waste. To assist this gathering data process some equipments such as balance, stopwatch, decibel meters, voltage and digital camera e surveys were used.

3.2.3 Evaluation of Opportunities, Implementation and Monitoring

For each solution presented in this study it was analyzed the level of impact of its implementation before its environmental and financial benefits. Regarding environmental benefits, environmental indicators were used to diagnose strokes to design a scenario of the initial situation and situation changed (as proposed or implemented—based on estimates or monitoring).

The criteria used for the financial analysis were: Net present value—NPV (the situation encountered and proposed—modified comparing the alternatives) and pay-back (i.e. the time for return on investment). The Future Value was also used based on a uniform series applied to the revenues from possible benefits of the implementation. For these calculations, a horizon of one year was adopted.

Based on the financial and environmental information some proposals were submitted to the top management who authorized their implementation or not. It has to be pointed out that some proposals which were not implemented up to the moment of this intervention were then transferred to a future medium to long term implementation. In this case, companies were once again stimulated to carry on with a continuing CP program.

4 Results and Discusion

4.1 Companies Description and Planning Program

Table 1.4.2 presents general information about the companies studied.

Table 1.4.2 General information about the companies studied

Company	Size	Initial year of the company	Number of employees	Description of products/services
1	Small	1998	30	80 bakery products and confectionery and a daily production of about 6,000 breads.
2	Small	1995	23	Cotton, polyester, dry and chop Basic T-shirts are the main products. The production capacity is 400 T-shirts printed per day.
3	Medium	1991	105	400 new cars are sold monthly as well as more than 700,000 parts and accessories, with an average attendance from 3500 to 4500 customers.

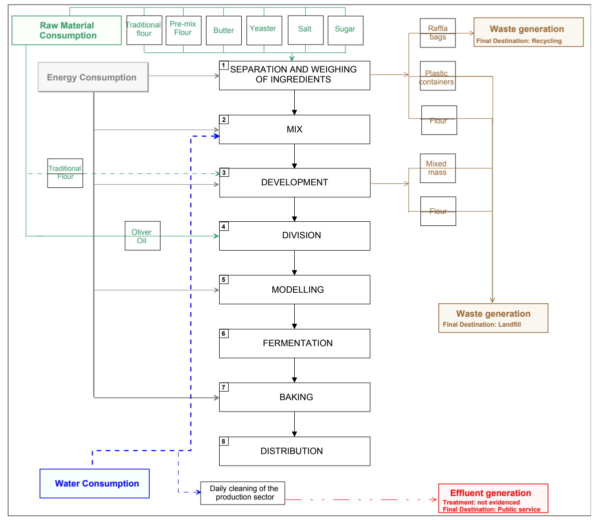

Fig. 1.4.3 Qualitative flow chart of company 1

In Company 1, the project has begun in July 2005 and finished in September of that year. Company 1 is a bakery store and the CP program aimed to reduce waste generation considering the production of breads (French bread which is a salt bread).

In Company 2, a small textile industry (only garment and printing), the project was from April to August/2007. The focus of the investigation was not set upon a single product due to the diversity of products of the company but it was carried out based on an overall assessment of the entire process.

Finally, in the Company 3, a car dealer, the project started in September/2007 and finished in february/2008. The CP program was based on the suitable management of solid waste and its reduction.

4.2 Implantation of CP Program

4.2.1 Company 1

The manufacturing process of the bread (just French bread—scope) was composed of the following steps: separation and weighing of ingredients (according to a standard recipe); mix of all ingredients with water in a mixer with a capacity of 40 kg and electric power of 7 hp; Development (use of mechanical drum with 6 hp aiming a complement to the development of gluten); Division (Division mass processed in quantities of 50 g with equal size and volume using a manual equipment); Modelling (definition of a format using an electrical bread machine of 0.37 kW); Fermentation (in smaller chambers with an average time of 4 h) and baking (baking the dough in an electric oven with four chambers burning, 7 hp each. Each batch takes approximately 15 min) (Please see Fig. 1.4.3).

The critical points observed in the process are described as follow: The dosage of water used in the mixer was done randomly without any measurement control made by the baker. It was observed that the volume of water in relation to the flour was 47% (5% below recommended by the flour manufacturer). This fact represents a loss of production from 67 breads per day (19,800 breads annually). In monetary values, the monthly loss was US$ 262.74.

During the first step of the process, separation and weighting of the ingredients, it was raised the possibility of performing a production test with a pre-mix flour. According to manufacturer's recommendations, the pre-mix flour requires only the addition of water and yeast to produce the bread. As a consequence, two days test were carried out at the production site considering 100% of pre-flour mixture. During the tests, it was estimated that waste generation would decrease by approximately 35% (instead of 25.3 kg per month of packaging materials—raffia bags, buckets of butter, plastic containers—the company would use only 16.5 kg).

Regarding the time spent for separation, weighing and feeding the mixer there was also a reduction of over 70% (initially the manipulation of every batch of production was around 15 min and after would reduce 4 min). Moreover, the cost per kilogram of mass for the bread went from US$ 0.97 to US$ 0.93. If we consider this reduction in a month period, the saving would be US$ 74.52.

Regarding energy consumption, was found a discrepancy in the use of time both in the mixer as the cylinder (special drum), reaching a difference of more than 40%. The daily production of bread were consumed in a mixer and drum 3.46 Kwh.

Based on the results, it was proposed to use a graduated bucket to standardize the suitable dosages according to production lots. This simple action would help to reduce the amount of water consumption (Level 1 of CP—source reduction, housekeeping).

It was also proposed the use of 100% pre-mix flour, eliminating the other ingredients (such as salt, sugar, butter and breeder). This would facilitate the production process which will only handle with flour, yeast and water (level 1—source reduction, substitution of raw materials).

In order to reduce the energy consumption at the production site, posters were fixed closed to the mixer and special drum (cylinder) indicating their respective standard time of use for each lot. This means: 3.5 min in the mixer and 2.0 min in the cylinder for 5 kg of mass and 5 min in the mixer and 2.5 min in the cylinder for 15 kg of mass (Level 1—source reduction, housekeeping). Thus, it was estimated that energy consumption would reduce to 2.68 kWh with an annual savings of 277 kWh (22%).

All proposal for the production of bread were accepted by the entrepreneur, being implemented immediately. Tables 1.4.3 and 1.4.4 list the feasibility study and environmental characteristics of the improvement opportunities.

From the results, it can be observed that the intervention on the environmental aspects at the production of French bread led to a total of saving of approximately US$ 4,681.22 per year. If we consider the NPV of initial situation, the amount of waste in a one-year horizon represented a total of US$ 4,154.34. The final outcome was a reduction of 34% in packaging waste, 73% less time on manipulation of ingredients and 22% reduction on energy consumption at mixing and development steps. It was also found 45% on cost reduction to produce the mass for the bread. Therefore, it was observed a better performance in production of breads, with decreased leadtime as well as increased quality of bread.

The continuing CP program outlined to Company 1 consisted on the implementation of a program selective collection of waste. In addition, it was specified that the ecoteam should orientate other sectors of the company to use the ingredients in an efficient manner. This could be achieved due to a series of visits at each two weeks as well as monthly meetings with all employees.

After 6 months that the program has been implemented, the company was visited. It was observed the following facts: the use of pre-mix flour is now used in other type of masses (sweet and semi-sweet); program selective collection of waste was not implemented in its entirely manner once only buckets and bags of raffia was been sold; the company began to support events on environmental awareness.

Table 1.4.3 Feasibility study of the improvement opportunities within company 1

Critical points	Solution	Investiment (US$)	Real or estimated income		Financial analysis		
			Monthly (US$)	Annually (FV) (US$)	NPV 1 (US$)	NPV 2 (US$)	Pay-back (Month)
Dosage of water without any measurement control	Use a graduated bucket to standardize the suitable dosages according to production lots.	98.73	262.74	3,332.18	–2,957.15	+ 2,858.42	0,37
Replacement of flour	Use 100% of pre-mix flour	0.00	74.52	945.13	–838.75	+ 838.75	0,00
Waste of energy usage during mix of ingredients	Standard time of use for each lot through fixed posters	3.18	31.85	403.90	–358.44	+ 355.25	0,1
Total		101.91	369,11	4681,22	–4,154.34	+ 4,052.43	-

NPV 1 Net Present Value of initial situation (situation encountered); *NPV 2* Net Present Value of situation proposed or modified; *FV* Future Value

Table 1.4.4 Environmental characteristics of the improvement opportunities within company 1

Indicator	Unit	Initial situation	Situation modified
Volume of water in relation to the flour	%	47	52
Generation of packaging materials waste	Kg/month	25.3	16.5
Time spent for manipulation of materials (separation, weighing and feeding the mix	Minute/day	15	4
Cost per kilogram of mass	U$	0.97	0.93
Energy consomption—mixer and cylinder	Kwh/day	3.46	2.69

4.2.2 Company 2

The process of garmenting and printing of Company 2 had seven major steps (Fig. 1.4.4). The first step was the product design and then modelling (cardboard template for each component of the product). Afterwards, the fabric is cut and printed and/or sewing (depended on the kid of product). The final steps are the quality control and dispatch of the final product. If during the quality control any minor errors of sewing, holes or stain are identified the products sent back to the production line for further corrections.

During this study it was noticed that Company 2 did not have any software to make the cutting process more efficiently. In fact, it was observed that the cutting process was carried out in a randomly manner according to the convenience of the operator. This resulted in a significant waste of material. It was decided to investigate the consumption of cotton and polyester which represented around 70% of the total fabric used in the company.

The results indicated an average waste of over 20% of these fabrics (cotton and polyester). This is almost 40 kg of fabric per day or more than 10 tons per year which represents US$ 11,484.42 per month or US$ 145,651.20 annually. These materials were left in the landfill.

In addition it was observed waste of water during the cleaning of printing plates. For example, the waste was due a broken valve that caused a leak of 4,000 l of water per month. Also, there was not a proper manner to wash the plates which could optimize the water usage such as by increasing the water pressure. The water consumption in the sector was estimated in 2,300 l per day.

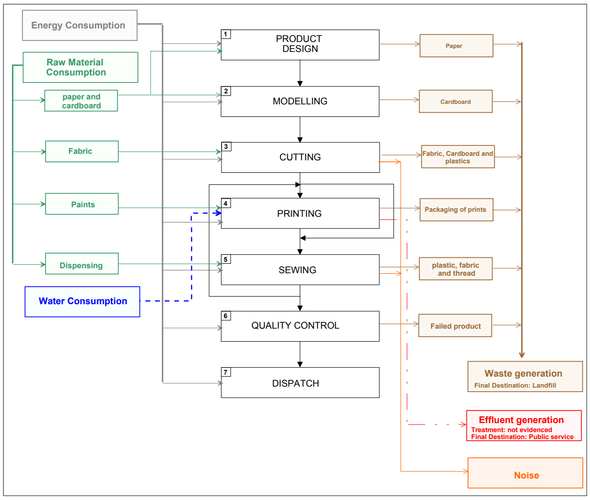

Fig. 1.4.4 Qualitative flow chart of company 2

During the drying process, it was also noted a waste of energy consumption. This process was carried out by using metal plates fitted with an electrical resistance (0.450 kW) called "cradle". These were installed in sets of six units or 12 per table (Fig. 1.4.5). However, the power supply control was not done individually. In other words, once the machine was switched on, all “cradles” were on at the same time. As a consequence, the machines were running at 70% of their efficiency based on average usage of 2.5 h per day and total energy consumption of 60.75 kWh per day. The waste of energy represented a loss of 400.95 kWh per month.

Fig. 1.4.5 Energy waste within company 2

Based on the results, some improvements were proposed. For example, for the cutting process it was suggested the purchase of a software and a plotter which would help to develop a more efficient cutting plan. Due to the high cost of these equipments (around US$ 57,434.40), the company has decided to not implement this idea.

The second proposal was to implement a training program which would give an idea of geometric figures and use of space in such a way that the cutting process could be carried out in a more efficient manner (level of housekeeping). Even if we would have some waste of materials (e.g. cotton, polyester etc) these could be classified for internal reuse. For example, pieces with an area of 600 cm^2 were destined to manufacture clothes for babies. If not possible, the spare material would be sold to craftsmen at the price of 0.45 US$ per kilogram (Please, see Fig. 1.4.6).

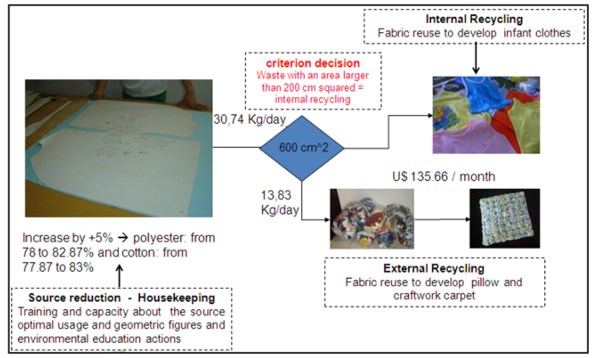

Fig. 1.4.6 CP System including source reduction, internal and external recycling

Once this proposal has been implemented, it was observed an increasing on the efficiency of the cutting process at the rate of 5% and reduction of the waste generated. It was also noticed that the internal material for reuse represented 55% of the total waste generated during the cutting process. Also, it was estimated a monthly income of US$ 135.66 for the company with the sales of recyclable waste to craftsmen.

In the printing sector, the proposed solutions were: the purchasing and replacement of the tap (housekeeping), purchasing and installation of a pressure washing equipment (technological change) and installation of cribs made in (technological change). The replacement of the tap which cost U$ 6.40 leaded to an economy of 48,000 l of water per year. The use of pressurized washer saved 35,420 l per month (70% according to manufacturer of equipment). The operating cost of the equipment was estimated at US$ 35.97 per month (including energy consumption). Thus, the monthly savings would be US$ 47.93 (US$ 607.87 annually).

Finally, it was proposed the use of two switches for each 6 “cradles” which led to an increasing in the efficiency of approximately 98%. It has to be stressed that the required investment was the purchase and installation of the switches at the cost of US$ 159.23. Unfortunately, the company has decided to implement this proposal later on during the plan for continuity.

Tables 1.4.5 and 1.4.6 present respectively the feasibility study and environmental characteristics of the improvement opportunities of Company 2.

From the results, it can be observed an increasing in the efficiency use of natural resources—water (70%) and fabric (5%); decreasing of effluents generated (71.23%). As a results, the annual savings was US$ 35,635.00.

Further proposals (continuing CP program) were: to install a wastewater treatment station to remove all chemicals; to purchase personal protective equipment; to hire a consultancy to perform labour gymnastics with all members of the staff; to purchase a software and a plotter for developing cutting plan; to organize meetings with ecoteam at each two weeks and to also organize monthly lectures concerning quality, safety and environment.

Six months after finishing the CP program a visit to the company was carried out. It was observed that the measures implemented were still in operation. However, few progress has been made regarding what has been initially established and no progress has been carried out in the continuing CP program, except meetings of ecotime (which became monthly, due to Increasing demands) and delivery of equipment to safe protection of staff.

Table 1.4.5 Feasibility study of the improvement opportunities within company 2

Critical points	Solution	Investment (US$)	Real or estimated income		Financial analysis		
			Monthly (US$)	Annually (FV) (US$)	NPV 1 (US$)	NPV 2 (US$)	Pay-back (Month)
Waste of fabrics usage (cotton and polyester)	Training of staff	191.08	2,736.77	34,709.10	−145,651.20	+8,612.41	10^{-5}
Waste of water—leaking	Purchasing and replacement of the tap	6.37	8.01	101.62	−90.18	+83.82	0.8
Waste of water—lack of plates washing control	Use of pressurized washer	159.24	47.93	607.87	−797.32	+380.22	3.4
Waste of energy usage	Purchase and installation of the switches	159.24	99.34	1,259.93	−1,118.12	+958.89	1.6
Total		515.92	2,892.06	36,678.53	−147,656.82	+10,035.32	–

NPV 1 Net Present Value of initial situation (situation encountered); *NPV 2* Net Present Value of situation proposed or modified; *FV* Future Value.

Table 1.4.6 Environmental characteristics of the improvement opportunities within company 2

Indicator	Unit	Initial situation	Situation modified
Average efficiency of the polyester and cotton usage	%	77.89	82.89
Amount of solid waste generated and disposed of in landfill (fabric)	Kg	873.84	0.00
Water consumption in the printing plates	m^3/month	53.55	15.18

4.2.3 Company 3

The first step of the diagnosis in the Company 3 was to identify all areas of waste generation in order to qualify and identify them as well as to understand their flow from generation to final disposal. It was observed that the solid waste generated at each sector was packed in non-standard pickups as well as that they did not have any kind of segregation and/or action for their reduction. When the collectors were filled up, they were emptied and their contents were dumped into the buckets. In fact, the company stored its waste in buckets placed on the sidewalk area which led to us to conclude that it was a serious risk for soil, contamination, specially on rainy days.

Table 1.4.7 presents the characterization of waste generated. From the results, it can be noticed that 2.05 tons of waste was generated per month and that 45.66% of them could be classified as recyclable waste (i.e. paper, cardboard and metal) which represented 939 kg per month. The remaining waste was classified as material without any possibility of reuse or recycling, such as rags, film for cars, air filters, disposable cups, food packaging, among others.

The sector that most contributed to the waste generation was the garage of the company which was responsible for 35.89% of the total (i.e. 738 kg per month). It has to be stressed that the garage was also responsible for the most generation of plastic (50.60% of the total) and metal (88.87% of the total) in the company. This can be explained by the fact that it is in this area where old parts of the vehicle are replaced by new ones. On the other hand, the shopping area for new parts and accessories was the largest contributor for generation of paper and cardboard (25.29% of the total). This occurs due to the fact that this sector supplies parts and accessories to the garage and body shop, retaining their packages.

Nevertheless, it can be observed that there is a potential action for the company to promote external recycling, mainly due to the increasing waste generation (more than 11 tons per year). Therefore, the indicator used for this approach was the amount of waste designated for external recycling.

Based on the type of waste generated at each sector and its mass and volume, it was selected different types of conditioners for each sector. The final outcome was to standardize this procedure. Therefore, the following code of colours was used: Blue for papers and cardboards; White for Plastic; Yellow for metal; Gray for non recyclable materials and Orange for plastic containers contaminated with oil.

The project involved 81 conditioners (14, 22 and 97 l) made of polypropylene as well as metal barrels made of reused package cleaned and painted (190 l each). An area for temporary storage with capacity of 9,700 l was also designated. This area was divided into four sections: paper and cardboard; plastics; metal and plastic containers contaminated with oil

Regarding to the potential for revenues arising from the sales of recyclable, it was concluded that the monthly income could be US$ 110.85.

Therefore, the analysis of economic viability was carried out considering the cost for purchasing the waste packagers (US$ 1,084.20), the cost for construction of a storage area (US$ 955,41) and the cost for training the employees (US$ 636,94). In addition, it was considered the monthly cost of US$ 802,55 for the final disposal of the waste (this because company 3 has to pay a licensed company to discharge non-recyclable waste). However, it is expected that there will be a possible reduction of 50% of this value during project implementation. From the results presented in Table 1.4.8 and considering an one-year horizon, the cost to dispose of waste at the landfill would be US$ 9,032.74. Once the project has been implemented, the annual cost of managing waste would decrease to US$ 5,945.34 (i.e. a reduction of 34% of the total cost and investment would be paid in 2.3 years) (Please see Table 1.4.8).

Aiming to become the company's employees environmentally aware and able to act in accordance with the procedures of waste segregation at source, it was performed a series of 10 hours of workshops and training on environmental aspects. In addition, several posters with environmental information were placed on strategic areas of the company and some theatrical plays were performed as well as some seeds of natives species were planted in order to also aware customers and employees.

It has to be stressed that after the implementation of these actions, the commercialization of recyclable material has increased considerably. According to analysis carried out from October 2007 to December 2008 18 tons of waste was destined for the external recycle. In other words, 11.3 tonnes were paper and cardboard, 2.4 tons of plastic and 4.6 tons of metal. In the first year, the average materials returned to the supply chain in the first year was 751.33 kg per month and in 2008, 1156.70 kg per month (figures higher than anticipated during the diagnosis). This increasing was attributed to a better participation of the stakeholders in the process and improvements on the infrastructure necessary to conserve the material. Regarding revenues, it was observed a proportional growth, allowing the company to gain an amount of US$ 1,547.04.

Tabela 1.4.7 Caracterização dos resíduos sólidos gerados pela Empresa 3

Waste	**Mass (Kg)**		
	Monthly	**Annually**	**%**
Paper/cardboard	508.8	6105.6	24.74
Plastic	364.6	4375.2	17.73
Metal	65.6	787.2	3.19
Material without any possibility of reuse or recycling	1,117.5	13410	54.34
Total	2,056.5	24678	100.00

Table 1.4.8 Feasibility study of the improvement opportunities within company 3

Investment (U$)	**Real or estimated income**		**Financial analysis**		
	Monthly (US$)	**Annually (FV) (US$)**	**NPV 1 (US$)**	**NPV 2 (US$)**	**Pay-back (Month)**
2676.56	110.85	1,405.82	−9,032.73	−5,945.34	27.8

5 Concluding Remarks

The present study aimed to evaluate CP as a tool for corporate sustainability based on a series of multiple case studies on companies at the Rio Grande do Norte State. The study examined environmental aspects among different industries on sectors responsible for waste generation. The study was based on technical and financial evaluation. As a result, it was possible to collect evidences and carry out discussions on how incorporate the environmental variable within the process of corporate management.

In the company 1, 19,800 breads were not manufactured annually due to the excess of water consumption above the technical specification. This was corrected with the use of a bucket which standardized the proper volume of water used. Energy consumption was also standardized resulting savings of 277 kWh per year. As a consequence, it was noticed savings of US$ 4,154.34 per year.

In Company 2, it was observed a loss of 10 tons per year of cotton and polyester due to problems on the cutting system. The solution was based on optimization of the cutting system as well as internal and external recycling. In addition, it was also optimized the consumption of water. In resume, the measures implemented have generated an annual savings of US$ 35,641.34.

Finally, in company 3, it was investigated the generation of two tons of waste per month, which were placed in the landfill, at a monthly cost of US$ 802.55. It was also observed that 45.66% of waste was recycled. Therefore, the project focused on the segregation of waste and sending this material for external recycling, resulting in a return of over 18 tonnes of waste for the production chain.

In general, it was observed that the waste generation increased due to the lack of knowledge by the owner/management on the environmental aspects as well as a lack of their vision on the need for rational use of resources. In addition, employees should be motivated to increase their awareness on environmental aspects.

It was also observed that significant part of the directors were reluctant when there was the need for higher values of funding to implement the project. This occurred even when economical and environmental advantages were presented. Based on this context, it was observed that even with the engagement of the ecoteam and employees as well as the presentation of technical and financial advantages the project can only be carried out with willingness and commitment of the directory board and external pressure (e.g. government, customers, investors, business partners, suppliers).

On the other hand, it is believed that the success of the project is associated with the simplicity of the opportunities implemented that brought significant results for the company, motivating the entrepreneur to force ecoteam and employees.

However, it was noticed that CP can be applied without any restriction on both industrial and service companies, bringing economic benefits (reduction of operating costs) as well as environmental (optimization of resources and reduction of waste) and social gains (gain environmental awareness, seeks to reduce risk to employees). These factors may show that CP can help companies to incorporate environmental and social attitude, as well as target in a better market position. Therefore, it can be concluded that CP can be used as a tool for corporate sustainability, once it continuously prevents the generation of waste and reduces the risks of operations, communities and environment.

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1.5 Sustainable Manufacturing: A Framework for Ontology Development

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Abstract

Ontologies provide an explicit and formal model of a given knowledge domain, allow knowledge sharing and reuse and are widely used in different applicative contexts. Knowledge can be reused and effectively exchanged at product, process, and system levels. Current sustainable manufacturing practices justify the interest in an in-depth study of this complex process of building ontologies. Few researches address the issue of structuring and integrating the existing corpus of knowledge concerning sustainability in the manufacturing context using ontologies. In this paper a conceptual framework is provided to support ontology development by structuring sustainability knowledge in the manufacturing domain.

Keywords:

Knowledge management, Ontology, Sustainable manufacturing

1 Introduction

Consumer demand, regulatory pressure and increasing resource demand have driven the desire for more sustainable products in the last decade. As a result, sustainability has become the revolution of the twenty-first Century. As a result, sustainability is being applied to manufacturing practices.

The evolution to sustainable manufacturing requires a fundamental paradigm shift. Instead of only focusing on economical performance, decision making should be have a much broader perspective to satisfy environmental, societal, and economic requirements; the so called “triple bottom line” (TBL) [1]. This requires transforming the traditional product life-cycle emphasis to a total life-cycle approach to reach the ideal case of closed-loop, near-perpetual material flow through multiple product life-cycles.

The subject of sustainable manufacturing has been widely addressed in scientific literature. Many various definitions and interpretations of the concepts of sustainability and sustainable manufacturing exist. However, a clear-cut and holistic understanding of these concepts still lacks.

Attaining a holistic understanding of sustainable manufacturing can be achieved by explicitly defining concepts and principles in order to implement a “sustainability corpus of knowledge”.

In the sustainable manufacturing domain, coherence and congruence are required in information exchange processes. Coherence addresses the completeness and validity of information, meaning that information sets should be complete and according to the purpose of their use. Congruence addresses the matter of usefulness and temporal significance of information. On the other hand, efficiency losses including lack of comprehension, misunderstanding and redundancy must be eliminated.

Therefore, the knowledge and information associated with sustainable manufacturing is becoming more and more complex. In this case, ontology can be used as a tool to model knowledge in the sustainable manufacturing domain to enable structuring, integrating and reusing knowledge and information.

The objective of this paper is to present a conceptual framework for the ontology development process in the sustainable manufacturing domain.

The paper starts by introducing sustainable manufacturing. Ontologies and their application in the manufacturing domain are then presented. Then a framework to apply ontology to the sustainable manufacturing domain is introduced. Finally, the details of the decisional space of the framework are discussed.

2 Sustainable Manufacturing

Sustainable manufacturing is defined as ‘the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound’ [2]. Sustainable manufacturing requires a deeper understanding of both sustainability concepts and manufacturing systems.

Understanding manufacturing systems is achieved by a holistic approach that integrates the three main facets: products, processes and systems as illustrated in Fig. 1.5.1. These three facets are interrelated; manufacturing processes transform materials into products. Processes and products are designed and managed through different manufacturing systems.

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Fig. 1.5.1 Three facets in sustainable manufacturing [3]

Products have four life-cycle stages: pre-manufacturing, manufacturing, use and post-use. Conventionally emphasis is placed on the first three life-cycle stages. Achieving sustainability TBL objectives requires going beyond the conventional approach and extending the emphasis to the total product life-cycle, including the post-use stage.

Another important concept in sustainable manufacturing is the application of the 6R methodology to reduce, reuse, recycle, recover, redesign and remanufacture [4]. This methodology promotes the total product life-cycle approach to enable the ideal case of achieving closed-loop material flow through multiple product life-cycles and achieve TBL objectives, as illustrated in Fig. 1.5.2.

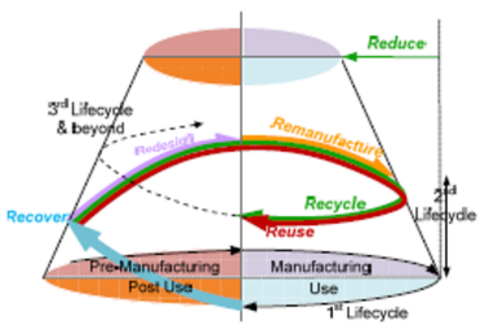

Fig. 1.5.2 Applying 6R throughout the total product life-cycle to achieve closed-loop material flow [5]

This integrated and holistic approach presented in this section is fundamental to sustainable manufacturing, and will be incorporated into the framework introduced next.

3 Ontology and Sustainable Manufacturing Domain

Gruber [6] defined ontology "an explicit specification of a conceptualization". Lately, Borst [7] updated Gruber's definition as "a formal specification of a shared conceptualization". The definition introduced by Neches [8] provides a list of ontology component parts: "the basic terms and relations including the vocabulary of a topic area as well as the rules for combining terms and relations to define extensions to the vocabulary". Ontologies are designed and used to improve communication between either humans or computers [9] and to enable knowledge sharing and reuse.

Pisanelli et al. [10] state that ontologies make knowledge reuse easier. They are the foundation of standardization efforts. Standardisation initiatives in the manufacturing context (e.g., STEP Standard [11] for products, IEC 62264 [12], for interoperability, Process Specification Language (PSL) [13] for manufacturing process information) merge heterogeneous information scattered within organizations and their IT applications by formalizing the knowledge related to products, manufacturing resources, and processes. This problem is related not only to how the information is managed, but also to what kind of information is needed at different stages of the manufacturing processes during product life-cycle. It is worth noting that the models in the previous reported standards provide formal definitions of basic concepts in a domain and the relationships among them, using a formal language [14].

In the manufacturing context, there have been some efforts in developing ontologies at different levels to support information exchange and reuse and enable the creation of new knowledge. A consistent number of ontologies developed in this domain are mainly taxonomies (i.e., particular classifications arranged in a hierarchical structure and organized by generalization-specialization relationships or parent-child relationships). Research that reaches the effective development of a formal ontology still lacks.

Lemaignan et al. [15] propose MASON (MAnufacturing's Semantics Ontology), an upper ontology (or top-level ontology, i.e., an ontology which describes very general concepts that are similar across the knowledge domain) for manufacturing. It has been built upon three head concepts: entities, operations, and resources. The main applications of the MASON ontology are to develop architectures and tools for automatic cost estimation and to link a high level ontology with a multi-agent framework for manufacturing simulation.

To achieve an effective and efficient support to product design decisions, Wang and Tong [16] propose an ontological approach to analyze manufacturing knowledge needed in design decisions. They develop an ontology in the domain of manufacturing knowledge with the intention to investigate its application in different design activities such as marketing, maintenance, and finance.

Ontology-driven solutions can be adopted to overcome difficulties in customer requirement identification and production knowledge interoperability, sharing, and developing. Zhou and Dieng-Kuntz [17] developed their top-level manufacturing ontology starting from the analysis of manufacturing knowledge characteristics embedded in products and composed by explicit, implicit, and potential manufacturing knowledge.

Knowledge management in industrial scenarios, instead of modelling, has been the objective of the Know-Ont ontology [18]. The proposed ontology was used to provide reusability of stored information in an efficient and effective way.

Few valuable attempts have been made in the sustainable manufacturing domain (see e.g. [19]).

3.1 The Structure of the Framework

Ontologies present a new methodology of formalizing knowledge over a specific domain. They enable knowledge sharing and allow newcomers to acquaint with the concepts and elements in a given domain. Born for information and communication technologies (ICT) applications, ontologies can be extended to the human realm, presenting a potential tool of measuring, comparing, and deciding for human actors.

The use of ontology may represent an extraordinary opportunity to spread the sustainability culture by transferring all the relevant concepts. It is possible to figure out the requirements an ontology might satisfy by specifying the possible use-cases of its instantiated version:

(1) *The transaction between an economic operator with its supplier in its search for reducing the environmental impact*: ontologies should provide elements to evaluate, give possible performance measures, provide a list of requirements to be satisfied whenever at least two suppliers with different cultures and technical capability share the same goal of producing a component or design/redesign a process for sustainability.

(2) *The selection between different technological processes*: ontologies should identify those technological variables impacting sustainability. It is expected that ontologies provide a framework for assessment, providing all those performance criteria that have to be translated into appropriate indicators by the decision maker.

(3) *The selection of the most appropriate technology for a product/process*: ontologies should provide a frame to outline elements to be evaluated. Ontologies should help derive decisional evidence for changing or assessing adequate and non-adequate components.

In the three use-cases highlighted, it is evident that the key role ontologies for sustainability play is decisional support: it is always the true scope, independent of ICT tools.

4 The Components of the Conceptual Framework for Sustainability

Ontologies are semantic structures encoding concepts, relations, and axioms, providing a model of a given domain; their structure might change according to the different contexts of use.

The main goal in designing and applying the framework proposed in this paper is to explicitly define the corpus of knowledge available on sustainable manufacturing up to date. The challenge is to develop a tool that is flexible enough to support designing ontologies for sustainability in a variety of applications and different modelling objectives.

This framework consists of two dimensions: *perspectives (What's)* and *aspects (Where's)* and *also* a third independent dimension, the *requirements (How's)*. The intersection of these dimensions results in ontologies that support a range of decisions related to sustainable manufacturing, such as:

- comparative analysis of sustainability policies in considered domains;
- evaluation of manufacturing processes within a given system;
- identification of strategic manufacturing industries;
- analysis of the environmental impact of new manufacturing industries on a geographical area;
- evaluation of policy incentives to attract desired manufacturing industry to a state or community.

In the next section, these dimensions are explained in detail.

4.1 The First Dimension: The Perspectives (W_i)

Similar to several approaches developed so far, the sustainability framework is based on three major elements in the TBL approach [20]. Each element represents the "What's" (W_i), meaning those concepts, actors or relationships that should be considered in its design and implementation of ontology for manufacturing sustainability.

A slight variation of the classical TBL is introduced here, by extending the "economic" element to the "functional" element. This point, which may seem trivial at first glance, offers a different concept of sustainability. The economic element brings a monetary meaning, which may be dangerous when focusing on sustainability. Referring to a functional line concentrates on needs instead, which ultimately are linked to the resource depletion. The translation into monetary value can be affected by several other factors not strictly related to sustainability (say, e.g., market fluctuations, speculations, etc.). By referring to functions it is easier to focus on the true features of products/processes, thus allowing the ontology to contribute to the objectives of sustainability.

To better structure the ontology, the proposed framework contains a further level of deployment. This level contains aspects to be considered within each perspective. This first level of details was provided according to literature on manufacturing sustainability. As a further specification to better help the ontology designer, this level defines requirements, or fundamental concepts to take into account.

For instance, the systemic aspect within the environmental perspective means that the ontology must consider the relations of parameters critical to sustainability in all the manufacturing processes (or systems or product). An example of the systemic aspect is to consider the potential effects of a lubrication strategy through the product life-cycle or its precedent and/or subsequent manufacturing operations: a lubricant might leave traces that may produce pollutant in a heat treatment process, or may require additional operations to be removed. The perspectives are presented in Table 1.5.1.

Table 1.5.1 The perspectives (W_j)

W_1 = Environmental	Raw materials and energy. Each manufacturing activity needs to relate to a process which transforms materials or energy in different forms. Ontologies for sustainability need to explicitly define this kind of information.
W_2 = Social	Living communities and nature that we share. Societal aspects cannot be forgotten because sustainability concepts embed the idea of human-kind survival. These aspects should include any effect of manufacturing on humans, such as safety, pollution, etc.
W_3 = Functional	By referring to the functional element of processes and products, true aspects of sustainability are realized. Some authors also mention "capability" referring to selling remanufactured products [20].

It is also easy to get sound financial information once referring to functions, since cost or revenues are easier to evaluate when appreciating to what extent a product satisfies a customer's need. In this sense, profitability can be measured from the extent a product is able to satisfy all the explicit functional requirements of the customers, or even from implicit ones. It is also evident the functional element is interrelated to the other elements. For example, a higher profitability with a poor functional performance is the effect of actions related to the societal element, e.g., poor products sold by force or by other malicious actions.

4.2 The Second Dimension: The Aspects (Wh_j)

Aspects represent the facets that explain the context of applications that are related to sustainability concerns. They correspond to the WHERE (Wh_j) in the decisional process of ontology building, as shown in Table 1.5.2. Most of these where derived from the literature analysed on eco-approaches in a wide sense (see, e.g. [21, 22]) other are quite original and come from different fields [23]. Despite are a good synthesis of the existing corpus of knowledge on the field, these are not intended to be complete. It is although questionable if other aspect are possible, since these are general enough to be exhaustive of all the possible contexts.

Table 1.5.2 The aspects (Wh_j)

Wh_1 = Systemic view	Addresses the system's theory outcomes, stressing the synergic/de-synergic effects of elements to be considered
Wh_2 = Organisational	Refers to recognition of the relevance of human subsystems to sustainability concern
Wh_3 = Life-cycle orientation	A necessity in any sustainable application
Wh_4 = Pro-activity	Necessary given the new wave of intelligence embedded in systems
Wh_5 = Bio-compatibility	Stems from closeness to the natural approach in managing complex systems

4.3 The Third Dimension: The Requirements (H_k)

The framework also includes a third dimension, not truly related to the others. It represents the principles and rules that have been frequently adopted to assure sustainability (the "How's"—H_k). Building an ontology requires taking into account at least one or more of the hot spots listed, i.e., allowing concepts or relationships to consider these critical points. The resulting ontology will surely satisfy the sustainability scopes.

A list of these How's are here explained in detail in Table 1.5.3, providing a number of hot spots based on the referred literature. They are presented to assist ontology designers.

These requirements (H_k) need to be cross-checked with the perspectives and aspects, thus conditioning decisions in a given context. Let's take, as an example, the H_4 "Quantitative approach": the statement following is that the ontology should provide means to measure the bio-compatibility aspect of a product/process (Wh_5).

5 The Decisional Space of the Framework

Deploying the three dimensions into an ontology assures the appropriate context of relationship amongst W_i and Wh_j so it becomes feasible to draw congruent conclusions upon the conditioning of the H_k dimension.

Table 1.5.3 The requirements (H_k)

H_1 = Optimisation orientation Operating condition monitoring; resource consumption orientation; physical output parameters; dematerialisation; substitution; multi-objective design; hybrid techniques, non-linear strategies; I.A. approaches (e.g., genetic algorithms, uncertainty reasoning;); structural equation modelling .
H_2 = Addressing physical aspects The ability to model physical phenomena, which is not a trivial task in an ontology modelling information (inherently discrete). This aspect is important since it pertains to exploring the true nature of sustainable processes. Some hot spots are technology oriented (for taking into account explicitly all the technological features which are behind any process or product); up-to-date equipments or machine tools; process related initiatives /input substitution; process design; embodied product energy.
H_3 = Supporting decisions It is critical for an ontology to highlight decisional processes and their variables, since these are the most critical points to consider and are rarely made explicit in ontological works. Hot spots are: theoretical science-based modelling; simulations; experiment based; performance-based criteria; green engineering design rules [21]; root cause analysis; source identification process; opportunity identification (summary; key mechanisms; strength; weakness); design inclusiveness review; design opportunity identification; uncertainty reasoning; option generation and alternative selection; scenarios analysis; knowledge conceptual framing; sustainable enabler recognition; best application domain; "counterfactual scenario" analysis; prospective/retrospective analysis.
H_4 = quantitative approaches Key performance assessment; condition indicators; sector data collection; cost oriented comparisons; exergy; impact assessment; life-cycle metrics, eco-efficiency analysis; hybrid analysis (LCA and I/O analysis); integration degree of tasks.
H_5 = satisfy the 6R principles These are the golden rules for sustainable manufacturing, deriving from the 6R's approach [4]. All these principles, in fact, have in common the idea of extending the useful functions of a good as longer as possible in the future. The concept introduced in the framework force to evaluate also that innovative part of processes which can be very effective for sustainability.

In general, the decisional space is made of a set of elements:

$$D_{ij,k} = f\left[\left(W_i, Wh_j, W_i \cap Wh_j\right) \perp H_k\right] \forall i, j, k$$

Where the decision ($D_{ij,k}$) in building an ontology should be driven as a function of the *i*-th *What* (W_i) and of a *j*-th *Where* (Wh_j) but with the constraint of *k*-th How (H_k). How's conditions have no intersection at all with the elements of the other two dimensions, even though the How's represent a constraint.

Since the first two dimension of the framework can rarely be considered independent of each other, so it is necessary to deploy the overlapping decisional region—the use case sound decision—in the final ontology design choices.

Figure 1.5.3 reports the pertinence of the third dimension upon the intersections of the other two dimensions. The overlapping elements (H_3, H_4 and H_5) holds for all the intersections, while the other two mostly pertain the rows indicated.

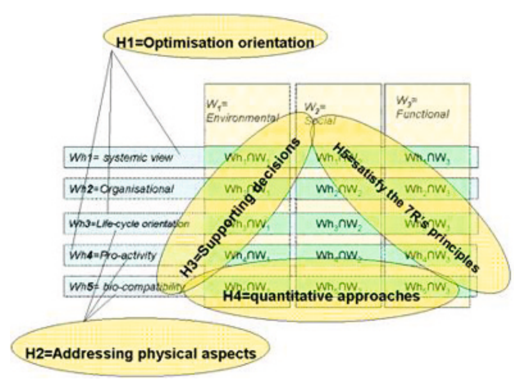

Fig. 1.5.3 Relational maps amongst dimensions

5.1 Deploying the Sustainable Knowledge

This section recognises and extracts the sound principles, concepts, and original ideas conceived to support sustainability so far. These were synthesised from a number of papers and scientific works available on manufacturing sustainability, not necessarily related to ontology building.

In order to provide effective decision support, meaning of the intersections of the first two dimensions (namely W_i and Wh_j) are explained.

Environmental perspective:

- **Systemic view aspect**: belongs to the "principle of ecosphere" presented in [24]. Events are always interrelated in nature: "side effects" should be considered. To a certain extent this aspect embraces the "planet orientation" point of view that several authors claim to be a very effective approach to sustainability.
- **Organizational aspect:** processes are performed by organisations made of humans and cultures that make sensible choices for the environment.
- **Life-cycle aspect:** life-cycle in this perspective addresses all those physical element of a product life that impact on environment.
- **Pro-activity aspect:** forces ontology designers to go beyond the conservative attitude, searching for best practices that are eventually implemented.
- **Bio-compatibility aspect:** concentrates on those aspects that tend to a perpetual compatibility of products with the environment.

Table 1.5.4 The corpus of sustainable knowledge from the point-of-view of the framework

	W₁ **= Environmental**	***W₂*** **= Social**	***W₃*** **= Functional**
Wh₁ **= Systemi cview**	Butterfly effect analysis; industrial system perspective; eco-system perspective; different system interrelationships; multivariate problem analysis; scale-up; multi-scale and scale-out effects; constraint reasoning or back casting	Sustainable marketing; market forces; anthropogenic impacts such as growing economies, cultural opportunities, immigration policies, spreading proneness or opportunities, input/output analysis	Effect throughout the whole supply chain; evolutionary approach for settings; sector pro and cons; process integration; unified frameworks; time dependency; counter-measure analysis. Also functions interrelationships aspects fall in this list, since products/processes tend to satisfy multiple functions. Each function might strongly affect others, making the whole process or product design unfeasible due to these interrelations (PLM/CAD/Interoperability aspect of data management)
Wh₂ **= Organiz ation**	Attitudes; management styles or visions; total quality environment management	Management & business practices; supply chain management; interoperability; corporate social responsibility; purchasing subcontracting strategies; worker commitment; lines of authority and responsibility; symbiotic approach; zero value discharge thinking	Management strategies (material flows; zero waste or discharge); process flow analysis; systematic review; documentation; paradigms orientation (e.g. product ownership; capability sale, distributed manufacturing; new business models; industrial, symbiosis etc.); process/plant reconfiguration strategy; reverse logistic; lean/clean technologies. Production strategies (feasibility/ viability oriented; X for disassembly; standardization (minimum energy consumption process); modularization; best available technologies (e.g. scale problems in machining); functional-unit based; near-net shape; design for manufacturability; material intensity reduction, design for energy minimization
Wh₃ **= Life Cycle**	Environmental impact; hot-spotting (prioritization); inventory analysis; environmental characterization; resource depletion forecasting, overall cost of disposal; robustness to destabilization; bio-staticity or bio-stability	Health hazards; economical opportunities for groups; training programs; taxation policies; work environment stress; commercial viability; operational safety; personnel health; responsible care strategies. Stakeholder aspect: goal explicating; sharing scopes; quality orientation; synergy w/ communities; why-needs analysis; consensus building, intra- and inter-generational equity, etc	Concurrent design; integrating logistics; feedback from end-user; design for re-manufacturing, design for adaptation, product life-span extension
Wh₄ **= Pro-activity**	Risk assessment; flexibility in use; pollution reduction strategies (air emissions, liquid effluent, waste streams); renewability features; multi-functionality of material	Dynamical nature of events; attitude and perception analysis; attitude and perception analysis	Prevention and/or anticipation approaches; application specificity, recognize critical differences amongst applications; legal concern; avoid unnatural rate of changes in concentration, reduction, etc.; impact sensitivity; problem reversing; recycling strategy (up-cycling; down-cycling), virtual design; pro-active control systems of contaminations. Product/process/system innovation: bio-mimicry; reconditioning traditional processes (hybrid energy integration); benign-by-design; new materials; industrial ecology; cyclic systems; technological strategies, use-intensity of products, modularity, convertibility, diagnosability, customer-driven adaptability, integrability, customization, etc
Wh₅ **=** ***Bio-compatibility***	Bio-based raw materials; renewable materials; bio-product; bioprocesses, biodegradability; eco-toxicity; bio-accumulability; bio-stability	Biodiversity preservation; growth models; mortality rates; local footprint concern; carcinogenicity /mutagenicity /teratogenicity/ allergenicity requirements; water endangering	Renewable sources; biodegradability; material biocompatibility; bio-based process (e.g. environmental /adaptable/friendly/ compatible lubricants), nature productivity of products

Societal perspective:

- **Systemic view aspect:** manufacturing is not an isolated activity but it is immerged into a social substrate. The effect of its activities reflects on societal aspects; these factors could be encompassed into ontology.
- **Organisational aspect:** there are a number of organisational issues affecting the welfare and the social equilibrium that should not be neglected, provided that the ontology we are looking for is a "cultural mediator" and not only a mere concept translator.
- **Welfare aspect:** almost equivalent to that of a life-cycle, since from a society point of view the cycle of life is strictly related to the state of welfare of the population.
- **Pro-activity aspect:** it is important to consider the dynamic nature of events that might by affected defining the interrelation between perspectives by modes or contingent subjective situations.
- **Bio-compatibility aspect:** strictly related to the Natural step framework [25], for sustainable development.

Functional perspective:

- **Systemic view aspect:** represents the correlation with other functions which are not always independent.
- **Organisational aspect:** concerns the strategies enterprises put into practice to satisfy customer needs
- **Life-cycle aspect:** functions that strongly influence the life of a products and vice-versa.
- **Pro-activity aspect:** considers functions needed to anticipate problems and risks.
- **Bio-compatibility aspect:** innovation by assuring functional requirements are always encouraged.

Table 1.5.4 offers a synthetic overview of the reports found in the literature related to sustainability, clustered according to intersections of the first two dimensions. The overview represents to a certain extent the proof of the validity and necessity of the framework presented given the amount of knowledge available on the topic of sustainable manufacturing. This framework can be applied when in building an ontology for sustainability.

6 Conclusions

The development of ontologies and real applications systems for sustainable manufacturing could give the chance to reach a better and complete understanding of the total value created in the TBL.

The framework proposed here is a viable tool to support modelling ontologies for sustainable manufacturing with different levels of details (from a general ontology to a more detailed one). It provides a methodology by providing a set of perspectives, aspects and rules to be considered whenever developing an ontology for sustainable manufacturing.

A clear proof of the need for a systematic view of the corpus of knowledge available is provided by classifying most of the approaches developed so far from the sustainable literature.

Future development of the presented research is ongoing to incorporate all the existing models and to translate these into an applicable use-case framework.

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1.6 Value Creation Model for Internationalization–Reducing Risks and Breaking Down Barriers

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Abstract

The participation in a promising international market provides a great opportunity for companies to increase their profit and growth, but also hides many risks. These risks can mean especially for small and medium enterprises (SME) the end of their existence, because of their limited experience and resources. Product, process and qualification are the main elements of the company's value creation and competitive advantage. In this paper an internationalization model will be presented as a tool to support companies to use the opportunities of growing through internationalizing their value creation and at the same time to avoid most of the associated risks. An implementation of this model has been conducted at Siemens AG, medium voltage components business unit.

Keywords:

Internationalization model, Qualifications, Scenario, Value creation

1 Introduction

Objective of economic activities is the satisfaction of human needs with the limited earth's resources. For fulfilling these needs and hence for wealth creation the manifestations of economic life were formed e.g. exchange, division of work, companies, markets and competition [1]. The center of economic life and of wealth is so far concentrated on about 1 billion people in developed countries like Western Europe, North America and Japan. China with its population of 1.3 billion and India with 1.1 as well as other developing and emerging countries are striving to catch up [2]. This calls the following challenges to be coped:

- Excessive resources consumption
- Economic life shift in form of market and competition

The excessive consumption of resources forces companies worldwide to improve their own value creation chain with focus on sustainable aspects in all three dimensions of economical, ecological and social. The Shift of the economic life in form of market and competition and the saturation of domestic markets in developed countries create a new competitive situation, which forces companies all over the world to participate in these promising markets (international markets) in order to ensure their growth.

2 Internationalization for Sustainability

The United Nations has defined sustainable development as "meets the needs of the present without compromising the ability of future generations to meet their own needs" [3]. At the 2005 World Summit it was noted that this requires the reconciliation of environmental, social and economic demands—the "three pillars" of sustainability [4]. Internationalization captures the essence of the UN definition of sustainable development by the contribution of developing countries in the chain of the value creation, hence improving the standard of living.

Therefore, internationalization of sustainable manufacturing can be seen as the creation of manufactured products which are produced in cooperation with different countries in order to promote international coherence and consistency for enhancing the financial profitability, the environmental integrity and the social equity. This concept can help companies to analyze their current products and processes, to innovate, and to identify new sources of revenue and cost reduction. With issues such as global climate change, dwindling natural resources, and deteriorating public health, at the same time improving international financial and technical cooperation to reduce the gap between developed and emerging countries.

3 International Markets

International markets are not only expanding business opportunities, they are also intensifying competitive pressure and causing the center of economic gravity to shift to new locations. In the years ahead, the economies of the so called BRIC countries—Brazil, Russia, India and China—are expected to grow twice as fast as those of their industrialized counterparts [5]. To ensure the long term existence of each and every company, the current market economy and the competitive situation also require that a company is growing with respect to its volume and its profitability [1, 6]. To achieve this goal companies intended to enter a new market must realize the barriers, risks, and should have a structured plan for entering the new market.

3.1 Barriers

The realization of company's profitable growth by serving the worldwide markets through export business is limited because of the market entry barriers. The biggest part of these barriers cannot be influenced by a single company, because generally they are constructed by competitors and the regulatory authorities [7–9]. With reference to [7, 9–13] some of the most common market entry barriers are as shown below:

- Import and export duties
- Local-Content-Regulations
- Currency effects
- Pricing rules

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- Price wars between competitors
- Demand behavior
- Nationalism
- Special standards

Worldwide active companies cannot change anything on the creation or the existence of market entry barriers. So the target is to break down the barriers for having unrestricted access to new foreign markets and hence to allow more profitable growth. This often means that parts of the value creation to be distributed on the foreign markets [6, 7]. Especially the local production in foreign markets can break down many barriers like local-content-regulations, import and export duties and currency effects [7, 14].

3.2 Risks

The successes and failures of internationalization may have very different reasons. One main reason are the existing risks of international activities e.g. production in international markets. According to a survey by the Fraunhofer Institute for Systems and Innovation Research (Fraunhofer ISI) and the Federal Ministry of Education and Research the following risks of international activities and production were the main result [11, 15]:

- Quality risks (Product, Process)
- Know-how- loss/-flow (staff turnover)
- Productivity of foreign locations
- Costs of production factors
- Staff qualifications
- Supplier quality
- Flexibility and ability to deliver
- Overestimation of the local market potential
- Cultural barriers

For SMEs the mentioned risks may mean the end of their existence, because of the very high efforts they have to invest in internationalizing parts of their value creation compared with their available resources [16].

4 Internationalizing the Engineering Qualifications

Engineers, whether working abroad or at home, play a critical role in addressing the above mentioned internationalization challenges. They need to have broad engineering qualifications and practical know-how, theoretical know-why, and strategic know what [17]. The knowledge, skill, or ability that makes someone eligible for a duty refers to professional qualifications. Professional qualification divided into three major elements: hard, soft and internationalization qualifications [18].

The strength of the person in possessing these qualifications, determine the successful performance of the tasks assigned to him. These three elements are not completely isolated, there is an interaction between them as shown in Fig. 1.6.1. The overlapped sections mean that the qualifications needed in the domestic market could be similar to the one needed in the foreign market with some adaptation according the specific country. For example, communication skill could be represented in the soft as well as in the internationalization part. On the other hand the skills needed for the communication in the local market is not similar to the one needed in the international market.

4.1 Hard Qualifications

Hard qualifications are the technical and managerial requirements of a job. They are specific abilities that can be defined, taught and measured. For example quality management, milling, solid-works. Hard qualifications enable the engineer to be technically flexible in designing and constructing a product/process that meet the foreign market demand. Engineer who has a broad knowledge of the hard qualifications can propose a better design considering the constraints in the foreign market.

Fig. 1.6.1 Components of professional qualifications

4.2 Soft Qualifications

Soft qualifications refer to the personal qualities and interpersonal skills, such as self-management and ability to participate as a member of a team. Contrast to the hard qualifications, soft qualifications are less tangible and harder to quantify. Engineers who possess these qualifications can be successfully build relations and communicate with the colleagues, customers and suppliers, hence meet the expectations.

4.3 Internationalization Qualifications

Staffs working with an internationalized company should possess extra qualification than their peer in a domestic company. Internationalization qualification means the capacity, knowledge, or skill that makes them eligible for working in another different country. The internationalization qualifications could be related to the main contents of any country as below:

- Environment such as physical adaptability and flexibility
- Government such as knowledge of the government regulations and incentives
- People such as acceptance of different culture, behavioral flexibility
- Market, such as knowledge of the market demand and competitions.

5 Internationalization Strategies

Internationalization strategy stands for *a model, an approach or a procedure to support the growth in various international* *markets*. In literature as shown in Fig. 1.6.2, the most common internationalization strategies are based on motivations of internationalization (e.g. market development strategy, cost reduction strategy, customer following strategy). [6, 19] the market entry forms (e.g. export, license, joint venture) [12, 20], or taken into consideration many factors in the worldwide Location Search to avoid as many risks as possible [7, 11].

5.1 Motivation Strategy

Motivation strategy stands for following a specific target with the internationalization activity. Every company has its motivation for internationalizing parts of its value creation. A survey by the Fraunhofer ISI shows that the most common motivations for any international activity are [11, 15]:

- Cost reduction
- Market development
- Close to great and key customers
- Technology development

Based on these motivations the following strategies has been defined [6, 7, 19]:

- Cost reduction strategy
- Market development strategy
- Customer following strategy
- Technology development strategy

The strategies based on motivations show, that each strategy follows a specific target with the internationalization, but it is up to each and every company how to internationalize. That means there is no guideline, which shows the companies how to internationalize to assure the set company targets.

5.2 Market Entry form Strategy

The market entry form strategy stands for the form of entering new markets. The most common entry forms are [12, 20]:

- Export
- License
- Franchise
- Joint Venture
- Subsidiary company

The entry forms describe how a company enters a new market especially international market. The entry form has to be determined depending on the regulations in targeted markets.

Market entry barriers, risks, market size and competitive situation to be considered in the determination of the market entry form. It is necessary to define the entry form, which helps breaking down most of the barriers (e.g. local-content-regulations), avoiding or distributing risks on different partners, being competitive in great markets with strong competition.

The market entry form strategy shows how to enter the market, e.g. with or without partner, with or without high investment, but also this give no guideline for internationalizing parts of company’s value creation.

5.3 Location Strategy

Location strategy stands for a location search, taken into consideration the most effecting factors [7], e.g.

- Market size
- Market potential
- Infrastructure
- Political stability and regulations
- Availability of staff and supplier
- Risks (quality, know-how-loss, costs)
- Competition

Target of the location search strategy is the definition and the consideration of most of the effecting factors in advance to enable the company avoiding most of the risks and to assure a better chance for a successful internationalization.

An extensive location search is a very important step for the internationalization process, but it is not enough to be guideline for how to internationalize.

Fig. 1.6.2 Internationalization strategies

The above mentioned strategies are concentrated on the big picture of the internationalization. It is necessary to integrate the value creation elements of each company in the internationalization activities to be able to act flexible with respect to the existing challenges (risks and barriers).

6 Internationalization Scenario

Profit and growth are the driving force for the companies to enter a new market. Barriers as discussed in Sect. 3.1 restrict the entrance of these new international markets. To break down these barriers companies have to shift some of their value creation elements (product, process, qualification) to the international markets. This normally ends up with some risks as discussed in Sect. 3.2, which could threat the existence of the company especially SMEs.

Fig. 1.6.3 Internationalization scenario

To avoid most of these risks companies must have strategies and models as tools for internationalization to assure goals achievement and risks avoidance at the same time. The internationalization scenario is shown in Fig. 1.6.3.

7 Value Creation Model (VCM)

Driven by the requirements of today's globalized competition in term of growth and profit, companies increasingly are concentrated on their core/know-how competencies for value creation. They organize themselves in value creation networks, thus, dividing value adding tasks among each other according to different criteria, which can be found in the factors of value creation. The factors of value creation represent the factors of industrial value creation which inseparable tied to each other. These are products, processes, production equipment and organization as well as the humans involved, representing Who, What, How, By what, Where and When, which have been denoted as a VCM (Fig. 1.6.4) [2]. The configuration of the potential improvement of the VCM factors' is the first step for improving the company competitive advantage in the international and national market.

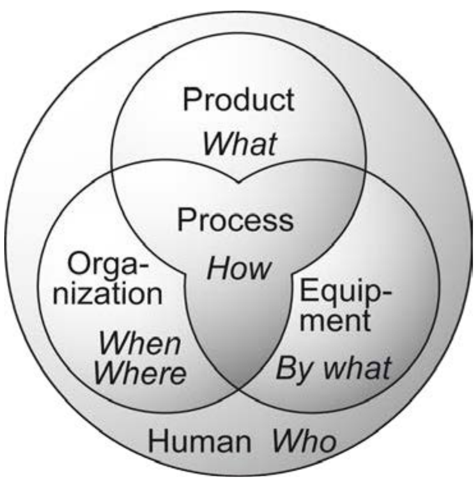

Fig. 1.6.4 Value creation module [2]

In this paper, we concentrate mainly on the company's know-how elements which are the products, processes and qualifications. Know-how stands for high knowledge and experience that assure quality and functionality of the product additionally to a high productivity and quality of the production. Know-how can be considered as a competitive advantage of a company which differentiates it from other companies. For any internationalization activity, major decisions are related to the mentioned elements for example:

- Which product to internationalize?
- Which process to internationalize?
- What qualifications are needed in home and foreign location?
- How to qualify foreign staff to assure product and process quality in foreign location?
- How to qualify people in home country and to prepare them to work deeply with foreign colleagues?

8 Value Creation Model (VCM) for Internationalization

After determination of the preferred market location and the type of the market entry form, it is necessary for the company to decide which product, process and qualification to be transferred to the local market. Therefore the value creation model for internationalization consists of these three elements, which are connected together as several value creation modules as will be discussed later. Purpose of the model is to have a guideline to support companies, especially SMEs in their internationalization process. Target is enabling companies to act flexible with all changes and conditions in international markets. Focus to be mainly on breaking down barriers, avoiding most of the risks and at the same time achieving set targets.

8.1 Elements of the VCM for Internationalization

The model is based on three elements that are product, process, and qualification. The relation between these three elements is similar to the relation between the component of a complete sentence (subject, verb and object) i.e. the product is considered as an object of improvement efforts, qualifications as the subject by whom the products are made, and finally the process as a verb or the tool needed to perform the job (Fig. 1.6.5).

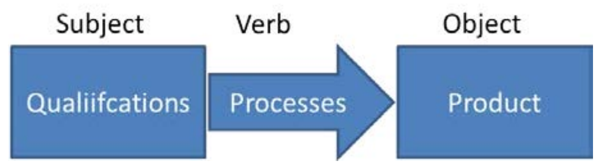

Fig. 1.6.5: Elements of value creation model for internationalization

These three elements have been selected because each risk discussed in Chap. 2.2 has a direct relation to one or more of these elements as shown in the matrix below Table 1.6.1, while the other two elements of the VCM organization and equipment have a very weak relation to the existing risks of internationalization. For the companies to enter successfully the new market, it is necessary to act flexibly with these risks.

Table 1.6.1 Elements and risks correlation matrix

Elements \ Risk	Quality	Know-how	Productivity	Costs	Staff qualifications	Supplier quality	Flexibility	Market Overestimation	Cultural
Product	●	●	O	●	●	●	●	O	Δ
Processes	●	●	●	●	●	●	●	Δ	Δ
Qualifications	●	●	●	●	●	Δ	●	Δ	●
Organization	Δ	O	O	Δ	O	Δ	●	Δ	O
Equipment	Δ	Δ	O	O	Δ	Δ	O	Δ	Δ

Interrelationship matrix
● Strong relationship
O Medium relationship
Δ Weak relationship

The model consists of several value creation modules. Each module includes a product component, its related processes and the associated qualification for each process. The modules are weighted according to the main risks, which at the same time can also be called as success factors. Success factor stand for factors influencing the internationalization process and effecting a successful internationalization of a company. After weighting these modules, the company can decide which modules to be kept in the home location and which one to be transferred to the target country market in order to overcome the barriers of entering the new market and to reduce the risks associated.

8.2 Value Creation Modules Construction

In this section a step by step procedure for constructing the value creation model will be discussed. The model to be created in the following steps:

1. Constructing the Bill of Material (BOM) to identify the product components (product components are product groups which can be handled independent from each other, that means they can be produced in different locations to be assembled later to one product)
2. Likert-type* scale weighting of the product components based on the product know-how (product know-how stands for high level of knowledge to assure functionality and quality of a product).
3. Definition of necessary process steps for production of the whole product
4. Likert-type* scale weighting of process steps based on the production know-how (production know-how stands for a high level of knowledge and experience to assure a high productivity and quality of the production)
5. Definition of the necessary qualification for each process step
6. Determination of the relation between product components and process steps and the associated qualifications
7. Each product component including its related processes and qualifications to be considered as one value creation module
8. The importance of each value creation module can be determined by multiplying the weight of the product component by the weights of each process step, that gives a total score for each value creation module
9. The value creation modules are weighted again according to the related value add costs (the difference between the raw material and the final product cost)

The total score of each module determines which module can be internationalized with lower risk, and the contribution percentage of the value add cost of each module determines the biggest cost advantage achieved through internationalization.

*The weighting of the product components and the process steps based on the five-level Lickert-type scale:

1. Not important
2. Slightly important
3. Moderate important
4. Important
5. Strongly important

9 Model Implementation

In cooperation with Siemens AG, Medium Voltage Components business segment, the value creation model for internationalization was tested with the SIMOPRIME medium voltage switchgear. SIMOPRIME is an Air-Insulated Switchgear, which is used from Siemens for Partnering (License business).

Medium voltage switchgears are used for current distribution in substations and power stations. The medium voltage level is from more than 1kV up to 52kV. The switchgears are used for securing the distribution of the current from energy generation to the end user. They switch automatically in case of any interference in the distribution network to minimize the off time and they can be isolated and earthed for maintenance. The picture shows a sectional view of one SIMOPRIME switchgear panel (Fig. 1.6.6).

Fig. 1.6.6 SIMOPRIME medium voltage switchgear (Siemens AG)

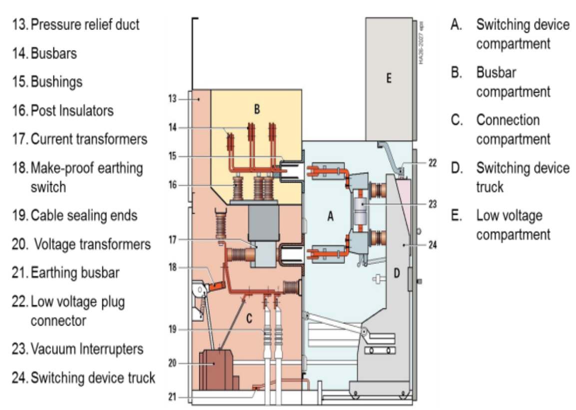

Fig. 1.6.7 Bill of material for SIMOPRIME (Siemens AG)

The drawing of the SIMOPRIME panel in Fig. 1.6.7 shows all main product parts of such switchgear. For creating the model, it is necessary to have the bill of material. For this reason the panel was divided into 11 product components out of a big number of materials. The division took place based on the functionality of each product component and its interdependency as one production unit as shown in the matrix below (Table 1.6.2).

Table 1.6.2 Value creation modules matrix

SIMOPRIME Medium Voltage Switchgear (Siemens AG)			Product Component Weighting	Process Steps: Engineering / Configurtion	Pre-Fabrication: Sheet Metal Work	Pre-Fabrication: Machining	Pre-Fabrication: Copper Processing	Pre-Fabrication: Welding	Pre-Fabrication: Cast Resin Production	Pre-Fabrication: Galvanizing	Pre-Fabrication: Painting	Pre-Fabrication: Vacuum Oven	Pre-Fabrication: Specialized Parts Prodcution (e.g. current strips, shock absorber)	Wiring	Assembly	Testing: Mechanical	Testing: High Voltage	Shipping Preparation	Total Score	% Costs (Value add)
Process Weighting				3	1	1	1	2	4	2	1	5	4	2	1	3	3	1		
Product Components: Switching Device Compartment		Switch Truck	1		1			2			1				1				5	3
	Vacuum circuit breaker	Drive Mechanism	3		3	3	3	6		6	3		12	6	3				45	10
		Pole with Vacuum Interrupter	5			5	5	10	20	10		25	20		5				100	20
Busbar Compartment		Busbar	1				1												1	7
		Bushing*	1		1				4										5	3
		Insulator*	1		1				4										5	3
Connection Compartment		Current Transformer*	1						4				4						8	7
		Voltage Transformer *	1						4				4						8	7
		Cable Sealing Ends*	1										4						4	2
Eearthing Switch			3		3	3		6		6	3				3				24	8
Low Voltage Compartment			1										4	2	1				7	30
Complete Product (AIS-Panel)				x										x	x	x	x	x		100
Technical Qualifcation				Engineer	Mechanic	Mechanic	Mechanic	Welder	Process Engineer	Process Engineer	Painter	Process engineer	Mechanic	Assembler	Assembler	Testing Engineer		Packer		

* Purchasing parts

10 Discussion of the Results

The above shown matrix was created as per described in the modules construction in Chap. 7.2. The result of the matrix is the following:

- The weighted value creation modules determine which of these modules can be internationalized with the lowest risks according know-how
- The percentage of each module according the value add costs determine which modules brings the biggest cost advantage in case of production in international markets

This means:

- Modules with high ranking in the know-how weighting and lower raking in the value add costs should not be internationalized
- Modules with high ranking in the value add costs and lower ranking in the know-how to be internationalized first
- Modules with high ranking in the know-how costs and in the value add costs should only be internationalized with restrictions (special measures to save know-how)

- Modules with lower ranking in the know-how and in the value add costs should be internationalized to complete the local value creation chain if necessary

Here in case of the medium voltage switchgear, it is clear to see that the vacuum circuit breaker has the highest rates in the ranking of the value creation modules. This means that the circuit breaker is the most important part of the complete product according to the know-how, the quality and the functionality of the switchgear. In this case the circuit breaker not to be internationalized or only with very high restrictions. Other modules with lower ranking and at the same time higher score in the value add costs weighting like the low voltage compartment to be internationalized first due to lower importance according know-how, quality and functionality of the complete product.

11 Conclusion

The introduced model shows how to enter international promising markets in a way to save know-how and to use the biggest possible cost advantage. After definition of the value creation modules, weighting of these modules and getting clarity about what modules to be internationalized, it is necessary to define measures how to achieve the necessary qualifications in targeted locations to assure the necessary quality, especially for modules which can only be internationalized with high restrictions. Based on this, the following steps to be considered in further researches:

- Weighting of each qualification needed based on experience, education and vocational education
- Definition of measures to qualify the staff in foreign locations in technical skills
- Definition of measures to qualify staff in home and in foreign locations in soft skills related to internationalization

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1.7 Fuzzy Application in Sustainability Assessment: A Case Study of Automotive Headlamp

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Abstract
Aspects of environment, economic and social are the three principal elements of sustainability. Within these elements, there are many sub-sustainability parameters need to be considered when sustainability evaluation is carried out which include pollution, cost, energy, health, acidification and others. The inclusion of these parameters and the uncertainty data increases the complexity in decision making process with respect to sustainable development as it not only evaluates the current situation but also the prediction and strategic decision for the future. Consequently, a simplified methods and tools are required in guiding the designers and decision makers to develop sustainable product. Hence, this paper present a fuzzy approach in evaluation of product's sustainability. The fuzzy logic approach is integrated into the evaluation process as it has a capability to handle severe uncertainty and ability to evaluate qualitative and quantitative data simultaneously. A case study of automotive headlamp is presented to demonstrate the capability of fuzzy technique in sustainability evaluation.

Keywords:
Sustainability index, Fuzzy logic, Sustainable product, Sustainability

1 Introduction

Sustainability is defined as *"a notion of viable futures*" which includes aspects of environment, public health, social equity and justice [1]. Sustainability level is greatly influenced by the size of population and impact [2]. With an increase in human population, the demand for domestic and non-domestic products also increases which results in drastic decrease in the world sustainability. Mass production of these products consumes great amount of energy, raw materials and fuels which results in rapid declining of the available natural resources. In addition, significant amount of wastes and emissions are generated at every stage of the product's life cycle. Chemical and hazardous wastes from industries flow into natural bodies of water, exerting harmful effects on humans, plants and animals [3, 4]. Subsequently, more land area is required to provide landfills for solid waste disposal, buildings and houses [5]. This situation contributes to the negative impact of humanity and decreases world sustainability. Therefore, these impacts must be reduced by developing sustainable products, processes and systems, which have the lowest effects on future generations [1].

Designing and developing a sustainable product is not an easy task as it involves many criteria such as environment, social and economic aspect [6, 7]. Other factors that must be considered in addition to fulfilling sustainability needs include organisational goals, objectives, local and international policies and legislation [8]. The action taken has to comply with the current national and international legislation such as ISO standard, EU directive and others. Consequently, these situations will lead to the complexity of designing sustainable product or process [9, 10].

Fuzzy approach integrates into sustainability assessment because it has the ability to model complex systems with ill-defined dynamics and inputs. Fuzzy logic can handle knowledge and data represented in disparate ways including mathematical models, linguistic rules, numerical values or linguistic expressions [11, 12]. It performs computation with words that are called "linguistic variables". Some certain factors, which are very important but at the same time cannot be quantified, would not be considered by applying a traditional mathematical model for assessing the sustainability level. For instance, opinions and values can be good examples of these kinds of factors. Fuzzy logic can show a good performance in this area of human thought [13].
Several tools are available to assess sustainability levels; these include life cycle assessment (LCA), the Ten Golden Rules, Volvo's Black, Grey and White Lists, Eco-indicator, Green Pro, Life Cycle Index (LInX) and etc. They are categorized according to the assessment method either qualitative or quantitative approach. Ten Golden Rules, and Volvo's Black, Grey and White Lists assess the sustainability in qualitative manner while LCA, Eco Indicator, Green Pro and Life Cycle Index uses a quantitative data. According to (citation), it is the best if it is assess the data or sustainability parameter qualitatively and quantitatively. The current tool measured sustainability in one or two dimension only whereas sustainability should be measured in all aspect of environment, economic and social. As an example, the Volvo's Black, Grey and White Lists consider only the environmental and social dimension while leaving of the economic aspect. Besides that, the boundary of analysis only limited in the manufacturing stage whereas sustainability require the mesurement of each life cycle of product.

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In this paper, a sustainability evaluation with an integration of fuzzy approach is presented in guiding the designer and decision makers. The fuzzy technique is capable of handling strong uncertainty in sustainability evaluations [9, 14, 15]. The sustainability evaluation considers all of the following main sustainability elements: environmental, economic and social. To aid interpretation exercise, index values and graphs are used to represent the results of the assessment.

2 Methodology

The methodology in determining the sustainability evaluation consists of three steps such as:

1. Data collection, classification and grouping of data towards their respective impact categories.

2. Calculation of sub element index using fuzzy inference system.

3. Calculation of main element (environment, economic and social) and sustainability index.

2.1 Data Collection

The first step in data collection is to define the boundary of analysis. There are two common types of system boundary which are *cradle to gate* and *cradle to grave*. According to Giudice et al. (2006) cradle to gate can be defined as the analysis of the portion of life cycle upstream from the gate [16]. The assessment is inclusive from the raw material acquisition to the processing and manufacturing stages until the product comes out from the factory or production plant. Whereas for the cradle to grave boundary system, the evaluation includes the upstream and downstream from the gate. The analysis must be conducted from the material acquisition, manufacturing, distribution, use and until end of life stages [17]. After the boundary has been defined, the input and output or elementary flow in and out from the boundary is collected for evaluation. For example, the input parameters or criteria for pollution material consist of the amount and type of material used, energy required and etc., while the output parameters may include the amount of waste (solid or liquid), toxic substance and etc. The collected data is then grouped or categorized accordingly to the sub element of the sustainability such as pollution, global warming, eutrophication, acidification, resource, energy, cost, human health, heavy metal and carcinogen. The grouping of the criteria or parameters is based on the potential impact categories at which the criteria will be affected. In this study, criteria or parameters were categorized into nine sub-sustainability elements and which were further reduced into three principal sustainability elements and lastly aggregated to obtain a single index of sustainability as shown in Fig. 1.7.1.

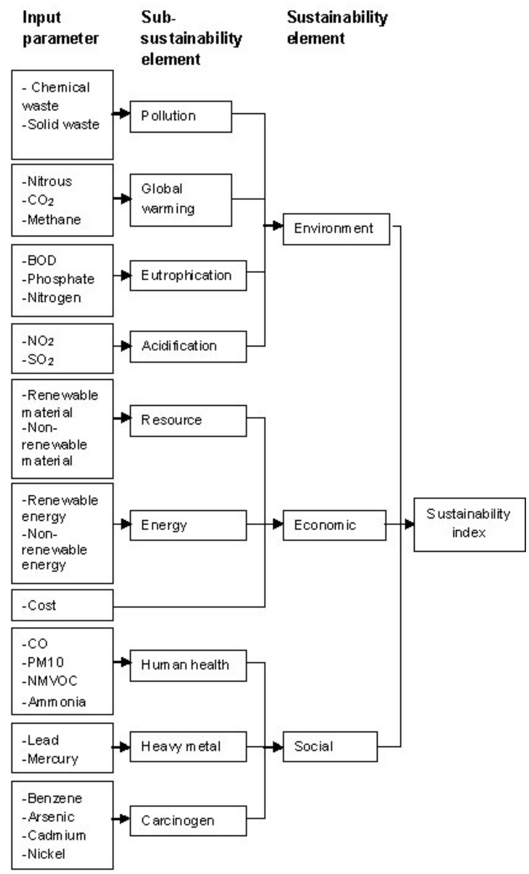


Fig. 1.7.1 Classification and grouping of sustainability parameter into sub element, main element and sustainability index

2.2 Determination of Sub-element Sustainability Index

The sustainability sub-element index is determined using the fuzzy inference system shown in Fig. 1.7.2, which consists of fuzzification, an inference engine, a fuzzy rule base and defuzzification. The fuzzy inference system is described below:

1. A linguistic variable, such as low, medium or high, and a number of possible linguistic values are assigned to each input and output variable. A membership function is then assigned to each variable. The widely used triangular membership function is used in this study.

2. Numerical input values are converted into linguistic variables in the fuzzification process. The model of the fuzzy system is encoded in its rule base. The rule base contains “if-then” rules that relate output to input linguistic variables.

3. An inference engine combines “if-then” rules and fuzzy inputs using appropriate composition/logical connectivity operations (AND, OR, NOT) and computes the fuzzy output. The fuzzy outputs are represented by the degrees (or grades) of membership of the outputs given the corresponding linguistic values.

4. Defuzzification combines the membership grades of the fuzzy outputs into a single numerical value.

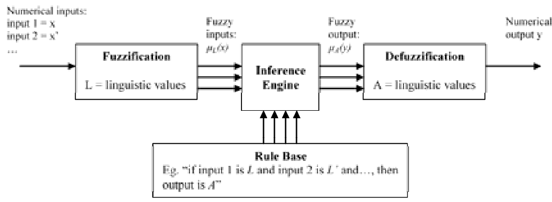


Fig. 1.7.2 Block diagram of the fuzzy inference system

Fuzzy membership function

The fuzzy membership function is the core of the fuzzy model and defines the strengths and weaknesses of the model [18]. The triangular membership function is the simplest and most commonly used membership function because it can be adapted to various assessments [19, 20]. The fuzzy triangular membership function is given by Eq. (1.7.1), and plots of the input and output membership functions are shown in Fig. 1.7.3 (a) and (b) respectively:

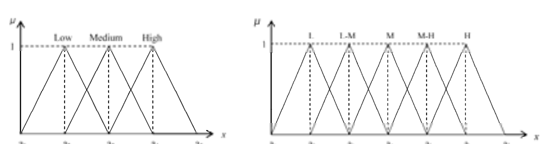
$$u_A(x) = \begin{cases} 0 & \text{if } x \le a_1 \\ (x-a_1)/(a_2-a_1) & \text{if } a_1 \le x \le a_2 \\ (a_3-x)/(a_3-a_2) & \text{if } a_2 \le x \le a_3 \\ 0 & \text{if } x \ge a_3 \end{cases} \qquad (1.7.1)$$

where $A = (a_1, a_2, a_3)$

and a_1 = minimum value

a_3 = maximum value

$a_2 = (a_1 + a_3)/2$ (symmetric triangle)



(a) (b)

Fig. 1.7.3. **a** Input triangular membership function having three degree (Low, Medium, High) and **b** output triangular membership function (L = *low*, LM = *low to medium*, M=*medium*, MH = *medium to high*, H = *high*).

Fuzzy rules

The fuzzy rules define the contribution of the input variables to the output responses using linguistic terms or *if-then* approaches. The rules are divided into two parts: *premise* (input) and *conclusion* (output). The *premise* represents the *if* part of the rule, while the *conclusion* represents the *then* part. The number of fuzzy rules used depends on the number of *facts* and the degree of the input variables, which is determined using Eq. (1.7.2) [20].

$$\text{No. of fuzzy rules, } R = n^v \qquad (1.7.2)$$

where *n* is the degree of input variables or number of input degrees and *v* is the number of input variables or number of *facts* in the premise.

An example fuzzy rule to determines the global warming sub sustainability index is shown in Table 1.7.1. It have three input variables *v* (nitrous oxide, carbon dioxide and methane) and three input degrees *n* (low, medium and high). According to Table 1.7.2, the first rule, R_1, is defined as follows: IF nitrous oxide is *low* AND the carbon dioxide is *low* AND methane is *low*, THEN the sub sustainability (global warming) index is *high*.

Table 1.7.1 Fuzzy rules for evaluating sub sustainability (global warming) indices

Rule no.	**Input 1**	**Input 2**	**Input 3**	**Output**
	Nitrous oxide, N_2O	Carbon dioxide, CO_2	Methane	Global warming
R_1	Low	Low	Low	H
R_2	Low	Low	Medium	MH
R_3	Low	Low	High	MH
R_4	Low	Medium	Low	MH
R_5	Low	Medium	Medium	MH
R_6	Low	Medium	High	M
R_7	Low	High	Low	MH
R_8	Low	High	Medium	M
R_9	Low	High	High	LM
R_{10}	Medium	Low	Low	MH
R_{11}	Medium	Low	Medium	MH
R_{12}	Medium	Low	High	M
R_{13}	Medium	Medium	Low	MH
R_{14}	Medium	Medium	Medium	M
R_{15}	Medium	Medium	High	LM
R_{16}	Medium	High	Low	M
R_{17}	Medium	High	Medium	LM
R_{18}	Medium	High	High	LM
R_{19}	High	Low	Low	MH
R_{20}	High	Low	Medium	M
R_{21}	High	Low	High	LM
R_{22}	High	Medium	Low	M
R_{23}	High	Medium	Medium	LM
R_{24}	High	Medium	High	LM
R_{25}	High	High	Low	LM
R_{26}	High	High	Medium	LM
R_{27}	High	High	High	L

(L=low, LM=low to medium, M=medium, MH=medium to high, H=high)

Fuzzification

Fuzzification is the process of determining the degree of membership $u_k(x_k)$ of an input variable (x_k). The first step of fuzzification is to consider the input value and to determine the degree to which it belongs to each of the appropriate fuzzy sets via the membership functions. The result is a single number that ranges from zero to one (0 to 1). An example of this process is displayed in Fig. 1.7.4, in which the input variable is the energy used (8 kJ). The fuzzification result shows that the membership value of 0.7.

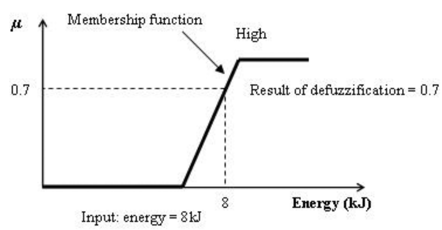


Fig. 1.7.4 Degree of truth of statement-energy is high

Fuzzy inference

The fuzzy inference process consists of two stages: the implication and aggregation processes. The implication process defines the fuzzy conclusion (N_i) for each rule (R_i). The first step in the implication process is to define a truth value (τ_j) for the premise of the proposition in R_i. If the premise consists of two or more *facts*, then (τ_j) is defined by a logical connective or a fuzzy operator such as AND, OR or NOT [20]. The output of the implication process is the fuzzy conclusion N_i of each rule. The implication process is represented by the horizontal arrow in Fig. 1.7.5.

Subsequently, the aggregation process takes place. In this process, the fuzzy conclusion N_i is combined into a single fuzzy set as indicated by the downward arrow in Fig. 1.7.5. The input to the aggregation process is the list of truncated output functions returned by the implication process for each rule or N_i, and the output is the overall fuzzy conclusion (N) [18, 21].

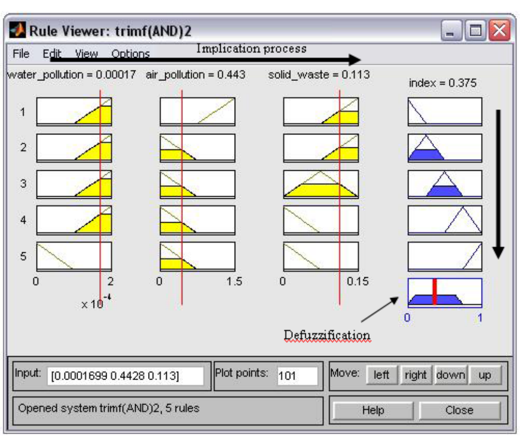


Fig. 1.7.5 The implication, aggregation and defuzzification processes of the fuzzy inference system

Defuzzification

The input to the defuzzification process is the aggregated fuzzy conclusion (N_i) or the overall fuzzy conclusion (N), and the output is a single number. The most common technique used for defuzzification is the *center of gravity method*, which was developed by Sugeno in 1985 [22]. This centroid defuzzification technique is expressed in Eq. (1.7.3).

$$X^* = \left(\int N_i(x)x \, dx \right) / \left(\int (N_i(x) \, dx \right) \quad (1.7.3)$$

where X^* is the defuzzified output, $N_i(x)$ is the aggregated membership function and x is the output variable. The output of this defuzzification method is the value that divides the area under the curve into two equal sub-areas.

2.3 Determination of Sustainability Index

The index value of sub-sustainability element which is obtained from the fuzzy evaluation process will be aggregated into three main sustainability element index such as environment index, economic index and social index by using Eq. (1.7.4)

$$I_j = \frac{\sum_{i=1}^{n} w_{ij} I_{ij}}{n} \quad (1.7.4)$$

where

I_j = index of sustainability element for *j*-th categories

w_{ij} = weight of sub sustainability element of *j*-th categories

I_{ij} = sub sustainability element index of i-th elements of *j*-th categories

i = sub sustainability element (pollution, global warming, eutrophication, acidification, resource, energy, cost, human health, heavy metal and carcinogen)

j = sustainability element (environment, economy and social)

n = number of element

Then, the sustainability element index will be further aggregated into a single index value which is known as sustainability index. It can be determined by averaging the three main sustainability element indices as shown in Eq. (1.7.5). The index value will be in the range between zero for low sustainability to one representing high sustainability.

$$I_{sustainability} = \frac{\sum_{j=1}^{n} I_j}{n} = (I_{envi} + I_{eco} + I_{soc})/3 \quad (1.7.5)$$

where,

I_{envi} = environment index

I_{eco} = economic index

I_{soc} = social index

3 Case Study

The sustainability evaluation using fuzzy approach was tested using a case study on automotive headlamp as shown in Fig. 1.7.6. The headlamp consists of five main components such as housing, FTS reflector, hall reflector, bezel and outer lens. The product structure is shown in Fig. 1.7.7 and the description of each component is described in Table 1.7.2.

Fig. 1.7.6 Automotive headlamp

Table 1.7.2 Description of the main part of automotive headlamp

Part name	Material type	Weight (g/unit)
Housing	Polypropylene (PP-TD40)	700
Bezel	Polybutyleneterephthalate (PBT)	292.2
FTS Reflector	Polybutyleneterephthalate (PBT)	54.9
Outer lens	Polycarbonate (PC)	600
Hal Reflector	Polyethylene terephthalate (PET)	500

Table 1.7.3 Example of input data for headlamp housing

Input Parameter	Product Life Cycle				
	Raw material	Manufacturing	Transport	Usage	EOL Option
N_2O (kg/unit)	3.38E-13	0	4.23E-08	0	0
CO_2 (kg/unit)	1.1690147	0	0.0040883	0	0
Methane (kg/unit)	0.008282	0	4.82E-08	0	0
NO_2 (kg/unit)	0.0023008	0	3.66E-05	0	0
SO_2 (kg/unit)	0.002649	0	1.29E-07	0	0
BOD[a] (kg/unit)	2.01E-05	0	0	0	0
Phosphate (kg/unit)	0.0003762	0	0	0	0
Nitrogen (kg/unit)	6.14E-07	0	0	0	0
Chemical (kg/unit)	3.10E-03	0	0	0	0
Solid (kg/unit)	2.38E-04	0.245	0	0	0.7
Renewable material (kg/unit)	28.556223	0	0	0	0
Non-renewable material (kg/unit)	1.92E+00	0.945	0	0	0
Renewable energy (MJ/unit)	2.84E-01	0	0	0	0
Non-renewable energy (MJ/unit)	4.66E+01	15.2208	0	0	0
Cost (RM/unit)	4.7748488	0.208333	0.006731	0	0
CO (kg/unit)	0.0042707	0	7.15E-06	0	0
PM10[b] (kg/unit)	0.0004168	0	7.69E-07	0	0
NMVOC[c] (kg/unit)	0.0024593	0	1.90E-06	0	0
Ammonia (kg/unit)	2.37E-06	0	2.38E-08	0	0
Lead (kg/unit)	1.66E-09	0	0	0	0
Mercury (kg/unit)	1.38E-09	0	0	0	0
Benzene (kg/unit)	2.34E-18	0	3.35E-08	0	0
Arsenic (kg/unit)	1.88E-10	0	0	0	0
Cadmium (kg/unit)	9.09E-11	0	0	0	0
Nickel (kg/unit)	1.80E-10	0	0	0	0

[a]Biological oxygen demand, [b]particulate matter less than10µm, [c]nonmethane volatile compound

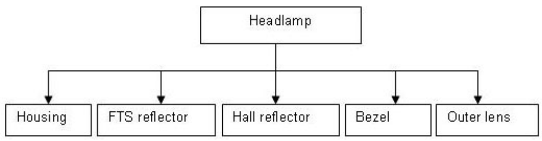


Fig. 1.7.7 Product structure of automotive headlamp

The input data for the sustainability evaluation of each part is gathered which include the amount of waste, emission, heavy metal produced and etc. The input data for the headlamp housing is according to the life cycle of the each component as presented in Table 1.7.3. The data for the raw material production and transportation are based on the European life cycle database. Data on manufacturing, usage and end of life option are calculated from manufacturing report. In this case study, the life span of the product is assumed to be five years and dump to landfill is considered as the option of product's end of life.

4 Result

Results of the sustainability assessment of headlamp housing are tabulated in the Table 1.7.4. It indicates that the sustainability performance of each headlamp component can be determined accordingly in terms of the environment, economic and social aspects. The hall reflector has a lowest environmental index while housing, FTS reflector and outer lens have a low economic index. In general all of the components show a better performance in the social aspect due to the low amount of heavy metal and carcinogen.

Table 1.7.4 Sustainability element index for headlamp

Part name	Environment	Economic	Social
Housing	0.8528	0.71191	0.9085
FTS reflector	0.88051	0.86537	0.91859
Bezel	0.8	0.80457	0.91337
Hall reflector	0.77917	0.77666	0.90291
Outer lens	0.800005	0.7717513	0.89912

The sustainability index for each component is then visualized graphically in Fig. 1.7.8 for a better presentation of the results. Results show that FTS reflector is the most sustainable-friendly component when compared to other components. On the other hand, hall reflector, outer lens and headlamp housing are among the components which need to be improved because of their low sustainability indices.

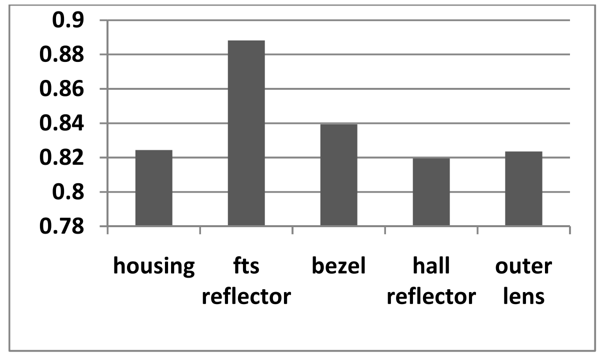


Fig. 1.7.8 The sustainability index for headlamp components

In order to identify the weakness area, the sustainability performance across the life cycle is investigated for the hall reflector. The sustainability element index for the hall reflector across life cycle is presented in Fig. 1.7.9. It was found that the low sustainability index occurs at the raw material and manufacturing stages. Subsequently, the sub-sustainability index during material extraction and manufacturing stage is analyzed and presented in Figs. 1.7.10 and 1.7.11. The critical point at the material extraction are acidification, eutrophication and energy. While during the manufacturing stage, the resources and wastes are the weakness point.

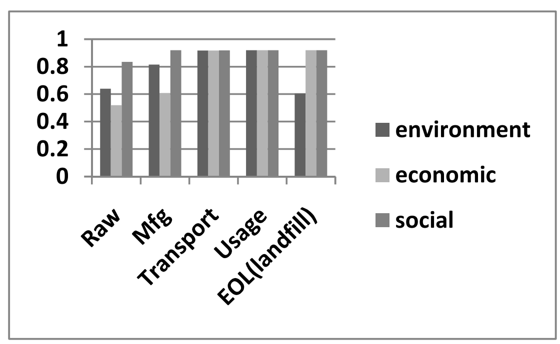


Fig. 1.7.9 The sustainability element index for hall reflector

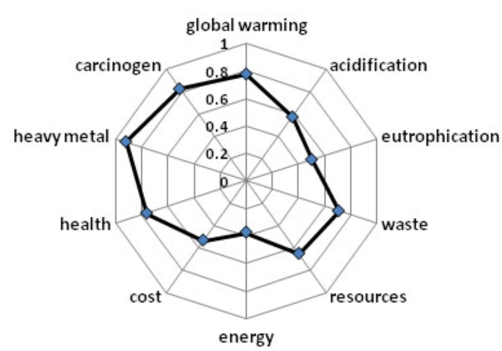


Fig. 1.7.10 Sub-sustainability element index of hall reflector at the raw material stage

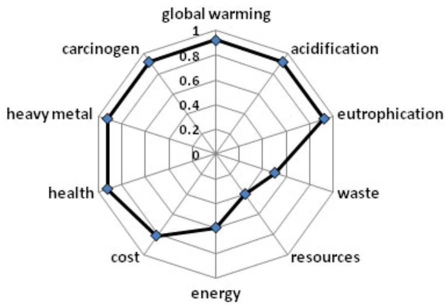


Fig. 1.7.11 Sub-sustainability element index of hall reflector at the manufacturing stage

5 Discussion

From the results, it is clear that the sustainability evaluation using fuzzy model is able to provide a comprehensive approach in product assessmnet. The transformation of various input/ sustainability parameters into fuzzy number and then converted into a single index value through fuzzy inference system contributes to the reduction of the complexity in product sustainability assessment process. Based on the above case study, it was found that the proposed assessment methods is able to identify the weakness area which need improvement. Based on the result, the following feedback can be made to the hall reflector :

1. Replace the current material with a material which produces low amount of biological oxygen demand, phosphate, nitrogen, nitrogen dioxide and sulphur dioxide during the material extraction stage.
2. Increase the use of renewable energy instead of using non renewable energy.
3. Reduce the waste at the manufacturing process stage.
4. The chemical for cleaning process can be re-used by filtration system.

6 Conclusion

This paper presents a comprehensive approach to evaluate sustainability by applying fuzzy interference system. The fuzzy assessment methodology is able to assess the various sustainability parameters either qualitative or quantitative data simultaneously. In addition, the strength of fuzzy technique lies on its ability to reduce data uncertainty which is an added advantage of this proposed method. The assessment can be used for product improvement by identifying the critical area which indicated by the low index value. The graphical representation serves as a useful guide to the designer for better interpratation of the results. The methodology is clearly demonstrated by a case study of the automotive headlamp.

The method can be treated as a interactive tool in which the target value or reference value can be changed according to the corporate objective or policy decision. Besides that, the input variables (sub sustainability element) can be added as required based on the increase of the data availability. This flexibility helps to continuously evaluate the system, process or product towards better sustainability result.

7 Acknowledgments

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Chapter 2:

Manufacturing Processes and Equipment

2.1 Metrics-Based Sustainability Assessment of a Drilling Process

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Abstract

Results from a preliminary investigation of a drilling process using a metrics-based sustainability assessment method are presented in this paper. The proposed metrics aim at addressing the impacts of a manufacturing process, from the economical, environmental and societal points of view. This study includes a total-life-cycle approach for all identified inputs and outputs of the process, and is carried out according to the different sustainability elements such as cost, energy consumption, waste management, environmental impact, personnel health and operator safety. A crankshaft oil-hole drilling process is taken as the target, which was optimized using machining performance criteria. The process is evaluated based on the metrics proposed, comparing its sustainability behavior before and after the optimization. The impacts of the changes to the process are addressed with a more comprehensive scope of sustainable manufacturing.

Keywords:

Machining, Metrics, Processes, Sustainability assessment, Sustainable manufacturing

1 Introduction

A set of six sustainability elements for sustainable manufacturing processes is proposed by Jawahir and Dillon [1] based on the triple bottom line considerations, namely economical, environmental and societal aspects. These six elements are shown in Fig. 2.1.1.

Fig. 2.1.1 Six elements of sustainable manufacturing processes [1]

Sustainability metrics for manufacturing processes are necessary for evaluating the performance of a manufacturing process considering the sustainability content of the process. Aside from the basic application of proper evaluation of the manufacturing processes, the ultimate goal of developing metrics for sustainable manufacturing is to provide improved decision-making capability when optimizing process design for sustainable manufacturing [2]. Current metrics focus primarily on company, regional, national and global levels. Technically complex methodology of assessing sustainability performance of manufacturing processes has not been fully addressed and there is a critical need for developing improved, comprehensive, and applicable metrics for sustainability evaluation of products and processes [3].

This paper presents a sustainability assessment method on an existing machining process, using a proposed set of metrics developed for manufacturing processes [2].

2 Previous Work

2.1 Sustainability Assessment Methodologies

When considering the impact assessment of manufacturing processes for sustainability, various focus points concerning economics, environmental friendliness and societal well-being have been previously chosen by many researchers. In this section, we concentrate on discrete product manufacturing processes, especially material removal processes.

Energy consumption analysis in manufacturing processes has been the most discussed topic. Dahmus and Gutowski presented an experimental analysis of the machine tool energy consumption in different scenarios [4]. Analysis of one of the scenarios, an automated production line machining center, shows that the coolant application consumes most energy among all the activities in such a system, equipped with concentrated coolant supply system and high machine throughput [5]. Iskra et al. [6] conducted an experimental investigation into the energy flow of a lathe. They measured the energy consumption for a range of cutting parameters, including the pure cutting energy, heat generation by material deformation, machine losses, noise and vibration. The noise and vibration are found to be a negligibly small part of the overall energy consumption. An interesting finding was that, the higher the load, the more efficient the machine will be because of higher electrical and mechanical efficiency of the machine. A theoretical analysis of energy consumption in modern manufacturing processes was discussed [7, 8]. A trend is summarized on how energy and material resources are used in manufacturing processes, stating that the amount of energy used per unit mass of material processed has increased enormously for modern manufacturing technologies over the past several decades.

Comprehensive environmental impact assessments of manufacturing processes have been carried out. Life-cycle-analysis (LCA) has been widely applied. Environmental concerns of machining processes mostly focus on the

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material reduction, resource consumption, cutting fluid application and waste management [4]. Apart from energy consumption, the use of recycled materials, more environmental-friendly coolant applications and waste minimization methods are discussed. Rao [9] summarized a series of investigations that address the environmental impact of manufacturing processes.

In addition to conventional ergonomic analysis of the workers such as the one shown in [10], there is also some specific discussion about the societal impacts of the machining processes, focusing on the coolant droplet formation and concentration and its impacts on human health. Theoretical and experimental analysis of the cutting fluid application in terms of mist formation are carried out by Yue et al. [11] and Sun et al. [12], respectively. Based on this, Adler et al. summarized the environmental and health concerns of cutting fluid application in machining processes [13].

While most of the assessment activities are carried out for a relatively limited portion of the overall sustainability concepts, there are some research works that address multiple aspects of the triple bottom line. Among the six sustainability elements of manufacturing processes, the manufacturing cost, energy consumption and waste management are considered as deterministic elements, and the environmental impact, personnel health and operator safety are non-deterministic elements as they are less easily represented in quantitative terms. Based on these elements, Wanigarathne et al. performed a sustainability assessment of a machining process [14] and this was followed by a quantitative model by Granados et al. [15]. In their work, all six elements are represented by a small number of machining process performance measurements. The measurements are normalized according to the best/worst scenarios and are aggregated with equal weight. Optimization targeting higher sustainability score was performed.

The problem with the above-mentioned impact assessment proposed by Granados et al. is that, they are either targeting at a relatively small aspect of sustainability, or performing overall assessment with a limited number of measurements representing each of process sustainability elements. The need for comprehensive metrics for sustainability assessment of manufacturing processes is addressed in a previous publication [2]. Conducting a comprehensive sustainability assessment of a manufacturing process based on a set of comprehensive metrics remains to be a direction to follow. This paper presents a portion of the on-going work at the University of Kentucky.

2.2 A Framework for Developing Sustainability Metrics for Manufacturing Processes

Structure of the metrics for a machining process

Lu et al. [2] suggested a three-level hierarchy structure for the sustainability metrics for manufacturing processes. This structure is shown in Fig. 2.1.2, using the energy consumption as an example.

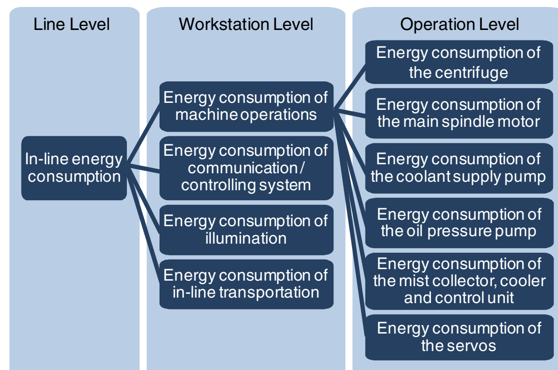


Fig. 2.1.2 Hierarchical structure of an example process metrics for energy consumption [2]

Framework for developing sustainability metrics

Sustainability assessment of a manufacturing process is based on comprehensive evaluation of the inputs and outputs of the process [2]. A set of metrics have been proposed by Lu et al. [2] according to the framework suggested. These metrics are organized in six clusters, corresponding to the six sustainability elements of manufacturing processes, as summarized in the Table 2.1.1. It should be noted that Table 2.1.1 is a set of line level metrics, aimed at machining plants which can be organized in the form of manufacturing lines with varying machining processes, machining cells or machining job-shops. For a complicated set of manufacturing processes carried out by a machining plant under various organizational forms, the overall sustainability evaluation of the plant consists of evaluations of its sub-components, such as each of the work-stations.

Table 2.1.1 Examples of process metrics for sustainable machining [2]

Environmental impact	**Energy consumption**	**Cost**
GHG emission from energy consumption of the line (ton CO_2 eq.) Ratio of renewable energy used (%) Total water consumption (ton) Mass of restricted disposals (kg) Noise level outside the factory (dB)	In-line energy consumption (kWh) Energy consumption on maintaining facility environment (kWh) Energy consumption for transportation into/out of the line (kWh) Ratio of use of renewable energy (%)	Labor cost ($) Cost for use of energy ($) Cost of consumables ($) Maintenance cost ($) Cost of by-product treatment ($) Indirect labor cost ($)
Operator safety	**Personal health**	**Waste management**
Exposure to Corrosive/toxic chemicals (incidents/person) Exposure to high energy components (incidents/person) Injury rate (injuries)	Chemical contamination of working environment (mg/m^3) Mist/dust level (mg/m^3) Noise level inside factory (dB) Physical load index (dimensionless) Health-related absenteeism rate (%)	Mass of disposed consumables (kg) Consumables reuse ratio (%) Mass of mist generation (kg) Mass of disposed chips and scraps (kg) Ratio of recycled chips and scraps (%)

3 Sustainability Assessment of a Drilling Process

3.1 Background

The process under investigation is a 90 mm deep hole drilling process in an automobile manufacturing plant. The process was comprehensively studied from the machining performance aspect [16]. In that study, the major problems identified were variability of the tool-life, shorter actual tool-life compared to expected tool-life and irregular and non-progressive tool-wear. An optimization on the tool geometry and process parameters has been carried out focusing on improving tool-life and predicting tool-wear.

To properly evaluate such a single manufacturing process, we consider the drilling process as stand-alone, and disregard the supporting utilities shared by the whole manufacturing plant, such as plant heating, ventilation, and air-conditioning (HVAC) systems. Thus, some of the metrics in Table 2.1.1 do not apply in the current evaluation of a single process. Most of the measurements can be adapted from the high-level metrics but they would be expanded according to the exact process. Generally, there need to be customized metrics for the specific machining process. If the assessments include the influence on other supporting equipments, then a scenario that consist both the corresponding accessories and the machine should be used.

Table 2.1.2 summarizes the process parameters and tool-life behavior before and after the optimization.

Table 2.1.2 Process parameters and tool-life before and after optimization

	Before optimization	After optimization
Speed (RPM)	795	600
Feed (mm/rev)	0.094	0.08
Feed (mm/min)	75	48
Tool-life	55 holes	270 holes

The process benefits significantly from the optimization in the form of reduction in scrap rates, maintenance labor hours on scrap and labor hours on tool changing. The changes in scrap rate, labor consumption and running time of the machine per 10,000 products manufactured are summarized in Table 2.1.3 that follows.

Table 2.1.3 Changes in the production statistics data before and after optimization

	Before optimization	After optimization
Scrap rate	1.02‰	0.36‰
Maintenance Labor	4.86 h	1.76 h
Tool changing labor	13.70 h	2.79 h
Running time	250.45 h	362.74 h

Note that the idle time and loading/unloading time are assumed to be at 18 s. The assessment is based on the consumption of one drilling machine with four spindles installed. Each product is assumed to have four holes on it and the production of 10,000 finished products is considered.

3.2 Identifying Influenced Factors

Input and output streams need to be evaluated to determine whether they are influenced by this particular optimization activity. This will address necessary data collection.

To be specific on the input streams, the processing parameters are changed. Cutting tool usage, coolant consumption and power consumption will be changed accordingly. The raw material consumption will be altered as the scrap rate changes; thus, the average raw material consumption per finished product will be influenced.

Similarly on the output side, we assume that the finished products are the same in terms of quality as all products manufactured need to fulfill the quality requirements. We fixed the chip-coolant mass ratio, so the mass of used coolant will be almost the same. Used cutting tools and chips are thought to have same unit mass, but in different numbers because of the different scrap ratio and tool-life performance. Other emissions are neglected in this case.

An additional point is that the labor use will differ and will influence the economical behavior of the process.

3.3 Metrics Expansion and Applications

As stated in Sect 3.1, in our case of evaluating a single machining process without considering its supporting equipment, there are no line level measurements. The measurements start at the workstation level.

Machining cost

In the section of labor cost, the machining center labor cost and the system maintenance labor cost are considered at the workstation level. They are calculated as the pay rate times the actual working hours.

For the cost of energy consumption, the energy input to the workstation is further divided into the main spindle energy consumption which is assumed to be the material cutting energy and the accessories energy consumption at the operation level. Note that the accessories of the workstation are assumed to consume energy at a constant rate as long as the machine is running properly for the ease of measuring. Other energy consumption such as transportation, environmental maintenance, communication and indirect labor are neglected in the current case of the analysis of a single process.

Cost of consumables covers two major sections, namely the coolant-related cost and the cutting tool related cost. The coolant-related cost is considered at the operation level, assuming a constant coolant flow rate during the running time of the machine. It is a concentrated coolant supply system and the coolant is reused for a very long period of time. Mist generation and evaporation loss are neglected in this study, and the only loss of coolant is considered to be taken away by the machining chips. Cutting tool related cost is addressed in a similar method. Expenses of purchasing and recycling are considered, but tool grinding and reuse are not taken into concern in this study. It should be noted that in some cases, a manufacturing industry may gain benefits from recycling their waste, thus, the gain may be represented as a negative “expense”.

Packaging, material cost during maintenance are assumed to be zero, as there is no package used in this process and the resource consumption in maintenance activities apart from the replaced cutting tools was not tracked.

By-product treatment focuses on the recycling of scrap parts and chip generated in the process at the operation level. Loss on the scrapped parts is usually considered as an expense here.

Indirect labor cost is considered usually at the manufacturing line level, thus, is not considered in our case.

There are some other measurements added. The cost of initial investment, including the cost of depreciation, the cost of jigs and fixtures are all neglected. This may not apply in the case that the initial investment has a great impact on the performance of the process. Other forms of costs, including the cost of health/safety incidents and the cost of violating regulations, are set to be zero on account of zero incidents and full compliance of regulations, respectively.

Energy consumption

As mentioned in the previous section on machining cost, the only energy consumption considered in this case is the energy consumption on the main spindle and the machine accessories. They are all in the form of electricity in this case at the workstation level. Other forms of energy consumption, including those consumed on maintaining plant environment, shared utilities such as chilled water and compressed air, transportation into and out of the workstation, are all neglected. It is noted that the plant where our study was conducted did not utilize any particular renewable energy, and this measurement is neglected in this case.

Waste management

The plant being evaluated has encouraged the practice of recycling all the solid waste. Thus, there is no disposal or land filling of used cutting tools, machining chip or scrap parts. The mass of recycled cutting tools, machining chip and scrap parts will be tracked, while their recycling rate remained to be 100%. The case of packaging material does not apply here.

The plant maintained their coolant system by continuous treatment of the used coolant and used the coolant for a very long time, thus, the disposed coolant is assumed to be zero. But there is still a waste stream of coolant loss in the form of machining chip carry-away.

Environmental impact

Energy consumption in the form of Green House Gas (GHG) emissions needs to be evaluated. It is rated according to the sources of the local electricity supply. Once again, there is no renewable energy used in this process.

The process does not need external cooling water supply, thus, the water consumption is considered to be only in the form of coolant consumption.

There is no restricted material used in this process, thus none of measurements concerning restrict materials applies here.

The noise level outside the plant is outside the boundary of current assessment of a single process. This process is not a significant source of heat dispensing to generate considerable environmental impacts. Thus, the measurement of waste heat generation is assumed to be zero in this study.

Operator safety

The process has a fully shielded working space, thus giving a perfect behavior in the sense of maintaining operators' safety. And, it has maintained zero incident record for several years.

Personnel health

Chemical contamination of the working environment and mist/dust level around the machining are so low that they are monitored only when an incident happens. In this assessment, they are set as zero.

Noise level at the normal operating position of the machine is measured. It should be noted that the datum is based on an occasional measurement.

Physical load index is calculated based on an evaluation method developed by Hollman et al. [10], which is in the form of questionnaire to the workers. We assume that there are no changes occurred after the process change.

Work related absenteeism rate is said to be zero according to the records of the plant.

3.4 Sustainability Assessment of the Process

Data collection

It should be noted that, there can be a gap between the metrics and the data to be collected from the shop floor. For example, the metric of labor cost is calculated by multiplying pay rate and labor hours consumed. The pay rate and labor hours consumed are the actual measurements people can take in an actual production activity, while the labor cost is a generated sustainability metric. In some cases, the metric is an actual measurement, such as the on-site measurement of mist/dust concentration in the working environment.

One actual measurement can be used by multiple metrics, representing different aspects of sustainability. For example, the electricity usage is used to evaluate both energy consumption and environmental impact.

A data collection table needs to be generated based on the exact metrics and the actual method to calculate the metrics. A part of the data collection table of the process under investigation is shown in Table 2.1.4.

Table 2.1.4 Part of the data collection table

No.	Term	Unit	Source	Category
1	Labor pay rate	$/hour	payroll	workstation level
2	Time of consideration	hour	production engineer	line level
3	Running time ratio	%	production engineer	workstation level

Data aggregation

By collecting all the data listed in the data collection table, the metrics can be computed as summarized in Table 2.1.5.

Some of the data mentioned are estimated based on design specifications, indirect measurements, open databases and machine specifications. The data are used here only to validate the assessment method, but not to evaluate the exact case.

It is worth pointing out that some elements in the metrics table are not reported because of their equal value before and after the optimization, including the cost of packaging, the cost of maintenance activities, the cost of health/safety incidents and that for violating the regulation in the machining cost segment. All of them are assumed to be equal to zero.

As far as the waste management is concerned, the ratio of used cutting tools and chip recycling and the recycled scrap parts are not reported since they are equal to 100%. No packaging is considered for this case so the mass of used packaging is zero. Considering a plant with zero landfill, the mass of disposed coolant and that of coolant recycled would also be equal to zero. For the environmental impact cluster it is possible to note that the mass of restricted material used

Table 2.1.5 Data comparison for the process before optimization and after optimization

Cluster	Workstation level	Operation level	Data (before optimization)	Data (after optimization)
Cost	Labor cost	-	$ 1648.08	$ 356.4
	Cost of energy use	Cost of main spindle energy use	$ 10.84	$ 10.83
		Cost of accessories energy use	$ 102.24	$ 148.08
	Cost of consumables	Coolant related cost	$ 1166.35	$ 1165.02
		Cutting tool related cost	$ 8955.78	$ 1858.30
	Cost of by-product treatment	Cost of recycling chip	$–260.07	$–259.77
		Cost of scrap parts	$ 1365.49	$ 493.10
Energy consumption	Energy consumption of the machine	Energy consumption on the main spindle	21.22 kWh	21.19 kWh
		Energy consumption on the accessories	200.08 kWh	289.79 kWh
Waste management	Mass of used cutting tools	-	14.98 kg	3.11 kg
	Mass of chips generated	-	472.85 kg	472.31 kg
	Mass of scrap parts	-	426.74 kg	154.10 kg
	Mass of coolant loss	-	315.23 kg	314.87 kg
Environmental impact	Mass of GHG emission	Mass of GHG emission from the main spindle energy consumption	20.83 kg	20.81 kg
		Mass of GHG emission from the accessories energy consumption	196.5 kg	284.57 kg
	Mass of water consumption	-	315.23 kg	314.87 kg
Personnel health	Noise level	-	80.3 dB	80.3 dB
	Physical load index	-	28.18	28.18

and the heat generation are not reported once again because of their numerical value of zero.

For the operator safety elements, since there is no exposure to corrosive/toxic chemicals or exposure to high energy component recorded, they would receive a perfect score in the related measurements. The Injury rate is zero according to the recent records.

No chemical contamination of working environment occurs, so the Personnel Health cluster does not contain this data. The level of mist and dust concentration of the working environment is also set to be zero. No health related absenteeism rate is recorded.

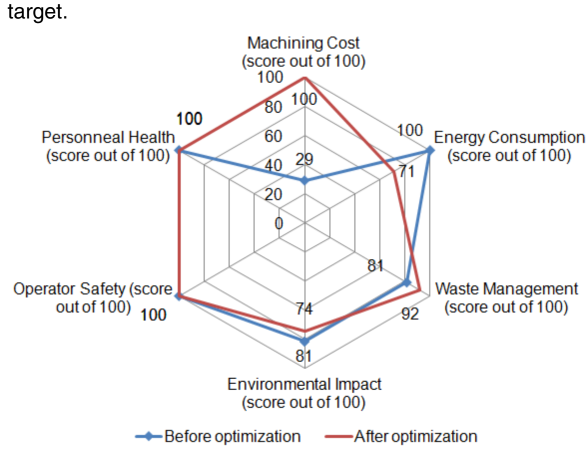
Evaluation

For the deterministic elements, including cost, energy consumption and waste management, it is relatively easy to aggregate the total number together to generate a single number which can represent the performance of the process in this particular area. For non-deterministic elements, including environmental impact, operator safety and personnel health, we normalize the data by giving them a score based on better/worse scenario for each of the measurement. Here the better case is given a 100% score and the score of the worse case is given proportionally to the actual value. Differences within 5% are considered as equal, and a 75% score for non-ideal status and 100% score for ideal status is given. By averaging the scores, we can get a performance index for the element. This is implying that we equally weighed the metrics within one element.

3.5 Comparison and Disscussion

From the summary of the behavior of the drilling process from the aspects of six sustainability elements shown in Fig. 2.1.3, we can observe the changes before and after the machining performance optimization.

From Fig. 2.1.3 we can also see that, significant economical benefits are gained through less cutting tool consumption and less related labor cost. This is indeed the original purpose of the optimization work and we can conclude that even from a sustainability point of view, the optimization work achieved its target.



	Score before optimization	Score after optimization
Machining cost	29	100
Energy consumption	100	71
Waste management	81	92
Environmental impact	81	74
Operator safety	100	100
Personnel health	100	100

Fig. 2.1.3 Sustainability scores of the drilling process before and after the optimization

But the energy consumption got a worse score, as the process has to run longer due to its longer cutting time and the accessories keep running at the same power consumption rate. It should be noted that we get such a behavior because we are evaluating the process alone, thus the influence of the upper stream and downstream of the line is neglected. In the real case, as long as this process is not the bottleneck, the process would have to stay idle to wait for the workpiece to come. The disadvantage of longer running time could be insignificant in that case. This also indicates that it is very important to decide the scenario and the boundary of study at the beginning.

Less waste is generated after the optimization, mainly due to reduced scrap parts. This implies enhanced material utilization without any effort on applying near-net shaping technologies. Poor environmental impact score is caused by increased usage of energy. Again, if we evaluate the process along with other machines in the manufacturing line, it might not be the case.

Operator safety and personnel health are found to be the same ideal status throughout.

We do not want to sum the scores of each of the aspects together to generate a Process Sustainability Index, as the relationship between the elements are yet to be defined.

4 Summary

This paper presents a procedural flow of utilizing a set of metrics to evaluate the sustainability performance of a machining process. The metrics are developed based on our previously proposed framework and the collected data for sustainability measurements within concern. This paper specifies the metrics according to the manufacturer's sustainability requirements. This study demonstrates the sustainability performance change of the drilling process influenced by a machining performance oriented optimization process.

5 Acknowledgments

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6 Disclaimer

No approval or endorsement of any commercial products by the National Institute of Standards and Technology (NIST) is intended or implied. Certain company names are identified in this paper to facilitate understanding. Such identification does not imply that their products are necessarily the best available for the purpose of sustainable products or manufacturing.

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2.2 A Systematic Approach to Evaluate the Process Improvement in Lean Manufacturing Organizations

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Abstract
Numerous tools and techniques have been developed to eliminate or reduce waste and carry out Lean concepts in the manufacturing environment. However, in practice, manufacturers encounter difficulties to clearly identify the weaknesses of the existing processes in order to address them by implementing appropriate Lean tools. Moreover, selection and implementation of appropriate Lean strategies to address the problems identified is a challenging task. Therefore, the authors developed a methodology to quantitatively measure the performances of a manufacturing system in detecting the causes of inefficiencies and to select appropriate Lean strategies accordingly. Value Stream Mapping (VSM), manufacturing performance metrics and maturity stage of an organization are used to specify the manufacturing problems. Finally, a case example has been presented to demonstrate how the procedure developed works in practical situation.

Keywords:
Performance improvements, Waste, Lean manufacturing, Mathematical model

1 Introduction

The goal of implementing new tools and techniques in a manufacturing system is to increase the performances of new or existing manufacturing processes. The tools and techniques that are effective for organizational performance improvements are different in new and old organizations. Evidence shows that some of these tools are more effective in some organizations than others. Lander [1] suggested that while the concepts are the same from organization to organization, the actual tools used to carry out lean are different. Some tools may not be applicable or need to be modified to be useful in a specific organization [2]. Liker and Morgan [3] showed that there is a need to determine how to adapt lean tools for individual organizational contexts. Therefore, systematic methods are crucial to successful lean implementation, or the successful implementation of any world class manufacturing principles, as these have roadmaps which illustrate the company's current status along with its most important performance parameters. A very common method used by many researchers to find the current state of the system is to use the lean assessment tool with surveys. The surveys are used to help the manufacturers evaluate the degree of adoption of the lean principles. Survey results often provide scores and show the differences between the current state of the system and the ideal conditions of a manufacturing organization predefined in the surveys. However, the predefined lean indicators may not be appropriate for every system. Besides, the responses are inevitably subjective and may be biased. Lean metrics are the performance measures used to track the effectiveness of lean implementation or continuous improvement. Allen et al. [4] categorized lean metrics into four major groups, i.e., Productivity, Quality, Cost, and Safety. Several lean metrics are suggested in each group, such as "changeover time" in Productivity, "yield and "scrap" in Quality, "material" and "Labour" in Cost, and "injuries" in Safety. Each metric is developed to evaluate the progress of improvement in a specific area. However, these metrics do not provide a way of identifying the problems and selecting appropriate tools according to the problem. Another way of measuring the performance of a lean manufacturing system is Value Stream Mapping (VSM). This tool was developed by Rother and Shook [5]. VSM graphically depicts the current level of leanness of the system, and the future VSM, serving as a target of improvement. One weakness of VSM is that "cost" is not shown explicitly, since it is created strictly based on the time frames of the processes. It has been found in the literature, evaluation of a lean manufacturing system is done in three different ways such as qualitative, quantitative, and graphical. However, consideration of organizational contexts such as a new or mature organization as well as detecting the causes of inefficiencies and selecting a lean strategy accordingly, lacking in the current literature.

Therefore, this research proposed a systematic and sustainable methodology to evaluate the process improvement considering the maturity stage of an organization. The proposed methodology is to firstly, define the maturity stage of the organization, secondly, identify the causes of wastes; thirdly, select appropriate Lean strategies based on the contexts of the organization and problems identified; and finally, implement and evaluate the implemented lean strategy. In this research, Organizational Life Cycle (OLC-5) scale is used to identify the maturity stage of an organization. Value Stream Mapping (VSM), Quantitative analysis of a process related parameters such as Lead Time, Quality, Overall Equipment Efficiency (OEE) and cost of goods sold (COGS) are used to measure the performance of a specific process. Then criticality analysis of these parameters are done by the lean implementation team to finalize the causes of specific problems. Then a set of tools are selected for this organization based on their maturity stage and removing the causes of low productivity. Finally, a case example has been presented to demonstrate how the procedure developed works in practical situation.

The remainder of the paper is structured as follows: Sect. 2 provides the systematic and sustainable approach to evaluate the process improvement, a case example of proposed method is presented in Sect. 3. Research findings are discussed in Sect. 4. Limitations and extensions of this work round out the paper.

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2 A Systematic Approach for Lean Implementation and Evaluation

A systematic methodology has been proposed for selecting appropriate lean strategies based on the contexts of an organization and identified problems. Figure 2.2.1 shows the process flow of the proposed methodology.

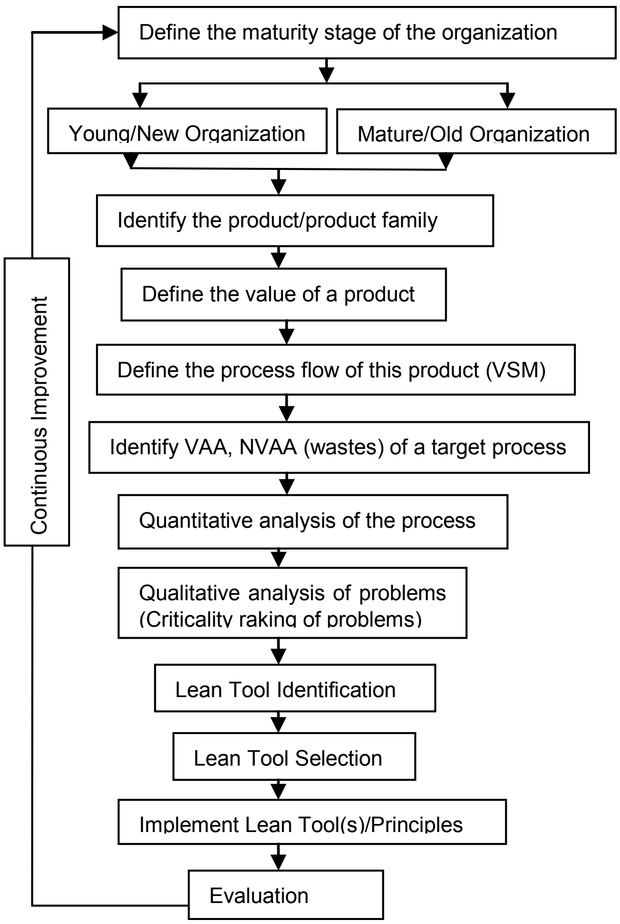

Fig. 2.2.1 A systematic lean implementation and evaluation process (LIEM)

2.1 Define the Maturity Stage of an Organization

Identification of maturity stage (new or old) of an organization is considered as the first step of selecting appropriate lean tools. A study by Pavanskar, Gershenson, and Jambekar [6] suggested that there is no empirical evidence that shows which tools are useful in a specific situation. Liker and Morgan [3] showed that it is necessary to determine how to adapt lean tools for individual organizational contexts. Organizations that are in the early stages of the organizational life cycle have little research or practice on which to build their own lean systems. New organizations are lack of resources. Therefore, choosing the most effective tools is imperative for young organizations. In this research, the Organizational Life Cycle (OLC-5) scale developed by Lester et al. [7] is used to determine the organization's life cycle stage. According to life cycle stages, organizations are categorized into two groups; young and mature.

2.2 Define a Product/Product Family

Once an organization is identified as a young or mature organization it is then important to identify the product or product family for lean process improvement. As Abdulmalek and Rajgopal [8] stated, the first step of implementing VSM is to define a particular product or product family as the target for improvement. Characteristically, a product family consists of a group of product variants that pass along comparable processing procedures and use ordinary appliances in the workshop.

2.3 Define the Value of a Product

Value can only be defined by the ultimate customer, and it is only meaningful when expressed in terms of a specific product (a good or a service, and often both at once) which meets the customer's needs at a specific price at a specific time [9]. In this research, product value is defined below by Browning [10].

Product Value = f (Product Performance, Product Affordability, Product Availability)

Therefore, the aim of lean implementation in an organization is to enhance product quality, at a low price, and at a shorter period of time.

2.4 Identify the Process Steps (VSM)

Once value is clearly defined, then value streams can be clearly identified. Value stream mapping (VSM) is a lean manufacturing technical methodology that helps to interpret the flow of materials and information currently needed to transfer goods or services to the end consumer. Manufacturing process activities are classified into three categories; namely: Value-added activities, Non-Value-added activities, Necessary but non-value-added activities. This step identifies the all activities related to producing the defined product.

2.5 Measuring Value of a Product

The measurements of different performance parameters described in this section are used to create facts for manufacturers to find improvement suggestions. Process maps and defined performance measures make the basis of building improvement suggestions.

Manufacturing Lead Time

The Lead Time can be expressed as a function of the throughput time, the activity cycle time, and the total number of units waiting to be produced. The total number of units can be further subdivided into those units in queue to enter production (N_q) and those that have been ordered and are going to enter the queue (N_0). The Lead Time is thus defined in Eq. 2.2.1 as

$$T_L = T_t + T_{ca}.\left(N_q + N_0\right) \quad (2.2.1)$$

$$T_t = (T_{ca})(N_a) = (T_{ca})(VA + NVA + NNVA) \quad (2.2.2)$$

This equation of throughput time can be expressed by a discrete event case by considering the m value-added activities and the n non-value added activities and z necessary but non-value added activities.

$$T_t = \sum_{i=1}^{m} T_{cai}.VA_i + \sum_{j=1}^{n} T_{caj}.NVA_j + \sum_{k=1}^{z} T_{cak}.NNVA_k \quad (2.2.3)$$

As the number of non-value added activities are reduced in making the system leaner, the throughput time reduces, while all else remains the same. Thus from a customer satisfaction perspective any removal of non-value added activities (waste) from the production system will result in better product lead time, and therefore increase their satisfaction with the company.

$$\frac{T_{Lf}}{T_{Li}} < 1 \tag{2.2.4}$$

This result impacts both the Lead Time for the product and the productivity of the process which will ultimately influence the process throughput rate, processing time, material handling time, set up time, equipment and personnel waiting time, material waiting time, and information waiting time.

Other parameters related to Lead Time;

- Processing time ratio is the ratio of value-added processing time to the total manufacturing lead time.

$$P_{tr} = \frac{VA_{pt}}{T_L} \tag{2.2.5}$$

- Material handling time ratio is the ratio of material handing time for creating a specific product to the total manufacturing lead time.

$$MH_{tr} = \frac{MH_t}{T_L} \tag{2.2.6}$$

- Change over time ratio is period required to prepare a device, machine, process, or system for it to change from producing the last good piece of the last batch to producing the first good piece of the new batch.' It is the ratio of set up time to the total manufacturing lead time.

$$CO_{tr} = \frac{S_t}{T_L} \tag{2.2.7}$$

- Equipment and personnel waiting time ratio is the ratio of personnel waiting time for equipment to the total manufacturing lead time.

$$EP_{tr} = \frac{W_{EPT}}{T_L} \tag{2.2.8}$$

- Material waiting time is the amount of time of waiting for materials to the total manufacturing lead time.

$$MW_{tr} = \frac{MW_t}{T_L} \tag{2.2.9}$$

- Information waiting time ratio is the amount of time waiting for specific information without that a production process cannot be started to the total manufacturing lead time.

$$IW_{tr} = \frac{IW_t}{T_L} \tag{2.2.10}$$

Overall Equipment Efficiency (OEE)

OEE is a quantitative metric used primarily to identify and measure the productivity of individual equipment. It improves equipment performance by identifying and measuring the losses of potential sources namely yields (Y), motion (v), and operational effectiveness (OE), availability (A). According to Federico et al., [11] OEE can be expressed as:

$$OEE = \frac{t_{qn}}{t_{np}}.\frac{t_{np}}{t_{ap}}.\frac{t_{ap}}{t_{available}}.\frac{t_{available}}{t_{effective}} = Y.v.OE.A \tag{2.2.11}$$

These above expressions are time-based only, thus being applicable to any production system.

Measuring Quality of a Lean Production Process

In this research, a measure of the quality of the system is defined as the ratio of the number of defect-free units produced (# of good units $=N_g$) to the total number of units produced. This ratio is called the quality factor (Q_f), the value of quality factor between zero (no good units produced) and one (no defects produced). The defects can be generated from the process or machine. The number of bad units produced (N_b) will thus be defined as;

$$Q_f = \frac{N_g}{N_u} \tag{2.2.12}$$

$$N_b = N_u.(1 - Q_f) \tag{2.2.13}$$

A certain number will be repairable (N_r) to meet specification from the bad units and a certain number will be unrepairable and will have to be scrapped *(Ns)*. The scrap ratio (S_r) is a number between 0 and 1, defines the percentage of bad units that cannot be repaired. So the total number of units to rework is thus defined as [12];

$$N_r = N_u.(1 - Q_f).(1 - S_r) \tag{2.2.14}$$

The number of rework activities (A_r) will rise in proportion (constant $=\alpha$) to the number of units that can be reworked. Since rework only exists because the product was not built right the first time, it is all non-value added. So, the total number of non-value added activities in the production system (NVA) will be the sum of the existing non-value added activities (NVA_e) and the rework activities as follows [12];

$$NVA = NVA_e + A_r \tag{2.2.15}$$

The expansion of Eq. 2.2.15 by substituting Eq. 2.2.14 yields

$$NVA = NVA_e + \alpha.N_u.(1 - Q_f).(1 - S_r) \tag{2.2.16}$$

The result of Eq. 2.2.16 is that any increase in quality will cause the quality factor to rise, thus reducing the number of non-value added steps in the process.

Measuring Value of a Product: Integrated Cost Equation for a Lean Product

In this research, value of a product is defined by calculating the cost of goods sold of a product. Cost of goods sold will determine the affordability of buying a product by a customer. Figure 2.2.2 shows the components of Cost of Goods sold of a product. The costs of goods sold ($COGS$) is comprised of labour costs (L_C), overhead costs (OH_C), Material costs (M_C) and lean implementation cost (LI_C).

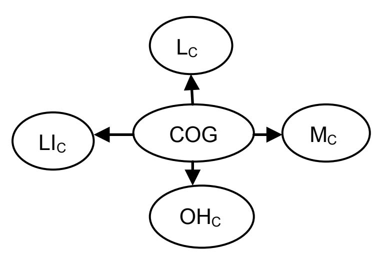

Fig. 2.2.2 Cost components of a lean product

The total cost can be expressed as;

$$COGS = OH_C + L_C + M_C + LI_C = (OH_{Cu} + L_{Cu} + M_{Cu} + LI_{Cu}).N_u + C_{ovf} \tag{2.2.17}$$

The labour cost per unit (L_{Cu}) can be represented as the product of the Labour rate (L_r), the labour time per activity (T_{la}), and the number of activities in the process. Equation 2.2.17 can thus be expanded to create Eq. 2.2.18.

$$COGS = \big((OH_{Ca} + T_{la}.L_r).(VA + NVA) + M_{Cu} + LI_{Cu}\big).N_u + OH_{Cf} \quad (2.2.18)$$

The cost of goods associated with improved quality is a slightly more complex relation. First, Eq. 2.2.18 must be modified to include the cost of scrap material (OH_{Cs}), which is a part of the total overhead cost.

$$COGS = \big((OH_{Ca} + T_{la}.L_r).(VA + NVA) + M_{Cu}\big).N_u + OH_{Cf} + OH_{Cs} \quad (2.2.19)$$

The scrap cost is defined as

$$OH_{Cs} = N_u.(1 - Q_f).S_r \quad (2.2.20)$$

Therefore, cost of goods sold can be expressed as;

$$COGS = \left((OH_{Ca} + T_{la}.L_r).\left(VA + NVA_e + \alpha.\frac{N_g}{Q_f}.(1 - Q_f).(1 - S_r) \right) + M_{Cu} \right).\frac{N_g}{Q_f} + OH_{Cf} + \frac{N_g}{Q_f}.(1 - Q_f).S_r + LI_{Cu}.\frac{N_g}{Q_f}.\frac{1}{n} \quad (2.2.21)$$

Lean implementation cost consists of engineering cost, investment cost, variable cost, and risk cost.

For 1 lean tool,

$$LI_{Cu} = (LI_{Cueng} + LI_{Cuinv} + LI_{Cuvar} + LI_{Curisk}) \quad (2.2.22)$$

For multiple tool,

$$LI_{Cu} = \sum_{i=1}^{m} (L_i LI_{Cuengi} + L_i LI_{Cuinvi} + L_i LI_{Cuvari} + L_i LI_{Curiski}) \quad (2.2.23)$$

All measurements should be documented in the database to compare the improvement. This step forces the manufacturers to be involved in the processes for a long time and gives them in-depth understanding of the processes and the production system. Further, the results from this activity should be analyzed to find additional improvement suggestions.

2.6 Criticality Analysis of a Problem

The previous steps provide the initial assessment of problem by using VSM and measuring process related performance parameters. As for example, analyse the process maps, find process steps, which can be removed, moved or simplified for an improved flow. Analyse the measured lead times, find long lead times with high variation. When the measurement data has been analyzed, it is time to decide in which order the improvement suggestions should be accomplished. This choice should be made in several ways. In this research, each suggestion should be sorted according to the most of the causes that determine the highest losses will occupy the highest places in the ranking. The purpose of this activity is to bring order and structure to the suggestions. The expected result is a lean implementation plan, which clearly states that what is the problem, which tool is applicable for identified problem, what is the deadline, and who is responsible for completing this task?

2.7 Tool Identification and Selection

Having identified the maturity stage of the organization and constraining parameters that limit the performances of the production system, appropriate lean tools and techniques should be selected from the toolbox provided in Fig. 2.2.3. For this study, the tools are categorized into groups suggested by a study performed by Abdulmalek and Rajgopal [8]. The lean tools are grouped into three different categories for comparison based on purpose and each category represents tools that all have similar uses and purposes. Categories are: (a) lean quality/continuous improvement tools, (b) lean process tools and techniques, and (c) support system tools and techniques [8]. The first category includes all tools that detect problems or opportunities in the environment, analyse them for the purpose of continuous improvement, and prevent quality problems in the future. The second category includes those tools that enhance efficiency and reduce process variability. The third category contains those tools and techniques that reduce waste outside the value stream. Then, these lean tools are also categorized into 9 broad areas provided in Fig. 2.2.3.

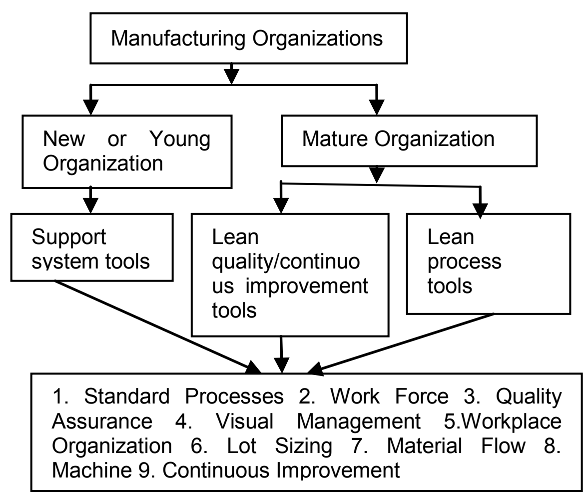

Fig. 2.2.3 Selection of lean tools based on organizational context

List of lean tools and techniques

Standard processes: SOPs, Standardized Work/Planning, Commodity Grouping, Common Processes & Best Practices, Trailer Loading & Unloading, Routing &Travel Paths

Work force: Safety & Ergonomics, Leadership Direction/Roles Management Style, Cross-Training, Teamwork & Empowerment, Power Distance & Daily Involvement, Recognition & Compensation, Communication Strategy, Absenteeism & Turnover

Visual management: Value Stream Mapping, Process Control Boards, Metrics & KPI Boards, Lean Tracking, Visual Control, Andon Systems, (A3) One Page Reports

Quality assurance: 5 Whys, Root Cause & Pareto, Inspection & Autonomation, Error Proofing Methodology, Inventory Integrity, Product & Process Quality, Data Mining

Workplace organization: 5S, Signage & Shadow Boards, Cleanliness, Supply & Material MGMT, Point of Use Storage (POUS), ID Problem, Parts Areas

Material flow: Pull Systems, Levelled Flow & Work, FIFO, Layout & Zones, Velocity & Slotting, Travel Distance, Cellular Structure, Demand Stabilization, Re-engineered production process, Cross-Docking, MTM analysis

Lot sizing: Batch Sizes, WIP, Kanban Systems, Quick Changeover, Lead Time Tracking, Inventory Turns, Order Frequency

Continuous improvement: PDCA, Kaizen Events, Employee Suggestions, Understand Systems View, Preventative Maintenance, Supplier Integration, SPC, Technology & Equipment

2.8 Solution Implementation and Follow-up

The lean tools/principles selected for the manufacturing process in the previous step are put in practice and evaluated after a period of time. Once the improvement procedure works, a new iteration should be performed in order to continuously set new improvement targets.

2.9 Continuous Improvement

Lean is aimed for ‘perfection’ and in doing so the improvement cycle is never ending. The connection between lean and sustainable manufacturing has been well documented in recent literature [13]. Sawhney et al. (2007) showed the connection between lean manufacturing and the environmental movement stating that “*it is natural that the lean concept, its inherent value-stream view and its focus on the systematic elimination of waste, fits with the overall strategy of protecting the environment”*, which they call Environmental Lean (En-Lean). Therefore, the organizations should follow the systematic methodology and invest the time and effort accordingly to assure sustainability.

3 Demonstration of the Proposed Methodology by a Case Example

The case organisation, Power Pty Ltd. (PPL) has been chosen because of its highly competitive environment that would have been more challenging for the methodology. The demonstration of proposed methodology is provided here.

3.1 Define the Maturity Stage of the Case Organization

By using OLC-5 scale developed by Lester et al. [7], the case organization is identified as a new organization. Therefore, the only lean tool category that has the potential to create value for young organizations is the third: support system tools and techniques (Fig. 2.2.3).

3.2 Define the Product and Product Value

This case organization manufactures low, medium and high voltage switchgear products. The Company is specializing in medium and high voltage auto reclosers for both pole mounted and substation applications from 10kV to 38kV. The challenge for the manufacturer is to deliver the product to the customer on time, at a low cost, and higher quality. Therefore, the value of product is defined in the eyes of a customer as a function of availability, affordability, and product performance.

3.3 Define and Observe the Manufacturing System

Currently, the company has four main manufacturing lines which are electrical control and communication cubicle assembly line, OSM automatic circuit reclosers’ assembly line, cable making line and switchgear assembly line. Although research has been carried out in all four manufacturing lines, this paper mainly focuses on electrical control and communication cubicle assembly.

VSM and Time study are used to help the manager to understand entire work processes, identify wastes, highlight problems and imply appropriate solutions. The following steps were used for the time study: **Process recording:** these steps video record the operator’s work process while working on this product. **Categorize the process:** after the time recording, the project team needed to discuss the work process with the manufacturing manager, and skilled operator to determine whether the process value added or non-value added category. **Break down and recording step time:** project team reviewed the recorded video and broke it into time segments that represent each of the details of work process. **Sketch Non-value added and value added time spread:** after estimating the time segments an excel spread sheet is used to generate a bar chart to identify the total processing time.

3.4 Quantitative Analysis

The data is collected to calculate the different performance parameters described in the previous section such as; throughput time, average cycle time, value-added processing time, material handling time, equipment and personnel waiting time, change over time, material waiting time, information waiting time, actual production time, breakdown time, amount of good parts produced in each process; lean implementation cost, amount of bad parts produced, amount of rework products, standard time associated to the operations performed in each step. In this organization, Industrial Engineering helped in the definition of the standard time for each process step. Finally, cost of goods sold of a product has been calculated from collected data and results are presented in Table 2.2.1.

3.5 Criticality Analysis of a Problem

Critical analysis was performed after completing the data collection in the previous step. From the VSM and time study result, following main problems during assemble process have been identified: **Walk distance:** operators need to walk to get assembly parts and tools all the time which some of the walking time can be treated as non-value added and are considered waste. **Handling:** some double handling problems have been identified, which mainly caused by operator’s working experience. **Part replenishment:** most of the assembled parts are loaded on the work bench within single different size of bins and there is a miscommunication between operator and the person responsible for replenishment. **Waiting and sharing tools:** currently operators are sharing one set of tools, which may cause increasing waiting time and can be treated as waste. The lean team finalize the problem that the operators are lack of knowledge about standard operating procedure of assembly process (handling materials) which is the reason of increasing lead time of producing a product and ultimately increase the price of a product. It was found out that there was no mention of the way the parts had to arrive to the process for processing.

3.6 Tool Identification and Selection

A lean implantation team is selected for solving the defined problem in a limited amount of time. In this case, organization is a new and the problem was related to the material handling activities of assembly process. Therefore, from Fig. 2.2.3 (support system tools), an analysis of working procedures (SOP) was decided to implement. The selected tool is quite simple, because it is merely a revision of the standard operating procedures that are used to train and to evaluate the performances of the workers of processes assembly of the product. A further improvement would be to redefine the layout of the factory and to review all the standard operating procedures, including the analysis of flowing parts, people and information.

3.7 Tool Implementation and Evaluation

This stage was the most critical activity where the proposal is implemented into the system. The implementation of the selected lean tool i.e. standard operating procedure for material handling is implemented in the assembly process. The system is evaluated by calculating the different performance parameters provided in the Sect. 2 and result is presented in Table 2.2.1. This system is monitored everyday to record the progress and improvement made by the new system.

Table 2.2.1 Comparison of before and after lean

Performance analysis	Pres-condition	After lean	Improve [%]
Implemented lean tool	No	Yes	–
Quality factor (%)	0.6	0.8	20
Lead time (h)	5	3	2
VA processing time (%)	70	81	11
NNVA material handling time (%)	10	7	3
Necessary changeover time (%)	5	3	2
NVA waiting time for sharing tools (%)	5	3	2
NVA waiting time for materials (%)	5	2	3
NVA information waiting (%)	5	4	1
Scrap rate (%)	7	5	2
Rework rate (%)	12	10	2
Material cost (AUD$)	8	5	3
Fixed overhead cost (AUD$)	5	3	2
Lean cost	0	2	–
Product cost [AUD$]	10	7	3

4 Conclusion

A systematic methodology has been developed to support lean manufacturers to effectively select lean strategies for their organization and sustainable process improvement. Initially, maturity stage of an organization has been identified. Then, several performance parameters have been calculated to identify the specific process related problems such as lead time, value-added processing time, material handling time, equipment waiting time, cost of product derived in the previous section. Based on the organizational context and the specific problems identified, lean tools are selected for improvement of the process. Results show that improved quality has positive effect on the cost of goods sold. The increase in quality reduces the rework and scrap rate, labour cost, material cost and overhead cost which ultimately decrease the product cost and increase the revenue. It is expected that the proposed methodology would make a significant contribution to evaluate the process improvement of any manufacturing organization. Future research will look for further improvement of the proposed methodology.

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2.3 A Method for an Integrated Development of Product-Production System Combinations

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Abstract

Emerging countries are rapidly gaining on the industrialized nations. Enterprises can only succeed in this global competition arena if they differentiate themselves through the products and their production systems. A new approach to the development of products and corresponding production systems which allows a just coexistence in competition and collaboration between different levels of development is necessary to face the challenge of sustainable development. It must combine the strategic forecast of markets, technologies and the business environment with a cross domain specification of concepts of products and production systems. In a strategic planning phase, prospective framework conditions are derived from field investigations and transferred into product and production scenarios. From the scenarios a promising combination of product and production system is selected. In a conceptual design phase a comprehensive specification of the product-production system combination is worked out. This is done based on a new specification technique taking into account the interactions between product and production system.

Keywords:

Strategic production system planning, Product concept, Production system concept, Conceptual design, Integrative development

1 Introduction

Emerging countries are rapidly gaining on the industrialized nations; if this boom continues under the utilization of predominant technologies, then resource consumption will exceed every accountable economical, ecological and social limit [1]. Today, enterprises can only succeed in this global competition arena when they systematically access markets in emerging countries, undergo strategic alliances with local enterprises and differentiate themselves through the products they produce and the production systems and technologies they deploy. Conventional, cost driven strategies to the relocation of production locations are outdated and promise little success as wage levels, as the main cost drivers, continue to approach the levels of early industrialized countries [2].

Therefore, in addition to resource saving technologies, new methods and approaches for their application which allow a just coexistence in competition and collaboration between different levels of development must be created in order to face the challenge of sustainable development; an appropriate new approach for strategic production system planning is necessary.

The interdependencies between product and production system are not adequately considered, resulting in time-consuming and cost intensive iteration loops during the development process. That is the reason why product and production system need to be developed integratively. In this paper, the product and the associated production system is called product-production system combination. They are to be evaluated according to economic and ecological aspects as early as possible in the product development process, thereby allowing product design to be influenced at an early stage.

The arena of competition, driven by globalisation, the required sustainability as well as the necessary shortening of time to market demand a method which empowers developers and production system planners to develop product and production system in close cooperation from the beginning.

Existing product development methods do not provide the possibility of a systematical forecast of markets, technologies and the business environment and the resulting constraints on the design of production systems adequately. The study Raw materials for future technologies—influence of the industry-sector-specific need for raw materials in raw material intensive future technologies on the prospective demand for raw materials, commissioned by the German Federal Ministry of Economics and Technology, for example stresses the problem of scarce resources for future technologies [3]. The identification on the future impact on product and production system and approaches to distribution and substitution of resources is required.

Until now, product-technology-portfolios as well as technology roadmaps are developed to manage technologies in particular for planning of new production technologies and process chains for the production of hybrid bundles of services [4]. Location specific framework conditions and their relevance to development and production are however not taken into account. Here, the works of SCHUH/HARRE on the subject of Global footprint design and Organization of international value chains provide an approach [5, 6]. WAGNER/NYHUIS introduce a concept for small and medium-sized companies to ensure the companies' ability to act on international mar-

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kets [7]. The conception of optimal production system concepts based on strategic framework conditions, considering the interactions of products and production systems, has not been developed.

The necessity of a parallel development of product and production system has been propagated for a long time; mostly in the sense of organizational approaches like Simultaneous Engineering [8]. The parallel development of product and production system, is not addressed. Some approaches to Design-for-X (DfX) attempt to consider production technology aspects in development [9]; interdependencies between products and production systems are however often considered only from the product-perspective. With the help of Axiomatic design according to SUH, a hierarchical structuring of products and production systems is possible [10]. All these approaches cannot support the early description of production systems under consideration of interdependencies between product and production system.

The necessary integrative conception of products and production systems is not ensured. Especially the derivation of requirements from different possible prospective framework conditions does not exist yet.

2 Approach

At the Heinz Nixdorf institute and the department for machine tools and factory management a method for the integrated development of product-production system combinations is being elaborated. The goal of the method is the development of product and its production-system under the consideration of aspects for global competition, meeting strategic, economic and ecologic framework conditions.

For this purpose, framework conditions are identified and evaluated to develop strategic options for the design of products and production systems. Market needs are linked with production potentials and restrictions in countries with different levels of development. It provides an integrated basis for decision-making and strategy-building of globally operating companies. Based on consistent product and production scenarios, integrative product and production system concepts are developed.

The procedure for this approach is shown in Fig. 2.3.1. The method consists of two phases:

1. Strategic planning of product and production system.
2. Conceptual design of product and production system.

At the beginning of the first phase, field scenarios for countries of different development levels are created. The field scenarios describe the different possible future perspectives of the business environment. Prospective framework conditions for products and production are derived from field investigations for each level of development. The framework conditions are transferred into product and production scenarios. Through the linkage of product and production scenarios in a map, companies are able to identify their current position in global competition and to derive strategies for desirable positioning. From the scenarios, a promising combination of product and production system is selected.

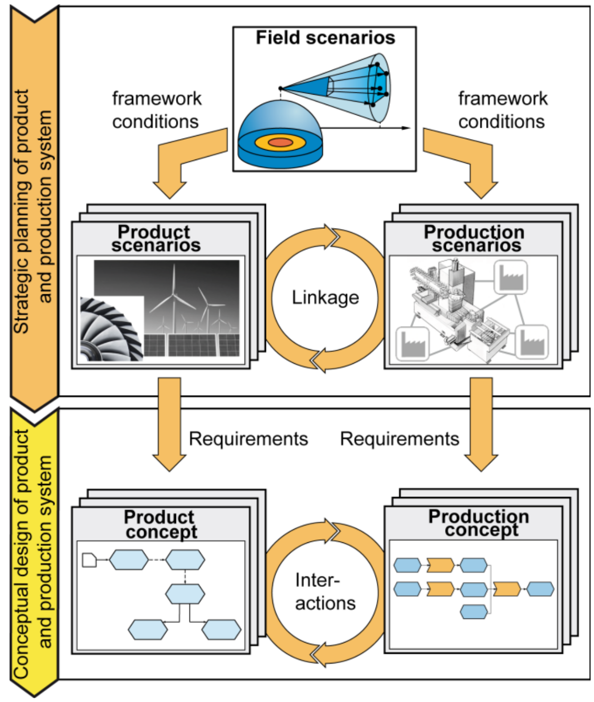

Fig. 2.3.1 Procedure for the integrative development of products and production systems combinations

In the second phase, the requirements on the development are derived from product and production scenarios. With the requirements and additional information, e.g. the qualification level of workers or stability of power supply, the conceptual design starts. In this process, selected product-production-system-combinations are worked out and their feasibility is analysed. A specification technique is used for the conceptual design which covers aspects such as environment, application scenarios, requirement, shape, behaviour, active structure, process sequence and resources. As part of the concretisation the interaction between the partial models, especially between the product concept and production system concept are examined. Finally, the concept is validated based on the requirements from the strategic planning.

The method described in Sect. 2.1 will be applied to the example of the DFG funded project "remanufacturing oriented production equipment development". To meet the challenges of sustainability, Brazil and Germany established the Brazilian German Collaborative Research Initiative in Manufacturing Technology (BRAGECRIM) in 2008. The goal is to research how production technology can foster sustainable innovation. In the project, technology and field scenarios for remanufacturing have been developed, whereby scenario technique helped to structure complex interrelationships between various areas of influence. The method described in Sect. 2.2 has not been applied to the example yet.

2.1 Strategic Planning of Product and Production System

In order to ensure the long term success of German enterprises, they must be enabled to determine their strategic actions according to changing global competition and to derive strategies for achieving a competitive position in the future. The following phase for strategic planning of product and production system should link prospective market requirements and production potentials for different levels of development.

In an initial stage, the surrounding fields of different levels of development should be illuminated for the object of examination. This is performed for reference countries using the scenario technique. In the following example, field scenarios for the remanufacturing market in an intermediate development level in Brazil were initially developed. This resulted in two field scenarios [11]. The scenario “Remanufacturing—a paradigm change for sustainable manufacturing” describes a very positive field for remanufacturing with a growing market. The scenario “Remanufacturing—still only a hidden giant” on the other hand illustrates remanufacturing potentials which remain untapped due to lack of qualification and government incentives and a stagnating market for remanufactured production equipment.

These field scenarios serve as a starting point for the development of product and production scenarios. The approach for developing production scenarios (Fig. 2.3.2) is described exemplarily for the remanufacturing of a grinding machine [12]. Various technological and organisational framework conditions for the remanufacturing system can be derived from the two field scenarios for remanufacturing in Brazil in 2020. For example, the low qualification level in respect to remanufacturing and the lack of financial incentive systems cause that only small portions of the equipment are remanufactured and that rudimentary methods are applied. These framework conditions also rule out processes using expensive facilities which require large capacity utilization for profitable deployment.

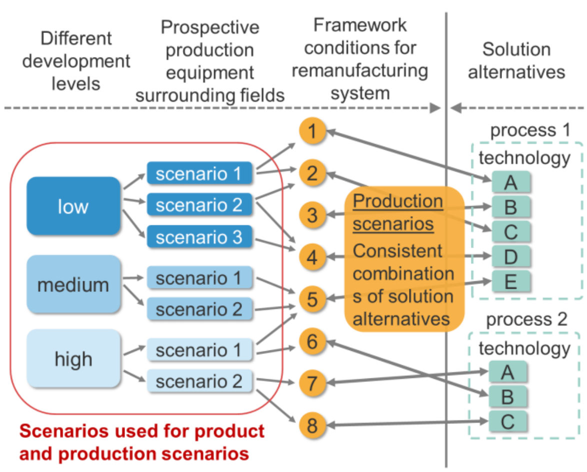

Fig. 2.3.2 Production scenario development approach

Technologies, or rather solution alternatives for performing the required grinding machine remanufacturing processes have been identified and combined to consistent technologies bundles according to these framework conditions. Eight bundles with diverging technology levels resulted. The scope ranged from cost driven approaches in "one piece remanufacturing“ up to high-tech solutions.

Product scenarios should be developed, analogue to the production scenarios. In contrast to the potentials represented by the production scenarios, the product scenarios especially illustrate the market requirements and their possible implementation in products.

The linkage of product and production scenarios for different levels of development in a map should enable enterprises to identify both potentials and needs of different production locations and markets and their interdependencies. They should be able to derive strategies for cooperation and competition within the area of observation. The needs and potentials are used for the conceptual design of product and production systems.

2.2 Conceptual Design of Product and Production Systems

Product and production system development needs to be executed in an alternating manner, taking strategic aspects into account. The product concept is affected by the considered manufacturing technology. This corresponds with common simultaneous or concurrent engineering approaches. But a close interaction between product development and production system development must already be applied in the early design stages “planning and clarifying the task” and “conceptual design”. The conceptual design results in the so-called “principle solution” [13]. The principle solution of the product determines the basic structure and the operation mode of the system and, subsequently, it is the basis for further concretization. Furthermore, it forms the starting point for the conceptual design of the production system.

In order to describe both the principle solution of the product and based on it the production system, a set of specification techniques has been developed [14–16]. Following the notion of systems engineering, it provides a common language for describing mechatronic products comprehensively. It provides a basis for the communication and cooperation of the specialists from the involved disciplines such as mechanics, electrical engineering, electronics, software engineering and control technology. The principle solution of a complex mechatronic product is described by the aspects requirements, environment, application scenarios, functions, active structure, shape and behaviour. The aspects requirements, process sequence, resources and shape describe the principle solution of the production system. They are mapped by partial models (Fig. 2.3.3). The partial models are in relationship with each other and form a coherent system, the principle solution consists of a coherent system of partial models.

As mentioned above, the product development process is not a straight sequence of activities. Therefore it is necessary to work alternately on the aspects and partial models. Nevertheless, there is a certain order. The description of the environment, the application scenarios and requirements serve as the starting point. First of all, the system is modelled as a “black box” embedded in its environment. Relevant spheres of influence (such as temperature, humidity, mechanical load, superior systems) and influences (such as thermal radiation, wind energy, information) are identified and the interactions between them are examined. Information about the environment can be taken from the respective field scenario, e.g. the low qualification level.

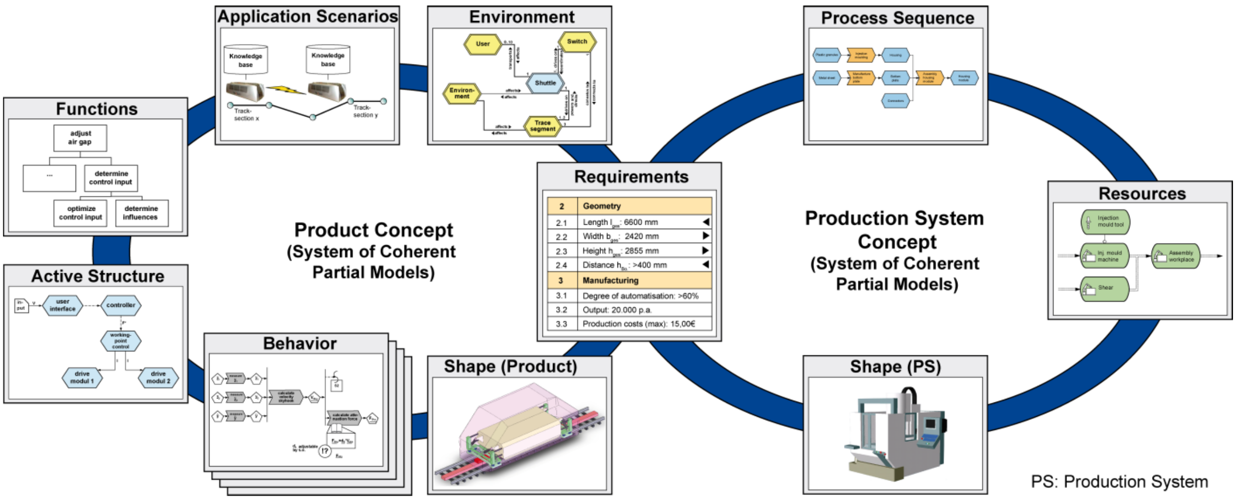

Fig. 2.3.3 Partial models for the description of the principle solution of the product and the production system

Next, the behavior of the system in a particular state and situation is described by application scenarios. The application scenarios additionally define what kind of events initiate a certain state transitions. They characterize a problem and roughly describe the possible solution. The partial models environment and application scenarios lead to the partial model requirements. It represents an organized collection of requirements that need to be fulfilled during the product development (e.g. performance data). The list of requirements sets up its basis. It also includes requirements posed to the production system (e.g. tolerances, number of units). Every requirement is textually described and, if possible, concretized by attributes and their characteristics. The initial requirements are derived from the product and production scenarios. In the next step functions are derived from the list of requirements. The partial model functions concerns the hierarchical subdivision of the functionality of the product. A function is the action expressed by a noun-verb-term between input and output parameters, aiming at fulfilling a task. The active structure describes the system elements, their attributes as well as the relation of the system elements. The relations will distinguish between energy, information and material flow. The goal is to define the basic structure of a system, including all possible system configurations. The active structure contains system elements, such as controller modules, actuators, sensors, housing, energy management and their attributes and their relations. Furthermore, incoming parameters are described, such as costs and time. The system is structured by logic groups in order to improve the necessary clearness. Based on the active structure, the rough shape of the system is modelled. The shape modelling takes place by using common 3D CAD systems. The active structure and a first model of the shape of the system form the core of the principle solution in the conventional mechanical engineering. For mechatronic systems the behaviour of the system must be specified as well. This is done in the partial model behaviour.

Based on the information from the partial models requirements, active structure and product shape a first building structure is developed. This building structure describes the spatial and logical aggregation of components to assemblies and products [13]. The information contained in the building structure is used to establish a first assembly and manufacturing sequence.

The processes as well as the product components are depicted in the partial model process sequence (Fig. 2.3.4).

The process sequence is the core of the principle solution of the production system. Each process is described by a manufacturing function. Those manufacturing functions are concretized to manufacturing processes and technologies. The interactions between the applied technologies need to be considered and alternative technology chains need to be evaluated using methods such as the methodology for evaluating manufacturing sequences by Brecher et. al. [17]. Next, resources are allocated to the several processes and depicted in the partial model resources. The chosen manufacturing technologies and resources are described by parameters. They are used for the early evaluation of manufacturing costs. The last partial model represents the shape of the production system. Analogue to the conceptual design of the product first definitions of the shape are made during the conceptual design of the production system. The shape is referred to as workspace, the required floor space of machines or the active areas of handling appliances.

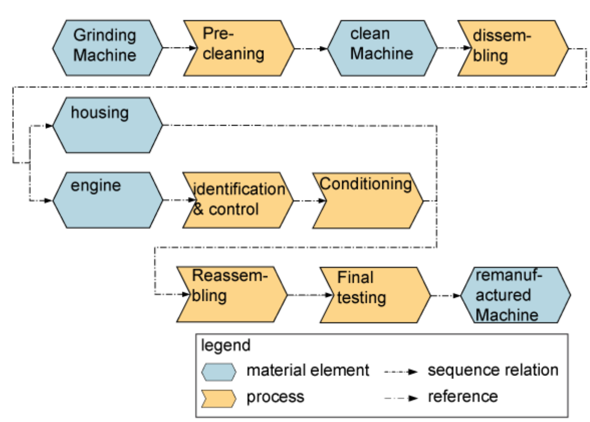

Fig. 2.3.4 First process sequence during the conceptual design (example)

From the interactions between product and production system concept, new requirement can be deducted. This must be compared against the strategy.

The result of the conceptual design is a domain-spanning description of the principle solution of the product and the production system. This not only forms the basis for the concretisation of the product and the production system in the following design stages, but also contains information enabling various analysis such as early failure mode and effect analysis of the product (FMEA) and manufacturing costs forecasts.

3 Outlook

A method for the integrated development of product and production systems was presented taking account of strategic considerations. On the basis of field scenarios, framework conditions are derived for product and production scenarios. This was exemplified by production scenarios for remanufacturing in Brazil in 2020. The linkage between the product and production scenarios should be considered in more detail in the future, in particular, the selection of suitable product and production system combinations. The selection must be supported by a method. The respective requirements are derived from the product and production scenarios. The specified process is still object of investigation for future research. Following the requirements and the scenarios used for the integrative development of product and production systems. Therefore, a specification technique for the description of product and production systems concepts is used. In the process of concretisation, new requirements are provided for the system. The concrete product and production system concept is finally compared with the product-production system combination from the scenarios. Such a simultaneous, integrated development of products and their respective production systems provides the potential to increase the efficiency of product creation and to further reduce time to market.

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2.4 Impact Assessment of Machine Tool Auxiliary Drives Oversizing to Energy Efficiency Aspects

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Abstract
The paper focuses on the energy consumption of machine tool auxiliary drives. A detailed analysis of the electric power consumption of production lines in the automotive sector shows that machine tool auxiliary drives often have a low power factor. For uncontrolled induction machines this is an indicator for an operation in partial-load range and thus for an oversizing. The scope of this work is the evaluation of the energy efficiency of this auxiliary drives. Loss mechanisms of asynchronous machines are pointed out. The efficiency of asynchronous machines of different rated power will be assessed for a constant mechanical load. Beside the machine losses, ohmic losses of the lead wires are investigated to allow for a holistic assessment of the energy efficiency. The work shown in the paper was conducted within the project BEAT which is kindly financed by the Federal Ministry of Education and Research in Germany (BMBF).

Keywords:
Energy efficient production, Machine tool auxiliary drives, Asynchronous machine losses, Lead wire losses

1 Introduction

Currently an increasing global demand on resources can be registered. The concurrent scarcity of resources, as well as the political ambition to reduce carbon dioxide emissions leads to a resulting increase in prices. Thus the manufacturing industry has to face energy efficiency as a central point. Actually a sufficient data basis for an energetic assessment of different process chains in the manufacturing industry is not available.

Within the project “Bewertung der Energieeffizienz alternativer Prozesse und Technologieketten” (BEAT), engl.: Assessment of the energy efficiency of alternative processes and process chains) production lines in the automotive sector are investigated exemplarily regarding to their energetic behaviour. Therefore, the entire energy and resource flows are measured. The data acquisition of the electrical energy consumption shows an extensive energy conversion of auxiliary drives (e.g. pump motors, hydraulic systems). Oftentimes in this area uncontrolled induction drives are applied. At the data acquisition a low power factor of many of these auxiliary drives was noticeable, which indicates an operation in partial-load range and thus an oversizing of the machine.

This paper presents the data acquisition of a gear wheel production line. The complete process chain, as well as a detailed overview over all energy and resource flows is presented in [1]. Furthermore, this paper pays special attention to the operation and the impact of oversized induction machines to energy efficiency aspects. For a holistic consideration lead wire losses of the investigated production line are discussed.

The project BEAT is kindly financed by the Federal Ministry of Education and Research in Germany (BMBF).

2 Data Aquisition

The electrical power consumption of the machine tools is measured with a power quality analyzer. The sufficient accuracy of the power quality analyzer for the data acquisition is shown in [1]. To allow for an uninterruptable operation of the machine tools, the current is measured with current probes. For each machine tool the electrical power consumption was measured in two steps. In a first step the main incoming supply is recorded. To separate the electrical energy consumption of the main drive and auxiliary drives, each consumer is measured separately in a secondary step.

The power consumption is measured in normal operation mode, in stand by mode and in power off. In the normal operation mode the power consumption is averaged over several cycles. As it can be seen in Fig. 2.4.1 auxiliary consumers take over 40 % of the full power. The main auxiliary consumers, e.g. hydraulic system pumps, cooling lubricant pumps and compressors, are mostly uncontrolled standard induction drives. The power factor of most of these drives is between 0.3 and 0.7 leading to high reactive power consumption.

For stationary induction drives this low power factor indicates an operation in partial-load range as it will be described in Sect. 3.

3 Stationary Induction Drives

Induction machines have been widely accepted in the range of stationary auxiliary drives. Standard induction machines have a simple construction. This leads to a low-priced

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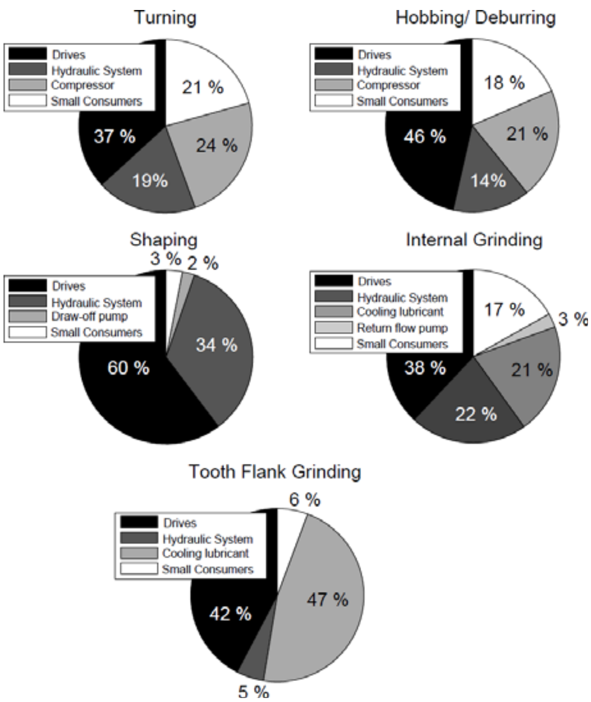

Fig. 2.4.1 Power distribution of the machine tools in normal operation mode

production. Due to their robustness, they can be applied in many different environments. For a stationary operation the induction machine can be directly connected to the grid.

3.1 Operation of an Induction Machine

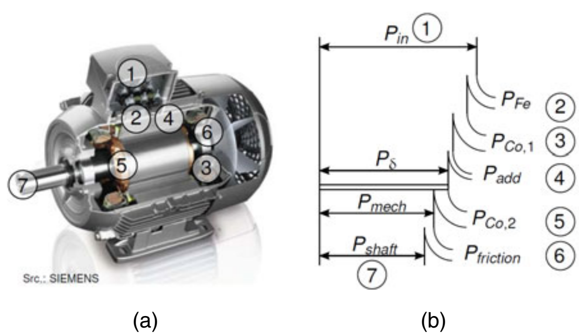

Fig. 2.4.2 Schematically depicted power flow of an induction machine [2]

This section describes the operation of stationary induction drives which are directly connected to the grid. The paper concentrates on squirrel cage induction machines as depicted in Fig. 2.4.2 (a). Only fundamental waves are considered for electrical quantities, therefore the power factor is equal to cos φ.

Figure 2.4.3 depicts a simplified current locus of an induction machine. This locus is valid for an operation range, where the current displacement inside the rotor bars can be neglected. This is the case for small slip frequencies. In the considered operation range from the nominal operation point (see Fig. 2.4.3: OP) to partial load, the slip will decrease. Values for the nominal slip are smaller than 5% depending on the rated power of the machine. It can be seen that the power factor depends on the point of operation of the machine.

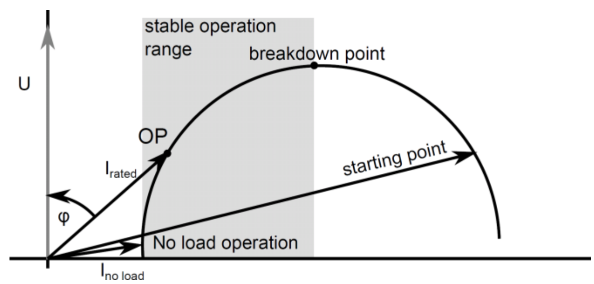

Fig. 2.4.3 Simplified current locus of an induction machine

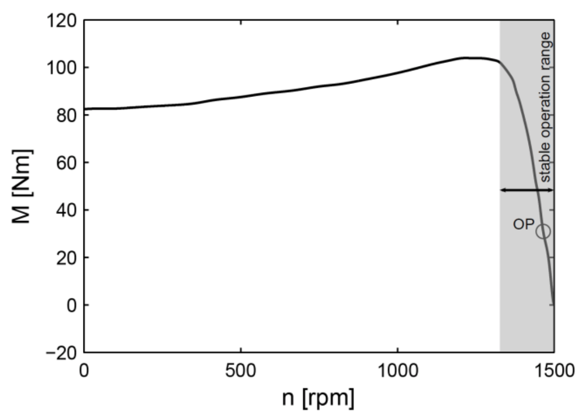

Fig. 2.4.4 Typical Torque–Speed characteristic of an induction machine

A typical torque speed characteristic of an induction machine is depicted in Fig. 2.4.4. The speed depends on the loading. In the partial load range the speed comes up to the synchronous speed n_{syn}.

3.2 Efficiency of Induction Machines

Figure 2.4.2 (b) depicts the power flow of an induction machine. Different loss mechanisms have to be regarded. Inside the stator winding losses, iron losses and load dependent additional losses occur. Ohmic losses in the three-phase winding are defined by:

$$P_{co,st} = 3 \cdot I_1^2 \cdot R_1, \qquad (2.4.1)$$

with the resistance R_1 and the current I_1. The load dependent additional loss term considers losses in the active part of the iron and other metal parts of the machine. According to DIN-EN 60034-2 [3] load dependent additional losses are defined by:

$$P_{add,rated} = P_{in} \cdot \left[0.025 - 0.005 \cdot \log_{10}\left(\frac{P_{mech}}{1\mathrm{kW}} \right) \right]. \qquad (2.4.2)$$

Equation 2.4.2 is valid for induction drives of a rated power $1\text{kW} < P_{mech} < 10{,}000\text{kW}$. For different loads than the nominal load additional losses can be calculated by:

$$P_{add} = P_{add,rated} \cdot \left(\frac{I_1}{I_{1,rated}} \right)^2. \tag{2.4.3}$$

Classical iron losses of the stator can be assumed as constant over the considered operation range. Iron losses are specific losses which increase with an increasing amount of stator iron, and so with an increasing rated power of the induction machine. Stator losses are frequency dependent. The rotor of an induction machine is only penetrated with a field alternating with the slip frequency of a few Hz and will be neglected. Then, the only considered electrical losses inside the rotor are ohmic copper losses, which are defined as:

$$P_{co,2} = P_{mech} \cdot \frac{s}{1-s}, \tag{2.4.4}$$

with the slip:

$$s = \frac{n_{syn} - n}{n_{syn}}. \tag{2.4.5}$$

Modern induction drives are classified into efficiency classes IE1 to IE3 according to IEC 60034-30 [4]. Figure 2.4.5 depicts the efficiency of induction drives of efficiency class IE1 and IE2 for different numbers of pole pairs p.

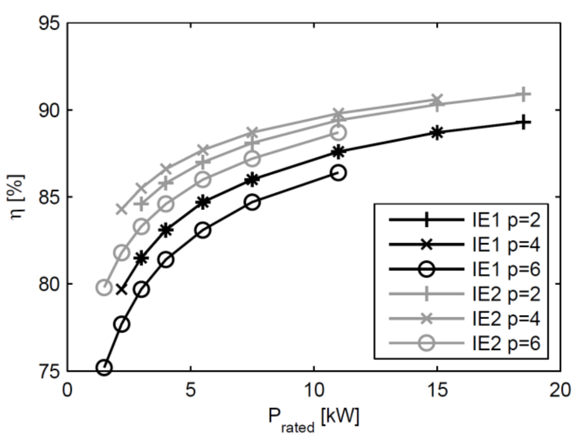

Fig. 2.4.5 Efficiency of standard induction machines of different rated power and pole pair numbers [5].

The efficiency of induction drives increases with an increasing rated power. The efficiency of an induction machine is nearly constant up to an operation of 1/2 rated load. This can be seen in Fig. 2.4.6. The depicted efficiency characteristic and the mechanical power are calculated from manufacturer data sheets [5]. Behind the marked range the efficiency decreases up to zero in no load operation. Due to the fact that machines with higher rated power have a higher efficiency, it seems to be possible that an oversized machine will have lower losses than a smaller machine operating in the nominal point. Therefore in the following section induction machines of different rated power will be compared at operation at constant load.

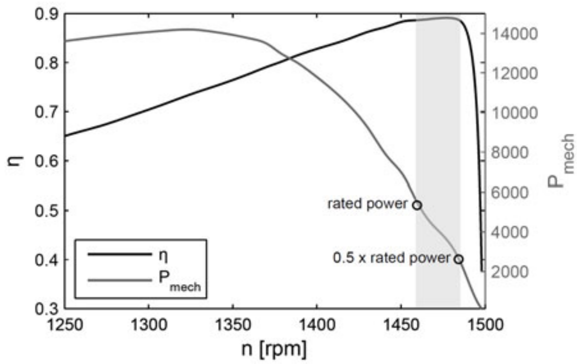

Fig. 2.4.6 Efficiency and mechanical power of a 5.5 kW induction machine

3.3 Loss Distribution of Induction Machines

The data basis of the following investigation is obtained from manufacturer data sheets [5]. The induction machines are classified with efficiency class IE2. Four machines with ratings between 2.2 and 7.5 kW are considered. The nominal input voltage is 400 V. The load is kept constant at 2.2 kW.

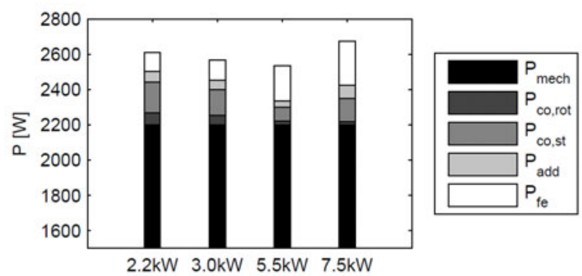

Fig. 2.4.7 Power distribution of different rated induction machines at constant load P=2.2 kW

Figure 2.4.7 depicts the comparison of the power distribution of different rated machines at constant load of 2.2kW. The losses are calculated based on data from manufacturer data sheets. As expected the iron losses increase with an increasing rated power due to the higher amount of stator iron. The rotor copper losses decrease with a higher rated power due to a decreasing slip. By the smaller winding resistance for larger machines the stator copper losses also decrease. Bearing and friction losses are included in the mechanical power and are not separated in this analysis. The power factor of the induction machine decreases by an increasing rated power. Table 2.4.1 shows the power factor and the efficiency of the investigated induction machines at 2.2 kW load and at rated operation of each machine. It is shown that the efficiency of the 3.0 and 5.5 kW machine for the applied partial load exceeds the efficiency of the small machine in rated operation. The 7.5 kW machine is loaded with only 30% of its rated load. In this operation point the efficiency decreases to 82.2% and the operation gets inefficient. The presented investigations affirm results from [6].

Table 2.4.1 Efficiency and power factor of different Induction machines

P_{rated} [kW]	$\eta_{100\%}$	$\cos\varphi_{100}$	$\eta_{2.2kW}$	$\cos\varphi_{2.2kW}$
2.2	84.3 %	0.81	---	---
3.0	85.5 %	0.82	85.7 %	0.75
5.5	87.7 %	0.80	86.8 %	0.62
7.5	88.7 %	0.83	82.2 %	0.40

4 Lead Wire Losses

4.1 Calculation of Lead Wire Losses

To get a holistic overview over the efficiency of induction machines lead wire losses, which will increase with a lower power factor, has to be considered. Lead wire losses are ohmic losses on the lead wires. They are defined as:

$$P_{Loss} = \frac{3 \cdot l \cdot I^2}{\sigma \cdot q}, \qquad (2.4.6)$$

with the length of the lead wire l, the lead wire current I, the electrical conductivity σ and the cross-section of a strand q. Assuming a constant active power which is submitted over the wire the current magnitude will depend on the power factor of the consumer:

$$I = \frac{P_{cons.}}{\sqrt{3} \cdot U \cdot \cos\varphi_{cons.}}. \qquad (2.4.7)$$

Applying Eq. 2.4.7 to 2.4.6 leads to:

$$P_{Loss} \sim \frac{1}{\cos^2 \varphi_{cons.}}. \qquad (2.4.8)$$

4.2 Calculated Lead Wire Losses of the Measured Production Line

The lead wire configuration of the investigated production line is not known in detail. Nevertheless, to consider lead wire losses a ring system as it is schematically depicted in Fig. 2.4.8 is assumed. The lead wire cross-sections are determined so that the maximum allowable voltage drop is abided. The length of the lead wire is fixed to 10 m for the line between a machine tool to the ring system and to 20 m of each section of the ring grid. Two feeding transformers are considered as they are classically used in ring systems. Data basis for the calculation is the measured power consumption of the machine tools.

The calculated lead wire losses by Eq. 2.4.6 are 552 W in normal operation and 243 W in standby mode. Taking as basis an average utilisation ratio of 52% for normal operation and 29% in standby mode, the annual energy consumption of lead wires is 3132 kWh.

4.3 Improvement of the Turning Machine

The power factor of the turning machine is with a value of 0.6 low compared to the other machine tools. From Fig. 2.4.1 it is known that the turning machine has two large auxiliary drives, the hydraulic auxiliary system and a compressor. The compressor has a power consumption of 2.2 kW with a power

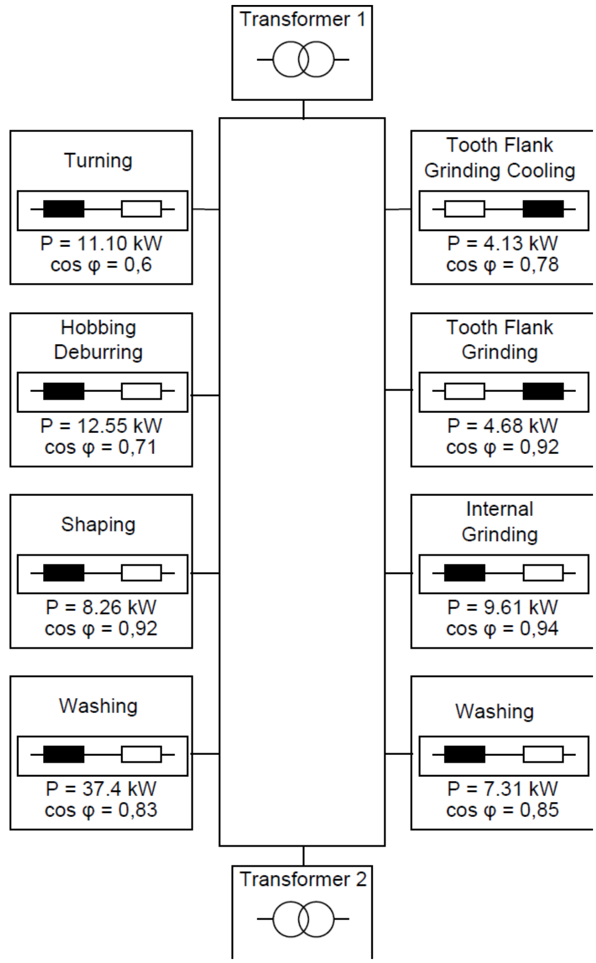

Fig. 2.4.8 Schematical power grid of the production line

factor of 0.6. As it was shown in Sect. 3 the low power is founded by an operation in partial load range. A replacement of the induction machine with an induction machine rated at 2.2 kW will lead to a higher power factor of the compressor of 0.81 (see Table 2.4.1). The adapted compressor improves the resultant power factor of the complete turning machine to 0.67. The input power increases due to the lower efficiency of the compressor to 11.13 kW. Due to the higher power factor, the complete lead wire losses are reduced by 41 W resulting in 511 W. A comparison of both machines shows that the turning machine with an adapted compressor operating at rated conditions has by 34 W higher losses, despite the better power factor.

5 Conclusion

This paper discusses the effect of oversized machine tools auxiliary drives to energy efficiency aspects. It is shown that the efficiency of typically used standard induction machines increases with an increasing rated power. The use of an oversized induction machine can be more efficient than the use of an adapted machine. It is shown that for a constant load of 2.2 kW an induction machine rated at 5.5 kW produces minor losses than an induction machine of 2.2 kW. But it has to be considered that the efficiency advantage vanishes, the more the machine is operated at no load condition. As an example a 7.5 kW machine is loaded with only 30% of its rated load and its efficiency decrease to 82.2 % compared to 84.3% of the 2.2 kW machine in rated operation.

For a holistic view on the energy efficiency, lead wire losses are considered. By the lower power factor of induction machines which operates in partial load range, lead wire losses will increase. Lead wire losses are estimated for the given production line. They amount to less than 1% of the consumed active power of the machine tools. An adaption of a compressor of a turning machine to improve the power factor of the complete machine decreases the lead wire losses, but due to higher machine losses the resulting consumed active power increases compared to an oversized compressor.

This paper shows that oversized induction machines can be more efficient than adapted machines, despite a lower power factor and therefore higher lead wire losses.

6 Acknowledgments

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2.5 Towards a Decision Support Framework for Sustainable Manufacturing

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Abstract
Every enterprise should track and asses its environmental impact for accountability reasons towards its consumers, employees, government, and society. The objective of this study is to design an eco-tracking framework and a decision support system architecture in order to provide energy visibility to enterprises by close monitoring the energy consumption of their manufacturing processes. The proposed architecture uses the energy consumption and production activity data as input. Energy consumption data is collected from meters and production activity data from manufacturing automation equipment (e.g. PLCs, CNCs, etc.). Collected energy data which is stored in a central data warehouse, is processed, contextualized with activity data and transformed to eco-KPIs in order to benchmark energy efficiency of the production processes and enable factory supervisors to make decisions towards better environmental footprint of the enterprise. The proposed decision support framework is founded on Software as a Service (SaaS) approach which can enable fast visibility of data throughout enterprise and provide easy scalability.

Keywords:
Carbon footprint, Decision support system, Energy efficiency in manufacturing, Life cycle assessment

1 Introduction

United Nations defines sustainable development as meeting the present needs without compromising the ability of future generations to meet their needs [1]. Sustainability of an organization is analyzed from three perspectives: environment, society, and economy. While manufacturing is a major driver of civilized development which provides high quality living standards, manufacturing can be harmful to natural environment. If not managed and minimized, this impact may include damage such as depletion of natural resources, global warming and toxic wastes which can significantly harm natural habitat and human health.

Sustainable manufacturing has emerged as the leading paradigm to address the dilemma of maintaining a progressive economic growth based on production of goods and services without continuing to damage our environment. U.S. Department of Commerce defines sustainable manufacturing as the creation of a produced product with processes that have less negative effect on the environment, conserve energy and natural resources, are safe for employees and communities, and are economically sound [2].

Sustainable development requires methods and tools to measure and compare the environmental effects of human activities for the provision of services and goods [3]. Many practitioners and researchers from multiple domains utilize life cycle assessment (LCA) methodology and tool kits to estimate indicators of the potential environmental effects that are linked to products, exploring opportunities for preventing pollution and reductions in resource consumption while taking the entire product life cycle into account. LCA provides a method to quantify the environmental impacts of emissions and resource consumption data in a life cycle inventory (LCI). LCI collects and compiles information for all processes in the product system boundaries including raw material inputs, transformed outputs, energy and resources, waste and emissions.

This paper reviews well known methods such as LCA for assessing of environmental impact during manufacturing activities and recent approaches to calculation of carbon footprint. Then it proposes a new framework, namely Sustainability as a Service (SuSaaS) fundamentally targeting to improve eco-friendly operation of regional SME clusters and large scale enterprises. The objectives of this framework and technology platform can be summarized as follows:

- Provide cost-effective sustainability services to SME clusters and OEMs.
- Develop eco-tracking and eco-improvement services/solutions utilizing cloud computing technologies.
- Focus on energy contextualization of manufacturing activity to deliver eco-KPIs.
- Optimize production processes for eco-efficiency and generate sector specific eco-design best practices.

2 Life Cycle Assessment

The life cycle of a product encompasses a sequence of stages comprising resource extraction, production, use and end of life activities. In the resource extraction stage, raw materials which will be used for the final product are prepared. Production stage involves manufacturing of components from raw materials and assembly of the components to complete the final product. According to its characteristic, final product is either used or consumed in the use stage. End of life activities includes either of reuse, remanufacture, recycle or disposal.

Life Cycle Assessment (LCA) is a methodological framework for estimating and assessing the environmental impacts attributable to the life cycle of a product [3]. Industries use LCA for focusing on the life stages or sub-stages of a product

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for identifying the areas of improvement, comparison of alternatives in product development, documentation of environmental impact and for decision support for the environmental management. A framework for LCA is developed by International Standards Organization [4]. LCA framework defines a systematic process consisting four main stages: Goal and scope definition, inventory analysis, impact assessment and interpretation (Fig. 2.5.1).

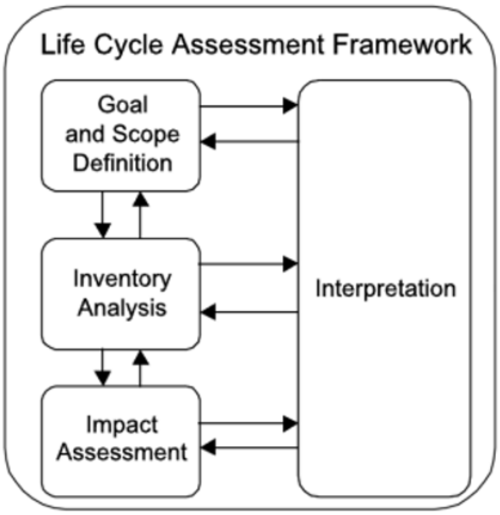

Fig. 2.5.1 LCA framework [3]

In goal and scope definition stage the purpose and the intended use of the LCA is defined and the boundaries of the assessment are structured. The function to be provided by the product is described in qualitative and quantitative terms as a functional unit [5]. Level of detail for the product, level of inventory detail, selection of relevant life cycle stages and temporal and spatial limits are determined as a part of the scope of the LCA. Goal and scope definition stage of the LCA shapes the inventory analysis and impact assessment stages.

The necessary data whose boundaries are determined in the scope definition stage is acquired in life cycle inventory (LCI) analysis stage. The aim of LCI is to quantify energy requirement, material flow, emissions and generated wastes throughout all life cycle stages of the product. The first step in the LCI analysis is to develop a detailed manufacturing flow diagram showing the inputs and outputs to a process or system. This necessitates a prior investigation of the bill of materials to list the resources used by mass, a material assessment of the product and determination of the manufacturing processes that the product will undergo. Second step of LCI involves data acquisition. Initially, data sources and types are identified according to the goal and scope of the study. Data can be collected by using readings from meters, equipment logs, laboratory test results, documents (e.g. reference books, journals, reports), engineering calculations or databases of some commercially available (e.g. SimaPRo, GaBi) LCA software packages. Assumptions are made aligned with the goal and scope when the data is not available or requires intensive effort to collect. Allocation procedures are determined in this stage to relate the energy consumptions, emissions and waste generations of the multi-functional processes to the product under analysis. ISO recommends [6] avoiding allocation by dividing processes into sub-processes to acquire the required data. If allocation cannot be avoided the environmental data should be partitioned to the product based on the physical relationships. A common physical relationship which is used as a basis for allocation is mass. If allocation based on physical relations is not possible, the environmental data is allocated based on other relationships. As the last step of LCI analysis, collected data is presented in a tabular or a graphical form containing the amount of energy and materials consumed and the quantities of environmental emissions.

Life cycle impact assessment (LCIA) stage aims at quantifying the potential impacts of resource use, emissions and wastes identified during LCI analysis on the areas of protection. Four groups of area of protection are human health, natural environment, natural resources and man-made environment [5]. LCIA is divided into five main steps [7]. First step is selection of impact categories where specific environmental concerns of the LCA study such as climate change, acidification, eutrophication, etc. are identified. This step should be considered in the of goal and scope definition to guide the LCI process. Second step is called classification where LCI data are assigned to the relevant impact categories. Third step is characterization where environmental impacts resulting from each emission are quantified for a particular impact category. There can be several releases from LCI having an impact on a single category. Therefore impact should be quantified as an impact score in a common unit to all contributions in the category. This is achieved by utilizing a characterization factor which is a conversion factor used to put different emissions on a common scale (e.g. all greenhouse gas emissions can be converted to CO_2 equivalents using proper characterization factors to calculate the impact on global warming potential). An impact indicator for a specific impact category is calculated by the following equation [9]:

$$S_j = \sum_i C_{i,j} \cdot E_i \qquad (2.5.1)$$

where S is the impact indicator, C is the characterization factor, E is the mass of the identified emission, i represents the emissions in the LCI classified under the impact category j. For some impact categories such as global warming and ozone depletion there is a consensus on acceptable characterization factors. For other impact categories such as resource depletion a consensus is still being developed [8]. Fourth step is normalization which is a procedure that normalizes the impact indicator data by dividing by a selected reference value so that the comparison among impact categories is possible. Normalized impact indicator (N) is found by:

$$N_j = S_j / R_j \qquad (2.5.2)$$

where R is the reference value. The goal and scope study may influence the choice of an appropriate reference value but it is generally chosen using impact indicator results for a specific region and for a specific year [9].

Fifth step is valuation where weighting factors are assigned to different impact categories to indicate their relative importance. Weighting factors are determined for the particular LCA study by consensus. Weighted impact indicator (W) is calculated by:

$$W_j = V_j \cdot N_j \qquad (2.5.3)$$

where V is the weighting factor. Overall impact indicator (EI) is calculated by:

$$EI = \sum_j W_j \quad (2.5.4)$$

According to ISO 14042 [7], selection of impact categories, classification and characterization steps of the LCIA are mandatory while normalization and valuation are optional. Since the choice of reference values for normalization step has different alternatives and since determination of weighting factors for valuation step are not objective those two steps are often omitted.

The last stage of LCA is interpretation where results of LCI and LCIA are analyzed aligned with the goal of the study so that recommendations are provided to decision makers. Interpretation is comprised of three steps. First step is identification of significant issues. The results of the LCA is analyzed for the life cycle stage or the process having the highest environmental impact, impact category contributing to overall environmental impact the most and presence of any unusual results. The results of this analysis reveal the significant issues for the LCA study. Second step is evaluation of the data used in LCA. Because substantial amount data is collected, only data that contribute significantly to the outcome is assessed. Therefore, significant issues found in the previous step are used in the evaluation step. This step verifies that the results of LCA are complete and reliable. There are three checks for this purpose [8]. Completeness check ensures that all relevant information and data required for the interpretation stage are available. In case of an absent data, additional actions are taken to fill the gaps. Sensitivity check verifies that the results of significant issues are robust by checking whether the uncertainties in the data affect the conclusions. If deficiencies exist, additional efforts to improve the accuracy of LCI data and LCIA models are needed. Consistency check validates the consistency of assumptions, methods and data used for the LCA for each alternative. If any of those checks fails and improvement is not possible, reporting the deficiencies and an estimation of the impact of that deficiency on the result is required. The last step of interpretation is drawing conclusions and recommendations. In this step, results of the LCIA stage are interpreted combined with the previous steps of interpretation to draw a set of conclusions. If alternatives are compared, the recommendation would be accepting the alternative with the lowest impact indicator (either overall or for the specific areas of concern defined in the goal and scope definition stage). If a single product is the focus of the LCA study, recommendations would be on how to decrease the impact indicator.

3 Calculating Carbon Emissions

The Greenhouse Gas (GHG) Protocol, which is the most widely used international accounting tool for government and business leaders to understand, quantify, and manage GHG emissions that was assembled in 1998 by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). With ISO 14064 adoption, the GHG Protocol became the international standard for GHG accounting and reporting. The mission of the initiative is to develop internationally accepted GHG accounting and reporting standards for business and to promote their adoption [10].

GHG Protocol states that compiling a comprehensive GHG inventory improves a company's understanding of its emissions profile. Most companies frequently mention business goals as reasons for compiling a GHG inventory such as managing GHG risks and identifying reduction opportunities, participating in GHG markets and mandatory reporting programs [10].

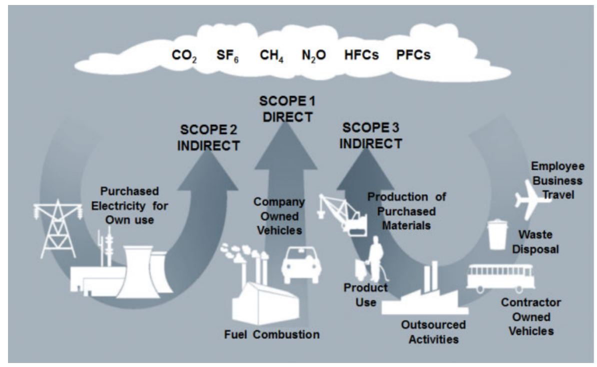

Fig. 2.5.2 GHG emission sources [10]

In order to achieve emission reduction goals, organizational boundaries are first be set. Afterwards, operational boundaries should be determined. According to GHG protocol, operational boundaries encompass scope 1, scope 2, and scope 3 emissions (Fig. 2.5.2). Scope 1 covers direct emissions from sources owned or controlled by a company. Scope 2 covers indirect emissions from the creation of purchased electricity used by a company. These emissions occur at the facility where electricity is generated. Scope 3 are indirect emissions resulting from the activities of a company, but occurs from sources not owned or controlled by a company. Scope 3 emissions include both upstream and downstream emissions, and represent the largest opportunity for GHG reductions. The established organizational and operational boundaries account for a company's inventory boundary. After inventory boundary is set, GHG emissions are calculated. First of all, GHG emission sources are identified, and then GHG emissions calculation approach is selected. After activity data is collected and emission factors are chosen, calculation tools are applied. Finally, GHG emissions data are rolled up to corporate level, leading to aggregate figures [10].

Often, companies make structural changes that alter their historical emission profile. Therefore, emissions have to be traced over time. To trace the emissions, base year is chosen, and afterwards, base year emissions are recalculated. Reductions in corporate emissions are calculated by comparing changes in a company's actual emissions inventory over time relative to a base year. After GHG emissions are calculated, they can be reported to public and regulatory agencies [10].

Electricity and heat generation constitutes 24.6% of worldwide CO_2 emissions [11]. Therefore reduction of electrical energy usage is a critical component of environmental concerns [12]. There are two energy types. These are carbon-based energy (with carbon emissions) and clean energy (no carbon emissions). When clean energy is considered, it is widely accepted that if any energy type like solar, wind or hydro, is used to create electrical energy on a power grid, the energy that is available on that grid is clean energy. When primary energy sources are considered, it is well known that fossil fuels cause carbon emissions. Today in many countries most of the energy supplied via electrical power grids originated from fossil fuels, causing carbon emissions [12]. There are four carbon nature fossil fuels: coal, oil, natural gas, and biomass.

The environmental goal is to reduce or if possible, eliminate carbon footprint originated from energy use. Therefore, there is a significant need for methodologies and techniques to estimate or measure energy consumed during manufacturing processes. Two similar approaches have been reported to estimate carbon emissions in manufacturing processes, compatible with scope 2 emission category.

Ameta et al. [13] proposed that machining energy, *E*, in a single machining operation can be calculated by using measured cutting parameters and estimating carbon emissions:

$$E \pm \Delta E = k\int_{t_0}^{t_1}(F(t) \pm \Delta F(t)) \cdot (v(t) \pm \Delta v(t))dt \qquad (2.5.5)$$

where *F* is cutting force (N), *v* is cutting speed (m/s), and *k* is a converting factor from W-s to kWh. Finally, carbon weight (*CW*) can be calculated using the machining energy by the following equation:

$$CW \pm \Delta CW = f \cdot (E \pm \Delta E) \qquad (2.5.6)$$

where *f* is a conversion factor for conversion of energy to carbon weight.

The second method for estimating carbon footprints in a system that uses electric power grids is proposed by Jeswiet and Kara [12]. This method proposes a Carbon Emission Signature (CES^{TM}) that has a unit of kg CO_2/GJ. CES^{TM} depends on the primary energy supplies of a power grid. The carbon emitted in manufacturing of a single part (CE_{part}) can be estimated by multiplying the electrical energy consumed for manufacturing that part (EC_{part}) by the Carbon Emission Signature (*CES*):

$$CE_{part} = EC_{part} \cdot CES \qquad (2.5.7)$$

CES can be calculated by the following equation:

$$CES = \eta\,(112 \cdot \%C + 49 \cdot \%NG + 66 \cdot \%P) \qquad (2.5.8)$$

where *C* (*coal*), *NG* (*natural gas*) and *P* (*petroleum*) are the fractions of primary energy sources; coefficients 112, 49, and 66 are the kilograms of carbon released per gigajoule of heat in each case; and finally η is the conversion efficiency.

EC_{part} can be found by:

$$EC_{part} = EC_T + EC_{ancillary} \qquad (2.5.9)$$

where EC_T is the energy consumed for the manufacturing process and $EC_{ancillary}$ is the ancillary energy which is consumed for supporting equipment like pumps, cooling media, etc.

The CE for a finished good can be used as a carbon label, if it can efficiently rolled up from parts to components to a product with the help of Product Lifecycle Management (PLM) system.

Realization of carbon labeling on individual products can affect environmentally conscious buyer decisions significantly [14].

4 Sustainability as a Service (SuSaaS)

For every manufacturing enterprise, environmental impact and resource efficiency will continue to be top priorities beyond this decade. Sustainability as a Service—SuSaaS will facilitate the transformation to eco-factories and standardize the methodology development for eco-labeled processes and products. SuSaaS is divided into three systems (Fig. 2.5.3): (1) Eco-KPI hierarchy which describes absolute sustainability indicators to measure sector specific normalized indicators focusing on industries of interest (2) Eco-tracking which helps long-term monitoring by collecting energy, emission, waste data along with production activity and transforming them into actionable intelligence by using eco-KPIs, (3) Eco-improvement which facilitates the eco-design and product engineering procedures through use of life cycle engineering and collected data of eco-tracking.

4.1 Eco-KPI Hierarchy

This system includes a framework of ecological based key performance indicator (eco-KPIs) hierarchy. Eco-KPI hierarchy will provide a set of sustainable performance metrics and facilitate decision making on different levels of manufacturing. Design of eco-KPI framework will also determine associated measurement, monitoring and analysis techniques as a basis for the remainder of SuSaaS model. Eco-KPI hierarchy has two subsets. First subset includes a generalized eco-KPI framework with detailed identification and definition of the KPIs which are used to measure industrial environmental performance. This subset is applicable to all manufacturers. Second subset includes sector specific eco-KPIs which focus on specific industry sectors to modify the more generalized framework to address the requirements of these specific sectors. For this subset, key value factors for these specific industries are be considered to allow for real, business based decision making.

4.2 Eco-Tracking

Every company should track its environmental impact, the resources it uses, harmful gases it emits and its waste. "What cannot be measured cannot be managed" is a well-known claim and truth in the environmental issues as well. The function of eco-tracking system is to monitor environmental performance of a company by use of hardware and software systems so as to manage the energy consumption of its manufacturing processes and keep the greenhouse gas emissions under control. Eco-monitoring system tracks scope 2 emissions (Fig. 2.5.2) resulting from the use of purchased electricity in manufacturing processes on the shop floor.

Shop floor manufacturing activity data collected from PLCs and CNCs and electrical energy consumption data from smart meters will be collected and stored in a central data warehouse. Energy consumption data related to the manufacturing processes will be acquired from the meters installed on the machine tools and other manufacturing equipment. Electrical energy consumption data due to the auxiliary infrastructural activities (lighting, heating, ventilation, etc.) will be handled by allocation methods developed for each consumption source. Energy consumptions of equipment or services which are infeasible for monitoring will be calculated by subtracting each individual energy meter readings from the total energy consumption reading of the shop floor.

The data in the store will be processed to reveal the scope 2 [10] greenhouse gas emissions. Emissions as a result of the

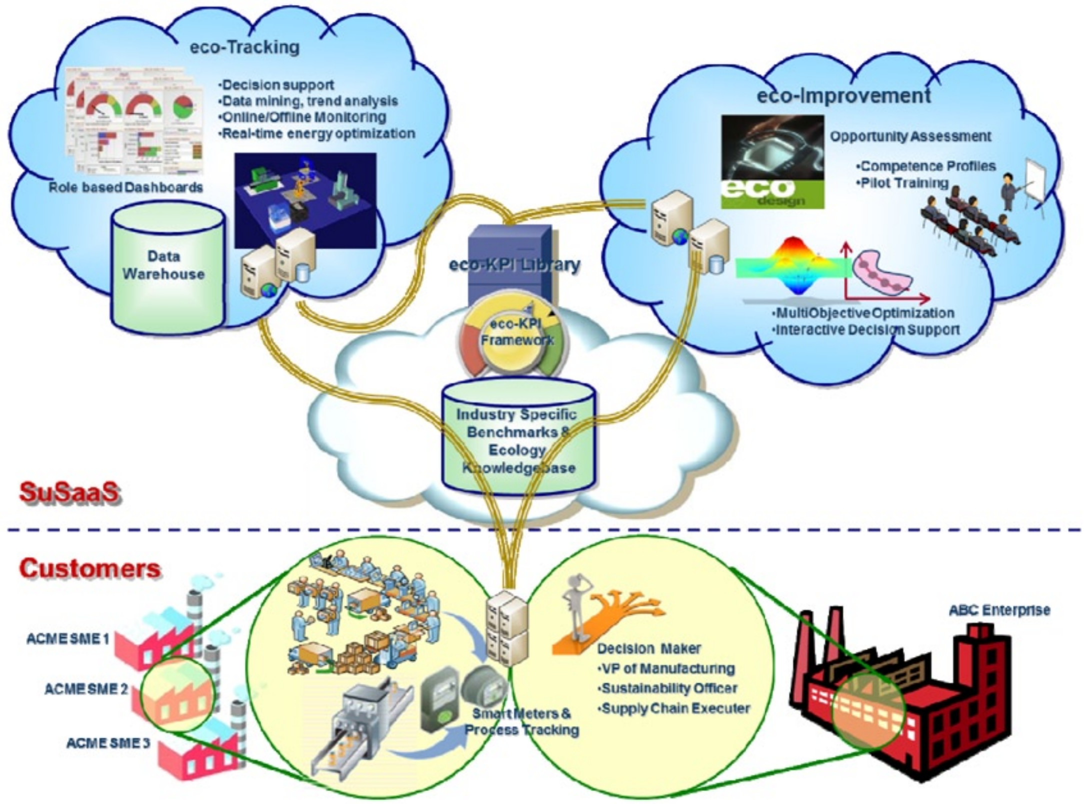

Fig. 2.5.3 SuSaaS framework

electrical energy consumption of manufacturing processes and auxiliary infrastructural activities will be estimated using methods similar to Eqs. 2.5.6 and 2.5.7.

The processed data will then consumed by a decision support system (DSS). Major role of the DSS is to enable interactive access to real-time data and provide decision makers in an enterprise the support they need to assess the performance, evaluate options, and initiate actions to improve the condition. Besides, eco-labeling of products and processes will be possible by aggregation of the quantified GHG emissions in product and process levels.

Leveraging data mining tools and methods, sustainable patterns in production systems will be determined and classified in order to understand energy—process efficiency patterns. Various scenarios will be executed in test bed lab for this purpose and also data collected from industrial partners will be utilized.

Considering the presented LCA methodology in Sect. 2, eco-tracking will fit in the data acquisition step of LCI. Automating the data collection for the production stage of the life cycle will reduce the time spent for LCI and increase the accuracy of the results since data from the actual system is used instead of a common database of an LCA package.

4.3 Eco-Improvement

Eco-improvement includes a methodology and decision support model which will be developed to minimize the energy consumption and emissions resulting from the manufacturing processes at early stages of product design and manufacturing planning. Eco-improvement system will mainly use monitored data of eco-tracking system and reference data from the available documents and databases for the remaining life cycle stages to make an LCA for what-if scenarios at the product engineering stage. What-if scenarios will focus on design improvements or manufacturing plan modifications for an existing product to understand the environmental impacts of changes in product or production characteristics. Environmentally optimized decision will be fed back to design and manufacturing planning phase where other economic and social concerns are assessed via a multi-objective decision making procedure. This system will use product level eco-KPIs to assess the success of the eco-improvement system.

LCA is generally viewed as a potential tool to be integrated to eco-design procedures. However, the inherent assumptions and high level approach of LCA for estimating the energy consumption of manufacturing activities limits its use as an effective tool for eco-design. Integrating SuSaaS eco-tracking system with eco-improvement system will increase the shop floor visibility and enhance the granularity of energy consumption data. This will enable to compare or validate the impact of design or manufacturing planning changes without changing the other parameters in the life cycle of the product.

5 Conclusion

Reduction of the global warming potential resulting from manufacturing activities of a product is this study's main motivation. It is known that greenhouse gasses are responsible for the climate change and CO_2 is the main contributor to the greenhouse effect. About 80% of CO_2 is released from energy transformation and 17% is released from the manufacturing processes themselves [15]. Therefore, if a manufacturing enterprise aspires to make sustainable production and minimize its global warming impacts, the enterprise should track and decrease its CO_2 emissions. It is evident that the way of achieving this goal is by decreasing the energy dependency of the enterprise and pursuing energy efficiency in its manufacturing processes.

Proposed framework is one of the most efficient solutions to track the energy consumptions of manufacturing processes and related CO_2 emissions as far as the deficiencies in the LCA (specifically LCI) are concerned. Implementation of the framework will provide visibility for the whole enterprise and enable monitoring of energy and carbon releases as well as identification of the areas of potential reduction. Increasing visibility in details will eliminate allocation problems of LCI in manufacturing stage substantially.

Collection and compilation of data for environmental exchanges between processes in the life cycle stages and the environment is normally the most labor intensive part of doing LCA [3]. Eco-tracking system will make the real-time data collection possible and reduce the collection time of data significantly. The developed DSS will automate the compilation and aggregation of energy consumption data in process, product and enterprise levels which will provide actionable intelligence to the decision makers at different levels. Furthermore, conversion of the compiled manufacturing data to environmental impact will facilitate the eco-labeling of products.

As the products of an enterprise evolve and as improvements in production technology are introduced, manufacturing processes of an enterprise change over time. This change will lead the alterations in the inventory data for manufacturing and rendering the previous data obsolete. In order to make correct decisions for sustainability, the enterprise must seek current data. Most publicly available LCI documents such as technical books, reports, conference papers, and articles may be old, present industry averages instead of an enterprise specific data and give theoretical data which may provide a poor representation of the actual data. Software packages for LCI study may lead to data utilization of unknown quality. Often they do not provide a record of assumptions and computational methods that were used, resulting in a decrease in the transparency of data [8]. Continuously collecting manufacturing data by eco-tracking system will eliminate these shortcomings of LCI as well.

The nature of LCA requires significant amount of data about the product of interest. This property of LCA restricts its full scale use for the initial design stages of a new product. However, data warehouse developed in eco-tracking system of the enterprise will enable better decision support for eco-improvement system for the initial design stages compared to a publicly available database. Implementation of eco-improvement for the different alternatives of design developments of an existing product is straightforward. For such improvements what-if analysis can directly be made by using LCA.

Finally, it should be noted that the proposed model will aid decision making based on the data from the production stage of the life cycle of a product. Other stages like extraction of raw materials, use and disposal are not taken into the scope of this study.

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2.6 The Effects of Depth of Cut and Dressing Conditions on the Surface Integrity in Creep Feed Grinding of Inconel 792-5A

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Abstract
Creep-Feed Grinding (CFG) is one of the none-traditional machining in which form grinding to full depth is performed in limited number of passes. During this study, samples were ground with variable depth of cut and dressing conditions while the other parameters were constant. Continuous Dressing (CD) and Non Continuous Dressing (NCD) with the different number of passes were applied. After machining, surface integrity was studied and in order to investigate the surface micro-cracks, Chemical Etch + FPI and Thermal shock + FPI were performed. For determining micro-structural changes in ground specimens as a criteria in measuring the level of residual stress, a set of recrystallization processes were carried out on them and average grain size were measured. The results show, however, changing in depth of cut hasn't influenced on micro-cracks, quality of surface roughness has descended in terms of increasing the depth of cut.

Keywords:
Creep feed grinding, Surface integrity, Recrystallization, Nickel-base superalloy

1 Introduction

Nickel-base superalloy has comprehensive properties such as high temperature strength, high corrosion resistance, good fatigue resistance and etc that are applied in aviation and gas turbine industries. Cast Inconel 792-5A is a cast high strength polycrystalline material used in manufacturing blades and discs of gas turbine. The critical turbine parts are subjected to repeated elastic–plastic straining, then low-cycle fatigue is an important consideration in the design of the components. In the other hands, critical parts expose to high temperature then creep resistance is also another criterion which should be mostly taken into account. Since, the surface conditions, superficial damages and microstructures changing during machining operations, has significant influence on fatigue life and creep resistance, so determination of suitable machining parameters to obtain proper surface condition is important.

These surface characteristics called Surface integrity, concern not only the topological (geometric) aspects of surface but rather the whole assemblage of their physical, mechanical, metallurgical, chemical and biological properties and characteristics [1].

Despite the wide range of applications and the appropriate properties of nickel-base superalloys in gas turbine industries, the low machinability of theses materials due to their peculiar characteristics, such as poor thermal conductivity, high strength at elevated temperature are challengeable issues in machining of these superalloys.

Among all manufacturing processes, Creep-Feed Grinding (CFG) comprehensively is utilized to produce gas turbine hot sections such as blades and vanes. The significant criteria related to surface integrity in CFG process that affects on the following complementary process and final parts life cycle are surface roughness, micro-cracks, burning and change in superficial metallurgical microstructure.

It is most desirable to estimate how machining parameters affect the surface layers by developing strategies to avoid surface damages. Since, the surface affected layer is the origin of some damage like micro-cracks and changing in microstructure, so study of the influence of machining parameters on the emersion of this field and topological information about its dimensions is useful to surface integrity control.

Zarudi claimed that the unstable grinding heating can lead to a poor surface integrity. Additionally they indicated that by increasing the depth of cut, promotes the stability of the heated zone at low infeed velocities. The instability of heating is undesirable as it made the grinding-induced layer uneven and the integrity of the ground material poor [2]. Several papers have studied the effect of CFG parameters on the depth of white layer. Xu and Yu investigated CFG machining of cast nickel-based K417 with an alumina Grinding wheel. In this study, the thermally affected zone has been within 40 µ. Excepting for surface roughness, the surface integrity is not affected by temperature provided that the temperature is not high enough to cause grinding cracks [3]. Österle and Li that investigated CFG machining of cast nickel-based Inconel 738 LC with an alumina Grinding wheel reported that the depth of this layer has been around 10 µ [4]. Ding Wenfeng et al. has also reported 10µ for depth of white layer, in their examination on CFG machining of cast nickel-based K424 with a CBN Grinding wheel [5]. In grinding of solidified nickel-based superalloy, surface burn, surface phase changes were reported and the depth of the affected layer exceeding to 0.5 mm [6]. Grinding process can be divided into two stages. In the first stage, the grinding can be conducted at a very high material removal rate without concern for the presence of a burning colour. The plastically deformed coating, which can directly roughen the ground surfaces, can be removed in the second stage at a much smaller removal rate [3].

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In this study, the influence of depth of cut on workpiece surface integrity of cast nickel-based superalloy (Inconel 792-5A) with alumina wheels was investigated. During this study, samples were machined with variable depth of cut while the other parameters were Constant. After machining, surface roughness of each specimen was measured and in order to investigate existence and dimensional situation of surface micro-cracks, Chemical Etch + FPI and Thermal shock + FPI were performed. For determining micro structural changes in ground specimens as a clarifier criteria in measuring the level of residual stress, a set of recrystallization processes were carried out on them and average grain size were measured.

2 Experimental Tests

2.1 Workpiece Material and Abrasive Wheel

Cast nickel-based superalloy 792-5A was used as the workpiece material in this research. Inconel 792-5A is the vital material for gas turbine blades and aeronautical industries. The chemical composition, mechanical and physical properties of cast nickel-based superalloy Inconel 792-5A are given in Table 2.6.1 and 2.6.2 respectively.

Inconel 792	C	Mn	Si	Cr	Ni	W	Ti	Fe
Nominal composition (Wt. %)	0.07–0.09	0.1	0.05	12.2–12.8	Balance	3.85–4.25	3.75–4.15	0.5

Table 2.6.1 Nominal composition (wt. %) of Inconel 792-5A

Tensile properties			
Temp (ºC)	Ultimate tensile strength (N/mm^2)	Yield strength, 0.2% offset (N/mm^2)	Elongation (%)
Room temp.	*	*	*
650	890	635	≥5
Stress rupture properties			
Temp (ºC)	Stress (N/mm^2)	Life (Horus.)	Elongation (%)
750	600	≥35	≥5
980	152	≥35	≥5

Table 2.6.2 Mechanical and physical properties of Inconel 792-5A

The grinding wheel size was 500 mm in diameter and 20 mm in width of the working zone. Wheel was made of 60 US mesh Al_2O_3 abrasive grains.

2.2 Experimental System

The process was conducted on four block-shape workpiece with 220 mm in length, 45 mm in width and 40 mm in height. The specimen's material Inconel-792 5A was casted and Hot Isostatic Pressing (HIP) was made to enhance homogeneity. Then the specimens were prepared according to Fig. 2.6.1. Each experimental workpiece was ground in six different depths of cut and the same width shown in Fig. 2.6.2. Two holes were made on both sides of each block to fix it on the fixture for easier clamping on machine table. It should be mentioned, the grinding direction was normal to the length of specimens.

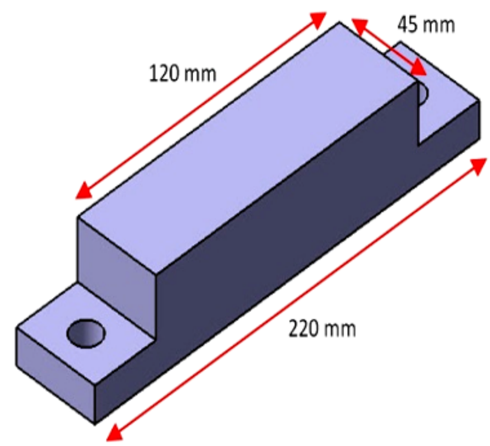

Fig. 2.6.1 The schematic illustration of unmachined experimental workpiece

The schematic of workpiece after creep feed grinding (CFG) was shown in Fig. 2.6.2.

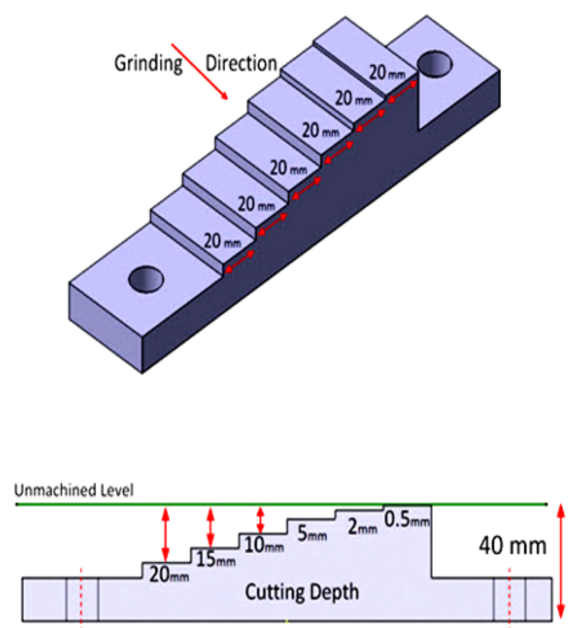

Fig. 2.6.2 The schematic of creep feed ground workpiece

All the experiments were conducted on DANOBAT 3-axis grinding machine. Up-grinding was used as a grinding mode during experimental tests. The wheel was trued and dressed using a roller dresser and both continuous dressing (CD) and non-continuous dressing (NCD) condition were implemented in this study. An emulsified liquid 5% dilution with the flow rate of 90 L/min and pressure at 1.2 MPa was applied as cooling mode. Cooling nozzles were attempted to adjust and fix on cutting region roughly. Position of nozzles for cooling in CFG is illustrated in Fig. 2.6.3.

Fig. 2.6 3 Nozzles position used in this study

The influence of different dressing conditions also has been considered besides altering the depth of cut which is shown in Table 2.6.3. All the grinding test were at a peripheral cutting velocity of V_S=20 m/s and feed rate of F=300 mm/min and grinding width b is 20 mm.

Series no.	Sample no.	Depth of cut a_e (mm)	No. of finishing passes with CD (depth of cut 0.05 mm)	No. of finishing passes with NCD (depth of cut 0.05 mm)
1	1	20	0	0
2		15		
3		10		
4		5		
5		2		
6		0.5		
7	2	20	1	0
8		15		
9		10		
10		5		
11		2		
12		0.5		
13	3	20	3	0
14		15		
15		10		
16		5		
17		2		
18		0.5		
19	4	20	3	1
20		15		
21		10		
22		5		
23		2		
24		0.5		

Table 2.6.3 Machining parameters and experimental conditions of CFG tests

3 Results

The surface roughness was measured on each ground surfaces of four samples. Surface roughness was measured using a MAHR perthometer MarSurf PS1 surface roughness tester before any cutting and heat treatment of samples. Each sample was sectioned perpendicular to the grinding direction with equal thicknesses of 15 mm by Wire Electrical Discharge Machining (WEDM) in three parts. Etch and Florescent Penetrate Inspection (FPI) were done on the first parts, then thermal shock + FPI were performed on the second parts and finally recrystallization processes were carried out on the third parts of cut segments. The etched samples using the solution containing 28vol% $FeCl_3$, 27vol% HCl and balance water was investigated by FPI. Then selected samples after the recrystallization method were mounted, polished and analyzed by optical microscope. Other samples after thermal shock test were inspected by FPI.

3.1 Surface Roughness

The surface roughness was measured on the ground surfaces based on ASME B46.1 [7] and the related results are revealed in Fig. 2.6.4. It seems there is an optimum point in step no. 4 in all samples with CD and NCD in CFG.

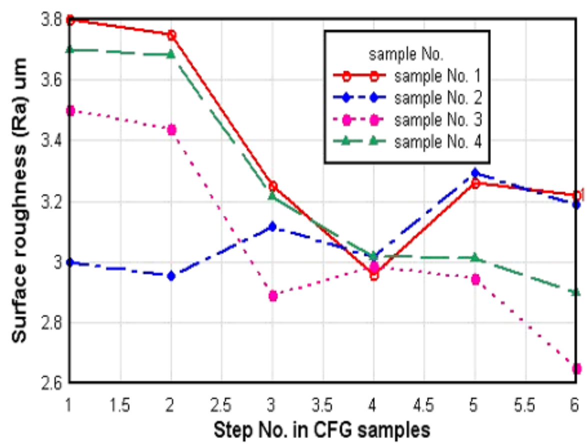

Fig. 2.6.4 Surface roughness results of ground specimens

3.2 Etch + FPI, Thermal Shock + FPI

The Etch + FPI results of ground specimens were indicated that there isn't any crack on the surface of samples. The thermal shock + FPI results is indicated the same result of Etch + FPI and the surfaces were free-crack and defects.

3.3 Recrystallization

Recrystallization method was applied to determine the plastic strain and residual stress resultant in a machined surface. Recrystallization took place in a very shallow layer in the machined surface after annealing it revealed a clear strain distribution. The recrystallization method was used to assess the effect of cutting parameters and the hardness of the workpiece on the plastic strain [8]. After recrystallization cycle, the average grain size was measured in two specified regions which are shown in Fig. 2.6.5 (6.5 mm).The results show finishing with one CD pass hasn't had any sensible effect on residual stress. According to the obtained result in this research, roughing can be performed with arbitrary depth of cut and it's suggested that final pass(finishing) should be ground with approximate 0.2 mm depth of cut under three CD passes (totally 0.15 mm) and one NCD pass(0.05 mm) concluded to minimum level of residual stress and proper surface roughness.

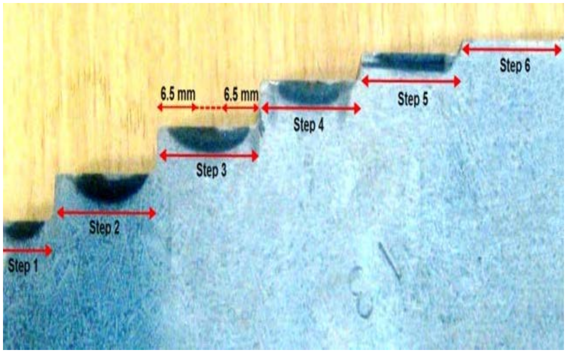

Fig. 2.6.5 Region for recrystallization in ground samples (6.5 mm)

In Fig. 2.6.6 microstructures of samples with three CD passes (finishing passes-series No.13 sample) after recrystallization method were shown. The Heat Affected Zone (HAZ) on the ground surfaces is perceptible and the depth of this layer is about 20 μm.

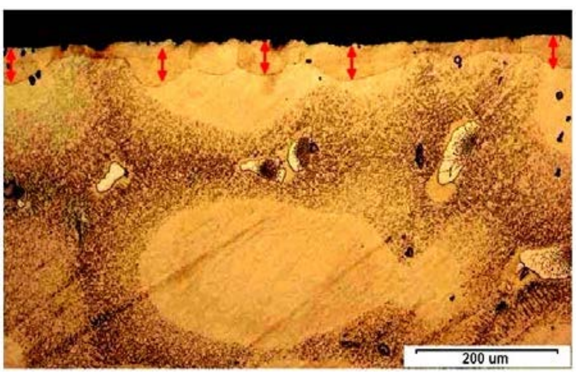

Fig. 2.6.6 Microstructures of samples after recrystallization (with three CD finishing passes)

In Fig. 2.6.7a and b microstructure of samples with any finishing passes (series No.1 sample) after recrystallization was shown. The depth of this layer is about 170 μm.

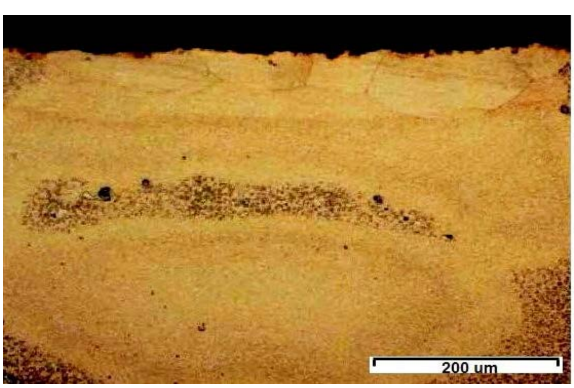

Fig. 2.6.7a Microstructures of samples after recrystallization (without any finishing passes)

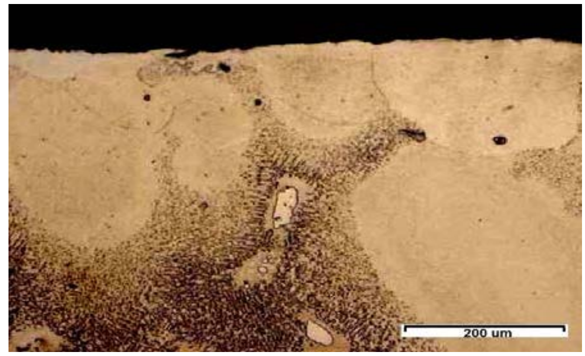

Fig. 2.6.7b Microstructures of samples after recrystallization (without any finishing passes)

The average grain size of ground specimens were displayed in Fig. 2.6.8.

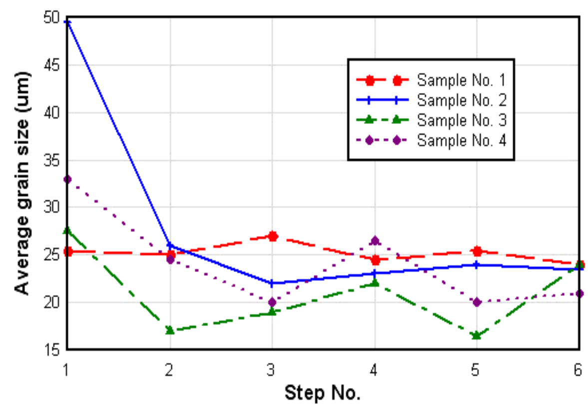

Fig. 2.6.8 The average grain size of ground specimens

4 Conclusion

Routinely surface burn occurs under the conditions of low grinding efficiency [9]. Any effect of superficial burning doesn't exist on the sample surfaces even in the samples with 20 mm depth of cut. In addition the specific material removal rate (Q') for CFG of nickel-based superalloy reported is 13 $mm^3/mm/s$ [10] while Q' for step 1 (a_e=20 mm) is up to 7.5 time of recommendations. This result can lead to increase in productivity through increasing the material removal rate, lower manufacturing cost and decreasing lead time without having adverse effects on the surface integrity (if there are controlled finishing passes exist). It should be noted that the research was done on the turbine blades that they are very expensive and the price of grinding wheel with comparison of these components is negligible.

The results of recrystallization indicated that the lower grain size related to samples with 3 CD in CFG therefore it can be concluded that the maximum depth of heat affected zone (HAZ) in rough CFG without any finishing passes is about 170μm that with three CD passes the effect of HAZ was minimized to about 30 μm. CFG with one pass NCD increase the depth of the affected surface layer and have negative effect on the ground superficial properties. Surface integrity in grinding with NCD passes due to the wear of the sharp edges get worse.

4.1 Surface Roughness

The obtained surface roughness results reveal that in the samples with 5 mm of depth of cut, the surface roughness, after and before the finishing passes, were same for four block workpieces. In finishing operation with three CD passes, surface roughness had better consequences than the other conditions. With increasing the number of CD Passes, the surface roughness of specimens with higher depth of cut (more than 5 mm) has been better. Additionally it is concluded that, surface roughness depends primarily on the dressing process.

4.2 Surface Defects and Cracks

The results of Etch+FPI and Thermal Shock+FPI tests showed that mainly the depth of cut doesn't affect the surface defects.

4.3 Residual Stresses

In this study the recrystallization method for prediction and prediction of residual stresses and cutting force was used. In general, as depths of cut increase, while uncut chip thickness, roughness and force decrease. Increase in the depth of cut causes raise the cutting force and heat generated in cutting zone, and finally bring about grain growth.

5 Acknowledgments

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2.7 Dry and Cryogenic Machining: Comparison from the Sustainability Perspective

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Abstract

Modern manufacturing processes continue to demand high quality products and processes at reduced costs and with greater environmental compliance. This has led to a critical consideration of the use of conventional cutting fluids used in most machining processes. Continued use of cutting fluids poses major problems as they are hazardous for the operating personnel on the shop floor. They are also carcinogenic, harmful to the environment and cause high costs. The major focus of the proposed paper is the analysis of experimental work on machining under dry and cryogenic conditions in turning of Al 7075–T651 alloy to achieve environmental and economic benefits and improved surface integrity and fatigue life of the machined product, thus aiming at a more sustainable product. In particular, a preliminary evaluation of the fatigue life of the component is presented based on a microstructure-based model, which varies with the used manufacturing process. The overall results show that cryogenic cooling has the potential to improve the product and process through its superior performance in terms of the machined surface and sub-surface characteristics and the related environmental and economic performance.

Keywords:

Fatigue life, Machining, Sustainable processes

1 Introduction

Considerable amount of waste is produced by machining operations such as turning, milling or drilling in world-wide product manufacture. In the past, the manufacturing processes were systematically developed in order to achieve, through innovation, maximum efficiency for increased profit, and the present trends push manufacturers to develop new methodologies incorporating a variety of sustainability concepts for improved performance and competitive advantage [1, 2]. Sustainable manufacturing processes are those which generate minimum quantity of wastes demonstrating improved environmental impact and energy efficiency while providing operational safety and personal health. In this context, numerous concerns are in place for machining operations. Among these, metalworking fluids (MWFs) are considered the most prominent environmental issue for machining processes. Nowadays, cutting fluids have changed dramatically due to recent regulations on environment, health and safety issues, which identify some of the ingredients in cutting fluids as problematic. In fact, the detection of a variety of illnesses and environmental hazards, that these ingredients cause, has led to their reduced use, or their elimination.

Generally speaking, MWFs are contaminants, they must be treated and disposed at the end of their life-cycle and their use is characterized by problems in the immediate working environment and hazards for the worker's health when they come in contact with them [3, 4].

The metalworking fluids also play an important role in machining processes in terms of lubrication and cooling [5]. For this reason, we cannot ignore the fact that a sustainable process must consider the final performance of the process, and above all, maintain the product quality and/or improved, during its service life.

It is well known that manufacturing processes significantly influence the type of surface being produced. The quality of the surface dictates the functional performance and service-life of engineered components. Surface characteristics of machined products such as roughness, residual stresses or microstructure are some of the important constituents determining the performance of a product. The aircraft industry is one of the most relevant examples where the final products must be produced in order to ensure the most desirable performance and lifetime.

Since there is no active feedback on how to correct the manufacturing process to achieve the desired surface integrity in the manufactured parts, expensive post-operations are used. Hence, knowledge about factors that cause microstructural improvements will contribute to a better fundamental understanding of manufacturing process mechanics and improved knowledge-driven manufacturing process planning, as well as better prediction of the component's lifetime.

For all the above-mentioned reasons, this paper preliminarily addresses an evaluation of the machined product in terms of surface quality and fatigue life. In particular, the relationship between the coolant action and final product characteristics are addressed when the machining process is carried out under dry and cryogenic machining conditions. The flood cooling and the Minimum Quantity of Lubrication (MQL) methods are ignored in this work due to the environmental concerns involved. In fact, an attractive alternative to conventional cutting fluid applications is cryogenic cooling. It consists of injecting liquid nitrogen coolant onto the exterior

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surfaces of the tool and the workpiece to maintain the strength and hardness of the cutting tool and workpiece. This method, when combined with tool geometry, gives the desirable control of cutting temperature and tool-life enhancement with no adverse environmental effects.

Liquid nitrogen is the most abundant gas—composes about the 78% by volume of the atmosphere, it is a colorless, odorless, tasteless and non-toxic gas and it is the commonly used element in cryogenics. It is produced industrially by fractional distillation of liquid air and its main functions in metal cutting were shown as removing heat effectively from the cutting zone, hence lowering cutting temperatures, modifying the frictional characteristics at the tool/chip interfaces, thereby changing the properties of the tool material and the workpiece [6].

As far as the latter is concerned, cryogenic cooling can potentially improve the service lifetime of the product. For example, quality is the major issue in aircraft industry because the product has to have a long life and it is subject to fatigue and corrosion effects. Hence, the work material of interest is 7075-T651 aluminium alloy, which is predominantly used in aerospace applications. Its major applications include welded parts, aircraft fittings, meter shafts, gears and shafts, missile parts, and numerous other components in aerospace and defence applications.

2 Fatigue Life in Engineered Components

A fatigue crack is the result of localized plastic deformation during cyclic straining which causes the failure of a component in service. “Crack initiation” is defined as number of cycles required to generate, nucleate, or form the smallest crack that is detectable by any means [7]. On this basis, assuming a homogenous and free of initial crack component, initiation sets the limit on the minimum size of a small fatigue crack [8].

The resistance of metals and alloys to fatigue crack initiation and propagation is known to be influenced significantly by grain size, and it is widely recognized that an increase in grain size generally results in a reduction in the fatigue endurance limit while a coarse grain structure can lead to an increase in the fatigue crack growth threshold stress intensity factor range and a decrease in the rate of crack growth [9].

In commercial materials, fatigue cracks often start at metallurgical stress concentrations such as inclusions and pores. The crystallographic anisotropy, i.e., texture, of a material also has a strong influence. In some alloys, fatigue cracks nucleate within a local region where a number of adjacent grains of nearly the same orientation have the slip characteristics of a single large grain. Furthermore, many cracks initiate from the surface of a component which is stressed when cyclic loads are applied.

In this paper the number of cycles before the crack initiates is evaluated. The calculation focuses solely on the surface microstructural effect on the fatigue crack initiation under uniaxial cycling loading.

2.1 Microstructure-Based Model

Many models have been proposed for predicting the fatigue crack initiation mechanism [10–12]. Basically, each model is based on stress or strain and some of the models also contain parameters which take into account the role of microstructure in crack initiation. Since most of the variation in useful lifetimes is in the initiation stage, we use a model incorporating that aspect for comparison purposes.

In this paper, the model proposed by Chan [8] is applied as follows:

$$(\Delta\sigma - 2Mk)N_i^{\alpha} = \left[\frac{8M^2\mu^2}{\lambda\pi(1-\nu)}\right]^{\frac{1}{2}}\left(\frac{h}{d}\right)\left(\frac{c}{d}\right)^{\frac{1}{2}} \qquad (2.7.1)$$

where $\Delta\sigma$ is the applied loading stress, Ni is the number of high cycles fatigue to start the crack initiation mechanism, α is an exponent and its values range from 0 to 1, 2Mk represents the fatigue limit below which fatigue-crack initiation does not occur; $\mu$is the shear modulus of the considered material, ν is the Poisson's ratio and d is its grain size; M is the Taylor factor equal to 2, the crack depth c and the slip band width h in the equation have been evaluated by the author for the used material respectively while λ is a parameter with a universal value of 0.005 [8]. Table 2.7.1 shows the calculated values for the Eq. 2.7.1.

Table 2.7.1 Parameters for the Eq. 2.7.1 as proposed by Chan [8]

μ MPa	α	2Mk MPa	c μm	h μm
25800	0.225	100	524	0.012

Equation 2.7.1 is utilized here in order to have a preliminary estimation of the fatigue life of final components in order to compare the effect of the two machining processes (dry and cryogenic conditions) on fatigue life via the surface microstructure.

3 Experimental Procedure

The experimental tests were performed under dry and cryogenically-assisted conditions. The initial material is Al 7075-T651 which is artificially aged and then stress relieved. More precisely, the T651 process involves a 1.5% stretch prior to 24 h at 121°C followed by air cooling. The initial bars were obtained by extrusion and their chemical composition and the mechanical properties of the material are given in Tables 2.7.2 and 2.7.3.

Table 2.7.2 Physical properties of the as received material

Physical properties	
Ultimate tensile stress [MPa]	612.9
Yield tensile stress [Mpa]	552.9
Elongation %	11
Hardness HV	160

The machining tests were conducted on a stiff high speed Mazak CNC lathe in an external turning operation using uncoated carbide tools (KENNAMETAL grade: K313 with a clearance angle of 11°) with triangular shape mounted on a CTGPL164C tool holder providing a lead angle of 0°. The turning tests were executed in both dry and cryogenic conditions and the tool holder was held in a Kistler 9121 three-component piezoelectric dynamometer for measuring forces (consequently the mechanical power being consumed during the machining process).

The turning experimental set-up is shown in Fig. 2.7.1. Table 2.7.4 shows the experimental plan.

Table 2.7.3 Chemical composition of the *Al 7075 T651* material

Chemical composition WT%										
	Si	***Fe***	***Cu***	***Mn***	***Mg***	***Cr***	***Zn***	***Ti***	**Other each**	**Other total**
Actual	0.08	0.17	1.4	0.03	2.7	0.19	5.8	0.02		
max	0.40	0.50	2.0	0.30	2.9	0.28	6.1	0.20	0.05	0.15
min			1.2		2.1	0.18	5.1			

Cryogenic machining presents a method of rapidly cooling the cutting tool or/and workpiece during machining. More particularly, it delivers the cryogenic cooling media to the tool, which normally experiences high temperature during the machining process, or to the workpiece to change the material characteristics and improve machining performance. In the current experimental work, the liquid nitrogen was applied by a nozzle to the tool flank face as indicated in Fig. 2.7.1.

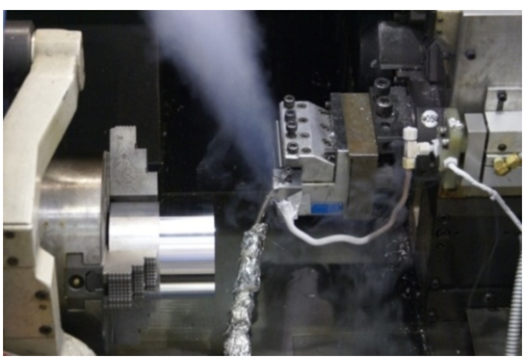


Fig. 2.7.1 Experimental setup for cryogenic machining

Table 2.7.4 Experimental plan: depth of cut = 0.5 mm and feed rate = 0.1 mm/rev

Test	**Tool geometry—tool nose radius [mm]**	**Cutting speed [m/min]**	**Cooling method**
1	TPG 431—0.4	320	Dry
			Cryogenic
2	TPG 432—0.8	180	Dry
			Cryogenic
3	TPG 432—0.8	320	Dry
			Cryogenic
4	TPG 433—1.2	320	Dry
			Cryogenic
5	TPG 432—0.8	720	Dry
			Cryogenic

After each test, the properties of the machined samples were evaluated. The roughness of each machined surface was measured by a Zygo®7300 optical interferometry-based surface profilometer. The final surface microstructure has been analyzed by means of a stereo microscope NIKON L-IM (with 1000X magnification), after each cutting test. In particular, the grain size of each machined sample, as well as the "as received" material was measured at different distances from the machined surfaces.

4 Experimental Results and Discussion

As previously mentioned, the average cutting force components have been acquired when mechanical steady-state condition was reached for each test. As shown in Figs. 2.7.2, 2.7.3 and 2.7.4, the application of liquid nitrogen has a significant influence on all three force components acting during the turning process. In particular, the measured cutting, thrust and radial forces for the cryogenic condition were found to be less than those measured during dry cutting in all the test cases.

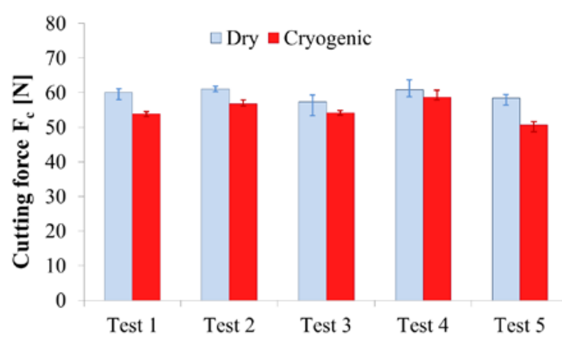


Fig. 2.7.2 The comparison of the measured cutting force (*Fc*) during machining under dry and cryogenic cooling conditions at varying cutting speeds and tool nose radii

It is important to emphasize that the direction of flooding of the liquid nitrogen was the same as the tool flank face so that the radial forces would not be much influenced by its cooling effect. As expected, the cutting forces have also been influenced by the cutting parameters and the tool geometry.

The mechanical power required by the process shows the same trend as previously stated for the forces. In fact, as shown in Fig. 2.7.5, in all the investigated cases, the cryogenic machining process requires less power than dry machining. This shows that cryogenic machining is a more sustainable process than dry machining.

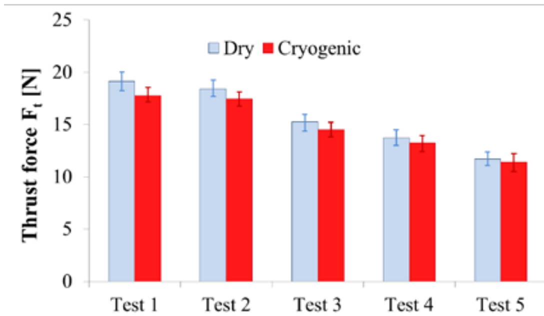


Fig. 2.7.3 The comparison of measured thrust force (F_t) during machining under dry and cryogenic cooling conditions at varying cutting speeds and tool nose radii

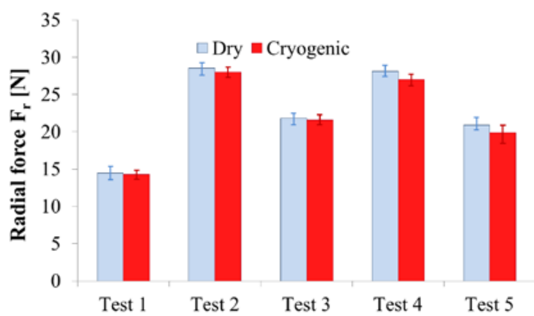


Fig. 2.7.4 The comparison of the measured radial force (F_r) during machining under dry and cryogenic cooling conditions at varying cutting speeds and tool nose radii

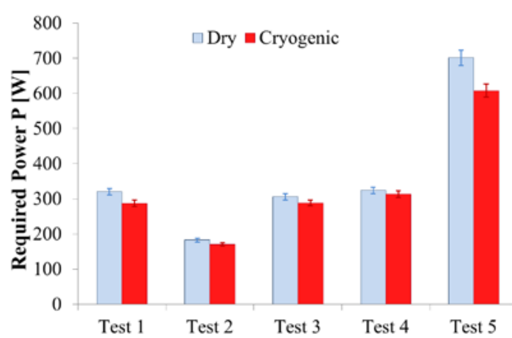


Fig. 2.7.5 The comparison of the "measured" mechanical Power, *P,* in dry and cryogenic machining

More specifically, the forces decrease with increasing cutting speed while they increase with decreasing tool nose radius. Assuming that the finish-machined component will be employed in an aerospace or automotive application, it is important to evaluate its performances in terms of surface quality and fatigue life under service conditions. It is well known that the crack initiation in a component starts from the surface.

Therefore, it is very important to keep the surface as smooth as possible and not to induce tensile residual stresses on the surface.

The mean average surface roughness, R_a, was measured on all machined samples in order to evaluate the surface quality of the final product (Figs. 2.7.6, 2.7.7). The obtained results highlight that the cryogenic condition improves the surface quality of the product. The roughness of the machined samples can be slightly improved by increasing the tool nose radius. Also, the known trend of improved surface roughness by increasing the cutting speed was verified.

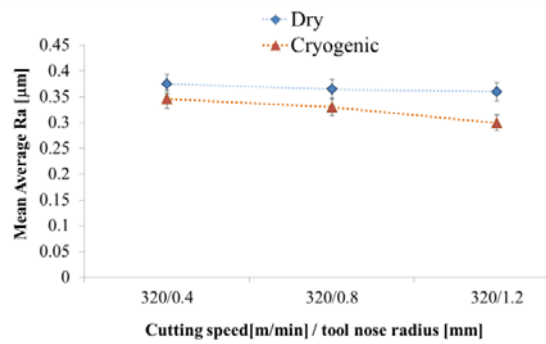


Fig. 2.7.6 Measured R_a data obtained during machining under dry and cryogenic cooling conditions with varying nose radii

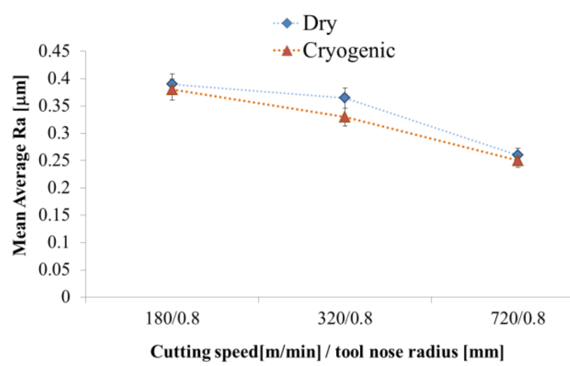
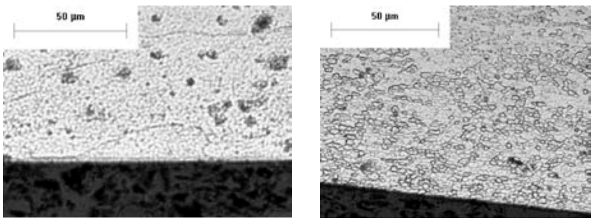


Fig. 2.7.7 Measured R_a data obtained during machining under dry and cryogenic cooling conditions with varying cutting speeds

The grain size of each machined surface has been measured, and, in all investigated cases, the recrystallization occurs. More precisely, all examined samples present a refinement of the mean grain diameter from the bulk to the surface. Due to recrystallization, the cryogenic machining has some positive effects as it helps to keep the surface grains smaller after the recrystallization phase than the initial size.

The results highlight a strong surface grain refinement for the cryogenically machined samples as shown in Table 2.7.5. As observed, the grain recrystallization takes place in all the performed tests but the cryogenic cooling allows the final surface grain size small. Figure 2.7.8 shows two different surface structures obtained from dry and cryogenic machining.

The micro-hardness, Vickers $HV_{0.05}$, of each sample was also measured in order to verify the microstructural changes in the machined samples. The results shown in Figs. 2.7.9 and 2.7.10 demonstrate that hardness increases when liquid nitrogen is applied on the tool flank face and compares with results from dry machining. In particular, the cryogenic machining generates higher hardness on the machined surface and within the subsurface layer than what was generated from dry machining.



(a) (b)

Fig. 2.7.8 Micrograph of the dry machined surface (**a**), and the cryogenically machined surface (**b**)

Table 2.7.5 Grain size refinement at varying cooling conditions and tool nose radii

Test N	Surface mean grain size [µm]	Cooling method
1	12.30	Dry
	5.36	Cryogenic
2	12.33	Dry
	5.60	Cryogenic
3	10.10	Dry
	5.01	Cryogenic
4	7.73	Dry
	4.50	Cryogenic
5	4.05	Dry
	1.79	Cryogenic

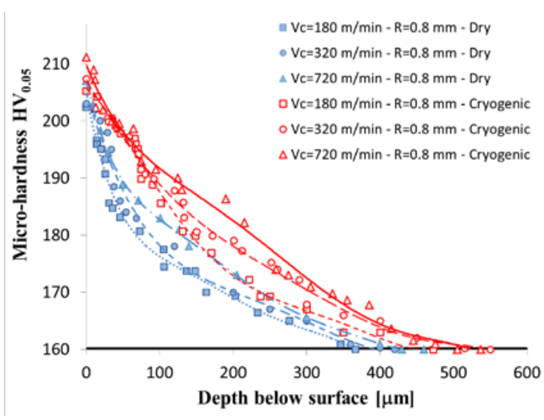


Fig. 2.7.9 Measured micro-hardness for specimens machined under dry and cryogenic cooling conditions at varying cutting speeds

Also, each cryogenically machined sample presents a higher surface hardness when compared with the dry-machined samples. The larger nose radius seems to generate a higher hardness value on the surface. Once again, the cutting speed has a greater influence on the generated hardness, and combined with cryogenic machining, it almost always results in a better surface hardness and quality.

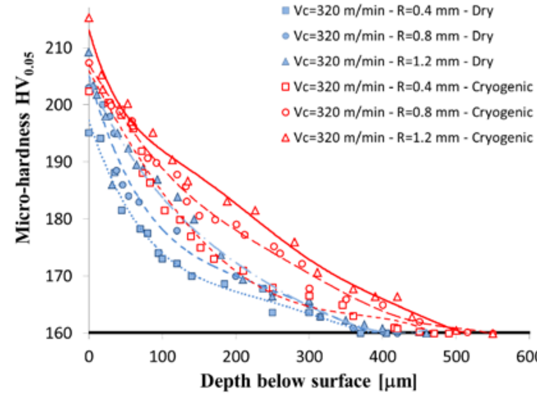


Fig. 2.7.10 Measured micro-hardness for specimens machined under dry and cryogenic cooling conditions at varying of nose radii

4.1 Fatigue Life Prediction

Figures 2.7.11 and 2.7.12 show the fatigue life prediction, using Eq. 2.7.1, for the investigated cases using the measured grain size data as reported in Table 2.7.5.

As seen from Figs. 2.7.11 and 2.7.12, all machined samples move from the High Cycle Fatigue- HCF- range (usually defined as run-out at 10^7 cycles) to a Ultra High Cycle Fatigue regime. It means that the surface theoretically exhibits an infinite fatigue life under a reasonable loading range.

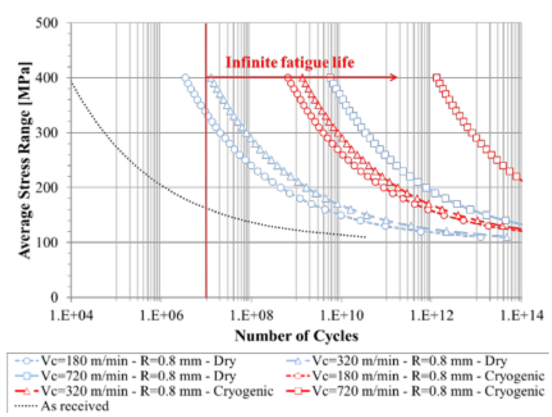


Fig. 2.7.11 Calculated fatigue life for the measured surface grain size at varying cutting speeds and cooling conditions

The meaning of these values is that the fatigue life of the component greatly benefits from the refined surface grains and it moves from a failure occurring on the surface to predominantly internal fatigue failure usually characterized by micro crack growth and fish eye formation [10]. Furthermore, due to the better surface resistance, the sub surface might fail rather than the void/ particle internal mode generating a new failure mode. It is important to note that the cutting speed plays a very important role in reducing the size of the grain and consequently in extending the life of the component. The cryogenic machining process, in comparison with dry machining, always produces a smaller grain size at the same cutting conditions.

It is worth pointing out that for the present experiments, the considered value of *c* was set equal to 524 μm while the slip band width *h* has been kept constant at the suggested value of 0.012. The model proposed by Chan [9] is dependent upon the slip band width and the initial crack length, which change with the variation of the initial grain size. Ultimately, they should be measured in order to obtain a more accurate prediction of fatigue life.

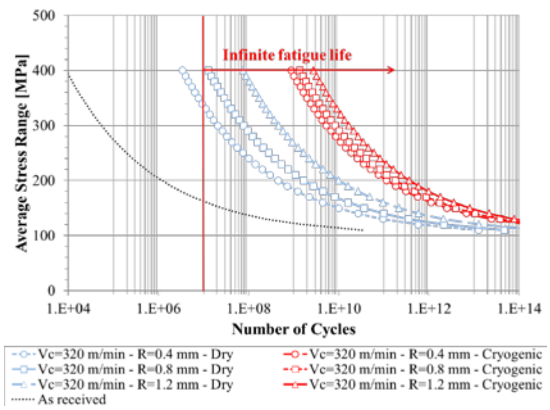


Fig. 2.7.12 Calculated fatigue life for the measured surface grain size at varying tool nose radii and cooling conditions

However, the proposed investigation reveals that the cryogenic machining process entails sustainability benefits for both the process and the product. In fact, as far as the product is concerned, the smaller surface grain structure and its better surface quality drive the component to have a longer fatigue life, to improve its performance and to be replaced at a later time. As for the process point of view, the cryogenic effect on the cutting forces reduces the energy consumption of the process and, consequently, the productivity rate can be increased without compromising the energy cost and consumption rate.

5 Conclusions

This paper presents results from a preliminary investigation showing the capability of cryogenic cooling to increase the sustainability performance of the product and the process in machining of Al 7075-T651 alloys.

Cryogenic coolant significantly influences the grain refinement of the final product which results in a better surface hardness and fatigue life performance. From a process perspective, cryogenic coolant allows one to achieve lower cutting forces and lower mechanical power as compared with the dry process, thereby ensuring benefits from the energy consumption point of view. Furthermore, cryogenic machining is, as previously stated, more environmental friendly when compared with the traditional flood cooling methods which use classical fluids, or MQL machining. Finally, it is important to emphasize that additional experiments should be carried out in order to optimise the process and predict product performances. Finally, a more comprehensive model may be needed for the prediction of the component fatigue life based on the surface microstructure and taking into account also the effect of the initial residual stresses on the life of the component under service.

6 Acknowledgements

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Chapter 3:

Remanufacturing, Reuse and Recycling

3.1 End-of-Life Treatment Strategies for Flat Screen Televisions: A Case Study

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Abstract

The European recycling directive increases the pressure to improve the recycling processes for the rapidly increasing number of End-of-Life (EoL) flat screen televisions. Based on a case study an estimation of the expected economic and environmental benefits of the availability of product information for different EoL treatment strategies is provided. This case study demonstrates that pre-processing operations, such as dismantling, product sorting and clustering, allow to increase the economic viability and sustainability of recycling flat screen televisions. One of the main challenges for implementing pre-processing operations in an industrial setting is that these operations require the ability of product identification and specific product information, such as product structure and material composition. To allow such an exchange of key information, a holistic life cycle approach is required, in which all different actors in the lifecycle are involved, as is achieved in the Flemish PRIME project.

Keywords:

Liquid crystal display (LCD), Plasma flat screen TVs, Product clustering, Recycling

1 Introduction

The costs and environmental impact caused by the End-of-Life (EoL) treatment of Waste of Electric and Electronic Equipment (WEEE) strongly depend on the adopted recycling strategies [1]. Therefore, these costs can be influenced by future technologic developments. There are multiple reasons why the optimization of the current recycling processes or the development of alternative EoL treatment strategies for WEEE is required. Firstly, there is a high cost for collecting and recycling WEEE, which cannot be covered by the revenues from the recovered materials. This total negative profit for recycling WEEE in EU27 is estimated to raise about 16% compared to 2005, increasing to 1.97 billion in 2011 [1]. Secondly, the European WEEE directive and the upcoming recast of this directive are another important reason for recyclers to optimize their recycling processes. The quotas of this recast will range from 50 to 70% with respect to recycling and a recovery rate of 70 to 80% depending on the product category [2]. According to the current WEEE Directive recycling means the reprocessing of a waste material for the original or other purposes, and recovery means the use of combustible waste as a means of generating energy through direct incineration, which currently is a common treatment for polymeric materials [3]. Achieving the recycling rates of the upcoming recast will be difficult with the current EoL treatment strategies, as plastics make up about 20% by weight of WEEE [4]. According to recent studies, Liquid Crystal Display (LCD) televisions (TVs) even contain about 30% polymers [1, 5]. Prior research also indicates that recycling polymers can reduce the environmental impact with up to 40% compared to incinerating polymers with energy recovery [6]. Besides polymers, different products in WEEE, such as flat screen TVs, also contain precious metals with a high economic value and a considerable environmental impact when not reclaimed [7]. For this reason, it is imperative to develop EoL treatment strategies which include recycling of polymeric materials and precious metals [8, 9].

2 Current End of Life Strategies for CRT and Flat Screen TVs

The current treatment strategies in Europe for Cathode Ray Tube (CRT) and flat screen TVs mainly involve direct shredding and to a minor extend (partial) manual disassembly. According to Huisman et al. [1] none of the currently adopted EoL treatment strategies for WEEE is economically viable. The main reasons for this low return, according to Huisman [1], are the high collection, transportation and treatment costs, which cannot be covered by the revenues from the recovered materials.

For the EoL treatment of CRT TVs manual disassembly is no longer required, as re-application of CRT glass is no longer possible [10]. Therefore, the current treatment of CRT TVs is comparable to the direct shredding strategy as applied for the treatment of Small Household Appliances (SHA), for which Huisman et al. indicate an EoL treatment cost of 259 euro per tonne. For the values of recovered materials from CRT TVs a wide range of data are available. Therefore, an update of the value of recovered materials from CRT TVs is given in Table 3.1.1 based on the average CRT TV material content as stated by Huisman et al. [1, 11] and Lamberet et al. [12]. These data indicate that nearly all treatment costs, as calculated by Huisman et al., can be covered by the revenues of recovered materials. Furthermore, the recycling rate required by the European WEEE directive is achieved for the EoL treatment of CRT TVs. The main reason for this high recycling rate is the fact that the significantly large fraction of CRT glass is used in the building industry, which is still counted as recycling according to the WEEE directive.

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Table 3.1.1 Value of recovered materials and recycling rates according to the WEEE directive for a CRT TV

Material custom name	Value of recovered material [1, 5, 13, 14] (€/tonne)	Material recovery efficiency [5] (%)	CRT TV weight [11] (%)	CRT TV weight [12] (%)
Cu (Copper)	5694	99,0%	3	5
Plastics send to incineration	-160	100,0%	21	34
Metals: Ferrous based	220	75,0%	17	8
Metals: Aluminum based	2060	88,0%	3	2
CRT Glass	-55	99,0%	55	47
PCB & Rest fraction	-160	100,0%	1	5
Value of recovered materials per tonne of CRT TVs (€/tonne)			**213**	**238**
Recycling rate according to the WEEE directive			**73%**	**58%**

Compared to the EoL treatment of CRT TVs, the EoL treatment cost is expected to significantly increase for flat screen TVs which use Cold Cathode Fluorescent Lamps (CCFLs) as backlight [1]. This increase in treatment cost is due to the required and costly additional process for the removal of toxic mercury vapors from the CCFLs. Furthermore, flat screen TVs contain substantially less copper, aluminum and steel compared to CRT TVs. Therefore, the costs of the EoL treatment of flat screen televisions can only be covered by recycling more precious metals and polymers in a cost efficient way. Such an improvement can be obtained by implementing advanced post-shredder separation processes. Different technologies have recently been developed for such a direct shredder strategy with advanced post–processing. These technologies can separate shredder output based on optical material properties. However, prior projects demonstrate that the main challenges for implementing such a strategy are the high investment costs for the optical separation equipment and the low separation efficiency of the optical separation processes [5, 15]. Furthermore, an additional purification step is required for polymers after optical separation, since possible metal contamination can impede their reuse. Consequently, still a relatively high gate fee would be required to make this EoL treatment economically viable for flat screen TVs. For this reason, such a strategy with advanced post-shredder separation involves a high investment risk, while new technologies or alternative EoL strategies can still emerge.

Another strategy to increase the amount of recovered materials is to manually disassemble EoL TVs. For manual disassembly the treatment cost is mainly related to the amount of time required to disassemble a flat screen television and the labor wages. According to Salhofer et al. disassembling a flat panel display requires 24 minutes on average, which results in a dismantling cost of 477 euro per tonne when considering an hourly rate of 18 euro [13]. Because of high labor costs in Europe, manual disassembly is generally characterized by a low to negative profitability [16]. Furthermore, there is a health risk when LCD TVs are not carefully handled and disassembled, since these products often contain fragile CCF backlight lamps with toxic mercury vapors.

3 Product Clustering as an End of Life Strategy: A Case Study

The low separation efficiency of optical sorting processes for polymers is mainly related to difficulties with the identification of polymer additives of shredded materials at high throughputs [8]. As a result, polymers can currently not be separated with high efficiency on the polymer additives, such as flame retardants. Consequently, it is difficult to separate plastics with banned flame retardants from non banned flame retardants with the current separation techniques. Therefore, a substantial amount of plastics cannot be recovered with the current EoL treatment strategies. Nevertheless, on average about 25% of all WEEE plastics contain flame retardants [4], depending on the product categories and product brands. Furthermore, a recent study shows that for housings from EoL TVs and monitors the amount of encountered bromide based flame retardants is decreasing [17]. Nowadays, about 50% of all flame retardants in WEEE are expected to be phosphor based, which is authorized for re-use by European legislation. However, still about 40% of all bromide flame retardants, used in EoL television and monitor housings, are nowadays banned by the European legislation [8]. Recent studies show that the presence of commonly used flame retardants is not a technical obstacle for polymer recycling. In some cases these flame retardants appear to even improve the performance and feasibility of the recycling processes [18]. Therefore, it is advisable to cluster flat screen TVs before shredding based on the additives used in the plastics in order to allow the recovery of polymers with non-banned flame retardants.

In the case study presented in this paper, the potential revenues of recovered materials and the potential recycling rate in accordance with the European WEEE directive are calculated for different EoL treatment strategies, as shown in Table 3.1.2. A comparison is made between an EoL strategy with clustering and a direct shredder strategy with and without advanced post processing, and a full manual disassembly strategy. Furthermore, the material contents of both a Philips 42” LCD and a Philips 50” plasma television are analyzed. The current market is mainly dominated by LCD televisions (90%). However, plasma televisions are also analyzed within this case study, as shown in Table 3.13, since they are expected to represent a significant share of the EoL flat screen TVs in the coming years, as mainly plasma televisions were sold before 2005 [1].

Table 3.1.2 Value of recovered materials and recycling rates according to the WEEE directive for a Philips LCD television for different EoL treatment strategies

Material Custom Name	Weight	Weight / TV	Value of recovered material	Direct shedder strategy	Direct shedder + advanced post-processing strategy	Manual disassembly strategy	Clustering + shredder + advanced post-processing strategy
	(g / TV)	(%)	(euro)	(%)	(%)	(%)	(%)
Polymers (incineration)	9976	34%	-160	100	88	6	27
Thermoplastics	330	1%	400	0	0	0	0
PET	1054	4%	660	0	50	100	50
PMMA	1170	4%	2920	0	50	100	50
ABS + PC	111	0%	2840	0	50	0	50
ABS + PC + FR 40	4647	16%	1370	0	0	99	90
PC + FR 40	2192	7%	1370	0	0	97	90
PC + GF10	472	2%	300	0	0	100	0
Glass LCD	2760	9%	50	0	0	100	0
Metals: Ferro based	13834	47%	220	75	75	75	75
Metals: Aluminum based	795	3%	2060	88	88	88	88
Value of recovered materials / Tonne of televisions (€)				**57**	**139**	**586**	**459**
Recycling rate according to the WEEE directive				**38%**	**42%**	**79%**	**63%**

Table 3.1.3 Value of recovered materials and recycling rates according to the WEEE directive for a Philips Plasma television for different EoL treatment strategies

Material Custom Name	Weight	Weight / TV	Value of recovered material	Direct shedder strategy	Direct shedder + advanced post-processing strategy	Manual disassembly strategy	Clustering + shredder + advanced post-processing strategy
	(g / TV)	(%)	(euro)	(%)	(%)	(%)	(%)
Polymers (incineration)	5396	9%	-160	100	99	15	36
Thermoplastics	820	2%	400	0	0	0	0
ABS	160	0%	1540	0	50	100	50
ABS + PC + FR 40	3756	8%	1370	0	0	100	90
PC + GF10	660	1%	300	0	0	100	0
Glass	18215	37%	-55	90	90	100	90
Metals: Ferro based	13005	26%	220	75	75	75	75
Metals: Aluminum based	5700	11%	2060	88	88	88	88
Value of recovered materials / Tonne of televisions (€)				**355**	**359**	**576**	**535**
Recycling rate according to the WEEE directive				**63%**	**63%**	**75%**	**70%**

The material recovery rates for the ferrous metals and the aluminum, used in the calculations, are based on the estimated efficiency of magnetic and eddy current separation processes for shredded material from flat screen TVs [5]. The recovery rates for the advanced post processing processes are based on the estimated separation efficiency of a Near InfraRed (NIR) TITECH device for the separation of Polystyrene (PS) and Acrylonitrile Butadiene Styrene (ABS) from mixed WEEE polymers [15]. The low separation efficiency for NIR separation processes is also due to problems with blackness detection, which has a significant influence, as television housings are dominated by black plastics [17]. Therefore, further research is required to determine more accurate recovery rates for Polymethylmethacrylate (PMMA) and Polyethylene Terephtalate (PET). These polymers are mainly white or transparent, since they are commonly used to diffuse the backlight in LCD TVs. Consequently, the recovery rate is expected to increase, since NIR separation processes do not have problems due to blackness detection for these polymers. Nevertheless, the main polymer fraction with flame retardants cannot be recovered with this strategy, since optical separation of polymers based on their flame retardants is currently not feasible at high material throughputs. For the manual disassembly strategy the recovery rates are calculated assuming that all big and easily identifiable components are disassembled and recycled.

All values of recovered materials used for this case study are based on estimates from prior studies. The values of recovered materials differ significantly between sources, since they are generally incinerated with energy recovery and not recycled [1, 5, 13, 15]. For this case study, rather optimistic values of recovered materials in Europe, as proposed by Huisman et al. are used [1]. However, to receive these values for recovered material a steady supply of polymers with an assured quality should be achieved. For polymers sent to incineration with energy recovery a cost of 160 euro per tonne is taken into account, based on data from Salhofer et al. [13]. Both for the LC display and for the glass of the plasma television the values of the recovered materials are based on data from Cryan et al. [5]. Only limited data are available about the precious metal content and value of PCBs from flat screen TVs. Therefore, the PCBs, as well as the cables connected to these PCBs, are not taken into account for the calculations in this case study. Nevertheless, the recovery of precious metals from PCBs can contribute to a more economically viable EoL treatment of flat screen TVs, as discussed further in the next section.

4 EoL Treatment Strategies for LCD and Plasma TVs

The case study, presented in this paper, indicates that there is a significant difference in material content between plasma and LCD TVs. The main difference is that LCD TVs contain a higher amount and more types of polymers, while plasma TVs contain a substantially higher amount of glass. Furthermore, compared to CRT TVs, LCD TVs contain less ferrous metals and aluminum. As a result, for an EoL treatment strategy with direct shredding and commonly used separation processes, such as magnetic separation and eddy current separation, only a low value can be recovered from LCD TVs. For plasma TVs a considerably higher value can be recovered with this EoL treatment strategy. Compared to the EoL treatment of CRT TVs a significantly lower value is recovered from LCD TVs. Also a much lower recycling rate is achievable for LCD TVs than required by the European WEEE directive. For plasma TVs, on the other hand, a relatively high recycling rate is achievable, since the large glass fraction can be recycled by the building industry. An EoL treatment strategy with advanced post-shredder separation processes, such as optical polymer separation, is mainly promising for the EoL treatment of LCD TVs, which contain a higher amount of polymers. For plasma TVs this EoL treatment strategy only comports low improvements, since most polymers of the analyzed plasma television are from the product housing and contain flame retardants. Although an increase in value of the recovered material can be achieved by means of advanced post-shredder techniques, only a low recycling rate is achieved for EoL LCD TVs.

Compared to other EoL treatment strategies, an EoL strategy with manual disassembly can significantly increase the value of recovered materials, as well as the percentage of recycled materials. Assuming the availability of detailed information about the material content, manual disassembly can be assumed economically viable for LCD TVs. Based on this case study. the value of the recovered material can cover the dismantling cost of 477 euro per tonne of flat screen TVs, as calculated by Salfhofer et al. [13]. However, in order to receive the material prices used in the case study for recovered materials, a steady supply of recovered polymers with an assured quality should be achieved. Furthermore, detailed information about the material content is required. Only with information about the polymer additives of every component a manual separation of polymers based on their flame retardant is possible, since the used type of flame retardant is generally not indicated on the components.

The case study also indicates that an EoL treatment strategy with clustering based on product information allows to significantly increase the value of recovered materials. This improvement is achieved by processing a cluster of products without banned flame retardants separately, which allows separating and recycling polymers with flame retardants. The recovery rates for these processes are based on those of density based separation processes for plastics without flame retardants, as presented by Gent et al. [19]. However, future research is required to determine more accurate recovery rates for density based separation processes for plastics with flame retardants. Furthermore, by processing products which mainly contain compatible polymers for recycling, such as ABS and Polycarbonate (PC), no further separation of these plastics is required. As a result, such a strategy allows recycling a significantly higher amount of materials for LCD TVs compared to strategies with unsorted shredding. Another advantages of an EoL treatment strategy which involves product clustering based on hazardous substances, is that certain separation processes can be omitted. For example a first clustering can be done based on the adopted flat screen television technology, as the material content strongly depends on the adopted technology. In this way, when clustering only plasma TVs, the process of mercury removal can be avoided.

A strategy which involves clustering can furthermore make the recovery of Printed Circuit Boards (PCBs) from flat screen TVs economically feasible. Based on the average material content of an LCD television, as described by Huisman et al. [1], and values of recovered PCBs, as used by Keller [1, 20], the PCBs of LCD televisions have an economic value of about 56 euro per tonne of TVs. Nevertheless, only about a quarter of the precious metals typically found in PCB components generally ends up in the fraction for precious metals recovery when mixed WEEE is mechanically processed [21]. The efficiency of the recovery of PCBs can be improved by adopting pre-shredder processes according to Meskers et al. [22]. Hence, a clustering strategy can improve the recovery of precious metals, as it allows differentiating the processes to recover PCBs applied for different clusters. For example, when destructively opening the housing of flat screen TVs the recovery rate of precious metals can be expected to improve. When considering flat screen TVs similar to personal computers (PCs), a recovery of about 75% of the PCBs by means of manual picking can be assumed [22]. Furthermore, manual disassembly can allow a recovery of more than 95% of PCBs for the EoL treatment of PCs [22]. Hence, manual disassembly can become feasible for clusters of flat screen TVs with higher value PCBs and/or faster accessibility to them.

5 Required Information for an Optimized EoL Strategy with Clustering

The case study shows that clustering of products based on product information can allow to significantly increase the material recovery, as well as the economic viability of the EoL treatment of flat screen TVs. However, to enable such a clustering strategy the availability of proper product information is required. Only based on relevant product information flat screen TVs can be correctly sorted in an optimal number of clusters. The desirable properties of this product information can be described by three dimensions: the level of detail of the product information, the ability of product identification and the product information location. Nowadays, products are already clustered during the EoL treatment based on their visually identifiable properties. For flat screen TVs such an identification can allow a first clustering, such as clustering plasma and LCD flat screen TVs. However, for further optimization of the EoL treatment of flat screen TVs, more detailed product information is required. For example, to improve polymer recycling and avoid pollution with banned brominated flame retardants, detailed information about the used polymers and additives is required. To allow such a clustering based on more detailed information, more advanced product identification processes are needed. For example, bar code labels, which are commonly placed on flat screen TVs for logistic reasons, can sometimes still be used to identify the product model at the EoL of the product. The product model can then be used to look up detailed product information. However, the reliability and efficiency of the identification can be improved by either applying modern identification technologies, such as Radio Frequency Identification (RFID), or by applying product recognition technologies at the EoL treatment. If product identification is possible, it does not necessarily mean that the information needs to be located at the product. Two extreme scenarios can be identified here: Information access through a data network or information integrated in the product [23]. A system which enables access to product information through a data network seems most appropriate for this application. In this way manufacturers will be able to better protect their Intellectual Property (IP) and can choose to only share product information when their products reach their EoL. Furthermore, such a system can support a business model in which the product manufacturer is able to sell product information in accordance to the surplus value it comports to the recycler [24].

To enable such an exchange of product information a holistic approach is required, where the product manufacturer is involved in the EoL treatment. Manufacturers possess a lot of valuable product information, which can allow an optimal product clustering. In the Flemish PRIME project such a collaboration between a manufacturer and recyclers is achieved through the participation of Philips, a flat screen TVs manufacturer, and two recycling companies, Van Gansewinkel and Umicore. The main goal of this project is to optimize the economical viability and sustainability of the EoL treatment of flat screen TVs. The opportunities of an EoL treatment strategy with product clustering based on product information from the manufacturer, which is presented in this paper, will be further investigated within the PRIME project.

6 Conclusion

The case study, presented in this paper, demonstrates that a higher recycling rate according to the WEEE directive and a substantial economic improvement can be reached by applying an EoL treatment strategy for flat screen TVs with product clustering based on material composition. However, to allow the implementation of such an EoL treatment strategy, a business model which includes both the flat screen manufacturer and the recycler is required. In this way the exchange of required and detailed product information for sorting EoL flat screen TVs in optimal clusters will be stimulated. To allow further optimization of the EoL treatment of flat screen TVs, a better knowledge of the product design and material content, as well as the material compatibility for different recycling processes is necessary. Only based on this information clusters of products can be optimized together with the corresponding economically and ecologically optimal EoL treatment.

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3.2 Assessment of Load-Dependent and Condition-Oriented Methods for the Lifetime Estimation of Ball Screws

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Abstract
Taking into consideration the complexity of today's machines an economical production is only possible if high availability is ensured at the same time. In order to be able to guarantee high availability values the maintenance of machine tools plays a key role. Thus, an approach is developed which permits the configuration of both a diagnostic and a forecast system for ball screws. Therefore, a hybrid approach is established which combines load-dependent and condition-oriented methods. The objective is to be able to make a forecast as precisely as possible of the failure of a ball screw with a minimum of effort. In the process, basic assessment criteria are in each case effort and prediction accuracy. Therefore, the results of the preciseness of condition determination are presented by the features solid-borne and airborne sound in this paper. The results of the accuracy of load determination are presented by the motor current.

Keywords:
Load and condition-based maintenance, Machine tools, Maintenance optimization

1 Motivation

Today, competitiveness on the global market depends on a high product quality which is to be achieved with lowest effort [1]. This applies especially to the machine tool sector. Besides the constantly increasing requirements concerning accuracy, machine rigidity, operational reliability and accident prevention a machine tool has to work in a highly automated, flexible and efficient manner. Taking into consideration the complexity of today's machines an economical, sustainable production is only possible if high availability is ensured at the same time. In order to be able to guarantee high availability values the maintenance of machine tools plays a key role [2]. So far, maintenance has consisted to 80% of reactive measures, i.e. repairing broken machines [3]. In order to permanently increase availability, approaches need to be developed to shift focus to condition and load-based maintenance activities [4].

Even today ball screws represent the most important drive element in feed drives of various machine tools. According to [5], ball screws will be a serious competitor of the linear motor in the field of feed motion and positioning also in the future. Despite a low failure rate this component can have a strong influence on the technical availability of the machine tool because high down times are to be expected due to failure [6].

Machine monitoring and diagnostic systems offer a possibility to increase availability. By means of these systems machine properties can be monitored systematically and errors can be quickly localized and corrected. The automated solutions for early fault detection provide information on the existing stock of wear-out and allow for an effective planning of maintenance measures and spare parts supplies [7]. Thus, down times are reduced and this, in turn, leads to an increase in machine availability [8].

Here, it can be distinguished between load-dependent and condition-oriented systems. Load-dependent systems determine or measure the load which acts on a component and draw conclusions about life time. Condition-oriented methods deduce life time directly from measured characteristics. The former are characterized by lower acquisition, training and operational costs. However, in contrast to the condition-oriented systems they are subject to the dispersion of the real life time referring to the calculated nominal life time.

According to [6], it is generally possible to determine the state of a ball screw (solid-borne and airborne sound, jerk and eigenfrequencies). According to [9], the determination of the load of components is possible from NC programs.

[9] was able to improve this result by means of drive signals and to simplify and accelerate it considerably by transfer functions.

2 Objective

The objective is an approach which allows the configuration of both a diagnostic and a forecast system for ball screws. Therefore, a hybrid approach was established which combines load-dependent and condition-oriented methods [11]. Thus, a forecast of the ball screw's failure has to be made with a minimum of effort and as precisely as possible. So a sustainable use of the ball screw is possible. For that reason a configurator is developed. On the one hand it determines in which methods should be invested at the beginning of the ball screw's lifetime and how this methods should be appliqued. On the other hand it teams the previously selected load-dependent with the condition-oriented method during the lifetime of the ball screw. In the process, basic assessment criteria are in each case effort and prediction accuracy. In this paper the results of the

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preciseness of condition determination are presented by the features solid-borne and airborne sound. The results of the accuracy of load determination are presented by the motor current.

3 Approach

In order to reach the defined objective the approach illustrated in Fig. 3.2.1 is followed.

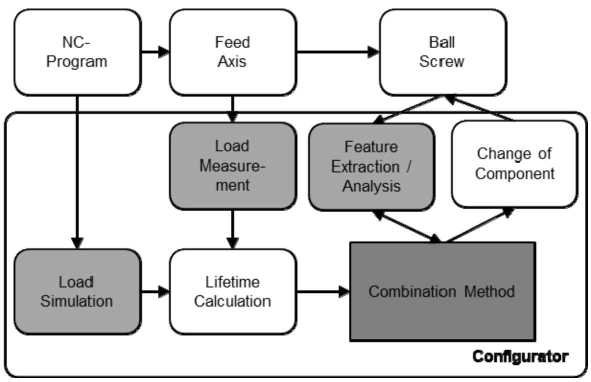

Fig. 3.2.1 Approach

The upper part shows the relation between NC program, machine tool, feed axis and ball screw. Underneath the actual configurator is illustrated. The configurator selects the methods and determines how they are implemented for economic reasons. For that purpose, two load-dependent approaches are examined. On the one hand load measurement by the consumed motor current and on the other hand the simulation of the load by means of a Matlab/Simulink model. The acting forces are the result of both methods. From these forces the life time can be deduced by means of the calculation according to [10]. The features of the condition-oriented methods have at first to be detected and then analysed. The final method combines the methods selected and implemented by the configurator in a way that effort and benefit are optimized and resolves manual condition measurements as well as the actual replacement of the ball screw. This method was presented in [11]. In order that the configurator can select the methods it is important that for every considered method the accuracy is determined.

4 Results Concerning Condition

The accuracy of condition determination was tested using as an example a sound-level measuring device and two solid-borne sound sensors. These sensors were applied to a test rig for life time tests. In this test rig a ball screw was tested with regard to its life time. During this test vibration measurements of the airborne and structure-borne sound were carried out according to [6] at regular intervals with the above mentioned sensors at different speeds and loads. The extracted feature is deduced from the difference between maximum and minimum of the measured vibration. In this paper the load is declared as percentage of the dynamic load rating according to [10]. Subsequently, for each sensor and each parameter combination the excessive raise of the feature at the end of life time related to the beginning and the repeat accuracy were evaluated. Additionally, temperature dependency of the features was analyzed in the range between 30 and 50°C.

4.1 Results Concerning Structure-Borne Sound (Triaxial Sensor)

In the following table the feature changes of the triaxial sensor in Z-direction (direction of the ball screw) at the end of life time related to the reference measurement at the beginning of the life time test are shown (Table 3.2.1).

Table 3.2.1 Feature characteristics of the triaxial vibration measurement depending on speed and load

Load\ Speed	300 rpm	500 rpm	700 rpm	1000 rpm
0%	250%	206%	154%	141%
10%	191%	210%	171%	113%
50%	250%	187%	240%	80%
80%	168%	151%	92%	86%
100%	200%	177%	175%	140%

Speed rise leads to a reduction of feature change. If considering only the change at lower speeds (300 & 500 rpm) it becomes evident that the impact at reduced load (up to 50%) is stronger. The best results in all three directions could be obtained without applied load and at low speed. The maximum changes in X-direction were at 290%, in Y-direction at 224% and in Z-direction at 250%. If looking at the mean standard deviation in percent of the mean value it can be observed that dispersion is at its lowest without applied load (Table 3.2.2).

Table 3.2.2 Standard deviation of the triaxial vibration measurement depending on load

Speed	300 rpm		
Load/ direction	X	Y	Z
0%	4.5%	3.8%	3.6%
10%	11.5%	17.9%	12.3%
50%	9.0%	10.8%	8.0%
80%	19.3%	13.1%	15.0%
100%	14.9%	13.5%	9.5%

In terms of repeat accuracy without applied load it becomes evident that the values disperse less at lower speeds (see Table 3.2.3).

Table 3.2.3 Standard deviation of the triaxial vibration measurement depending on speed (without applied load)

Speed/ Direction	X-direction	Y-direction	Z-direction
300 rpm	4.5%	3.8%	3.6%
500 rpm	5.3%	4.6%	3.4%
700 rpm	8.6%	14.0%	5.4%
1000 rpm	7.5%	43.4%	21.8%

On the occasion of the analysis of temperature influence of the used triaxial sensor no direct impact of temperature on load range could be observed.

4.2 Results Concerning Structure-Borne Sound (Single Axis Sensor)

As a more economical alternative to the triaxial sensor the solid-borne sound vibrations were also detected by means of a single axis sensor. Table 3.2.4 illustrates the change of feature characteristics in percent in relation to the reference measurement at the beginning of the life time test.

Table 3.2.4 Feature characteristic of the single axis vibration measurement depending on speed and load

Load/ Speed	300 rpm	500 rpm	700 rpm	1000 rpm
0%	361%	228%	187%	159%
10%	180%	196%	215%	166%
50%	455%	404%	288%	248%
80%	419%	380%	292%	206%
100%	457%	303%	234%	220%

At the load levels of 0, 50, 80 and 100% it is obvious that at an increasing speed the values in the table become lower. The reason is that at higher speeds the characteristic values in the reference state increase more than the maximum values during the life time test. In order to be able notice a significant change of the analyzed vibrations in axial direction, measurements should be carried out at low speed. The analysis concerning an optimal load shows that the biggest changes occur at a load from 50%. Given that feature change does not improve significantly at over 50% load but rather becomes less in most cases, this load level can be taken as the optimal value for vibration measurement in axial direction. In contrast to speed, in the case of load no linear correlation could be noticed. At a load of 10% feature change is at its lowest level. Here, only a doubling of the output value could be noticed. In contrast, at low speed and if no load is applied feature change is higher than at a load of 10%.

With regard to repeat accuracy it could be noticed in case of the cheap single axis sensors used that standard deviation in percent of the mean value is lower at lower loads than at higher loads. Furthermore, it can be seen that on the highest level of load dispersion is at its highest level. In addition, it can be assumed that dispersion becomes lower when speed is increasing. In the table below the mean standard deviation is indicated in% of the mean value of the single axis sensor depending on speed and load (Table 3.2.5).

Table 3.2.5 Standard deviation of the single axis vibration measurement depending on speed and load

Load/ Speed	300 rpm	500 rpm	700 rpm	1000 rpm
0%	15.3%	13.1%	10.1%	10.2%
10%	10.1%	9.4%	10.9%	7.6%
50%	18.6%	15.1%	11.1%	14.2%
80%	13.1%	17.1%	15.9%	10.4%
100%	24.9%	17.1%	22.0%	15.0%

Within the context of the analysis of temperature dependency no direct correlations between feature characteristic and temperature, as before with the triaxial acceleration sensor, could be noticed. Analyzed was the load range between 30 and 50°C.

4.3 Results Concerning Airborne Sound

The course of the wear curve, which is known from vibration measurements according to [6], could also be observed during sound level measurement. The following table shows feature change at the total life time concerning reference measurement at the beginning of the life time test (Table 3.2.6).

Table 3.2.6 Feature characteristic of the sound level measurement depending on speed and load

Load/ Speed	300 rpm	500 rpm	700 rpm	1000 rpm
0%	154%	132%	160%	154%
10%	125%	130%	170%	179%
50%	142%	153%	140%	178%
80%	103%	176%	157%	151%
100%	105%	151%	147%	158%

When measuring the sound level no clear correlation between speed or rather load and feature change could be detected. This may be related to the susceptibility to external influences.

In the following table the medium standard deviation is specified in percent of the mean value depending on load and speed when the sound level is measured (Table 3.2.7).

Table 3.2.7 Standard deviation of the sound level measurement depending on speed and load

Load/ Speed	300 rpm	500 rpm	700 rpm	1000 rpm
0%	8.5%	6.7%	8.3%	4.8%
10%	10.9%	16.9%	6.2%	5.6%
50%	14.0%	4.3%	8.9%	6.8%
80%	30.1%	8.3%	6.4%	6.0%
100%	39.7%	7.7%	12.3%	6.0%

The analysis of standard deviation shows that the dispersion at higher speed is lower than at lower speed. Given that the external influences also have an impact on dispersion, neither here a statement can be made with regard to optimal parameters.

As before with the vibration analyses, a direct influence of temperature on feature characteristic and on dispersion could not be noticed.

4.4 Results Concerning Load Measurement

Besides the condition-oriented methods also load determination was analyzed by measuring the motor current concerning accuracy. For that purpose, the test rig shown in Fig. 3.2.2 was installed.

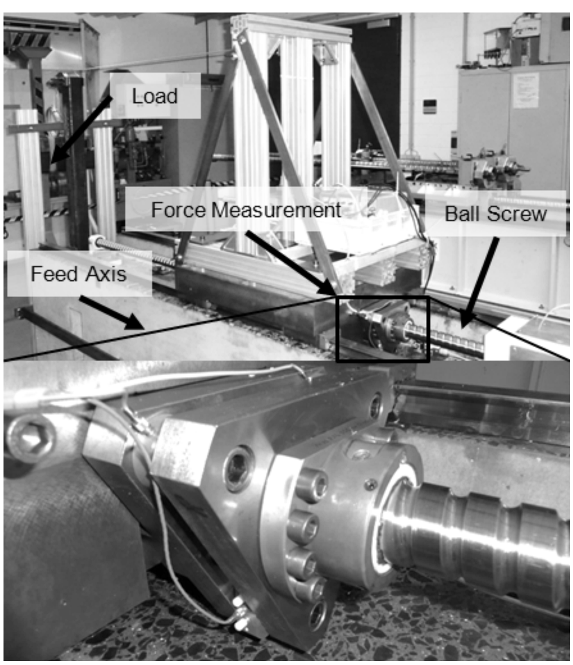

Fig. 3.2.2 Test rig for force measurement

The test rig consists of a feed axis on which a load unit was put in order to be able to induce constant loads. In addition, a force measurement unit between table and ball screw was mounted. By means of this test rig it is possible to measure the force really acting on the ball screw. The tests were to position on a defined value at a given maximum acceleration, speed and a maximum jerk under a defined load. During the tests, end position and jerk were constantly held. Acceleration values were varied between 0.1 g and 0.5 g. Speeds were changed between 500 and 2000 rpm. The tests were carried out without constant load, with a load of 660 N and a load of 990 N. Besides the real force between table and ball screw also the motor current was detected. Given that a synchronous motor was applied as it is usual with feed axes, the motor current can be easily converted into a moment. From this moment the force on the ball screw can be calculated.

In Fig. 3.2.3 the measured force progression is compared exemplarily for two sets of parameters to the force progression calculated from the motor current. In each case it can be seen that both curves agree very well with each other.

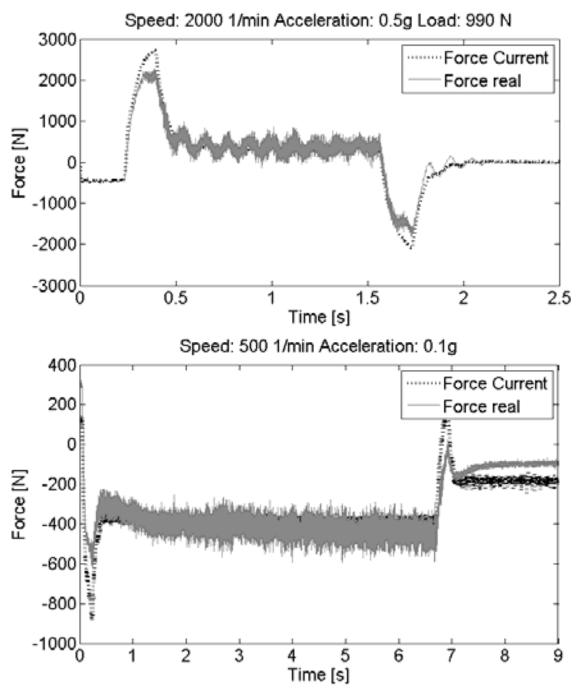

Fig. 3.2.3 Measured force progression compared to the force progression calculated from the motor current

For each set of parameters (acceleration, speed, load) the life time of the ball screw was calculated according to [10]. Thus, the accuracy of load determination could be defined from the motor current. The results are illustrated in Fig. 3.2.4.

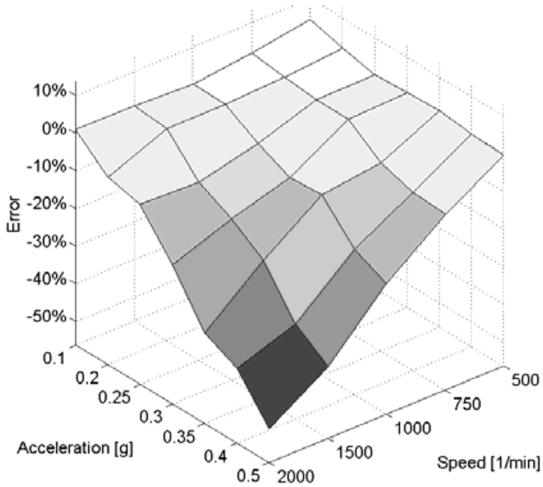

Fig. 3.2.4 Accuracy of load determination

The relatively high deviations of up to 50% are due to the influence of force by the power of three. For that reason, relatively small deviations at a maximum force result in high deviations concerning life time.

5 Summary

An approach was presented which permits the configuration of a hybrid diagnostic and forecast system for ball screws. The objective is to be able to make a forecast as precisely as possible of the failure of a ball screw with a minimum of effort. For this purpose the load-dependent and condition-oriented methods to be employed are selected. Furthermore, it is important to determine how respectively if more methods are combined. In the process, basic assessment criteria are in each case effort and prediction accuracy. Besides, the results of prediction accuracy of the condition-oriented diagnostic methods solid-borne and airborne sound were presented. In addition, the error of a load measurement from the motor current depending on acceleration, speed and load in contrast to the real load was assessed. Using these results it will be possible to realize the configurator in later works.

6 Outlook

In further works the quality of results for the features overswing and eigenfrequency according to [6] will be analyzed. Besides that, for all features the dependency of prediction accuracy on life time is determined. Furthermore, at the moment a simulation model of a feed axis is being implemented in Matlab/Simulink. This simulation model contains a model of mechanics, of a speed dependent friction model, of the motor and of a converter. This model is compared to the already detected measurement results so that a statement can be made about the accuracy of the simulation model. These results are used for the further development of the method for configuration and combination.

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3.3 Synthesis of Wollastonite on the Basis of the Technogenic Raw Materials

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Abstract

Studies of the synthesis of wollastonite on the basis of technogenic raw materials are executed (nephelinic slime, micro-silica). The results of raw material studies and their chemical composition and physico-mechanical properties are given. It is shown that synthesized material predominantly consists of wollastonite and they can be used as filler of silicate masses the preliminarily ground state.

Keywords:

Nepheline slime, Micro-silica, Synthesis of wollastonite

At present natural wollastonite is obtained by a comparatively small number of adventure. The use of a wollastonite in the production grows. This stimulates interest in the development of the methods of obtaining the synthetic wollastonite from the accessible raw material.

One of the methods of increasing the profitability of production is the complex use of raw materials, development and introduction of wasteless technologies with maximally possible processing of coproduct. Technogenic materials are raw materials, which can be used for the production of different forms of building materials, and so be basis for the synthesis of initial products for preparing the materials with the increased operating characteristics.

The basic parameters with the synthesis are the duration of synthesis, the reduction of harmful impurities, the output of end product, power and material expenditures. Basic parameters influencing the process of the synthesis: composition and the relationship of the components of initial mixture, the initiating additives and catalysts, the parameters of the preliminary preparation of source material, the temperature of synthesis, the holding time at a maximum temperature.

It is known from the literary sources that artificial wollastonite can be synthesized from both natural and technogenic raw material. The problems of complex use of the mineral raw material and ecological problems are solved.

At present the general reserve of nephelinic slime comprises more than 100 million t (Achinsk alumina centre). Plants are not capable of processing this volume of waste. Therefore studies on the expansion of the branches of its application are immediate. The basic suppliers of micro-silica in the Siberian region are the plants of Novokuznetsk (more than 20 million t per year) and Bratsk to 2.5 million t per year.

Nephelinic slime is the by-product of complex processing of nephelinic ores to the alumina and the soda products. Nephelinic slime to 70–75% consists of the grains of B-2(CaO)•SiO_2 and by its hydrated forms. Grains of в-2(CaO)•SiO_2 form the aggregate accumulations of irregular shape and are painted with the oxides of iron into the brown colored size of separate grains in the aggregates it reaches 5 μm, and in essence they have smaller sizes. The mass of intermediate substance, which cements grains of dicalcium silicate, is vitreous phase, moreover glassy films around the grains of в-2(CaO)•SiO_2 are distributed evenly. The total number of hydrated particles of в-2(CaO)•SiO_2 small and comprises not more than 5–7%. Grains of nepheline, oxides of iron and other admixtures are observed. Micro-silica is condensed silicate dust, which is by-product of the production of crystalline silicon. The chemical composition of nephelinic slime and micro-silica are given in Table 3.3.1.

Nephelinic slime and micro-silica are promising raw materials by the chemical and mineralogical composition for the production of different designation materials. Nephelinic slime is characterized by high porosity 30–60% with the size of interstice from 10 to 1000 μm. The sizes of the particles of the nephelinic slime vary over wide limits from 2–10 μm to 30–70 μm. The binding properties of natural nephelinic slime are weakly expressed. Therefore its use as that binding without the additional working and additives is inexpedient. Micro-silica consists of particles with the sizes from 0.1 to 0.4 μm with average size of grains of approximately 100 nm. The average particle sizes of binding is 150–500 times less specifies high reactivity of micro-silica. The physico-mechanical properties of nephelinic slime and micro-silica are given in Table 3.3.2.

System "CaO-SiO_2" is the basic chemical compounds: tricalcium silicate ($3CaO{\cdot}SiO_2$), dicalcium silicate ($2CaO{\cdot}SiO_2$)—the basis of nephelinic slime; rankinit ($3CaO{\cdot}2SiO_2$) and metasilicate of calcium ($CaO{\cdot}SiO_2$)—wollastonite. From the nephelinic slime, whose basis composes belite, it is possible to obtain wollastonite according to the solid-phase reaction [1]:

$$2CaO{\cdot}SiO_2+SiO_2=2(CaO{\cdot}SiO_2), \quad \Delta G^{o}_{1400K}= -75\ kJ \qquad (3.3.1)$$

The thermodynamic analysis of reaction shows that Gibbs's energy to reaction it composes −75 kJ at a temperature 1400°C although the formation of wollastonite it can occur at lower temperatures. Mechanism of reaction is solid-phase synthesis.

The synthesis of wollastonite from the nephelinic slime and silica flows through the formation of the intermediate compound of rankinit and is complicated by the kinetic difficulties of the flow of the solid-phase reactions: by the diffusion of reactants and structural reconstruction of the material:

$$3(\alpha\text{-}2CaO{\cdot}SiO_2)_{rhombic}+SiO_{2hexagonal} = 2(3CaO{\cdot}2SiO_2)_{monoclinic}, \qquad (3.3.2)$$

$$(3CaO{\cdot}2SiO_2)_{monoclinic}+ SiO_{2hexagonal}=3(\beta CaO{\cdot}SiO_2)_{monoclinic/triclinic} \qquad (3.3.3)$$

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Table 3.3.1 Chemical composition of nephelinic slime and micro-silica (%)

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Δm	∑
Nephelinic slime	30.80	3.29	4.04	56.28	1.43	0.18	1.52	0.59	1.87	100
Micro-silica	94.20	0.47	0.60	0.36	0.30	–	–	0.69	3.43	100

Table 3.3.2 Physico-mechanical properties of nephelinic slime and micro-silica

Material	Real density (kg/m^3)	Packed density (kg/m^3)		Porosity of the layer of the material (%)		Specific surface (cm^2/g)	Natural humidity (%)
		Free state	Condensed state	Free state	Condensed state		
Nephelinic slime	2770	980	1500	64.4	44.0	9300	5.3
Micro-silica	2180	150	300	82	79	25000–30000	2–3

The raw components were used for the synthesis of wollastonite: limestone, nephelinic slime and micro-silica.

The technology of autoclaving silicate materials is needed for using lime in the finely dispersed and preliminarily hydration state $Ca(OH)_2$. Liming is accompanied by a notable increase in the volume and can lead to deformation and destruction of articles. Lime and siliceous components must be finely dispersed. High dispersiveness ensures the development of the larger surface of interaction between CaO and SiO_2 and to the intensity of the chemical reaction between them with the hydrothermal treatment of articles. Lime was dissipated, dried and ground. Nephelinic slime was ground and heat treatment at a temperature 200, 300, 400 and 500°C for an increase in its activity. Micro-silica was used in the natural state.

Composition, structure and properties of synthetic wollastonite depend on initial components, ratio of calcium to silicon, conditions it was obtained.

The component mix was calculated taking into account data of the activity of lime on CaO, the gross content of silica in micro-silica and nephelinic slime containing in its composition both CaO and SiO_2 with different ratio $CaO:SiO_2$. Ratio is changed from 0.7 to 1.8. Component mix is given in Table 3.3.3.

The thermodynamic calculations for selected compositions were carried out (1–3). For conducting the calculation initial thermodynamic data for each reaction with the participation of the selected raw material by standard procedure were used [2]. The analysis of the obtained results showed that for all compositions (1–3) in the range of temperatures of

800–1000°C energy of Gibbs (ΔG) has the negative value, which indicates of the possibility of the synthesis of wollastonite of all selected compositions.

The prepared components were weighed and mixed with the addition of 10% bond of methylcellulose and were briqueted by extrusion under the pressure 40 MPa. The samples hardened under the conditions of air-dry medium, then were weighed, measured linear dimensions and annealed at temperatures 800, 900 and 1000°C with endurance 1 h and by slow cooling furnace.

The results of heat treating the samples showed that the preliminary kilning of nephelinic slime at different temperatures does not substantially influence a change in the phase composition of fired material.

Form and strength preserve only the samples, which consist of the nephelinic slime (composition 1) by kilning temperature of 800°C, nephelinic slime and micro-silica (composition 3). Samples burnt at higher temperatures everyone preserves their form. The obtained samples (composition 2) they have the greatest values of compression strength (17–20 MPa) of those burnt with 900 and 1000°C, but with the small defects on the surface.

For the identification of the synthesized wollastonite was conducted X-ray analysis on the diffractometer DRON-3M, where X-ray tube BSV-24 with CuK_α—radiation (2θ = 10…90°) are used, sensitivity of survey 1000, 2000, the speed of rotation of goniometer was 4°/min, stress anode-cathode 30–40 kV, the anode current of 15–25 mA.

Results showed that the peaks of wollastonite were discovered in all samples under investigation; however, the greatest content of wollanstonite peaks is observed in the X-ray photograph of samples on the basis of nephelinic slime and micro-silica (composition 3), Fig. 3.3.1.

As a result executed studies, it is established that the synthesis of wollastonite flows in all utilized compositions, most fully flows the synthesis of wollastonite in the compositions of micro-silica with the nephelinic slime (composition 3) at a temperature of kilning from 800 to 1000°C.

Synthetic wollastonite was tested in the composition the of previously developed thermoresistant materials on the basis of natural wollastonite for the aluminum industry [3]. thermoresistant materials were obtained on the basis of the lime-diatomaceous binding and natural wollastonite in the ratio of 65:35 respectively.

Siliceous component of binding is high-reaction natural diatomite (amorphized high-silicone opal species with high natural porosity) with the activity on the absorption of lime from the saturated solution to 300 mg/g. The high dispersiveness of natural diatomite and the optimum ratio of initial raw components in the lime-diatomaceous binding (recalculation CaO to SiO_2), equal to 1.2. This ensures the completeness of the chemical interaction of siliceous component and lime and the directed synthesis of the low-basic calcium hydrosilicates by hygrothermal treatment [4].

Table 3.3.3 Component mix and calculated value of ratio $CaO:SiO_2$ in silicate mass

№ compositio n	Ratio of $CaO:SiO_2$	Content of the components, % (mass)			Content of the oxides, % (mass)	
		Lime (A = 91.8%)	Micro-silica (SiO_2 = 96.6 %)	Nephelinic slime (CaO = 55.83 SiO_2 = 30.55 %)	CaO	SiO_2
1	1.8	–	–	100	55.83	30.55
2	1.3	40	20	40	56.26	43.73
3	0.7	–	33.3	66.6	41.41	58.58

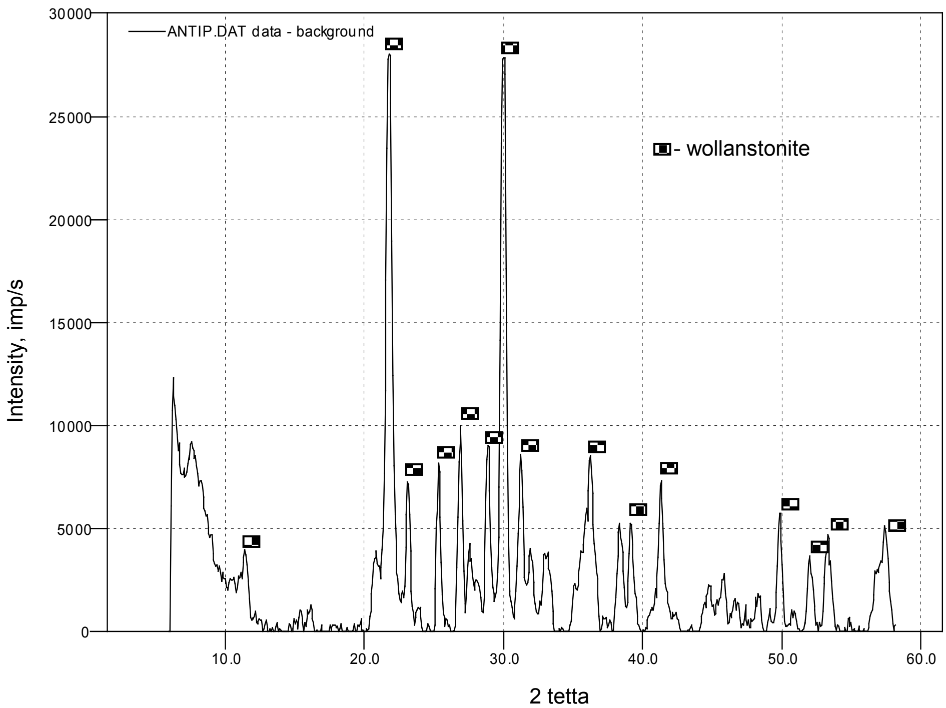

Fig. 3.3.1 X-ray photograph of sample on the basis of nephelinic slime and micro-silica at temperature of 800°C

Production of thermoresistant wollanstonite materials is two-stage technology, which ensures during the first stage (hygrothermal treatment) the forming of the specific indices of phase composition, structures and properties of silicate stone by the hydrothermal synthesis of the durable and steadfast low-basic calcium hydrosilicates. The second stage (heat treatment—slow heating with the rate of 5°/min and endurance at a temperature of 800°C during 1 h)—the formation of second wollastonite in the cementing silicate bond, which leads to an increase in the heat resistance of articles due to the proximity of the values of the thermal coefficients of the linear expansion of the bond of metasilicate composition and wollanstonite filler ($\alpha = 6.5 \times 10^{-6}\ K^{-1}$).

Natural wollastonite replaced by synthesized obtained from the technogenic raw materials by developed technology [3]. The obtained results compared with the previously obtained samples on the basis of lime-diatomaceous binding and natural wollastonite, and asbothermosilicate articles utilized in the aluminum industry, Table 3.3.4.

The results of experiment show, that the samples on the basis of the lime-diatomaceous binding and synthesized wollastonite differ from other samples in terms of denser structure and smaller value of strength. The tests results of samples showed heat resistance in the regime “heating-air” more than 30 thermal cyclings without the manifestation of shrinkage phenomena and destruction.

Table 3.3.4 Technical properties of the articles

Property	Samples of the lime—diatomaceous binding and natural wollastonite	Samples of the lime—diatomaceous binding and synthesized wollastonite	Samples of the asbothermosilicate
Bulk density of samples after hygrothermal treatment (kg/m^3)	950	1100	–
Strength by pressing of samples after hygrothermal treatment (MPa)	8.0	6.3	–
Bulk density of samples after heat treatment (kg/m^3)	850	900	700–800
Strength by pressing of samples after heat treatment (MPa)	14.2	8.4	10–15
Number of thermal cyclings with the testing for the heat resistance	>30	10	6–7 destruction of the samples

The losses of the mass of samples composed to 2%, and the residual strength of samples after 34 thermal cyclings—45–55%. The resistance of wollanstonite articles to the action of aluminum fusion in the regime «fusion-air» was studied. Samples dip into the fusion and endurance during to 12 h. Samples freely were extracted from the fusion without the signs of the adhesion of aluminum fusion [5].

The obtained articles can be used as the independent material or as the filler of silicate masses preliminarily in the ground state.

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3.4 Review of End-of-Life Management Issues in Sustainable Electronic Products

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Abstract

Concerns about climate change and other related environmental challenges have prompted increased interest in sustainable development. In the industry, many manufacturers such as the electronics manufacturers have strived to improve their environmental footprints through sustainable manufacturing while also making sure that the bottom line is being met. Electronic products, while bringing technological progress to mankind, generate numerous environmental challenges, especially at their End-of-Life (EoL) stage.

This paper review and discuss the current situation and issues in designing, manufacturing, collecting and marketing of electronic products with respect to the EoL stage. Certain decisions about electronic products made in the early production stages can have serious implications in the management of the products at EoL. For example, a product designed such that it is difficult to disassemble in order to remove hazardous substances can be very inefficient to manage at the EoL stage. Discussion of electronic products' EoL management approaches is presented in this paper. Subsequently, suggestions for the stakeholders to address the complexities in making electronic products more sustainable are proposed.

Keywords:

Sustainable electronic product development; End-of-Life (EoL); E-waste, Life cycle engineering, Product life cycle management

1 Introduction

Sustainable development has gained much attention over the last few years since the highly publicized 4th Inter-Governmental Panel on Climate Change [1] report was released. It sparked an array of initiatives towards protecting our environment while striving for progress in our society. These initiatives are coming from different stakeholders across the board in terms of political, economical, environmental and societal aspects.

Over the past century, industrialization has fuelled the rapid growth of many countries; there should now be a fundamental re-examination of the way industries deliver products to consumers. This re-examination will reveal the need to transform today's manufacturing systems to become sustainable.

Sustainable manufacturing aims to manufacture better performing products using fewer resources, cause less waste and pollution, and contribute to social progress worldwide. It has been widely regarded as the next industrial revolution and has been touted as inevitable for all production eventually, given the finite resources of the Earth. Sustainable manufacturing is a concept that requires a holistic approach. Product developers are moving towards closing the product life cycle to bring about a cradle-to-cradle approach and incorporating different aspects of sustainability at the different stages of a product's life cycle. Figure 3.4.1 illustrates a generic product development cycle with 'greening' options [2].

From the conceptual stage to the EoL of a product in the product development cycle, there are options that can contribute to product sustainability which can be considered in each stage. As indicated in Fig. 3.4.1, guidelines on Design for Environment (DfE) can be followed at the design stage. Specifically for electronic products, the more critical areas will be design for EoL, toxic reduction, energy efficiency and materials reduction. These design options can directly affect the sustainability issues in the subsequent stages; this influence is particularly evident at the EoL stage. At the marketing stage, external certification, good corporate social responsibility, extended producer responsibility and innovative sales model such as Product/Service Systems (PSS) are approaches to a more sustainable production paradigm. Finally, at the EoL stage, tackling all the current e-waste issues, improving the management and technology level of the EoL operations and cooperation among the different stage stakeholders is the right approach to take.

This calls for close collaboration between product manufacturers and their various partners in the other stages of the life cycle so that a system optimization of environmental benefits with respect to economic benefits and societal benefits is achieved. In this paper, the aim is to review and discuss the issues occurring at the EoL stage due the various product life cycle stages. Subsequently, an approach to improving the sustainability of the total life cycle will be discussed. The methodology used here is mainly by literature review and interviews with stakeholders.

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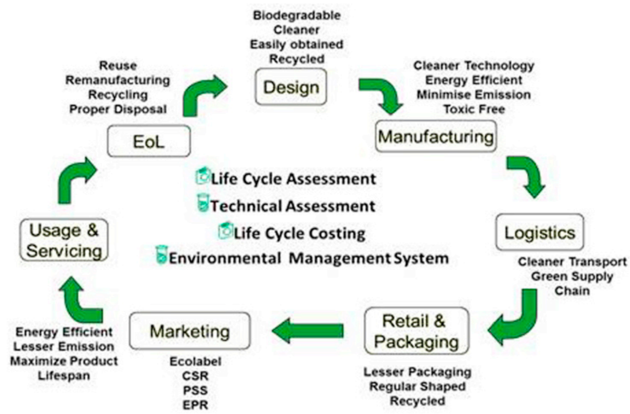

Fig. 3.4.1 A Generic green product life cycle

2 Sustainable Electronic Product Development

Out of the many manufacturing industries, electronics manufacturing sector has one of the most pressing need to improve its sustainability due to escalating sales volume and the increasing complexity of electronic products. Every year the sales volume of electronic products soars [3]. As more units are produced, more units need to be taken care of at the EoL stage. This is made worse by the shortening of the technology cycle, which results in faster accumulation of older generations of electronic products in the waste stream. TechNavio, a major market research company, has projected a Compound Annual Growth Rate (CAGR) of 9.2% in the e-waste management market from 2010 to 2014 [4]. The current e-waste situation has resulted in pervasive environmental and human health problems related to e-waste in the dumping grounds of developing countries in South America, Asia, and Africa [3].

In response, many countries have started to legislate the manufacturing, sales, usage and EoL management of electronics, such as the landmark Waste in Electrical and Electronic Equipment (WEEE) Directives by the European Union (EU) [5]. There are similar directives in some states of the United States (U.S.) and Japan [6, 7]. The U.S. federal government also recently announced a new strategy to promote more sustainable electronics.

In recent years, major electronics manufacturers worldwide have responded to the call for sustainable electronic products. For example, Panasonic's Eco Ideas Strategy seeks to equate environmental performance with profits and to reduce carbon dioxide (CO_2) emissions through a combination of greener products and factories, thus encouraging resource conservation and promoting eco-friendly individual actions [8]. HP is another manufacturer with a long-standing environmental commitment; HP Planet is an important thrust in their organisation, focusing on climate and energy, sustainable design, supply chain responsibility and product reuse and recycling. Under the HP Renew, HP Planet Partners, and HP Asset Recovery Services programs, spent products get a new lease of life and the average environmental performance of the products per lifetime is improved [9].

3 Design and Manufacturing Implications on EOL

3.1 Lack of Considerations for EoL Handling

Lack of Efficient EoL Technology

As discussed earlier, it is imperative for the product to be designed with an end in mind, thus Design for EoL has emerged as a key factor in the electronics industry. Many impediments to greater EoL efficiency are related to the inability to process spent products economically due to the products' design and manufacturing. Recycling still lags behind product development, despite a greater emphasis within the recycling industry to be more efficient and reduce the environmental impact of electronic products.

The emergence of new technology calls for innovations in recycling technology and a new workflow. An example is the replacement of the magnetic hard disk drive with the solid state drive. The solid state drive is too small to be shredded and cannot be physically destroyed with a magnetic degausser. The only way to ensure that data security is not breached is software wiping, which increases the time required to handle the destruction of the drives and reduces efficiency.

Lack of Labelling and Information

When a product reaches the EoL, it typically goes through a screening and assessment process to sort and filter spent products into different categories based on their condition. Then a decision on the appropriate EoL option will be made based on the hierarchy of EoL options show in Fig. 3.4.2.

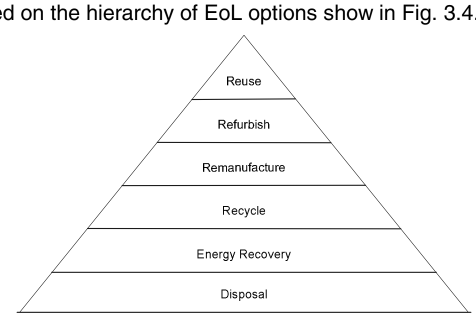

Fig. 3.4.2 EoL hierarchy

The highest two levels of the EoL hierarchy—reuse and refurbishment for the second-hand market—bring the most environmental benefits and profit potential for EoL companies. However, they are the most disparate and difficult to achieve options because of the lack of product information and performance requirements, resulting in insufficient volume collected to sustain the system. EoL stakeholders have always contested with lack of information about the spent products they have on hand, especially those with proprietary features and difficult-to-find replacement parts. This makes product reuse and remanufacturing very difficult. Many electronic products are not designed for a second life cycle, thus there are no features to facilitate efficient disassembly and refurbishment. For example, iPhones require special tools for disassembly and some power supply units in the Mac present problems in reuse [10].

In addition, in their pursuit of higher efficiency and durability batteries, the industry has produced many different battery variations catering to different requirements. This has created another pitfall for the EoL management of e-waste. Often, the batteries are not adequately labelled to allow better sorting, and there is no one treatment available for all kinds of batteries, especially for niche and specialised batteries. This situation is also common with plastics.

3.2 Increased Miniaturisation and Complexity of Product

Volume is not the only quandary in e-waste issues. Technological innovation has created more complicated and sophisticated products, which calls for more advanced EoL techniques and handling. This situation has three aspects.

More Sophisticated and Compact Products

Electronic products are becoming more sophisticated and compact, adding difficulties to disassembly and separation processes. Often, only a few components such as batteries and printed circuit boards (PCBs) are designed to be easily detached from the product, while the rest of the product is shredded and then recycled or disposed of. From an environmental perspective, this is unlikely to be the minimally impactful approach. Instead, some components could be reused or remanufactured instead of being recycled , which is a lower option in Fig. 3.4.2. While shredding is the common method for all recyclers because it is straightforward and efficient, the process loses much of the embodied value within the parts. For example, a study of the flow of gold in mobile phones in Germany and the U.S. reported that only 10% of the gold is recovered; the rest is lost through uncontrolled dispersion during pre-processing [11].

Smaller and Sleeker Products

As a product gets smaller and sleeker, the disassembly of its battery may not be as direct as it once was. For example, the catch could be hidden or is very obscure, requiring more time in disassembly and slowing down processing. When the size becomes smaller and more delicate, often extra care is required; this also slows down disassembly. A good example is small rechargeable devices that come with a built-in battery. Such devices are usually not designed for their battery to be detached easily; often the battery is encased within the product. The non-removal of the battery is considered as hazardous material and this has two major consequences on the effectiveness of EoL value chain. First, when a small fraction of the waste contains hazardous material, it is considered contaminated and deemed unsafe for recycling; hence, it must be filtered out. Second, it adds to the cost of handling these hazardous materials because more resources are required to treat non-hazardous materials the same way as hazardous materials. This is considered wastage. For example, some products contain beryllium, which is difficult to be separated out; hence the entire module must be sent out for hazardous treatment. This can mean sending out a 1 kg of module due to the presence of merely 100g of hazardous materials.

Novel Products

New products entering the market with cutting-edge technology will demand a totally new way of handling due to the novel technology they embodied. While DfE is highly encouraged, EoL is not always considered thoroughly. Also, being new, there is virtually no information on the EoL of these new products. One example is flat panel display where it is almost impossible to separate out the mercury strips without destroying the product, thus rendering the entire unit unsuitable for any EoL options except general proper disposal. At the same time, due to the mercury content, the panel requires careful and specialised handling to ensure the mercury is not released to the atmosphere in excess of the allowable limit [11]. Despite the RoHS directive, there are still many legacy products containing mercury in the market, and they will require attention in the near future as they enter the EoL stage. A high technology infrastructure that is feasible with relatively low volume will be required for this kind of recovery to be viable.

Another new product family that could pose challenges to the EoL industry will be tablet PCs (surfpads) and laptops, where computing devices are reduced in size onto a smaller platform using more complex components, thus limiting the ability to remanufacture or upgrade for a second life. The shorter life span of these products is also contributing to the problem of e-waste. With the announcement of the second generation iPad, there is already concern about where the retiring 11-month-old first generation iPad will end up [13]. The sleek design of the iPad will probably require maximum disassembly for maximum recovery value.

3.3 New Materials and Manufacturing Methods

As technology advances to meet the desires and needs for electronic products with better performance, quality, cost, environmental impact and durability, new material technology development is getting shorter and more heterogeneous. This trend is particularly evident in the electronics industry, where product requirements are more stringent and complex. Higher performance materials are required to withstand the rigorous operating requirement of today's electronics. Smarter materials that can deliver the require function at the right time are preferred. Materials that are lightweight and yet durable enough are also popular. Thus the smarter the materials get, the more difficult it is to recycle them efficiently. There may also be problems finding applications for the recycled materials, as components usually are customized for specific products. For example, a material might undergo special processes such as coating to improve their performance, and this coating might be a hindrance to the recycling process.

The trend in material development has been to move towards composite materials for better strength and other desirable properties. This began with combining different types from the same family such as metal alloys and mixed plastics, and has moved into mixing different material family types. For example, wood and plastics composites are becoming more popular as well as are metalized polymers or polymerized metals. These exotic composites can defeat current recycling processes. All these factors increase the complexity of products today and lead to the demand for more advanced recycling technology.

4 Marketing Implications on Eol

As technology advances and markets become more competitive, many manufacturers are focused on pushing better, cheaper and faster products in volume to improve their bottom line. Refreshed or new versions with marginally enhanced features get launched shortly after the previous or initial launch, while many existing products are still functioning well. This can result in excessive consumption, and functional products may pile up in basements or are sent off to the landfill. The earlier mentioned iPad is an example.

In addition, many manufacturers are riding the 'green wave' to market their products as 'greener' choice—but not all such claims can be substantiated. 'Green washing' aimed at misleading consumers into buying 'not-so-green' products is a concern. As consumers become more environmentally savvy, manufacturers need to ensure that their products meet certain environmental performance criteria, and that they communicate to customers through good marketing efforts without green washing. The most common method is to obtain a related eco-label certification for their products. According to the ISO-14020 series [12], there are three types of eco-labels: multi-criteria labels administered and accredited by independent established national/international bodies[13]; voluntary single attribute labels by manufacturers according to standards [14]; and eco-labels based on life cycle quantification of environment impact [15]. In recent years, eco-label bodies have established categories for consumer electronics such as the German Blue Angel [16] and Ecoleaf from Japan [17].

In addition, in order to provide consumers with even more information, there is a registry of greener electronic products named EPEAT being established in the U.S. EPEAT is a guide for consumers to evaluate and compare certain electronic products based on their environmental performance [18]. The list of criteria for EPEAT is contained in the 1680 standards of IEEE, a professional worldwide standards body, thus giving the criteria a strong reputation. For instance, many government organizations, universities and large corporations in the U.S. have minimum EPEAT requirements for their computer purchases. However, the standard itself does not have stringent enough EoL requirements that will help to increase the effectiveness of e-waste management; it is also not yet inclusive of all major electronic products. These are still in the process of development.

Another issue is the lack of strong standards to qualify recyclers. The current R2/RIOS [19] in the U.S., WEEE LABel of Excellence in the EU [20], or e-Stewards [21], are still new and need to go through rounds of refinements to achieve the intended results. Among the three certification schemes, the oldest one is e-Stewards, which was officially launched more than 2 years ago in April 2010.

5 Reverse Logistics Implications on Eol

The EoL sector is also being held back from operating at an effective and sustainable level by the logistical bottleneck of spent products collection. The rate of recycling e-waste in many countries remains low. For example, the U.S. Environmental Protection Agency reported that only 17.7% of the 3.19 million tons of disposed electronic products in the municipal waste stream were recycled in the U.S. in 2009 [3]. This is mainly attributed to stockpiled electronic products in consumers' homes. Sweden, which has one of the world's highest rates for collecting and recycling of electrical and electronic equipment in 2010, managed to collect 15.99 kg per inhabitant [22]. However, this is still much less than the amount put on market and there is room for improvement [23]. Studies have shown that electronics must be handled with care in reverse logistics in order not to be damaged before being remanufactured [24]. Many consumers are still unaware of the various schemes or not concerned with the issues.

6 Suggestions to the Stakeholders

In attempt to address various issues mentioned in the previous sections, here are some suggestions to stakeholders so as to improve the overall life cycle sustainability of electronic products.

6.1 Design and Manufacturing Stage

Facilitating ease of reuse, remanufacturing or recycling can occur at the same point in time as research and development work to develop new EoL technology. Incorporating more DfE elements and life cycle thinking during the conceptual stage should be a norm in product development. For example, during new product development, planning can focus on a generic family set of products with the same base technology; then the variations can be designed with more compatibility between models to accommodate upgrades or changes later on. The emphasis on the use of modularity can also be increased. Although this is currently available, the implementation rate can be increased. This will have another added benefit to the consumers in that greater choice to upgrade to features they prefer. For example, a consumer might prefer to start off with a basic unit, and then move on to a more advanced unit in a short time. If most of the basic unit is designed with an option to upgrade (similar to software upgrading), it will reduce the amount of physical resources needed to fulfil the same functions at the same price, if not lower. From a value standpoint, it does not change.

Also, improving the homogeneity of materials in a product, such as setting a quota for the maximum different types of plastics to be used, can reduce the effort needed to sort out the product. This is already taking place in Japan, where electronics manufacturers such as Toshiba are starting to restrict the selection of materials to the more commonly used plastics [25]. Finally, new joining techniques can be developed to facilitate dismantling and do not affect recycling processes. Examples of this is kind of technology is called 'active disassembly' [26] which so far being quite expensive material and not yet suitable for cheaper consumer products.

6.2 Marketing Stage

At the marketing stage, a product's sales model can make a difference. By focusing on the services or functions provided by a product vs. the physical product itself, it can decrease the total physical resources being utilised while still fulfilling the needs of consumers. It will also be easier to manage and encourage the adoption of PSSs where a combination of products and service are offered to the customers instead of having a main focus only on physical products [27]. PSSs have many benefits, such as achieving closer customer connection and getting more profits out of the manufactured products. However, in order to achieve a PSS which is adapted for this business approach, the products and services used must be considered from a life-cycle perspective including EoL [28]. The business approach of PSSs allows for the provider to control both the flows of physical product to the user and the reverse flows of products coming back to the provider. This new logic of material/product flows allows for adaptations along the product life cycle. For example, maintenance and end-of-life strategies such as remanufacturing can become more beneficial due to the new circumstances that PSSs provide to the manufacturers [29]. Products that are not ideal for inclusion in PSS can be marketed by highlighting their green aspects so that consumers can make informed decisions. Stakeholders can be more engaged in the development process of EPEAT to improve the standards and make it a powerful tool for consumers to use for making better choices.

Certification and compliance of standards of the e-waste stakeholders are also instrumental in bringing about more sustainable e-waste management. To improve the effectiveness of EoL, stakeholders need to manage the e-waste and ensure the quality and sustainability of the EoL process, certification and compliance to e-waste recycling standards such as R2/RIOS [19] in the U.S., WEEE LABel of Excellence in the EU [20], or e-Stewards [21] globally. These certifications will help ensure that the quality of handling e-waste is at a minimally accepted responsible level if not greater. It will generally encourage recyclers to push for better operations to secure more market share through better reputation. Hence, going through this will help to upgrade the expertise of the EoL stakeholders, promote higher volume to be handled and increase the credentials of the EoL stakeholders for the customers to rely on. It also gives manufacturers and consumers more confidence and information in choosing EoL management companies to handle their waste in a responsible manner. This will aid in eliminating the illegal or unethical export of e-waste to developing countries to process in a cheap but hazardous manner.

6.3 Reverse Logistics Stage and EoL Stage

In order to encourage more willingness to upgrade or replace electronic products with take-back and not to keep them in the basement, easier methods to copy and transfer data from one device to another device should be developed so that consumers will be less reluctant to bring back their electronic products for upgrade or trade-in. Together with this, more sophisticated yet efficient data-destruction methods using software wiping must be invented so that data security is not compromised; this will help encourage consumers and business to bring in their obsolete equipment.

More efforts in promoting and incentivising consumers to bring in their old products are needed. Manufacturers can provide incentives such as rebates, reduced waiting time, additional features and services, or other perks and motivators that will let consumers experience the ‘feel-good’ effect so as encourages them to bring back products. This is demonstrated in a promotion that Nokia has carried out in India [30]. Promoting PSSs or leasing models will also encourage this take-back process as mentioned earlier. Another way is to incorporate the need to bring back into the natural function of the product such as single-use camera [31, 32].

Also, having a green image in today’s highly competitive and well-connected world, or at least not being highlighted as environmentally irresponsible, is important for a company to do well in the market. Not only are consumers alert to the environmental performance of their electronic products, there are many NGO watchdogs such as Greenpeace and Basel Agreement Network (BAN) that keep a close tab on these manufacturers. Greenpeace publishes a quarterly ranking of the major electronics manufacturers with respect to their environmental performance, the Guide to Greener Electronics. A few companies have been lauded for leading this effort, such as Dell, Panasonic and Nokia. The companies are also worried about bad press if their products land up in third world countries.

A good solution would be for manufacturers to collaborate with their contracted EoL service providers and other stakeholders to investigate this area. It can potentially be another growth area for manufacturers to secure future resources and business opportunities. Forging strategic partnerships between manufacturers and EoL stakeholders is a win-win situation. The manufacturers can be assured that their products will not get into the second-hand market in a lousy condition and thus protect their brand name; at the same time, the EoL stakeholders have better access to information and parts to bring the spent products back into product life cycle through any of the EoL options. In certain situations, EoL stakeholders might be suppliers to manufacturers thus increasing their sales volume. An example is the HÅPLA (Sustainable recycling of flat panel displays) project in Sweden where the various stakeholders collaborate to work on the development of an automated LCD recycling system [11].

It is also important to communicate and pass the information about the intended EoL option down the product life cycle so that appropriate actions can be implemented at all times. Information management systems for tracking of the components and materials in products are required in order for improving the productivity at the EoL stage and to promote information sharing between the different stages. An example would be the DELII project by Lee in 2008 where feedback from the EoL stage is made available to the designers for decision making [33].

7 Conclusions

The problem of e-waste has grown over the past decade to be one of the world’s most important issues. Despite the challenges, there is enormous potential for the e-waste industry to grow and play a very significant role in enhancing the sustainability of both business and the world. This paper has summarized the product life cycle issues from the various stages of electronic products that affect the EoL stage, and it has made suggestions for improvements. Together with more legislation, manufacturers, designers and EoL stakeholders must cooperate to present more sustainable solutions from the entire life cycle perspective to manage the future of electronics manufacturing, bringing technology for human progress at the minimal environmental impact and feasible economic cost.

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3.5 Remanufacturing and Reuse of Production Equipment at an Automotive OEM

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Remanufacturing of production equipment represents an opportunity to increase use productivity of components and materials of products. Make-to-order production has to consider recovered components already in engineering and design. In comparison to mere substitution in material supply, recovered components increase the yield of once produced products providing the same functionality and ability of integration. For test equipment, this approach was implemented at an automotive OEM. Based on the promising results of an initial project, the concept of reverse logistics for recovery of components is presented. Required changes in forward and reverse logistics are identified and implemented in an adopted forward process, integrating all recovery operations into existing IT systems.

Keywords:
Remanufacturing, Automotive, Production equipment, Logistics design

1 General Motivation

In traditional supply chains, two fundamental problems arise: on the supplier-side, rising costs of primary resources reduce profits. On the customer-side, the disposal of used products creates (external) costs (Fig. 3.5.1). Designing closed supply-

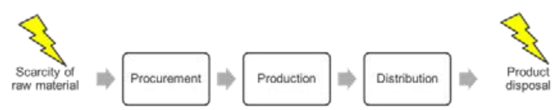

Fig. 3.5.1 Fundamental problems in traditional supply-chains.

chains in analogy to biological cycles can resolve both problems: used products become inputs to the supplier-side and therefore, disposal- and supply-costs can be decreased. Especially in production equipment, long lifetimes and high wear reserve ease implementation of this concept. In make-to-order production, products are engineered and designed according to customer specifications. To utilize the full potential of remanufacturing, recovered components should be used in design phase. Then, new and recovered components with similar functionality can be used likewise if compatibility can be maintained.

In current production systems, operations in forward logistics are supported by information technology (IT) such as CAD software, procurement software, and inventory control systems Product recovery operations have special requirements on information handling, making adjustments in IT systems necessary.

2 Recovery of Products and Production Equipment

This paper uses the terminology introduced by Thierry et al. [1], see Fig. 3.5.2.

In reuse/resale (1), no disassembly will be performed. In recycling (5), complete disassembly and recovery of raw materials will be done. In contrast, during the recovery on component level (2, 3, 4) the product will be disassembled to a component level. Refurbishing, remanufacturing and retrieval are recovery options on component level. For refurbishing (2), defective components are replaced by new ones. In remanufacturing (3), defective components are worked over and used once more in new products. In retrieval (4, termed "cannibalization" by Thierry et al.) only selected non-defective components are used in new products.

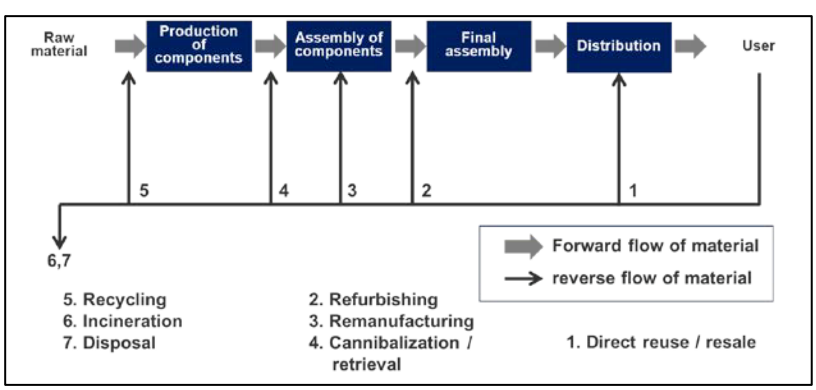

Fig. 3.5.2 Terminology (q.v [1]).

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2.1 Drivers for Recovery

Currently, neither in the European Union nor in Northern America OEMs of production equipment face legal obligations to recover their products [2, 3]. Nevertheless, recovery can lead to remarkable cost-savings by reducing procurement costs for new material [1, 4–6]. Corporate ethics present the third reason for recovery [7, 8].

2.2 Consumer Products and Production Equipment

Consumer products and production equipment offer different properties that influence feasibility of recovery and reuse. First, the company inventory listing tracks production equipment. The latter is registered as a movable asset, thus depreciation takes place in accounting. Current numbers and types of production equipment as well as the expected end of use are therefore known. Reliable forecasts of future returns can easily be derived from this data; such data seldom exists for consumer products. OEMs of production equipment usually have closer relationships to customers than OEMs of consumer products [9]. So, OEMs can obtain access to aforementioned data.

Second, production equipment is often customized. Modular systems for the design of these products enable efficient customization. At the same time, modular systems offer advantages in product recovery: interchangeable components can be replaced by new ones or retrieved and used in other products. Consequently, customization widens recovery options.

On the other hand, longer lifetimes of production equipment compared to consumer products can result in a large quantity of outdated components at the time of disassembly. The pace of technological advancement in the specific industry is the most relevant influence factor. The automotive industry is a mature industry. Disruptive technological changes in its core production systems are scarce. Thus, recovery and reuse of production equipment of the automotive industry is expected to be easier than recovery and reuse of consumer products.

2.3 Evaluation of Recovery

To evaluate efficiency and effectiveness of product recovery, several performance indicators have to be used. For financial evaluation, cost-benefit-analysis provides a simple yet proven approach to assess both effectiveness and efficiency. However, pricing or valuation of recovered material poses a problem. This will be discussed in detail further on. Ecological performance on the other hand, can be assessed by measuring material and implicit savings in carbon dioxide emissions. Depending on the business model, financial performance can be measured with performance indicators available from accounting (revenue, cost, earnings) or with specially designed indicators.

Cost-Benefit-Analysis

The following costs can be associated with product recovery operations and therefore need to be considered: 1. Take-back costs, 2. testing costs, 3. costs of disassembly and sorting, 4. transportation costs, 5. remanufacturing / repair costs, 6. implicit costs of risk, 7. disposal-costs and 8. implicit not-realized revenue of material recycling. [10]

Benefits result from savings (implicit benefits) of material costs. They are calculated based on current costs of new material that offer the same functionality.

Pricing and Valuation of Recovered Material

Problems arise in comparing flows of recovered material to new material. This comparison is necessary to perform the general assessment of profitability of product recovery. For new material, its price reflects almost all of its procurement costs. For recovered material, no given price exists. To calculate actual savings in procurement by applying product recovery, prices of new material have to be compared with recovery costs of recovered material. Depending on scarcity or availability and legal obligations of re-use, Lethmathe [11] has identified several options and recommendations. Two options can be applied to production equipment, since there are no obligations for product recovery of production equipment apart from recycling (q.v. 2.1). In case of lower procurement costs for recovered components as opposed to similar new components ($c_R^C < c_N^C$)[1], available recovered components are used to the full extend and valued with the price of new components ($c_R^V = c_N^C$). After all, they are perfect substitutes.

In case of higher procurement costs of recovered components ($c_R^C > c_N^C$), recovered components are priced with their higher procurement costs ($c_R^V = c_R^C$) and thereby are inferior to new components. No recovery takes place.

Ecological Assessment

To keep ecological assessment short and simple, only a rough estimation of material savings is used. These are based on the average mass of each production equipment and the average carbon dioxide emissions in material production. The resulting estimation of carbon dioxide savings can be used in marketing and public relations to promote a green image.

3 Known Obstacles for Reverse Logistics

In current scientific literature, the main obstacles in explicitly designing reverse logistics are well described [12]:

1. Uncertainties about reverse flows in number and time make inventory planning a challenging task. Continuous planning is described as a promising way to deal with this [13, 14].

2. Disassembly. Gaining experience in test projects gives valuable insight into technical obstacles and helps to plan future disassembly operations.

3. Uncertainties about the state of returned products. Again, only experimental projects can provide reliable information.

4. Coordination of reverse logistics networks. This task has not been considered in this study.

5. Compatibility of returned components with new components and new product design. Knowledge about old components, long-term stability of component-design and new components that enable compatibility (“fixes”, “couplings”) are crucial to complete this task.

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1 $c^{C/V}$: cash-based/value costs; $c_{R/N}$: costs of recycled/new components

6. Uncertainties regarding the duration of return operations. As for point 3 and 4, again only a pilot project can give enough information to minimize these uncertainties.

7. Balancing reverse flows with demand is critical to avoid excess stock and meet demand at all times. Using buffers (inventory) and proactive demand planning can solve this problem. However, overall returns need to exceed a critical volume. If they do not, implementation of new processes and building up inventory has no economic reason.

4 Case Study on Test Tool Equipment

A case study was performed at a test tool equipment manufacturing department of an automotive OEM. Used production equipment with an average age of seven years was dismantled, its components were sorted and reusable components identified. Cleaning, work-over and stocking followed. Designing and engineering of new production equipment was started whilst recovering old ones. Remanufactured material was used in that phase and in procurement. New production equipment was made of recovered material and new material. Material costs of new production equipment could be cut by thirty percent.

In general, the process of transforming production equipment fallen into disuse into new production equipment is depicted in Fig. 3.5.3.

In car manufacturing, start of production (SOP) and end of production (EOP) of a car model on one production line

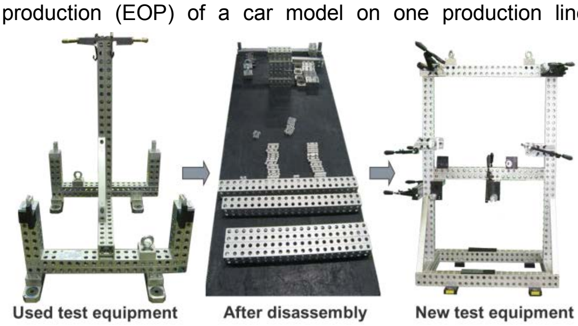

Fig. 3.5.3 Process input and result.

usually overlap. Production equipment is needed for tests and ramp-up before SOP. It falls into disuse at EOP. Figure 3.5.4 displays the problem resulting from this overlap: returned production equipment cannot be remanufactured for the reuse in the same production line. Only by serving multiple customers with distinct EOPs returns exceed an economically critical return volume. In this case study, only the examined test tool equipment manufacturing department at the OEM has enough customers and parallel projects to meet this requirement. Other competitors are too small to perform regular, systematic remanufacturing at reasonable revenue. Furthermore, most other competitors also produce and sell their own components. Though, remanufacturing is less attractive to them since they will only accept returns of test tools made of their own components.

For a lasting implementation at the automotive OEM, reverse logistics has to be installed as well as forward logistics has to be adapted. Reverse logistics covers returning, disassembling, sorting and remanufacturing. Forward logistics includes considering returned components in engineering and design, procuring only additional components, picking all necessary components and manufacturing new production equipment. As reverse and forward actions can seldom be carried out serially (one after the other), recycling inventory, representing a buffer between forward and reverse operations, is necessary.

4.1 Specific Design of Reverse Logistics

Figure 3.5.5 represents the newly designed process.

Requirements for Test Tool Remanufacturing

The following relevant features of the analyzed test tools enable remanufacturing: modular design; use of non-corrosive materials; mainly detachable, non-permanent joints; standardized components; absence of disruptive technological changes of components in the last ten years; high number of structural parts that build up the carrying structure (low wear and low technological change) and low number of functional parts (higher wear or higher pace of technological change).

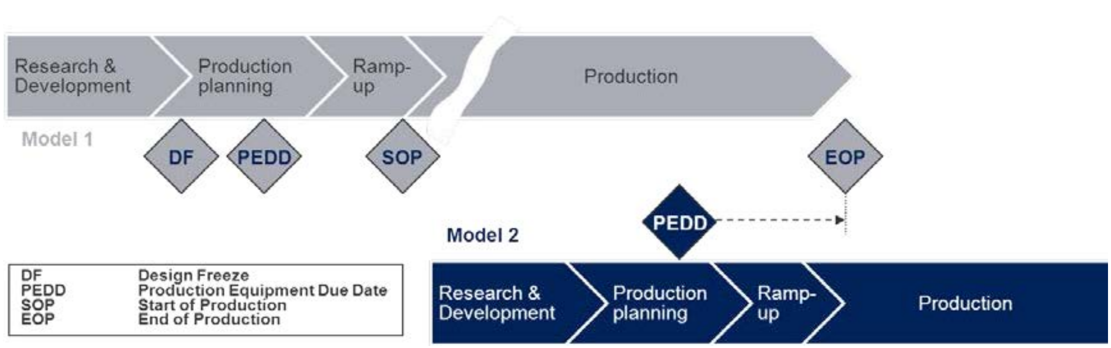

Fig. 3.5.4 Overlap of return and demand

Advertising

To receive reverse flows of material, customers need to be aware of recycling[2]/remanufacturing activities. Marketing material has been sent to current customers, a special page on recycling of test tool equipment was set up in corporate intranet and a follow-up via phone was conducted.

Inspection and Valuation

Photos and a listing of identification numbers are primary information sources for inspection and valuation if a personal inspection cannot take place due to long distances. Valuation is based on gathered experiences, mainly from the pilot project. Expected costs of recovery are also forecasted based on this data.

Buying

After valuation, a buy or no-buy decision will be taken, considering expected transportation costs. An offer is proposed to the customer to sell his production equipment on "buy", all test equipment is disposed of in case of "no-buy".

Transport

After accepting an offer, transport is carried out. Whenever possible, empty returns are used to minimize financial costs and environmental impact.

Disassembly

Disassembly takes place in the facilities of the OEM. The same employees that assemble test equipment also perform disassembly. Thus, all available experience on test equipment is used and disassembly is quick and correctly done. Documentation about the number of recoverable components is carried out and used to improve valuation.

Component Testing and Repair

Components are tested according to a recovery testing manual. Heavily damaged components or outdated versions of components are sorted out and are transferred to material recycling. All other components are repaired and labeled ("Tested recycling material"). They are stocked in recycling inventory. Here, the reverse process ends.

Tender and Negotiation

Independently from reverse actions, the adapted forward process starts with tender and negotiation. Competitiveness of offers can be raised when the use of recycling material is accepted by clients.

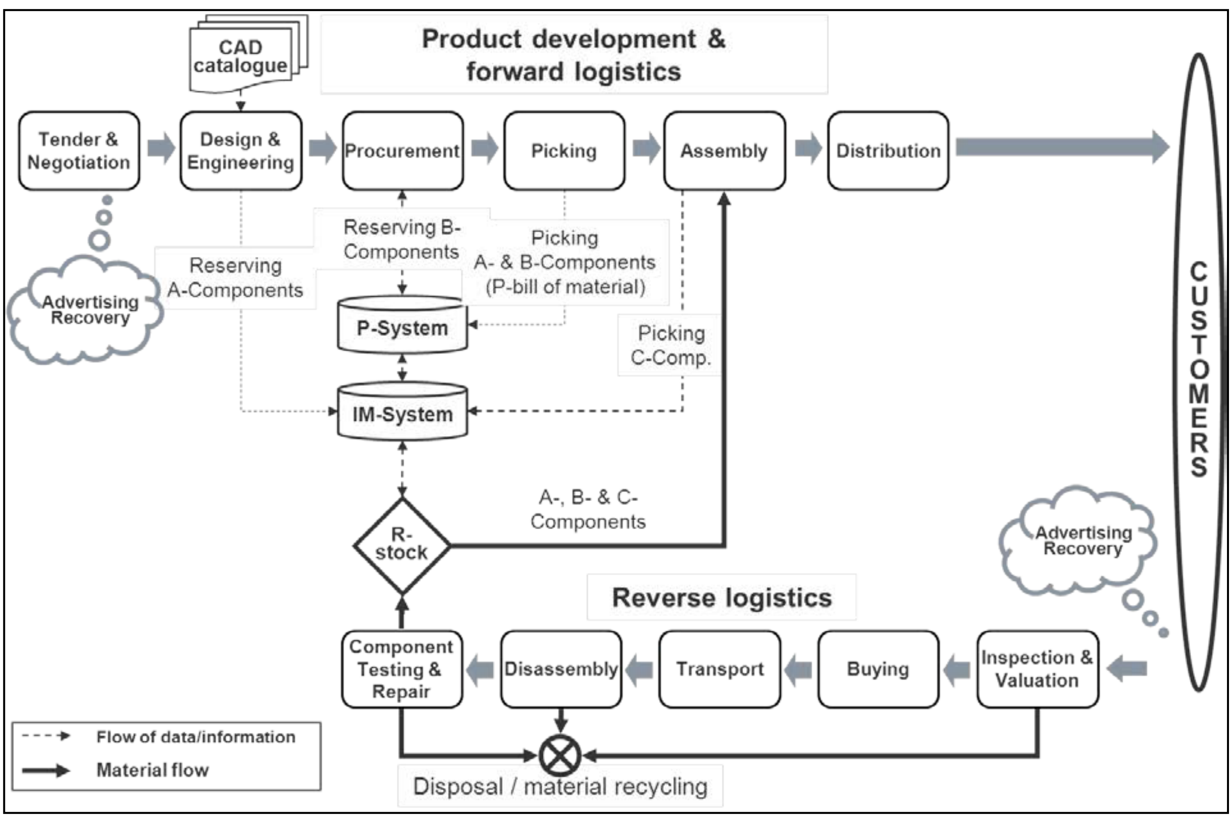

Fig. 3.5.5 Scheme of developed forward and reverse logistics
P-System: Procurement system, IM-System: Inventory management system, R-Stock: Recycling inventory.

[2] For easier understanding on customer-side, the term "recycling" instead of "product recovery" or "remanufacturing" is used throughout all marketing documents.

Design and Engineering

In design and engineering, so-called “A-components” are selected from inventory and considered in make-to-order design. To avoid double use of the same components, a reservation-function in the inventory system is used.

Procurement

In procurement, available “B-components” replace new material in the bill of material. This is done automatically by a new function in the procurement system.

Picking, Assembly and Distribution

The Picking of A- and B-components from inventory takes place after procurement has finished. In assembly, C-components are taken from inventory and combined with new components as well as A- and B-components. Test equipment containing remanufactured components are marked with a graphical label (“Recycled material”) to enhance the visibility of recovery operations for customers. Then distribution takes place.

A-, B- and C-Components

A multi-ABC-analysis was performed on the data of the pilot project and procurement data of new material. Classification was performed based on the value and frequency of use. A-components have a high value but low frequency of use in production equipment. B-components have medium value and medium numbers per product. Finally, C-components have a low value per piece but are used in high numbers.

The different classes of components are treated differently in reverse and forward logistics. C-components are priced depending on their mass for buy-back. No remanufacturing except cleaning is applied, sorting is done strictly. In forward logistics, C-components are used as needed without consideration of cost-savings per project. B-components are priced depending on their length. They are cleaned and minor faults are repaired if possible. Their use in forward logistics is implicit: the bill of material is scanned for replaceable components and recovered material is considered automatically before procurement starts. Finally, A-components are intensively remanufactured, defunct parts are exchanged and testing occurs. They are explicitly considered in engineering and design phase. In draft phase, demand is precisely estimated by design. Reservations of available recovered components are performed and included into CAD-models and by those means into the bill of material.

This differentiation ensures high throughput of recovered material at revenue-optimized costs for recovery and reuse: high effort is put into high-value components and low effort into low-value components.

4.2 Insights into Implementation

Forward logistics operations in production are supported by IT-systems. These systems can provide all process-members with information about demand, state of current orders and errors. Communication between process-members can be improved, traceability of problems is enhanced and in-process control is made possible.

For reverse logistics, similar requirements have to be fulfilled. Especially when adopting forward processes to new workflows that consider returned material, a “seamless integration” enhances acceptance of process-changes: a high rate of automation, easy access to recovered inventory stock and the merging of regular forward process and adopted forward process with reuse minimize adoption costs.

Complete Integration

To minimize change of workflows in existing forward logistics, a complete integration of new operations should be achieved. This includes both layers of logistics: material flow and information flow.

Information Flow

Existing information systems include the CAD software for design, a procurement system based on bills of material, and a stock management system.

In order to support recovery and reuse operations with little change to regular workflows and without creating complicated new workflows, the existing systems have to communicate: CAD has to tell the procurement system which parts are recycled parts or can be replaced by recycled parts. The inventory management system has to provide procurement system with information concerning current stock of recycled material. This way, semi-automatic consideration of recovered material can be implemented.

On the reverse logistics side, inventory management system helps to proactively manage stock of recovered material by providing distinct reports of usage over time. Furthermore, the current stock listing serves as a “whitelist” to identify components that are to be recovered from old production equipment. At the same time, an electronic “blacklist” describes components that are not suitable for recovery (either for technical or economical reasons). The high number of different components is processed efficiently in disassembly with the use of these two listings. Furthermore, the ineffective stocking of not usable components can be avoided.

Material Flow

New storage space for recovered components is co-located to existing storage. Regular storage and recovery storage is managed by the same employees with the same systems and the same equipment. Recovered material and new material take the same path side by side through the workshop, no differentiation is made. Workflow in production therefore maintains almost unaltered, improving acceptance of recycling actions.

Customer Awareness and Benefits

Changing behavior of customers from disposal to returning needs incentives on one hand and power on the other. By offering money for old production equipment and presenting carbon dioxide savings in the pilot project, customers could be interested in the new concept. Management awareness was obtained by presentations in management meetings and by integrating key managers of customers. In order to enhance visibility of this innovative concept, simple but clear high quality advertisement material was created and distributed to customers and management. Web and print were used as channels of distribution. Production equipment containing remanufactured material is labeled with a specially designed sticker. Connection to a corporate environmental campaign was explicitly made. Articles in corporate print media informed the general public about the remanufacturing activities.

Customer Acceptance and Customer Relationship

To compensate customers returning production equipment, vouchers or similar future discounts on orders of new production equipment can be offered. Alternatively, direct monetary compensation is possible. The use of vouchers strongly encourages customers to place the next order with the same production equipment manufacturer. Neither the acceptance of vouchers by industrial customers could be obtained in the case presented nor could a “production equipment use as a Service”-model find acceptance. Here, no sale of production equipment would take place. Instead a lease/rent-model would be pursued. Recovery would already be included in the general business model, as all production equipment would be returned to the producer and owner after end-of-use. Data about distributed production equipment would be necessary in that scenario. But also for traditional sale, data about past transactions should be gathered and saved for future use. A solution could be found in using movable asset management software that is available but was sparsely used for detailed storage of information. To improve forecasting of product equipment returns, knowledge about time of delivery, place of use, contact person, technical details, such as bills of material and the number of products, is necessary.

5 Summary and Conclusion

On average, double-digit savings in percentage of material costs are expected based on the promising first results. A lasting implementation of the described recovery is being performed at this moment.

Make-to-order production of production equipment with a modular concept permits recovery on component-level.

1. Forward and reverse logistics are separated. This leads to a high flexibility of reverse logistics as forward processes are not influenced by reverse operations. Separation takes place by using a remanufacturing inventory and supporting IT systems.

2. Transport of recovered products or components preferably uses available carrying capacity of forward transportation, e.g. empty returns.

3. Quality assurance on component-level ensures reusability as well as customer acceptance.

4. By proactively managing inventory stock via white- and blacklists, a high capital lockup can be avoided.

5. Design and engineering consider reuse of remanufactured product components. Given same functionality, components which differ from the current standard regarding geometry can be used. A high yield of once produced products can be obtained.

6. Buyers of test tool equipment didn’t accept vouchers in exchange for old test equipment. They insisted in cash.

7. Sophisticated use and adaption of IT systems can be successfully used to integrate recovery operations seamlessly into existing processes.

8. Labeling of components and data storage in corporate systems provide long-term access to information that is crucial for recovery operations.

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3.6 Machine Tool Optimization Strategies: Evaluation of Actual Machine Tool Usage and Modes

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Abstract
The research activities of today not only strive to cope with the legislative pressure given by the Directive of the European Parliament on Energy Using Products but also aim for economic advantages for the machine tool user by investigating and applying suitable procedures and methods that help to model, forecast, and reduce the overall energy and resource consumption. The common goal is to reduce the amount of resources consumed and increase machine tool efficiency with the help of selective methods and a minimum investment. An approach to identify the above mentioned advantages is given on the presented research work and paper. This paper introduces a methodology for detecting and defining reasonable investments for retrofit solutions and optimization strategies depending on the actual circumstances, an approach for the effective acquisition of the required data, and the strategy used to detect optimization potentials based on these findings.

Keywords:
Sustainable manufacturing, Retrofit, Machine tool evaluation, Resource efficiency

1 Introduction

As the costs for resources for manufacturing on shop-floor level, e.g. energy, can be identified and directly assigned to their consumers, the further need is to determine potential fields of action for the energy efficiency improvement.

Today, machine tool manufacturers and their customers are beginning to adjust their behaviour towards environmentally benign manufacturing by having a clearer picture of the energy use of machine and production lines. Multiple measurement initiatives, e.g. Duflou [1] and own measurements [2], can provide a clear picture of a machine tool energy and resource consumption behaviour. Unfortunately, today, this ability is not very common in the industrial environment. The ability to decide consciously based on hard facts about design aspects that have influence on both the energy consumption and investment is an important aspect of competitiveness in the future and might also be mandatory due to EU legislation [3].

Without the knowledge of manufacturing and machine tool operational information, as well as the adequate interpretation of this data, a reasonable prediction of the energy consumed and corresponding design changes cannot be made. As machine tools are complex and individual and the energetic behaviour of their components is strongly dependent on the operation mode, energy prediction models are uncertain in many cases.

This knowledge gap could lead to false or ineffective investment strategies. For instance, a machine tool that is used in a three shift work pattern requires different optimization actions and retrofit solutions from machine tools for occasional use on shop-floor level. As the machine tools lifetime and use phase is expected to last more than ten years [4], retrofit must be considered, not only for maintenance and service reasons but also for continuous improvement during this period.

2 State of the Art

To fulfil the above mentioned challenges and to provide an effective way to improve a production system, retrofit is seen as an effective technique for optimization. An internal study among Swiss machine tool manufacturers discloses an underestimated potential for retrofit solutions. Kirchner [5] ascertains that the machine tool design is not suitable to energy consumption criteria, mainly due to the peripheral design and the inter-peripheral adjustment. Weule [6] and Weyland [7] point out the ecologic and economic potential of the re-use of peripheral systems, which also affirms that the combination of change and the improvement of system components can only be made by retrofitting. Control suppliers such as Heidenhain, Siemens, and Bosch provide methods and a list of potential solutions for the resource efficiency improvement. The challenge remains the proper localization and selection of appropriate, economic, and ecologic solutions.

The focus within this research paper is the detection of potential for retrofitting particularly in respect of peripheral equipment whereas the process zone and its needs remains unquestioned. This focus is preferred since a broad measurement database shows that there is less potential for optimization for inner process related components.

Within the Life Cycle Assessment of machine tools, a gap in the ability to determine the potential field of action for a given machine tool setting and process by can be identified.

The goal, with the herewith presented research work, is to propose a method to identify the most reasonable measures for the improvement of energy efficiency by retrofit. In the following, retrofit procedures are primarily understood as a modification or optimization of the peripheral equipment of

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the machine tool, including inner-peripheral adjustments, control, or the re-sizing of the components according to the given requirements.

3 Methodology

3.1 Retrofit Indicator

The developed methodology is represented by three steps. It is based on two major aspects of a machine tool that are assumed to define the energy efficiency of a machine tool as follows:

- Energy consumption of the machine tool component: Components with high share of the energy consumption are assumed to also have high saving potential.
- Mode of operation: Open loop controlled components are assumed to have a higher potential for efficiency improvement than closed loop controlled components.

These assumptions are combined in the following formula and represent an indicator for potential retrofit $\boldsymbol{I}_R$:

$$I_R = A_E \cdot A_O \qquad (3.6.1)$$

Formula (201) with $\boldsymbol{A}_E$ [-], representing the energy share of one component during operational state of the total and $\boldsymbol{A}_O$ [-] as a weighting factor, representing the mode of operation of the component, defines the retrofit indicator $\boldsymbol{I}_R$. Herewith $\boldsymbol{A}_E \approx 1$ represents a constant energetic behaviour, e.g. an open controlled-, and $\boldsymbol{A}_E \approx 0.5$ represents an alternating, closed loop controlled mode.

3.2 Methodological Steps

Step 1: Detailed Machine Tool Measurement

A detailed machine tool effective power measurement and assessment is mandatory, most suitably by a multichannel measurement system to gain coherent data. The machine tool measurement and assessment includes several subtasks:

- Definition of appropriate system boundaries.
- Definition of operation states and definition of shift regime for the given machine tool manufacturing environment, i.e. the share of time of each operation state within the observation period.
- Definition of a reference process for the operation state “machining”, that exploits the capabilities of the machine tool and defines a bases for optimization.
- Accounting of all relevant energy forms as in- and outputs to and from the system boundaries simultaneously.
- Selection of appropriate component clustering for the retrofit evaluation, e.g. functional oriented machine tool components that refer to machine or process cooling, tool and part handling, or waste handling.

A sequential component measurement can be applied as well, however the energetic behaviour of the components depends on environmental and infrastructural constraints, e.g. thermal state, a simultaneous measurement is recommended. For an example for a potential measurement system and appropriate consumer selection, it is further referred to Gontarz [8].

Step 2: Calculation of Retrofit Indicator $\boldsymbol{I}_R$

For each selected and investigated machine tool component, the retrofit indicator $\boldsymbol{I}_R$ must be determined. According to formula (3.6.2), the energy share of each component i, $A_{E,i}$ is calculated as follows:

$$A_{E,i} = \frac{E_i}{E_{System}} = \frac{\int_{t_0}^{t_1} P_i(t) \cdot dt}{\int_{t_0}^{t_1} P_{System}(t) \cdot dt} \qquad (3.6.2)$$

$\boldsymbol{E_i}$ [kWh]: Energy supplied to component i during observation period.

$\boldsymbol{E_{System}}$ [kWh]: Energy supplied to machine tool, accordingly to system border definition.

$\boldsymbol{P_i(t)}$ [W]: Effective power of each component i during the observation period.

$\boldsymbol{P_{System}(t)}$ [W]: Total effective power of machine tool, accordingly to system border definition.

$\boldsymbol{\Delta t = t_1 - t_0}$ [s]: Observation period.

For the calculation of the second factor $\boldsymbol{A}_0$, representing the operational mode of the component, the time at level counting procedure is used. It is taken from the fatigue strength analysis to analyse rotating loads, and the load characteristics, and to determine the life time of a part. Methods like rain flow or time at level counting [9] were investigated and reviewed for this application.

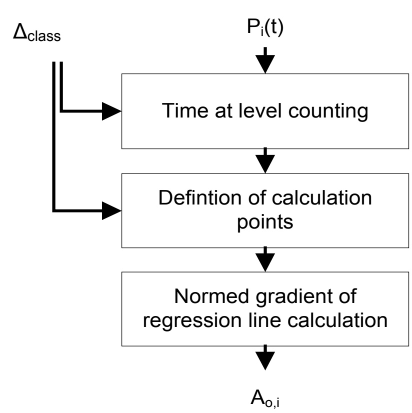

Fig. 3.6.1 Process chart for $\boldsymbol{A}_O$ calculation

An analysis of available counting methods revealed that time at level counting fulfils the analysis requirements to the full extent through a clear and easy-to-read statement. Due to high value levelling, the application of mathematical variance calculation is not sufficient for the mode of operation definition from the effective power plot. Figure 3.6.1 shows the procedure by using a modified and extended time at level counting calculation.

Time at level counting is suitable for providing a mathematical verification of the operation mode of the consumer. The effective power levelling during the process duration is classified into equidistant classes of, for instance 0.1 kW. In each class, the duration of remaining on specific power level of each component can be determined. This represents a clear picture of the energetic behaviour of each component.

A component with a constant energetic behaviour requires energy on one specific level. Components with an open loop controlled energetic behaviour are represented by more different energy levels. Resulting from this, components with several different energy levels represent variable components and can be classified with this applied mathematical approach. To estimate the indicator A_O in formula (3.6.1), it is needed to add up the duration within the defined classes. This is represented graphically in Fig. 3.6.3. This levelling can be approximated with a regression line. Finally, the gradient of the applied regression line represents the degree of the operational mode of each component (Fig. 3.6.4).

The appropriate definition of the class width Δ_{class} [W] is needed for the signal interpretation, but is also dependent on several aspects, e.g. signal noise and signal quality and the resulting calculation period. Wide class ranges could lead to false interpretations of the effective power signal; tight class ranges increase the calculations time without any improvement in the information content.

A class width of $\Delta_{class} \approx 0.005 \cdot (\max\{P_i(t)\} - \min\{P_i(t)\})$ is selected and verified accordingly to the above mentioned requirements. The class definition and corresponding quantity are represented by:

- Positive-oriented effective power leveling:

class n = {x | (n–1)•Δclass < x ≤ n•Δclass} for

$$n \in N \cap 1 \leq n \leq \frac{\max\{P_i(t)\}}{\Delta_{class}} + 1 \quad (3.6.3)$$

- Negative-oriented effective power leveling:

class p = {x | (p–1)•Δclass < x ≤ p•Δclass} for

N: natural number

$$p \in N \cap \frac{\min\{P_i(t)\}}{\Delta_{class}} - 1 \leq p \leq 0 \quad (3.6.4)$$

- In the case of $\min\{P_i(t)\} \geq 0$, no classes are needed in the negative-oriented effective power leveling. Herewith it is considered:

$$n \in N \cap \frac{\min\{P_i(t)\}}{\Delta_{class}} - 1 \leq n \leq \frac{\max\{P_i(t)\}}{\Delta_{class}} + 1 \quad (3.6.5)$$

The applied class definition and the time at level counting is visualized in the following figures (Figs. 3.6.2 and 3.6.3).

Figure 3.6.2 shows the measured effective power leveling, represented by the black dotted line, and the assigned classes, indicated by the black horizontal lines.The time at level counting, respectively the duration of the measured effective power values, are shown in the following Fig. 3.6.3. Beginning with the highest effective power level, in descending order, values of each class are summarized. To provide a comparison over all evaluated machine components, both axes must be normalized with the maximum effective power $\max\{P_i(t)\}$ and time t_1. This calculation is done for each component.

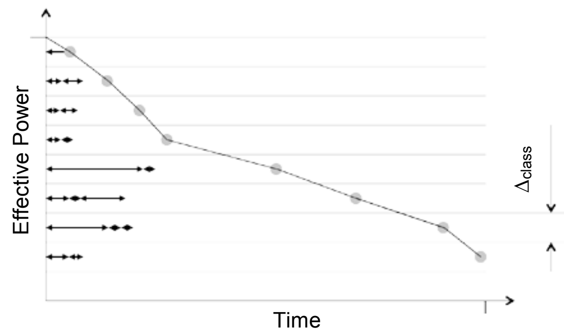

Fig. 3.6.2 Example of classifying an effective power-time measurement

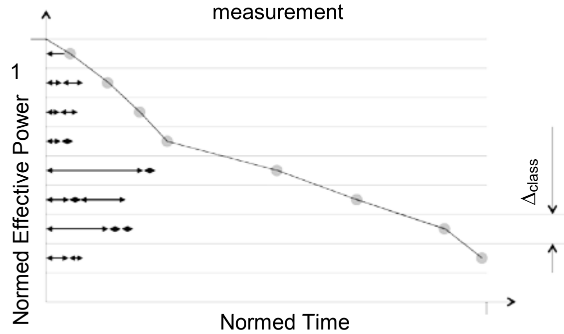

Fig. 3.6.3 Summarized level durations on each effective power level and resulting data points

The discrete normalized effective power values are organized equidistantly in the ordinate direction (Y-axis) with a constant width of Δ_{class}. The data points allocation in abscissa direction (X-axis) is dependent on the sum-level-duration levelling plot and, for this reason, is not equidistant.

The quantity of data points between the two axes as well: horizontal levelling is defined with few data points and the vertical levelling is defined by many data points, which leads to a parameter sensitivity of the regression line gradients depending on Δ_{class}. This effect increases the more classes are passed by the measurement signal.

To solve this problem, an algorithm was applied to sample the sum-level-duration levelling plot equidistant along the data points. Therefore the horizontal and vertical sequence plots are weighted equally in the calculation of the regression line.

At first, the total length of the sum-level-duration plot is calculated by connecting all discrete normed effective power values by lines. The sum of these intervals is L_{tot} [-]. Here from the length increment L_{inc} [-] is calculated with formula (3.6.6):

$$L_{inc} = \frac{L_{tot}}{ceil\left\{\frac{P_{\max} - P_{\min}}{\Delta class}\right\} - 1} \quad (3.6.6)$$

L_{tot} [-]: Total length of sum-level-duration plot.

ceil{x}: Function to round the following element to the next integer.

P_{max} [W]: Highest effective power among all consumers.

P_{min} [W]: Lowest effective power among all consumers.

To find the corresponding points for the evaluation plot, a linear interpolation between the discrete normed effective power values is performed.

Finally, the gradient of a regression line through the allocated points quantifies the dimension of the operational mode of each consumer. The weighting factor $A_{O,I}$ is calculated according to formula (3.6.7).

$$A_{O,i} = \frac{90\left[°\right] - \left|\alpha_i\right|}{90\left[°\right]} \tag{3.6.7}$$

α_i [°]: Gradient of the regression line.

Figure 3.6.4 shows the resulting graph with its gradient. Each gradient of the corresponding consumers can be herewith analyzed. By having both specific values $A_{E,i}$ and $A_{O,I}$ of each component, the retrofit indicator can be calculated.

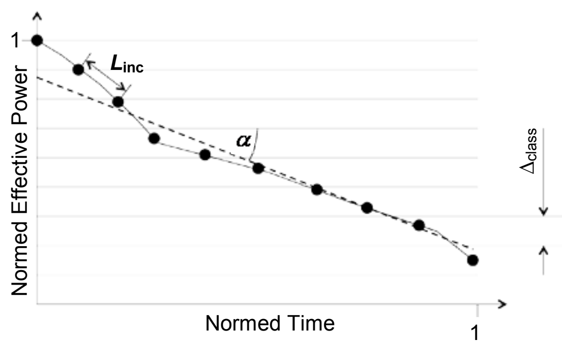

Fig. 3.6.4 Resulting regression gradient

Step 3: Determination of Retrofit Activity

The above shown procedure for the evaluation of a retrofit indicator can now be applied to specify concrete fields of action after the performed and assessed measurement.

Consumers with the highest retrofit indicator value must be considered and approved for potential retrofitting activities with priority. These activities depend on:

- use and impact on the process stability and quality
- technical and operating expense for retrofit
- economic aspects.

In consideration of the above mentioned points, only retrofit measures are assigned with $A_{E,I} \geq 5$ [%]. The following measures can be considered, sorted by increasing complexity:

- turn off consumer, if applicable
- apply adjusted control or reduced duty
- replace consumer by a more efficient one
- replace complete subsystem while providing same function.

4 Verification of Methodological Approach

4.1 Example on Conventional Lathe

The developed methodology was applied on different machine tools, including a conventional lathe and milling machine. Due to extended machine measurements and efficiency and effectiveness assessments, the following example can be pointed out to verify the retrofit indication with the developed calculation methodology.

The herewith presented methodological approach was applied on a horizontal turning center with a two axis tool positioning system, dry processing and compressed air process cooling. The following retrofit indication depends on:

- reference scenario
- machine tool infrastructure and design
- reference process.

4.2 Reference Scenario and Process

For the most important mode of operation, machining, the definition of a reference process is needed for representative measurements. As by now there is no standard available. In the ISO 14955 series, currently under work in ISO TC 39 / WG 12, the definition of test pieces or test procedures is planned. This is not published at the moment. Nevertheless those discussions on action for retrofit must be based on the real application.

Within this work a reference process is defined as a typical machine tool process that represents the target process of the designed machine tool. In the present example, a hard turning process of an automotive pinion is applied with the following process data:

Table 3.6.1 Reference process

Data	Value	Unit
Duration	100	s
Cutting rate	150	m/min
Feed rate	0.15	mm/r
Cutting volume	3605	mm^3
E consumption	0.156	kWh

Figure 3.6.5 represents the effective power plot of this process. The process scenario defines a typical process and a default shift regime. In the following process scenario contains the workpiece handling by the operator, the use of the tailstock to hold the workpiece, the workpiece clamping with the chuck, and the process cycle itself.

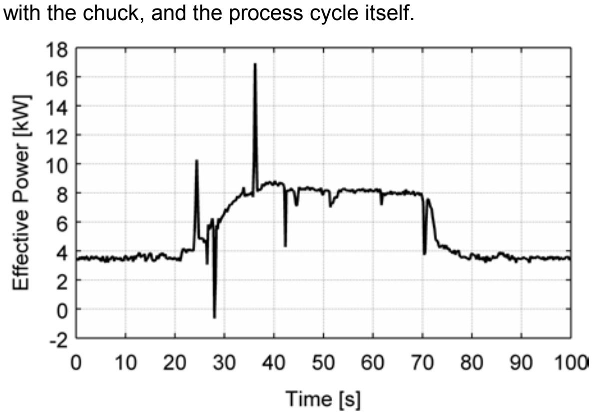

Fig. 3.6.5 Effective power plot of reference process

Furthermore, it is assumed that the machine tool operational mode is primarily in "cycle" and less in "standby" or "off" mode. Additional measurements of operational modes can be performed according to assigned scenarios. The observation period for this example is defined by the reference process within machining.

In the following an example calculation for the retrofit indicator I_R is shown for a specific consumer.

4.3 Calculation of Retrofit Indicator I_R

Due to the amount of calculations, for each relevant consumer, one calculation as an example is selected. The energy required for the compressed air system is suited due to a clear statement within this methodology and it also represents one of the main potential retrofit activity options. The measurement bases upon the above mentioned reference process and scenario.

Figure 3.6.6 shows the isolated effective power measurement of the compressed air system. A detailed calculation of the required compressed air energy is referred to Gontarz [2].

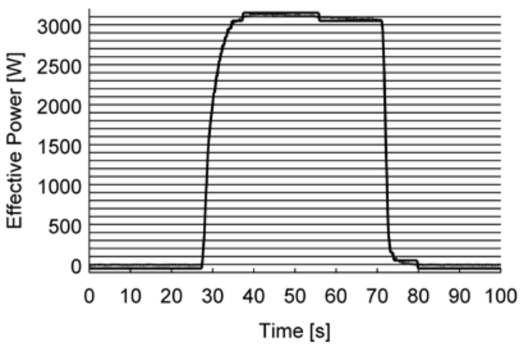

Fig. 3.6.6 Effective power of compressed air during reference process

Figure 3.6.6 also shows the classification with defined class width. The effective power characteristic shows two major power levels, during and off the process cycle, and compared to the total effective power use a high share of effective power. With a maximum effective power over 3 kW and a resulting required energy use of 0.036 kWh during the reference process $A_{E,Air}$ results according to formula (3.6.2) to:

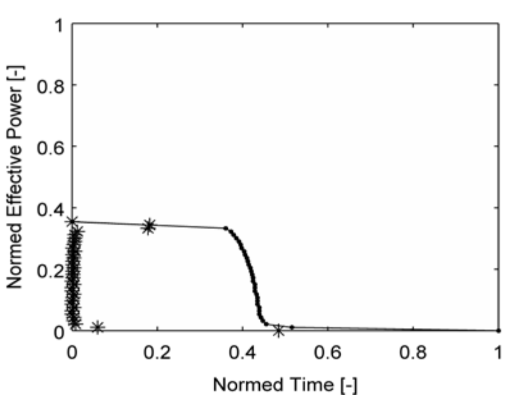

Fig. 3.6.7 Normed summarized level durations

$$A_{E,Air} = \frac{E_i}{E_{System}} = \frac{0.0365}{0.1560} = 0.234$$

In addition, the calculation of the mode of operation factor A_O is shown exemplary in Figs. 3.6.6, 3.6.7 and 3.6.8. By adding up all measurement point durations and scaling, Fig. 3.6.7 approves the assumption of a two level periodic energetic behaviour of the compressed air system.

In the next step, the regression line can be drawn according to the given measurement points and formula (3.6.3) in the scaled plot Fig. 3.6.8. This formula provides multiple equidistant points along the path. This plot can be compared among each component to determine its actual mode of operation.

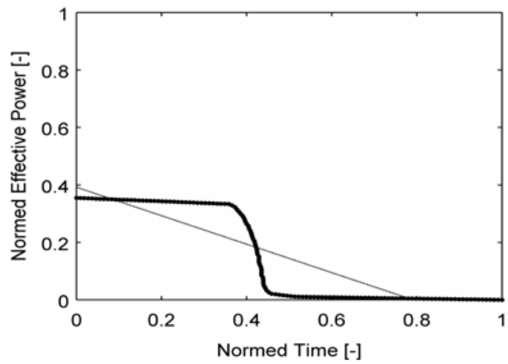

Fig. 3.6.8 Scaled plot with regression line

Finally, the angle of the regression line can be determined to calculate the $A_{o,\ Air}$ factor with formula (3.6.4). In the present case, the angle α_i is α_{Air} = 26.4 ° and results in $A_{0,\ Air}$ = 0.707. Table 3.6.2 shows the results for the detected possible retrofit activity points.

Table 3.6.2 Consumers ordered by I_R.

Measurement M12, lathe, pinion Δ_{class} = 100 W E_{System} = 0.156 kW·h	$A_{E,i}$ [-]	A0,i [-]	I_R [-]
Air compressor	0.234	0.71	0.166
Cooling fan spindle	0.166	0.993	0.165
Hydraulic system	0.119	0.982	0.117
CNC Total	0.182	0.612	0.111
Spindle cooling pump	0.109	0.993	0.108
Sealing air	0.058	0.993	0.058
...	...	...	...

4.4 Definition of Retrofit Activity

The performed assessment with the retrofit indication pointed out fields of action on the given machine tool and in the given process. It revealed that the process and machine tool cooling, as well as the hydraulic system should be investigated in more detail for potential retrofit solutions.

As the machine tool and process cooling directly influence the machining process, the investigations were focused on an auxiliary system, the hydraulic system. In the given case the hydraulic is used to open and lock the chuck for the workpiece clamping. Figure 3.6.9 shows the effective power of the hydraulic system during the applied reference process. The hydraulic pump constantly requires 680 W effective power to maintain the system pressure. Apart of maintaining a constant pressure it is actually used less than 10s during the total reference process.

According to the given retrofit definition and the possible retrofit activities (Chap. 3) the hydraulic system can be either controlled or replaced by a more efficient and appropriately dimensioned one. It could be replaced by a hydraulic pump combined with a reservoir system.

This retrofit solution is suitable for the assessed reference scenario. It might be not suitable for other applications.

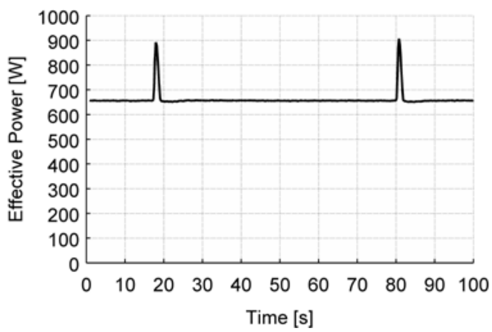

Fig. 3.6.9 Effective power of hydraulic system with open- and lock chuck for workpiece clamping

Further research with the focus on the appropriate selection of retrofit action as several dependencies, e.g. economic, service and maintenance, as well as flexibility issues must be considered.

5 Conclusion

According to the given reference process and scenario, as well as the machine tool system design, the retrofit indication determined and rated potential retrofit fields of action. It approves the assumptions of potential improvement fields by a mathematical statement that can be furthermore evaluated under the consideration of different scenarios or machine tool system designs. This method is considered as a promising assessment to deal with energy measurement data; however, it requires a detailed energy measurement on the component level and needs to be approved by a retrofit verification measurement.

6 Summary

The research evaluates how retrofit activities under the aspect to reduce energy consumption could be found based on machine tool measurements. It is primarily addressed to the auxiliary but could also be extended to process related components. Measurements on the machine tool level are necessary only if instrumental information cannot be withdrawn from the control. It is therefore necessary to interpret the measurements accurately. For appropriate data information, methodologies and calculations from other research fields can be adopted.

Starting with the overall machine tool measurement, this methodology evaluates the energetic behaviour and share of each machine tool component. The central point is represented by the time at level counting. This calculation detects the mode of operation of each component.

This methodology likewise enables the machine tool builder in the future machine tool design and machine tool users to improve machines in the field.

Further research must be done to determine at which spots and degree retrofit could be applied, principally considering economic requirements, e.g. return on investment. Appropriate retrofit decisions are also needed in service and maintenance applications.

As the presented methodology relies on a clear input, the effective power measurement and corresponding components, it is considered a quick and powerful assessment tool and serves furthermore as a base for further research.

7 Acknowledgments

We gratefully appreciate the funding of CTI Switzerland and extend our sincere thanks to MAG Switzerland for cooperation.

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3.7 Condition Assessment Model for Maintenance of Vehicles Fleet Based on Knowledge Generation

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Abstract

Instead of fail to fix, the maintenance strategy has being developed more predictively and intelligently. So called Condition Based Maintenance (CBM) enables real-time condition monitoring, diagnosis and prognosis with the help of information and communication technology. But for a large number of old equipment without relevant sensors or cost inefficient to install them, e.g., garbage trucks, a suitable maintenance strategy is needed for further use of such equipment in remaining lifetime. This paper presents a model of knowledge supported maintenance for vehicles fleet which contains modules of knowledge generation and maintenance planning for above mentioned equipment. Conditions of equipment or components could be assessed to calculate remaining lifetime and plan future maintenance activities. A case study of maintenance system for fleet of garbage trucks is shown in the paper with a condition-oriented parameter model which used as indicator for preventive maintenance and a knowledge feedback model for continuous improvement of whole equipment lifecycle.

Keywords:

Condition assessment, Maintenance, Knowledge generation, Vehicles fleet

1 Introduction

Traditional corrective, planned maintenance is being replaced by Condition Based Maintenance which includes the ability to diagnose the machine condition or failure, calculate the remaining lifetime and schedule maintenance operations [1]. Predict and prognosis is becoming the trend of maintenance instead of fail to fix, an advanced implementation of condition based maintenance is the accurate diagnosis of existing component faults and the ability to predict the failure [2]. Machinery failure should be prevented before it happens in order to decrease or avoid the downtime [3].

In view of sustainability, condition based maintenance can prevent economic loss due to unplanned breakdowns by lifetime prognosis, so that optimize the maintenance planning to increase the quality of customer service. Different configurations have profound impact on the performance of the system in terms of reliability and productivity, product quality, capacity, scalability, and costs. Adapting the design to reduce idle and operation costs and an ongoing adjusting of service times requires awareness about the system behavior and the system conditions.

Furthermore, facing to the shortage and price fluctuation of raw materials, resource efficiency is becoming a new challenge of manufacturing industry worldwide. Remanufacturing and reuse engineering provide a huge potential for a large number of used equipment and contribute sustainability in aspect of resources saving. But for old equipment which usually have no or less real-time condition monitoring system or cost inefficient to install them, their health condition is needed to be assessed before further processing. Therefore, an effective condition assessment model is needed to evaluate their performance status and asset value to increase the reliability as well the availability of such equipment.

This paper presents a condition assessment model with help of knowledge that generated out of data and information along the whole machine lifecycle. In order to prevent failure, maintenance planning would be implemented along continuous improvement process, which enables failure prevention by appropriate redesigns, adoptions in planning and usage of the machine. A case study of maintenance for fleet of garbage trucks is introduced to implement knowledge supported strategic maintenance planning based on condition assessment and knowledge generation.

2 Condition Assessment Model for Maintenance

Condition assessment is defined as the collection of data and information through the direct inspection, observation, and investigation and in-direct monitoring and reporting, and the analysis of the data and information to make a determination of the structural, operational and performance status of capital infrastructure assets [4]. Condition assessment is one step of condition based maintenance, which helps the maintenance planning based on sensor signals or machine performance data. After data processing condition assessment could provide the critical information needed to assess the health condition and functionality of a system. Using a set of systematic methods, the useful information could be produced for following data analysis that generates a kind of new knowledge about the system behavior, e.g. failure and use pattern.

Figure 3.7.1 shows the condition assessment model for maintenance which integrates with the concept of continuous improvement process (CIP) as well as DMAIC cycle. CIP is

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an ongoing effort to improve product, service and process [5]. As a model of continuous improvement process, “DMAIC cycle” can be divided into 5 phases: define, measure, analysis, improve and control [6], presents the basic process of all six-sigma projects in quality management. Macroscopically, maintenance is a kind of service plays an important role in product usage and recycling, which should be improved continuously for optimizing product and service in its product lifecycle to increase the service quality and resource efficiency. Microscopically, maintenance planning can be divided into different phases as the DMAIC cycle divided. Using the DMAIC cycle the condition assessment and maintenance planning can be lead to a more sustainable way.

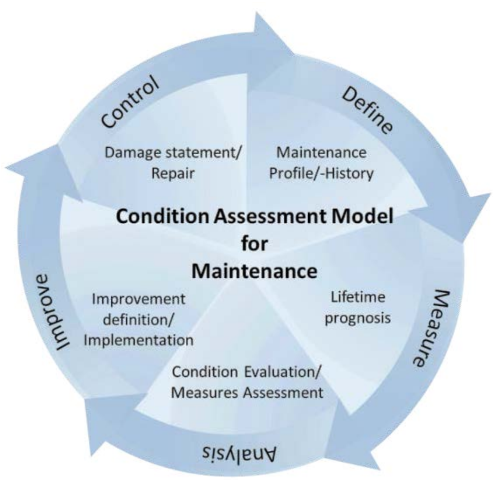

Fig. 3.7.1 Condition assessment model for maintenance

- Definition of maintenance profile

In this phase the maintenance profile will be defined to find the critical components in maintenance. The aim of definition is to understand the risk, frequency, and costs of failure of each component.

Failure mode and effects analysis (FMEA) is often employed to evaluate the failure risk of components. FMEA is a systematical method which fundamental idea is the determination of all possible failure modes for arbitrary systems or components [7]. FMEA is able to discover failure potentials of any kind of components by analysing the function structure of whole system. With such understanding of potential risks and machinery failure, maintenance planning could be more predictive. As a significant criterion in FMEA, risk priority number of each component is counted by evaluation around failure potential, importance for overall performance and detecting possibility of damages, which can enable the ranking coupling with evaluation of costs and frequency.

- Measurement of remaining lifetime prognosis

Lifetime prognosis facilitates a minimum costs for spare parts due to facilitate the maximum use of resources and prevention of unseen production breakdowns. Of course this implies that the exchange can be made within the time to the predicted breakdown. From the point of the planning, this might be not always economical. It might be cheaper to replace a part during an inspection, than sending a technician two days later again to replace the worn part [8]. Lifetime prognosis allows a condition based scheduling for maintenance and also enables the reuse of components. Combined with a condition diagnosis it is possible to decide if a used component can have a second life phase in another application. This saves further resources and satisfies the sustainability so that leads to a more competitive business.

To maximize the lifetime of components and to replace them at the time before it breaks not too early and also not too late, to ensure the functionality, calculation of remaining lifetime is required for product usage. The processing is being done with statistical analysis and algorithm out of the field of Data Mining [9]. With the help of condition prognosis the need of maintenance can be identified and maintenance activities can be automatically deployed.

- Analysing system behaviour

To ensure the functionality, to enhance the maintenance plan of the machine and to adopt services, the machine designer needs knowledge about the system behaviour. The system behaviour is the knowledge about correlations between product, processes and services. Every product in use is usually a unique system, but only in certain conditions it leads to a machine behaviour, which bases on design, usage etc. Assuming that the machine manufacturer knows about the usage patterns of customer, the design and planning would be made perfectly matching to the customer needs or the manufacturer would give advises to his customer how to produce more availability.

Data and information acquired in certain situations will be processed with the objective to generate knowledge, e.g. inferences between product or process parameters and failures, condition correlation or lifetime prognosis. This information has detail information about time and failure type, e.g. failure due to wear on bearing, identified by vibration characteristics. The quality and detail level of the diagnostic or prognostic result depends on the processed data and used algorithm. Simple time frame interpolation give just the time of failure, while in combination with failure classification, the failure type can be predict, e.g. statistical pattern classification. Those algorithms use existing knowledge and identify the time a failure occurs, but to prevent failures new correlations leading to a failure need to be identified.

- Improvement and control with knowledge management

The aim of improvement is reducing the maintenance costs during whole product lifecycle by rationalization measures. With the knowledge generation, strategic maintenance planning is able to define the maintenance profiles for each machinery system, component and part. Concrete improvement measures are defined based on evaluation of detailed measures and relevant saving potentials for maintenance. This should be initiated in connection with CIP experts, who organize and supervise the implementation. The reaction may be done internally by the workshop, or externally by outsourcing contract. With an increasing number of performed measures for improvement, the potential of each measure can be judged on the basis of increasing knowledge about whole system. The generated knowledge set the foundation for a competitive business. Therefore knowledge generation is an enabler for the redesign, planning or delivery of intelligent machine failure prevention.

Generated knowledge enables three types of feedbacks as feedback to planning/development, feedback to usage and feedback to provision. In other word, knowledge should support the product supply chain along its life cycle. The knowledge should feedback to the provision immediately so that user can maximize the functionality and avoid the failure. Regarding the feedback from usage, it is possible to distinguish between subjective and objective information [10]. Subjective feedback refers to suggestions for improvement or positive/negative reviews from customers as well as demands for future generations expressed by users. Objective feedback, on the other hand, covers objectively measurable information accumulated during the usage. The machine failure prevention should start from the design step of a product. The generated knowledge provides the advices for the continuous improvement process of next generation products in order to prevent the failure fundamentally.

3 Knowledge for Maintenance

3.1 Knowledge Generation

Condition assessment plays a role as transition between the data acquirement and maintenance planning. Such generated knowledge by condition assessment is used to prognosis the remaining useful lifetime, long-term use, and further performance. Thus, condition assessment could be seen as a process of knowledge generation. In other words, an effective knowledge management provides opportunity and challenge for condition based maintenance.

The definition of knowledge by North [11] is becoming more and more popular within the last years. Knowledge is defined as the appropriate linking of information which plays a role as one of the foundations for competitiveness. Figure 3.7.2 shows the definition of knowledge as well as the sturcture of knowledge generation based on data resoures which can be processed by statisitic methods and data mining algorithms.

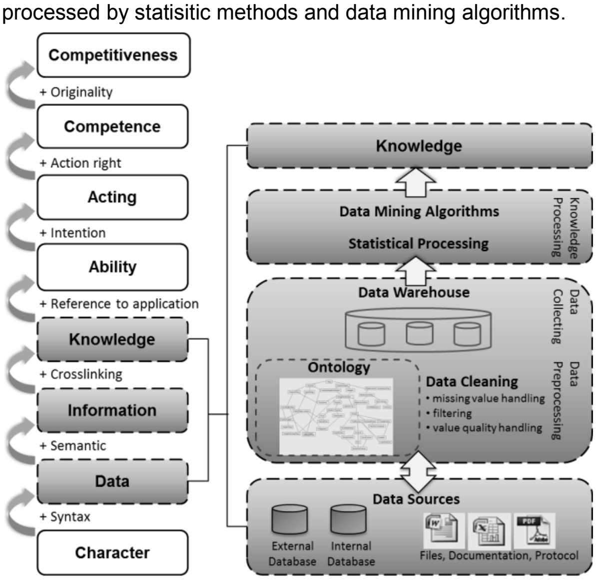

Fig. 3.7.2 Definition of knowledge by North [11] and structure of knowledge generation

The basis for any data discovering are the consulted data, which can be divided into online data and offline data. Online data are the real-time condition monitoring data from machine performance and sensor signals. Sensor data out of the use from the machine is being used to assess the working status and evaluate the performance degradation of the machine or its components. Offline data constants the registered non real-time data, e.g. operation schedule, maintenance protocol. State of the art is, that almost all kind of documentation is made digital and managed by enterprise resource planning software, many of them, e.g. machine datasheets, is even public available on internet. Other data is company internal digital available on digital databases, e.g. personal database with information about technician qualification levels, timetables, maintenance protocols, machine operation protocols etc. Furthermore, in order to improve the accuracy of the life time prognosis, other relevant data or information should be considered. Analysing data from personnel, material, environment and maintenance protocol of same machines allow identifying new correlations.

For instance, in the process of condition assessment the main categories of information are:

- Condition monitoring data (e.g. running time, engine speed, ambient temperature, load)
- Customer data (e.g. customer profile)
- Personnel data (e.g. qualification, experience, age)
- Service data (e.g. maintenance frequency, incidences of maintenance, failure/breakdown)

The challenge lies in getting access to relevant data sources, which means data having a relation to the queried process knowledge. Those data needs to be acquired for the further data processing procedure. In industrial applications a network of companies are taking part on manufacturing processes and related services, e.g. machine manufacturer, spare part distributor, service technicians, machine operator etc. An ontology is built to represent the relationship between the contained elements in database, and it integrates all the heterogeneous databases. Ontology is defined as a formal, explicit specification of a shared conceptualisation [12]. It defines a set of representational primitives with which to model a domain of knowledge or discourse in the context of computer and information sciences [13].

3.2 Knowledge for Condition Assessment

Knowledge could be generated by crosslinking between any other relevant data and information. The product lifecycle data, especially from the operation and maintenance phase, is the source to discover more knowledge for future use, especially, for maintenance against performance degradation. The value of knowledge will be shown, when it is referenced to an application and the ability for acting is facilitated. The acting itself needs an intention and if acting correctly and original or inventive, the competitiveness is given. Besides of the new generated knowledge from various data, the other topic is how to manage the existed knowledge and lead them to positive effects.

For condition assessment, required knowledge would be generated during the whole product life cycle, i.e. design data, operation information, system performance during use, customer information and so on. Discovered knowledge about the correlations on failure might lead to redesign of the machine. And the knowledge is essential for cost and resource reduction in maintenance planning and delivery. Continuous improvement process could be enabled by coupling with knowledge supported strategic maintenance planning. This knowledge includes rules about the process and its operations, as well as prognosis and classification of machine health condition [14]. Diagnosis based on rules is the most intuitive form of diagnosis, where through a set of mathematical rules generated from data and information. The observed parameters are assessed for conformance to anticipated system condition. It is possible to classify the influencing parameters and variables to each parameter with knowledge discovery algorithm, e.g. data mining.

4 Case Study

4.1 As-Is Situation

Garbage truck, as the common public facility for city life, is usually owned by city cleaning company, who manage all the trucks and arrange the cleaning jobs around the city. For example, the city of Berlin with nearly 900 km² and over 3 million people needs over 5,000 variant garbage trucks for the city cleaning. Maintenance for such big fleet of garbage trucks takes a large expenditure of parking, maintenance and controlling. A benchmarking study around city cleaning companies from German big cities shows us the costs for maintenance of garbage trucks in the year of 2008: in the view of working distance, the company should pay about 1.2€/1000 km for repairing each garbage truck; In view of hourly rate, the average expenditure for garbage trucks in workshop is 70.8€/h, and the proportion of various costs is shown in Fig. 3.7.3.

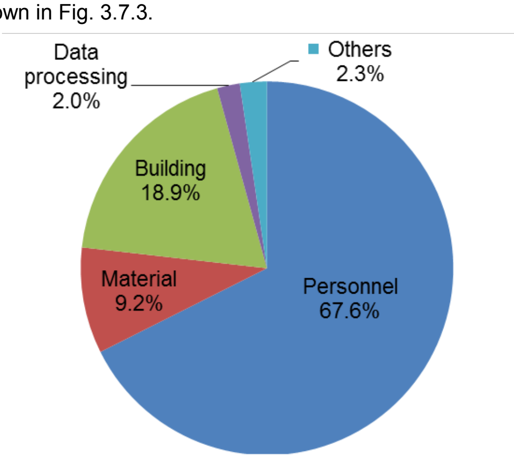

Fig. 3.7.3 Perception of costs in garbage trucks workshop

Personnel costs take the 2/3 of total expenditure due to frequent maintenance activities, such as, inspection, replace, repair, etc. On the contrary, the materials for maintenance that caused by renewing consumables or replacing the broken parts, cost only 10%. In this point of view, the personnel-intensive maintenance for garbage trucks could be substituted by condition based maintenance which shows its huge advantage in increasing efficiency and effectiveness of maintenance compared with traditional maintenance strategy. Machines will be monitored by sensors and relevant software instead of person. But in the fact, only small part of components owns the sensory condition monitoring. For many components it is cost inefficient due to restrictive requirements, e.g. costs of implementation, lack of meaningful metrics and limited rationalization potentials. Meanwhile, with enterprise resource planning system the city cleaning company has saved abundant data which provide the chance for knowledge generation. Therefore, knowledge supported maintenance could be introduced into the garbage trucks maintenance.

Within the case study, the object is a vehicles fleet of 45 same type compression garbage trucks which manufactured in the year of 2002 without any real-time condition monitoring system. A forementioned Condition Assessment Model has been implemented to rationalize the maintenance strategy for garbage truck with the help of knowledge generated out of the information along their lifecycle.

4.2 Defining Critical Components

To assess the condition of garbage trucks, a condition assessment model is to be built. Based on the maintenance feedback the technically or economically critical components are to be determined. Following is the identification and selection of critical parameters for describing and diagnosing the condition of vehicle. Tolerance value is determined to express the parameters as references of condition. Based on these tolerance values, the final parameter model is developed for condition assessment.

Due to a large number of maintenance data and information, knowledge generation efforts as a time efficient tools for building condition assessment model. Maintenance profile of each component will be defined firstly based on the data of maintenance protocol. In order to assess the condition of whole vehicle, the status of critical components should be acquired as adequate as possible. An evaluation based ranking helps to define the critical components of garbage truck according to qualitative and quantitative aspects of maintenance profile. Three indicators are counted as criteria in the evaluation of critical components.

- Costs
  - mean costs of each maintenance activity
  - personnel work time
- Frequency
  - frequency of general maintenance
  - percentage of inspection
  - frequency of damage-resulted maintenance
- Functionality
  - failure possibility
  - importance for overall performance
  - detecting possibility of damages

Based on the data saved in enterprise resource planning system, the maintenance costs and frequency of each component can be easily calculated. A function structure of one of the garbage truck has been built with different functions and relevant components. After that, the method FMEA could be carried out to analyse the risks of each component of the truck. Risk priority number of each component is counted by evaluating around failure potential, importance for overall performance and detecting possibility of damages. Coupling with maintenance costs, maintenance frequency and functionality risk, a ranking of technically and economically critical components is shown in Table 3.7.1, the most critical ten components on maintenance have been found by the statistic data from 2004 to 2010.

So called Pareto principle shows that usually only 20% components responsible for 80% of all failures. These ten components spends the 77.2% personnel work time and almost 69.5% costs on maintenance. Therefore, fuhter conditon assessment would be carried out for these most critical components. After defining the critical components of garbage truck, lifetime prognosis is to be used to improve the maintenance planning.

Table 3.7.1 Ranking of critical components in maintenance

No.	Assemblies	Components	Mean costs of each activity (€)	Frequency
1	Hydraulic system	Hydraulic cylinder for tilting plates	695.75	15
2	Brake system	Membrane cylinder	332.75	42
3	Brake system	Brake caliper	234.91	95
4	Hydraulic system	Hydraulic cylinder for lifter	289.55	18
5	Brake system	Brake disc	216.26	89
6	Filling device	Bearing for tilting plates	875.85	20
7	Brake system	Brake block	161.86	88
8	Central lubrication	Lubricant ducts	60.50	65
9	Cooling system	Water pump	461.53	9
10	Hydraulic	Hydraulic hoses	58.47	130

4.3 Condition Assessment with Knowledge Generation

Knowledge about remaining lifetime is generated from the history data of maintenance. Actually, the maintenance registration consists only the date, time, object and activity. Such data show when the failure happens and who did the maintenance activity. But from such simple data, it is hard to know why this failure happens.

To evaluate the conditions of equipment, remaining lifetime prognosis can be a indicator to show how long the instic lifetime is. by Weibull distribution would be used to present the values of condtion. Components which have the same or similar function are required to be divided into different component groups. The needed knowledge could be generated by the help of statistical methods. With statistic method the machinery failures can be represented graphically with different functions. Weibull distribution is the most common lifetime distribution used in mechanical engineering [7] (Fig. 3.7.4).

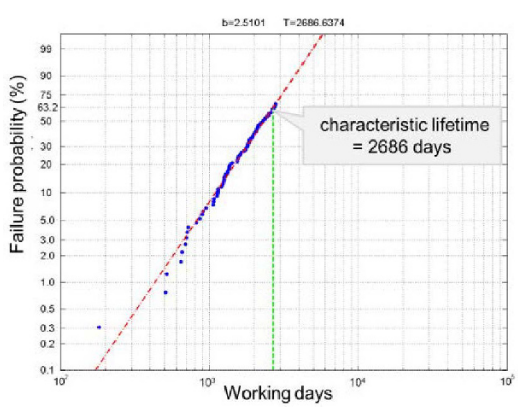

Fig. 3.7.4 Lifetime prognosis by Weibull distribution

Focusing to the critical components, corresponding ditributions could be built by using information of maintenance intervals. Such distributions present the relationship of failure probability and working days for different components. And the charateristic lifetime of Weibull distribution can also be found from the distribution which used as a predictive lifetime. Therefore, with the failure probability and predictive lifetime a knowledge about the performance degragation could be generated. The company would plan further maintenance activities according to this knowledge. For example, reduce the personnel costs by decreasing the frequancy of regular maintenance, plan maintenance activities with lifetime prognosis to reduce ecomonic loss of unexpected failure.

As to condition assessment, this knowledge provides a reference to the health evaluation of total truck. A graphic model for condition assessment is shown in Fig. 3.7.5, the conditon of critical components are laid on each axis of graphic model. The achievable characteristics of the parameters have normalized the length of the axis. And the limits values of measurement or lifetime are marked in points. Due to that, graphic model is divided into three areas that represent different health condtion of components. The further away from origial point, the shorter remaining lifetime or the worst condtion this component has.

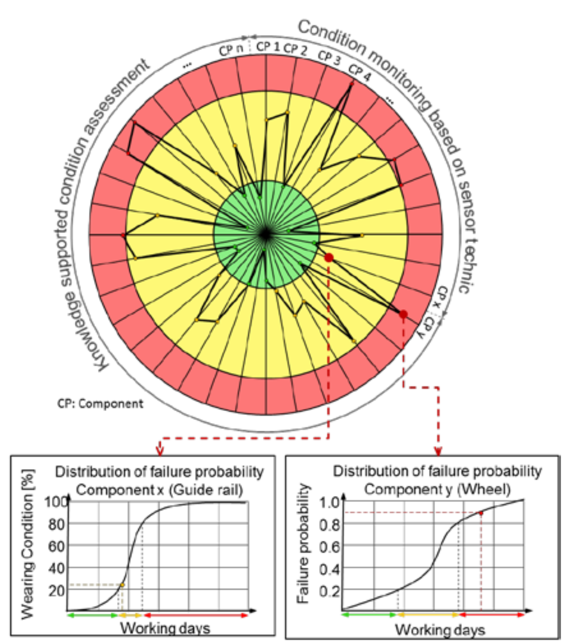

Fig. 3.7.5 Graphical model for condition assessment

This graphic model that built based on geenrated knowledge, could combine the real-time condition monitoring system and history data and information. The graphical presentation of condition helps to determin the health condition of any specific garbage truck by the areas where component locates in. By the quantitative description of condtion assesment model, the health comparison between vehicles or even different vehicle types is enabled.

5 Conclusion

To satisfy the requirements of sustainable development, an efficient and effective maintenance is needed to be carried out in the manufacturing factory. Condition based maintenance provides the chance in saving resources and reducing economic losses. As a part of that, condition assessment enables predictive and intelligent maintenance. And condition assessment is also one of the key processes in for used equipment where huge potentials in remanufacture and reuse engineering lie in.

In this introduced condition assessment model, knowledge of health condition, remaining lifetime, system behaviour, and defect of product design could be generated and used for maintenance planning as well as remanufacture and reuse engineering which satisfies the requirement of sustainability development. The generated knowledge is especially meaningful for such old equipment that has no real-time condition monitoring system. Using concept of continuous improvement process the failure along the whole product lifecycle can be prevented. The generated knowledge feedback to the whole product life cycle which includes the design, operation and usage processes. The case study of maintenance of garbage trucks shows how the knowledge supports condition assessment. By this model, the technical and economical critical components in maintenance can be discovered. Furthermore, knowledge of system behaviour is generated such as lifetime prognosis, regulars of failures, which provides advices for machinery failure prevention. Knowledge enables the maintenance planning to reduce downtime of machine, optimize function of machine, extend effective lifetime and save the resources.

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3.8 WebCAN for Remanufacturers: A New Automotive CAN-Bus Tool Analyzing and File Sharing Application

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Abstract
The present paper summarizes the developed methodologies, technologies and tools in the field of analyzing, extracting and file sharing of CAN-bus information used for communication between automotive mechatronic and electronic systems. The results have been developed within the European research project "CAN-REMAN", conducted by Bayreuth University in cooperation with two other universities and eight industrial partners—mainly remanufacturing companies. Results of this project are developed analyzing, diagnosing and file sharing technologies and applications that enable small and medium sized enterprises (SME) to remanufacture automotive mechatronics and electronics.

Keywords:
Remanufacturing, Automotive components, Mechatronics, Electronics, CAN bus, WebCAN

1 Introduction

Raising requirements on occupant safety and comfort on the one hand and the introduction of new emission regulations on the other hand, force the automotive manufacturers to enhance their products continuously. In order to achieve these improvements, electronic systems, based on microcontrollers, have found their way into modern cars and they contributed considerably to many new advantages in terms of safety and comfort such as antilock breaking system (ABS), electro hydraulic power steering (EHPS) or electronic power steering (EPS). Nevertheless, the new trend of modernization has an immense impact on the remanufacturing business. It can be seen that new branches in electronic remanufacturing arise. In contrast to that, the knowhow of traditional remanufacturing companies has eroded rapidly and even the industrial principle of remanufacturing is at risk. Due to the fact that modern cars incorporate up to 80 of these mechatronic and electronic systems that are communicating with each other e.g. via the vehicle controller area network (CAN), remanufacturing of these automotive systems requires innovative reverse engineering knowhow, methodological innovations and new technologies, especially focussing on the tasks testing and diagnostics of systems and their subassemblies. Since traditional remanufacturing companies do not have much capacity to build up the appropriate know how, the Chair of Manufacturing and Remanufacturing Technologies at Bayreuth University assists these companies in reverse engineering, as well as finding new methodologies and technologies for remanufacturing [1, 2].

The results have been obtained within the European research project "CAN-REMAN" which is conducted by Bayreuth University, Linköping University (Sweden), the University of Applied Sciences Coburg, Fraunhofer Project Group Process Innovation and eight industrial partners. The target of this project is to enable independent after market (IAM) companies to remanufacture modern automotive mechatronics and electronics for multiple life cycles with innovative reverse engineering as well as to appropriate and affordable testing and diagnostics technologies.

2 State of the Art in Remanufacturing

In the process steps for remanufacturing (entrance diagnosis, disassembly, cleaning, testing, reconditioning, reassembly and final testing) great progress has been made, as it can be found in the literature [3, 4, 8–11].

3 Automotive Mechatronics Remanufacturing

The term "mechatronics" was formulated in 1969 in Japan and it is an artifice that describes a system which combines mechanics, electronics and information technologies.

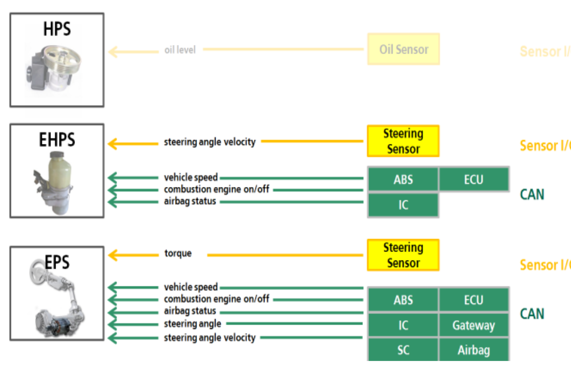

Fig. 3.8.1 Trend towards complex automotive mechatronics on the example of a steering system (HPS = hydraulic power steering/CAN = controller area network)

A typical mechatronic system gathers data, processes the information and outputs signals that are for instance converted into forces or movements [5].

3.1 Technological Change of Vehicles and CAN Bus

Automotive parts should no longer be seen as isolated standalone applications with few mechanical and electrical inputs and outputs. Now, they have the capability to

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communicate with each other and to share the same sensor information—as shown in Fig. 3.8.1.

Subsequently, the communication of the different automotive subsystems helps the OEMs to reduce weight and cost by sharing the same sensors and reducing cable doubling (cable length) in modern vehicles. For the driver the network and communication within the car remains invisible and he feels the car behaving like ten years ago despite of some additional comfort functions.

Several embedded computers—often referred to as electronic control units (ECUs)—communicate, share information and verify with each other over the vehicle network. One of the commonly used communication networks in vehicles is the CAN bus beside others like LIN bus, FlexRay and MOST bus (Fig. 3.8.2).

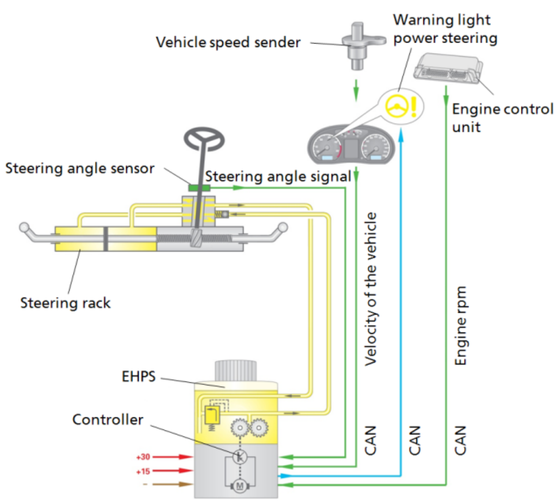

Fig. 3.8.2 Linkage between the electro hydraulic power steering pump (EHPS) and other sensors, actuators, mechatronic and electronic systems via bus systems like the CAN

This article especially focuses on the CAN bus. Within this network structure, each control unit has at least one unique identifier (ID) by which it broadcasts messages that again incorporate different signals and information [5]. Easily speaking, in case of a missing or faulty participant in the network, all other controllers will notice the participant as they have a lack of information. The lack of information or errors on the CAN bus force the other systems to operate in a "safe mode". In reverse, a controller not connected to the specific vehicle network stops its operation patterns and falls into "safe mode".

3.2 Requirements for Testing Automotive Mechatronics Communication via CAN Bus

As stated before, the introduction of electronic networks into modern cars entails enormous problems for remanufacturers. Modern electronic and mechatronic vehicle components cannot be tested as traditional electrical and mechanical ones. While it was usually sufficient to link electrical systems to the power supply (battery), modern mechatronic and electronic systems gather a lot of information from the vehicle environment and driving conditions using plenty of sensors and the CAN bus network of the vehicle. As a consequence, connecting all sensors and the power plug to the device under test (DUT) is insufficient unless the device is connected to the network of a real car or an adequate simulation of the communication in the vehicle.

Following these statements, the key for successful remanufacturing and testing of a certain automotive system lies in the simulation of the complete network communication in the vehicle. Unfortunately, there are no tools in the market available that allow the remanufacturer to simulate a complete car of a specific type and model easily.

One step toward this direction is the WebCAN tool introduced in this paper. In each case, the can bus car matrix (CAN database) of the specific vehicle model is required to build a simulation of the CAN communication in a vehicle. However, the OEMs will not release any information on the communication parameters to non-OEs and therefore they will not support the independent remanufacturing business. As a consequence, the independent remanufactures have to do a great amount of reverse engineering efforts themselves or in cooperation with others in order to design their remanufacturing process chain and to come up with test solutions to ensure the quality of their products. The reverse engineering activities focus on the system, its components, the system behavior in the vehicle and the vehicle CAN bus communication.

The testing and diagnosis of the system to be remanufactured imply that the product itself and its communication patterns have been reverse engineered before and the appropriate simulation model of the reference vehicle has been developed so that the tested product "feels" like in its original environment.

4 Reverse Engineering of Automotive Mechatronic Systems

The term "reverse engineering" has its origin in the mechanical engineering and describes in the original meaning the analysis of hardware by somebody else than the developer of a certain product and without the benefit of the original documentation or drawings. However, reverse engineering was usually applied to enhance the own products or to analyze the competitor's products [6].

Chikovsky describes reverse engineering in the context with software development and the software life cycle as an analysis process of a system, in order to identify the system (sub-) components, to investigate their interaction and to represent the system at a higher level of abstraction [6]. In this context, he also clarifies the terms "redocumentation" and "design recovery".

"Redocumentation" is the generation or revision of a semantically equivalent description at the same abstraction level. That means that the results are an alternative representation form for an existing system description. However, redocumentation is often used in the context of recovering "lost" information [6].

The term "design recovery" defines a subset of reverse engineering that includes domain knowledge, external information (of third parties) and conclusions additionally to the original observations and analyses in order to derive meaningful abstractions of the system at a higher level [6].

Overall, reverse engineering of software in the software development focuses on the following six targets [6]:

- Coping with the system complexity
- Generation of alternative views
- Recovery of lost information
- Detection of side effects

- Synthesis of higher abstractions
- Facilitation of reuse

These targets, that have originally been defined for software reverse engineering, can also be transferred to a certain extent to the reverse engineering of automotive mechatronic systems and hence to the remanufacturing of these systems.

First, remanufacturers face the same problem that they usually have to cope with complex mechatronic systems as stated before. “Cope” means in this context, that it must be possible to operate an automotive mechatronic system independently from its original environment (the vehicle).

Second, it is possible to detect universal taxonomies which can then be abstracted and used in order to transfer the gained knowledge to similar mechatronic systems or to other variants of the system. Especially the high degree of variation of similarly looking mechatronic systems and control units makes it difficult for the remanufacturers to cope with the complexity of automotive components that usually differ by a slight detail [7].

Third, recovery of missing information rather than lost is one of the most important aspects for the remanufacturing.

The following chapter demonstrates how a reverse engineering analysis can be conducted for an automotive mechatronic system.

5 Analyzing an Automotive Mechatronic System

After a reference system for the analysis has been chosen, it is necessary to procure at least one, ideally brand-new, system to grant correct functionality, for all following investigations. In order to analyze the system in its normal working environment, the original vehicle, in which the reference system commonly is built in, should be procured as well.

This investment might be unavoidable, because a mechatronic system communicating via CAN, detached from all other vehicle communication will not work anyway, as essential input information, transmitted via CAN, is missing otherwise (refer to Chap. 3). In this case it is very difficult to understand the ECU communication and put up the system into operation isolated from the vehicle.

A cheaper way to investigate the communication between vehicle and reference system is to create a CAN trace using a software tool such as “CANoe” from Vector Informatics or the “canAnalyser” from IXXAT. These tools allow easily recording of the complete vehicle communication for instance while doing a test drive with a vehicle that may be available only once.

Whatever strategy is chosen, it is essential to figure out which input information (CAN data) is necessary to start, operate and control the system.

5.1 Electrical Wiring

After having obtained a reference system, it is essential to know the pinout of all connectors of the system. Therefore, the very first step is to find out which pin belongs to which wire and signal.

First of all, the power connector (ground and positive terminal), including ignition, must be identified. One opportunity to obtain this information is the utilization of wiring diagrams or similar credentials. If such documents are not available, for example a visual inspection of the connectors and wire harness in the vehicle or continuity measurements can be beneficial.

Afterwards, it is indispensible to identify the CAN connection pins. These can easily be recognized by inspection of the cable harness. In most cases two twisted wires indicate a CAN bus connection, but single wire CAN connection is possible, too.

Finally, all connectors for sensors and actuators (auxiliary power and sensor/actuator signal) must be known as well to go further in the analysis process (Fig. 3.8.3).

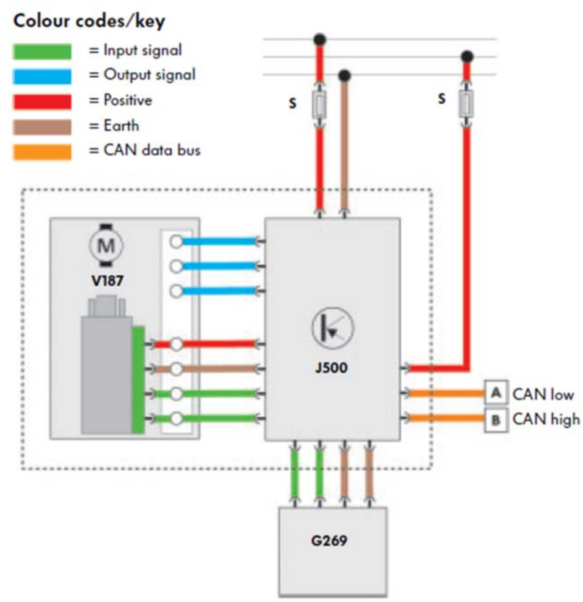

Fig. 3.8.3 Example of an electrical wiring of a steering system [12]

5.2 Vehicle Network Topology

The investigation of the structure of all bus systems in the vehicle is placed in front of the proper CAN bus analysis step. It is necessary to determine how many (CAN) bus networks are established and in which network the reference system is located. Additionally, the network speed, the presence of a separate diagnosis network (e.g. K-Line), and all ECUs of the specific networks must be found out. Especially those ECUs that provide essential input as mentioned before. Furthermore, possible gateway ECUs should be identified.

A feasible solution to gain this information can be for example a web inquiry, documents from the manufacturer of the vehicle or the system, third party documents or technical journals.

5.3 CAN Bus Communication

Having collected all information about the (bus) network structure of the vehicle, detailed knowledge about the received CAN messages and transmitted CAN data is necessary.

In the first step, all ECUs and their associated CAN message IDs must be determined. For this purpose CANoe can be used. First of all, a physical connection to access the CAN bus using CANoe has to be installed in the vehicle, ideally nearby the reference system ECU. With the “trace functionality” of CANoe the bus communication and all CAN messages of all ECUs can be displayed easily.

Beside of the CAN IDs, the cycle time and the length of each message can be analyzed. This information is relevant for a later rest bus simulation of all participating ECUs to ensure correct functionality of the reference system.

Fig. 3.8.4 Recording of CAN bus data

The assignment of CAN ID and the associated ECU is more difficult. One possibility to gather this information is, to locate all ECUs which provide relevant data on the CAN bus and to separate the CAN wires out of the cable harness. Afterwards, a kind of software gateway is installed in between the DUT and the other ECUs using CANoe and a simple CAPL (CAN access programming language) program.

Each end of the CAN wires in the vehicle must be connected to a computer via CAN hardware. By this means, it is now possible to detect the messages on the bus as well as the transmit direction—receive or transmit. In addition to this, it is also possible to add some filters to the CAPL program in order to filter out unnecessary messages and hence to reduce data complexity.

This step is repeated for each ECU which provides relevant input data for the reference system.

After having identified the relevant CAN messages, it is inevitable to examine the message data bytes in detail to determine the physical signals. This can be achieved by generating physical inputs manually (e.g. open the throttle, drive, break …) and observe the particular CAN messages as well as its bytes in parallel.

After that, a correlation between a certain CAN message, its CAN data and a physical input value can be established.

Having performed the steps above, it is possible to setup the desired restbus simulation for the reference system.

5.4 Sensors

Besides the CAN data, analog inputs of sensors and analog outputs of actuators are important in order to ensure correct functionality of the reference system. Therefore, each sensor and nearly each actuator has to be analyzed and simulated, too.

The sensors can be analyzed using an oscilloscope and a multimeter in order to characterize current consumption, supply voltage and signal transmission. Typically, sensor output signals are analog to:

- Current/voltage, amplitude
- Frequency/cycle time
- Pulse width/duty cycle

Or they are discrete in the following forms:

- Binary
- Multi-staged (different scaled)
- Multi-staged (equidistant) → digital

For the simulation, the measured values must be interpreted and emulated. For example, the internal resistance of a sensor can be calculated from the sensor current consumption. Afterwards, the presence of the sensor can be simulated by a (simple) resistor.

The simulation of the sensor signal can be realized using a waveform generator, an analog circuit, a microcontroller or a combination of them.

5.5 Diagnostics

Finally, to test the reference system completely, detached from the vehicle, it is necessary to know how the diagnosis communication works in order to check the fault memory and to read internal sensor information of the ECU (e.g. for temperature).

First, the applied protocols for transport and application layer must be identified. Often, standardized communication protocols for ECU diagnostics are used (e.g. ISO TP, KWP2000 or UDS). In some cases OEMs use proprietary self-developed keyword protocols (e.g. KWP1281). Thus, it is more difficult to build up a diagnosis connection to the reference system because the protocol specification is unknown to the remanufacturer. Hence, a detailed analysis of the CAN or K-Line communication during a diagnosis session is essential. Sophisticated reverse engineering capabilities are necessary to analyze, understand and recreate such a diagnosis communication. The message IDs, used for the communication, must be investigated independently by observing the diagnosis communication with CANoe. If the CAN IDs and protocols are known, the diagnose communication can be reproduced for example in CANoe.

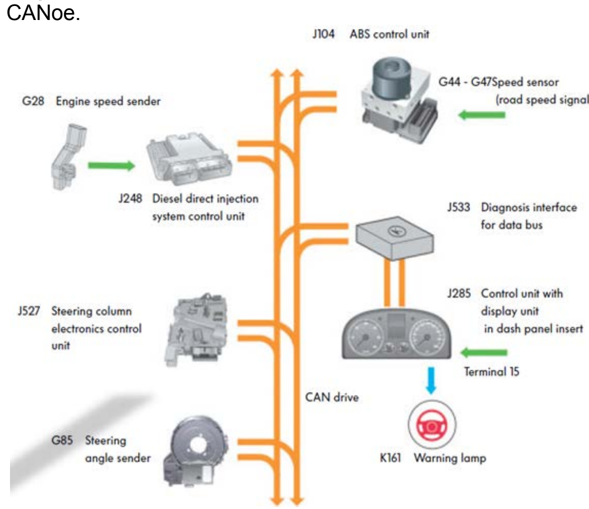

Fig. 3.8.5 Part of a vehicle network [12]

After a remanufacturing company has accomplished all mentioned steps for the reference system, it is able to operate this system detached from all analog (sensor signals) or digital (CAN) inputs.

Finally, a test bench can be developed for entrance and final testing in series production scale.

6 CAN Corder

The main part in analyzing an automotive mechatronic system is the diagnostics of the system as it was mentioned in the previous chapter. To support the IAM and to avoid doing the same work twice, the idea for a new diagnostic and analyzing tool was born. This tool consists of the parts CANCorder and WebCAN.

The general idea is, that the engineer, who is collecting all the necessary information, which is used to start running the mechatronic system, can provide other remanufacturing companies with these important information or even can get access, for his own issues, to these information through others. The CANCorder can help realizing such a system. The CANCorder records all the CAN bus data, which is actually on the bus (see Fig. 3.8.4). This is also possible with the commonly known tools from Vector Informatics or IXXAT. Beyond that the engineer can make some comments to the collected data. The comments can be made directly in the data section or in a general description box. Once, when the data has been recorded and commented, this information can be stored in a database file and also can be combined with a lot of information, like date, size, vehicle type, part name, age and so on. If necessary you can reload the stored data and replay them.

Example: An electro-hydraulic power steering (EHPS) pump of a car. The engineer is in the car, the engine is running and the CANCorder is connected to the CAN bus of the vehicle. Now the engineer is moving the steering wheel to the left and to the right, while recording the whole data set on the CAN bus.

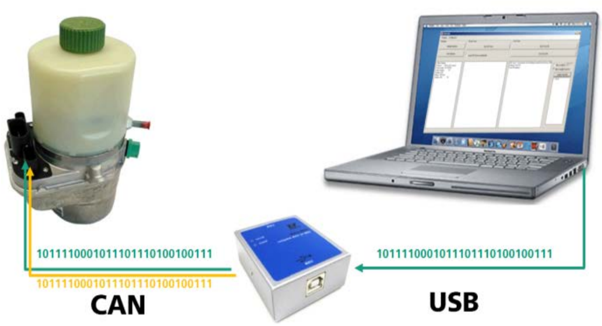

Fig. 3.8.6 Playback of CAN bus data

After that he does some comments and adds some properties to the new database file, containing the recorded CAN bus data. Next, let us assume, the engineer has only the EHPS pump with the electronic control unit (ECU) available, but not the whole car. Now it is possible to control the EHPS pump by connecting it to the CANCorder and by replaying the previously stored file (Fig. 3.8.5). In the best case the EHPS pump is then moving and has the behavior similar it has had in the vehicle (Figs. 3.8.6, 3.8.7).

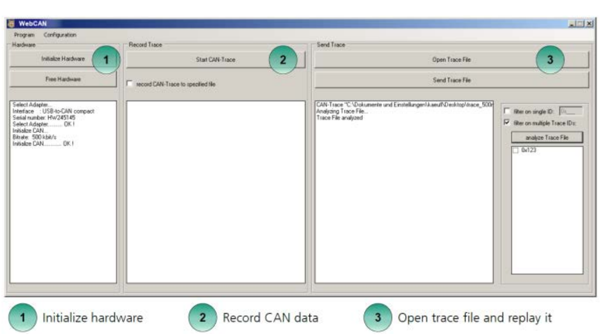

Fig. 3.8.7 CANCorder user interface

7 Web CAN

The second part of the new tool is called WebCAN. The WebCAN is an extension for the CANCorder to make the data public in the world wide web by using a forum. The web site, containing the secured data in a database, is based upon a forum, which can be programmed in a language called “phpBB”. In this forum registered users can discuss specific topics, as well as upload and download data (Fig. 3.8.8). For uploading they can obtain credit points. For downloading data, they have to pay or they have to use their obtained credit points. The probability to obtain the data, searched for, is getting higher the more users are uploading data to the WebCAN forum. The conclusion is that the engineering part in diagnostics can be reduced by using information from other users who have been faced with a similar problem before.

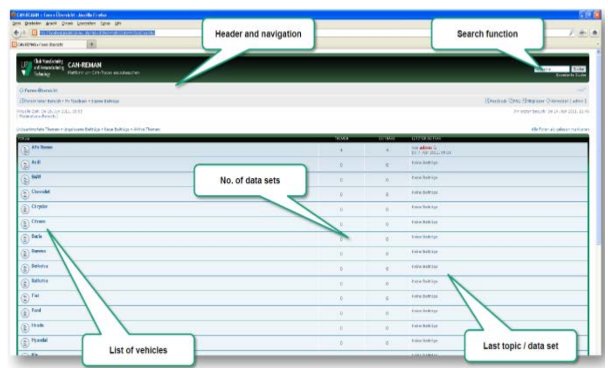

Fig. 3.8.8 WebCAN forum web site

8 Conclusion

An ever increasing number of mechatronic and electronic systems is built into today’s vehicles. In the future, even more of these systems will be introduced to the cars as a result of increasing demand for comfort, safety and reduced fuel consumption. Remanufacturing of complex interconnected mechatronic systems offers a great opportunity, but also huge challenges.

Independent remanufacturing companies have to reverse engineer the functionality of the systems most of communicating via CAN bus. The paper shows methodological innovations as well as developed new technologies, especially focusing on CAN bus recording, analyses and diagnostics of automotive systems. The reverse engineering process is demonstrated on the example of automotive steering systems. The developed application CAN CORDER makes it more efficient to record, analyze and play back CAN bus communication, to enable independent companies to remanufacture and test modern automotive mechatronic and electronic systems.

Furthermore the paper shows for the first time the new application WEB CAN. WEB CAN makes it possible to easily share CAN bus data with other companies or research institutes to build up a broad CAN bus data archive. This will help remanufacturing companies to extend their portfolio on remanufactured automotive mechatronic and electronic systems.

9 Acknowledgements

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Chapter 4:

Product Design for Resources Efficiency and Effectiveness

4.1 Context-Aware Smart Sustainable Factories: Technological Framework

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Abstract

A growing number of research efforts have been undertaken in the area of flexible, ecological and energy efficient manufacturing systems as steps towards the low carbon economy. One of such directions is Sustainable manufacturing assuming resource-efficient, competitive, low-cost and renewable resource-oriented production. In this paper an approach to support of sustainable manufacturing based on the idea of smart factory is proposed. The approach incorporates such technologies as ontology and context management, competence profiling, and smart environment. The ontology and context management technologies enable for unification and formalization of the domain description. The competence profiling simplifies choosing the right person, machine, resource in a particular situation. The smart environment integrates devices (smart factory equipment, information systems, sensors, etc.) that can share information and services. Smart environments based on ubiquitous computing extend boundaries of automation in manufacturing environments due to flexible and seamless integration of different sensors, warehouse management systems, intelligent machine control systems, etc.

Keywords:

Smart factory, SOA, Ontology, Context, Constraint satisfaction

1 Introduction

Evolving of flexible, ecological and energy efficient manufacturing systems can be considered as one of the significant steps towards the knowledge-based green ICT (Information & Communication Technologies) applications in low carbon economy. Above regard a growing number of research directions have been developed in this area. One of such directions is sustainable manufacturing assuming be resource-efficient, competitive, low-cost and renewable resource-oriented production. Development of ICT offers new solutions facilitating appearance of sustainable factories.

New information technologies open new boundaries for researchers. The recently appeared technology of smart environment is one of such steps towards the information-driven collaboration. Smart environment can be defined as a physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives, and connected through a continuous network [1]. This term is closely related to other terms as ubiquitous computing, pervasive computing, smart space and similar. These areas significantly overlap each other [2]. In this paper the smart environment is defined here as a number of devices that can share information and services independently of their physical location.

Sharing information in smart sustainable factories is extremely important and since factories have various equipment often uncoordinated and independent, efficient information sharing in smart factories is complicated. The possibility to share information and services between different equipment units independently of their physical location could be beneficial for smart factories. For example, the possibility to capture information at any stage of the production process would enable permanent automated production control and quality management.

In this paper an approach to support sustainable manufacturing based on the idea of smart factory is proposed. This work is work-in-progress and the paper proposes conceptual ideas for their further development. Smart factory is a factory that is context-aware and assists people and machines in execution of their tasks by using context [3]. The context is any information describing the current situation (e.g., location of a resource, current conditions affecting the choice of preferable processing mode, etc.). The approach incorporates such technologies as ontology and context management, competence profiling, and smart environment. The ontology and context management technologies enable for unification and formalization of the domain description. The competence profiling simplifies choosing the right person, machine, resource in a particular situation. The smart environment integrates factory equipment that can share information and services. Smart environments based on ubiquitous computing extend boundaries of automation in manufacturing environments due to flexible and seamless integration of different sensors, warehouse management systems, intelligent machine control systems, etc.

The paper is structured as follows. Section 2 describes application of the smart environment to smart sustainable factories. The service-oriented architecture of the smart factory is presents in Sect. 3. Section 4 explains the context-aware information management. Section 5 describes

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application of the ontology management technology to interaction between smart factory elements. The major results are summarised in conclusion.

2 Smart Environment

Issues investigated in the approach are oriented at application of the idea of smart environments. Actors of the smart environment expect the resources of this environment to be capable to cooperate [4]. The approach considers the actors to be smart factory equipment, information systems, sensors, etc.

It is supposed that in the smart environment there are resources capable to perform same functions or fill same roles. A simple example of different resources that can fill the same role is patrallel production lines with the same functionality.

The idea behind the approach is self-organisation of the resources of the smart environment according to a situation that takes place in this environment. The purpose of the resources self-organisation is taking joint actions to adjust production processes of the smart factory based on new orders, equipment malfunctions, etc. At that an efficient community of the resources is supposed to be organised. As criteria of the efficiency resources' functionalities, availabilities, reliabilities, access times, and costs are used.

In the approach the resources of a smart environment are represented by Web-services. This representation allows self-organisation of the resources to be replaced with that of the Web-services (see Sect. 3).

Figure 4.1.1 shows interaction between actors of the smart environment. One actor (e.g. production manager) can send some information to another actor (e.g., automated warehousing system) or get information from it. One device can also send information to another device without any human intervention. Ontology in the smart environment allows actors to interact with each other and exchange knowledge for the interoperability.

3 SOA-Based Smart Factory Architecture

The approach originally presented in [5] is based on the idea to characterize all elements of a complex system by their roles and to describe them via profiles. The profiles are associated with services that negotiate to take into account their explicit and tacit preferences. The negotiation can be based on the constraint-based contract net protocol developed by the authors [6].

This paper extends the above approach via application of SOA and smart environment. The extended approach integrates efficient sharing of information in the smart environment with service-oriented architecture taking into account the dynamic nature of the smart sustainable factory. For this purpose the models proposed are actualized in accordance with the current situation. An ontological model is used in the approach to solve the problem of service heterogeneity. This model makes it possible to enable interoperability between heterogeneous information services due to provision of their common semantics [7]. Application of the context model makes it possible to reduce the amount of information to be processed. This model enables management of information relevant for the current situation [8]. The access to the services, information acquisition, transfer, and processing (including integration) are performed via usage of the technology of Web-services.

Figure 4.1.2 represents the generic scheme of the SOA-based smart factory architecture. The main idea of the approach is to represent the smart factory elements (smart factory equipment, information systems, sensors, etc., earlier referred to as smart environment actors) by sets of services provided by them. This makes it possible to replace the information sharing between smart factory elements with that of distributed services. For the purpose of interoperability the services are represented by Web-services using the common notation described by the application ontology. Depending on the considered problem the relevant part of the application ontology is selected forming the abstract context that, in turn, is filled with values from the sources resulting in the operational context.

Figure 4.1.2 basically repeats Fig. 4.1.1 but extends its technical details. One can see the corresponding levels at the left hand side of Fig. 4.1.1.

The service-oriented architecture has a number of advantages resulting from its principles [9]. Among these the following once should be mentioned (the specifics related to flexible supply network modelling are indicated with italic):

1. **Service Autonomy**. Services engineered for autonomy exercise a high degree of control over their underlying run-time execution environment. Autonomy, in this context, represents the level of independence which a service can exert over its functional logic. *With regard to smart factory the autonomy also reflects independence of the actors, which in real life are often independent*.

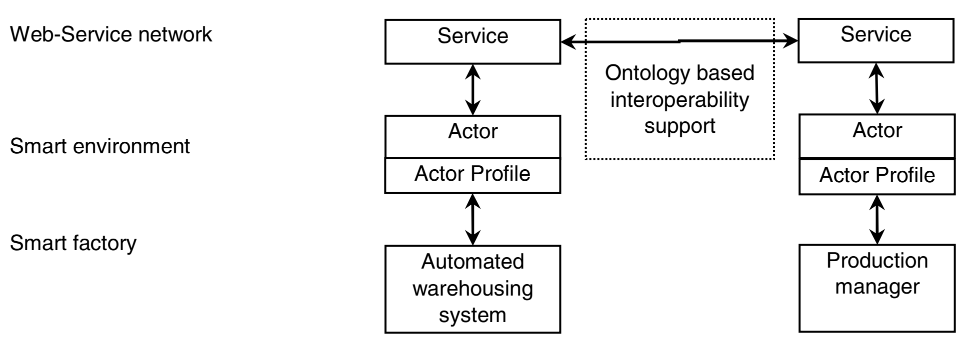

Fig. 4.1.1 User and device interaction in the smart environment

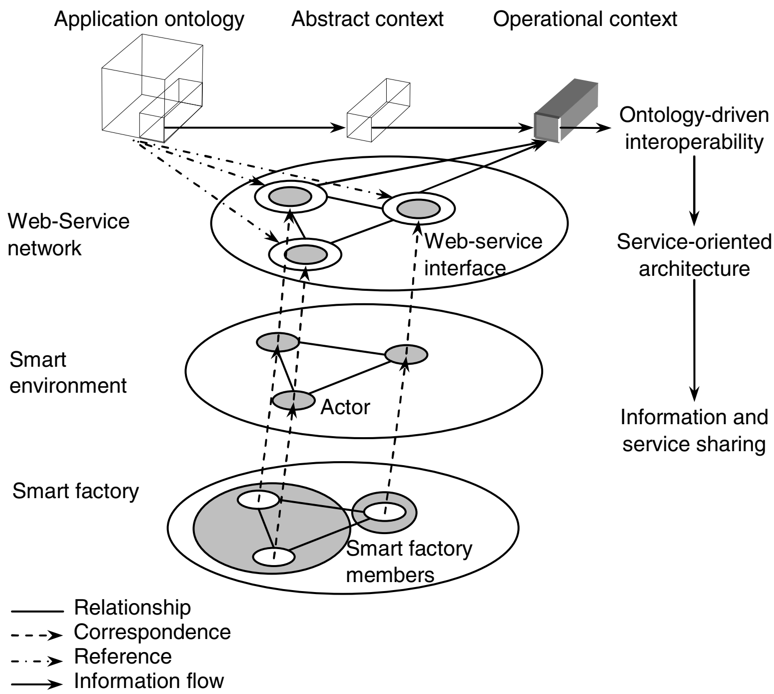

Fig. 4.1.2 SOA-based smart factory architecture

2. **Service Abstraction**. Further supporting service autonomy, service-oriented architecture advocates that the scope and content of a service's interface be both explicitly described and limited to that which is absolutely necessary for the service to be effectively employed. Beyond the service interface, abstraction applies to any information, in any form, describing aspects of the service's design, implementation, employed technologies, etc. *This principle helps to abstract from real services provided by the actors and concentrate on their representation via Web-services.*
3. **Service Standardisation.** As services are typically distributed throughout networks, they must be easily accessible by other entities in terms of discoverability and consequential invocation. Given this requirement, service-oriented architecture recommends that services adhere to standards, including, for example, standards for the language used to describe a service to prospective consumers. *In the proposed approach the standardisation is achieved via usage of the common standards such as WSDL and SOAP as well as common terminology described by AO. As a result the services constituting the network are fully interoperable and can communicate with each other without any problems.*
4. **Service Reusability.** Reusability is a central property of any successful service. It denotes the capacity of a service to be employed in support of not just one but rather a variety of business models. Service-oriented architecture promotes such functional reuse through stipulations for service autonomy and interface abstraction. With these features, the same service can be invoked by multiple consumers, operating in various business domains, without requiring the service provider to re-code service internals for each application domain. *Service reusability significantly facilitates the service development process and decreases the amount of work required. Besides, the existing services of PLM network members can be used.*

In [9] two more service-oriented architecture principles are defined, namely **service composability** and **service discovery**. However, in the presented approach the benefits from them are not as high as from those described above in detail.

4 Context-Aware Information Management

The main idea behind the methodology framework consists of (i) creation of an ontology-based model of the problem to be solved or of the situation and (ii) solving the problem as a Constraint satisfaction problem (CSP). A situation is considered as the problem model where the data values change over time.

The methodology relies upon a heavy central application ontology (AO) representing knowledge of the application domain. To ensure compatibility of ontology-based knowledge representation and CSP, the formalism of object-oriented constraint networks (OOCN) [10] is used for AO specification. CSP model consists of a set of variables; a set of possible values for each variable (its domain); and a set of constraints restricting the values that the variables can simultaneously take.

The OOCN paradigm defines the common ontology notation used in the system. According to this representation an ontology (A) is defined as: $A = (O, Q, D, C)$ where: O—a set of *object classes* ("*classes*"); each of the entities in a class is considered as an *instance* of the class. Q—a set of class attributes ("*attributes*"). D—a set of attribute domains ("*domains*"). C—a set of *constraints*.

For the chosen notation the following six types of constraints have been defined $C = C^I \cup C^{II} \cup C^{III} \cup C^{IV} \cup C^V \cup C^{VI}$: $C^I = \{c^I\}$, $c^I = (o, q)$, $o \in O$, $q \in Q$—accessory of attributes to classes; $C^{II} = \{c^{II}\}$, $c^{II} = (o, q, d)$, $o \in O$, $q \in Q$, $d \in D$—accessory of domains to attributes; $C^{III} = \{c^{III}\}$, $c^{III} = (\{o\}, True \vee False)$, $|\{o\}| \geq 2$, $o \in O$—classes compatibility (compatibility structural constraints); $C^{IV} = \{c^{IV}\}$, $c^{IV} = \langle o', o'', type \rangle$, $o' \in O$, $o'' \in O$, $o' \neq o''$—hierarchical relationships (hierarchical structural constraints) “is a” defining class taxonomy ($type = 0$), and “has part”/“part of” defining class hierarchy ($type = 1$); $C^V = \{c^V\}$, $c^V = (\{o\})$, $|\{o\}| \geq 2$, $o \in O$—associative relationships (“one-level” structural constraints); $C^{VI} = \{c^{VI}\}$, $c^{VI} = f(\{o\}, \{o, q\}) = True \vee False$, $|\{o\}| \geq 0$, $|\{q\}| \geq 0$, $o \in O$, $q \in Q$—functional constraints referring to the names of classes and attributes.

Below, some example constraints are given:

- an attribute *costs* (q_1) belongs to a class *cost centre* (o_1): $c^I_1 = (o_1, q_1)$;
- the attribute *costs* (q_1) belonging to the class *cost centre* (o_1) may take positive values: $c^{II}_1 = (o_1, q_1, R^+)$;
- a class *drilling* (o_2) is compatible with a class *drilling machine* (o_3): $c^{III}_1 = (\{o_2, o_3\}, True)$;
- an instance of the class *cost centre* (o_1) can be a part of an instance of a class *facility* (o_4): $c^{IV}_1 = \langle o_1, o_4, 1 \rangle$;
- the *drilling machine* (o_3) is a *resource* (o_5): $c^{IV}_1 = \langle o_3, o_5, 0 \rangle$;
- an instance of the class *drilling* (o_2) can be connected to an instance of the class *drilling machine* (o_3): $c^V_1 = (o_2, o_3)$;
- the value of the attribute *cost* (q_1) of an instance of the class *facility* (o_4) depends on the values of the attribute *cost* (q_1) of instances of the class *cost centre* (o_1) connected to that instance of the class *facility* and on the number of such instances: $c^{VI}_1 = f(\{o_1\}, \{(o_4, q_1), (o_1, q_1)\})$;

The AO is made up of two constituents: domain and task knowledge. The domain knowledge represents conceptual knowledge about the domain. The task knowledge formalises problems that may require solutions in various situations arising in the application domain. In the AO tasks are represented by classes, input and output arguments of tasks are represented by class attributes.

The AO does not hold instances, i.e. values for attributes of the AO classes are not specified. Instead, the AO refers to Web-services responsible for supplying the data values. Web-service descriptions and the task knowledge are harmonised. Input and output arguments of functions that a Web-service implements correspond to class attributes of the task knowledge. At that, the same attribute can be instantiated by several Web-services. The domain and task knowledge are interrelated by functional constraints showing which attribute of the domain knowledge takes its value as a function of the output argument of a task.

An ontology-based context is composed of knowledge relevant to the current situation. Description of the situation is generated based on the information supplied by smart factory elements (equipment, information systems, sensors, etc.). Based on this information, internal mechanisms extract knowledge relevant to the request from the AO. This knowledge is extracted along with references to Web-services. The extracted knowledge is integrated into the *abstract context* that is an ontology-based model of the situation along with models for problems to be solved.

At the same time, the abstract context is an OOCN. Attributes of the classes of the ontology-based context correspond to variables of the OOCN. Since the AO and correspondingly the abstract context do not contain instances, variables of this OOCN do not have values.

Abstract context is the basis for self-organisation of the Web-services to which the abstract context refers. The Web-services self-organise an ad-hoc service network according to this context. The purposes of the network are to produce a real-time picture of the current situation and to support the decision maker with solutions for the problems to be solved in this situation.

These purposes are achieved through instantiation of the abstract context. Since some attributes specified in the abstract context can refer to several Web-Services, the idea of self-organisation is to pick out from the set of Web-Services being referred, currently available Web-services that the most satisfy user preferences. Preferences can be dependent on various criteria as precision of data, cost/time of the service network organisation, etc.

Web-services trying to organise the service network communicate their needs (input arguments) and possibilities (output arguments) taking into account the user preferences. Since the Web-service descriptions and the AO have been harmonised, the Web-services can use the AO vocabulary for communication.

As soon as a service network is organised, Web-services constituting this network start instantiating attributes specified in the abstract context. Instantiation of the domain knowledge produces a real-time picture of the current situation. Instantiation of the task knowledge produces OOCN with values for the variables. This OOCN can be interpreted as CSP. The instantiated abstract context is an *operational context*.

The Web-services obtain data values as results of (i) interactions with information sources from which data values can be taken and (ii) problem solving. The procedure of the AO creation is supported by the subject experts, knowledge and ontology engineers.

5 Ontology-Based Interaction

The detailed scenario of the ontology-based interaction between the smart environment actors is presented in Fig. 4.1.3 and described below on an example of an information request (referred to as “task”).

An actor of the smart environment generates the task (1). Based on this task, the ontology (its part in the form of the abstract context), and current situation in the smart environment, the operational context is built (2).

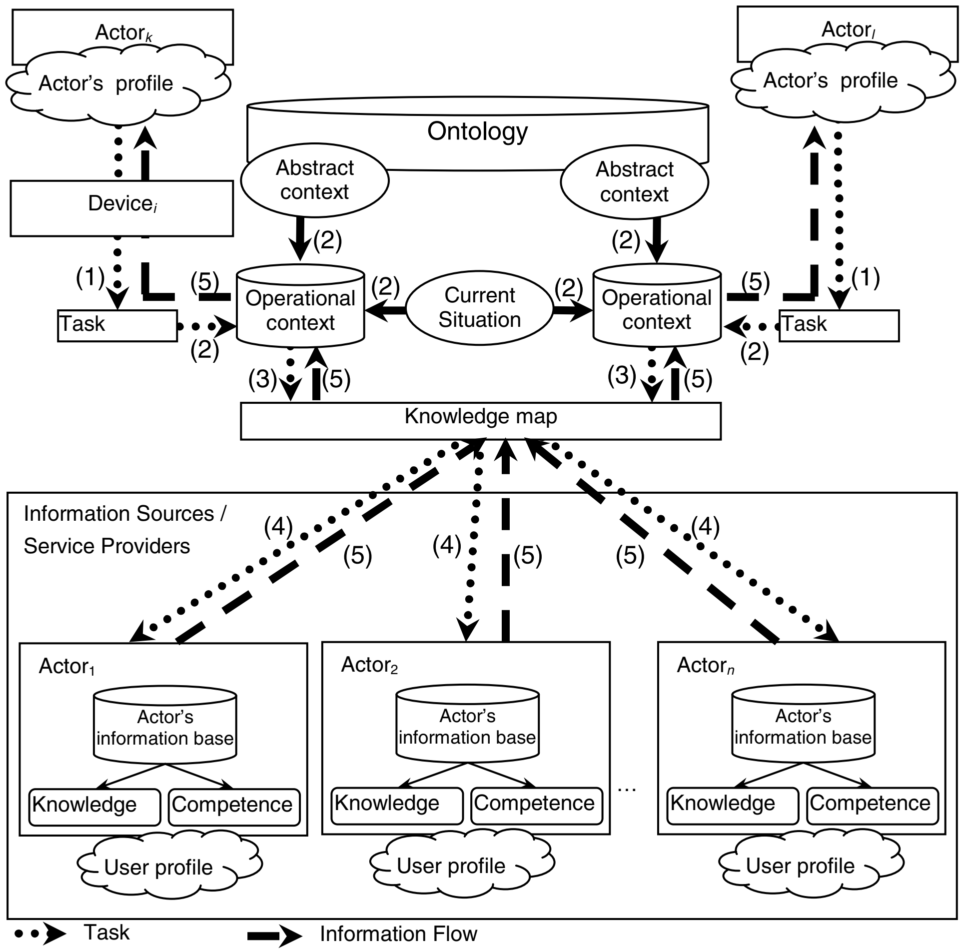

Fig. 4.1.3 Ontology-based interaction in the smart environment

The knowledge map defines references between the ontological model (3) and information sources & members' competences available in the smart environment. The formalised task then is transferred to the appropriate actor(s) (4). This makes it possible to use uncoordinated services as a single distributed system (the smart environment). Based on the knowledge map and the formalized task, the knowledge and information required for the actor are acquired from the appropriate sources (5).

If an actor who is a smart environment member serves as an information source, it provides services for the system to access the owned information. Information about the actor is obtained from its profile. Using this information the smart environment can provide it to other participating actors.

For these purposes, the actor's profile has to contain information about the actor, domain specific information, information that describes its preferences, feedback information and history that contains previous actor's activities in the system. The detailed description of the profile can be found in [5].

6 Summary

The paper presents a conceptual model integrating the smart environment technology and SOA for smart sustainable factory management. SOA makes it possible to abstract from real equipment units, information systems and other actors and represent these via Web-services. Taking into account the described SOA advantages this enables a higher level of abstraction and ontology-based interoperability. Smart environment allows integration of a larger number of smart factory elements.

7 Acknowledgments

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4.2 ICT Enabled Energy Efficiency in Manufacturing

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Abstract

Today, manufacturing is faced with a sustainability paradox in maintaining economic growth while consuming fewer resources. Information communication technology (ICT) has proven central to the performance driven development of modern manufacturing in supporting production systems on all levels. Given this pervasiveness ICT's have an unparalleled opportunity to address this sustainability paradox by enabling energy efficient viable manufacturing. The paper introduces the newly developed REViSITE methodology and taxonomy used and posited as a common means of categorising, comparing and qualitatively assessing ICT impact on energy efficiency. The approach was utilised in identifying that which is homogenous, heterogeneous and synergetic in terms of ICTs and best practices across multiple sectors within the project. This paper outlines ICTs that can support energy efficiency throughout the main lifecycle phases of a production system, identifying current gaps and describing a vision as to where future research technology development (RTD) efforts should focus. Optimizing the energy usage of a production system often has implications that extend beyond its boundaries and as such this paper also highlights potential synergies with the energy grid sector, the built environment and support infrastructure like lighting. Finally, the paper reiterates some of the more important ICT elements to consider throughout the Manufacturing lifecycleand re-emphasises the opportunity ICTs have for integrating manufacturing into a wider sustainable eco-system.

Keywords:

Energy efficiency, Enabling impact, Information communication technology, ICT, Methodology, Smart manufacturing

1 Introduction

1.1 Manufacturing the Case for ICT Enabled EE

In 2008, European Commission President José Manuel Barroso stated "...the real gains will come from ICT as an enabler to improve energy efficiency across the economy... especially in ... energy intensive sectors [1]. In 2011, President Barroso suggested "...Since our best source of energy is in fact energy efficiency, and also considering the prices of energy, I think it is important from all points of view to achieve real progress of energy efficiency very soon…' [2].

Manufacturing accounts for ~20% of EU27 energy consumption [3]. The need for manufacturers to imbed sustainability as a prime decision criterion is becoming increasingly evident given increased energy costs, regulation and shareholder cognisance in terms of ecological impact. As they become conscious of the business and ecological case for good corporate citizenship companies are moving from a reactive attitude, of only meeting legislative regulations, to a proactive behaviour, of improving the environmental impact not only of their products but also of their manufacturing and business processes.

The enabling role of ICT appears inherently apparent, yet understanding which ICT's are best positioned to deliver meaningful impact is less evident. Mindful of this challenge the main aim of the REViSITE project is the development of a common cross-sectoral ICT enabled energy efficiency (ICT4EE) roadmap that identifies synergies for positively impacting energy across four target sectors—namely Smart-Grids, Buildings, Manufacturing and Lighting.

1.2 REViSITE Framework and Approach Justification

While desirable, in practice, quantitatively assess the impact of ICT on energy efficiency is often an arduous process. Situations where an existing system and a replacement ICT enabled system can be directly measured are not so common. Where feasible, the task is often complicated in that the replacement system rarely differs from the old with respect to just the ICT element, while in some cases the impact may reside in a different life cycle phase or sector.

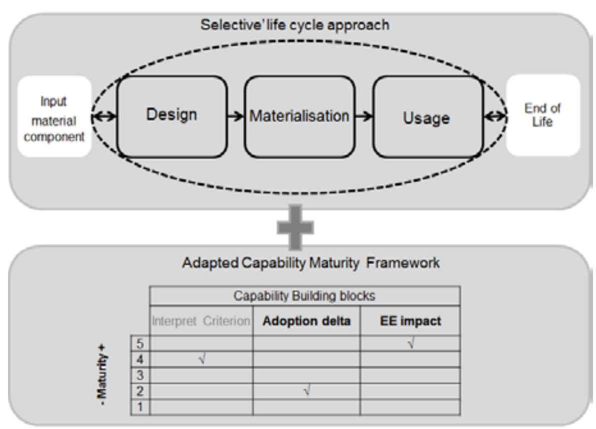

Fig. 4.2.1 Combining life cycle thinking and CMF

Typically, in scenarios where opportunity for direct quantitative comparison is limited, some form of estimation is required based on heuristics, part-measurement, secondary data and specialist knowledge etc. In that vein, the REViSITE framework combines 'Life cycle thinking' and an adapted

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'capability maturity framework' (CMF) to build an 'informed view' (Fig. 4.2.1) regarding those ICTs best positioned to positively impact on energy efficiency. Within REViSITE we define 'energy efficiency' as 'a process that uses less energy per unit of service.

1.3 The Need for a Taxonomy

Before comparing different sectors it is essential to first speak a common technical language so as to compare 'like with like'. The REViSITE developed SMARTT taxonomy utilises six high level categories with sub-categories nested within these. The high level categories are aligned to a generic bounded life cycle (Fig. 4.2.2). This life cycle offers an overarching structure with which the four target sectors could relate. Both categories and sub-categories are fixed and deemed to cover the scope of the ICT4EE domain allowing for common categorisation of ICT themes across sectors. Individual ICT themes are nested within the sub-categories. The categories 'Specification & design ICTs', 'Materialisation ICTs' and 'Automation & operation support ICTs' all vertically align to the bounded life cycle phases. 'Resource & process management' together with 'Technical integration' are horizontal themes, while 'Trading/transactional management ICTs' aligns primarily to the 'usage' life cycle phase.

1.4 Use of the Framework/Taxonomy

The framework was used throughout the project as a research guide, as an analysis tool and to frame research write-up. Specifically the life cycle aligned SMARTT taxonomy was utilised as an integrative classification system and as an aid to cross sector ICT4EE assessment.

The capability maturity element of the framework was utilised initially to assist in conceptualising the likely magnitude of impact with regard to the ICT themes identified. A survey based on an adapted CMF was subsequently used to rate the 23 sub-categories in terms of relevance for a future strategic research agenda (SRA), potential impact and vision development.

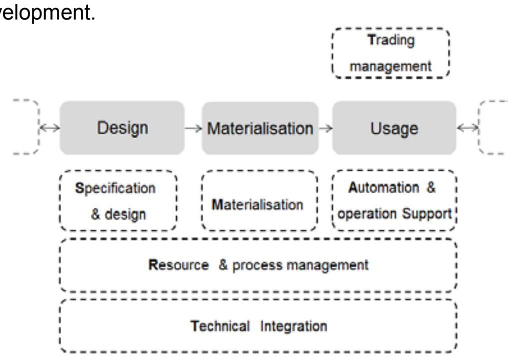

Fig. 4.2.2 SMARTT taxonomy mapped to life cycle phases

2 ICT4EE in Manufacturing an Overview

2.1 ICT4EE: Knowledge and Current Practice

During recent decades industry moved from traditional labour intensive structures towards the use of automated production technology and in fact today's modern manufacturing cannot be envisaged without the support of ICT [4]. Achieving holistic energy efficiency in manufacturing requires the optimization of all three parts of a production system (product, processes and resources) and on different levels from enterprise down to machine or process level.

Moving forward ICT will act as the communication backbone enabling a sustainable manufacturing network through all life cycle phases of a production system. Using the REViSITE SMARTT taxonomy as a classification system, promising ICTswere identified in terms of ICT4EE manufacturing [5]. And what follows highlights such ICTs, current practice as well as gaps which should be addressed in future research work.

ICTs in Specification and Design Phase

The planning phase of a production system is well supported by various ICTs. Starting in the early definition phase with requirement management tools, followed by CAD tools for the detailed design of resources as well as computer aided process planning (CAPP) and CAM tools for the planning of processes and machine operations (e.g. generation of NC files) and finally various simulation tools for validation and verification of the future production systems (e.g. material flow simulations). All tools can be summarized under the concept of the "digital factory" [6] and all required information and data are managed in product lifecycle management (PLM) systems which also support the integration of other IT solutions used throughout the whole product lifecycle, not only in the product development phase. However, especially in manufacturing planning, tools remain isolated. As such, fully integrated planning and validation of complete production systems and manufacturing process chains has yet to be achieved [7].

Even though decisions in the design phase influence significantly the energy consumption in the usage phase of a production system, energy related aspects are rarely considered due to absent methodical support in the factory planning phase [8, 9]. Specifically energy performance requirements are seldom captured in the specification phase, electronic catalogues of resources or process templates poorly cover energy consumption, while energy dependency aspects are typically not considered in early stages. The result being holistic energy simulation is not supported while decisions are not verified by evaluating and accessing the energy consumption of the future production system.

ICTs in Materialisation Phase

The term materialisation refers in this content to the formation of a production system, this encompassesthe building, setting up the production equipment within the factory but also implementation of control and automation ICTs as well as any retrofitting. From an energy consumption perspective this phase is dominated by the construction of the building and the transport and erection of the building components including the production equipment (e.g. machines). This phase is supported by conventional logistical and project management software mainly from the construction sector. In terms of EE, ICTs tools should be used to define strategies and support decisions for on-site/off-site production of components of the building but also of large production equipment as well as the optimization of its transportation and the selection of ideally local suppliers.

ICTs in Usage Phase

The usage phase of a production system is identical to the manufacturing phase of the product being produced and is mainly assisted by ICT in terms of automation, status and process monitoring as well as controlling and scheduling of production tasks.As in the design phase ICTs for automation and control of manufacturing processes includes methods and technologies on different levels. On the machine level, resources are controlled with programmable logic controllers (PLC), which are responsible for controlling single machine tasks on the lowest level. Machine data and operating data which can be acquired by means of supervisory control and data acquisition (SCADA) systems for example, are processed by manufacturing execution systems (MES) and used for controlling purposes. Production planning and control systems (PPC) assist the management and scheduling of the overall production processes. "The energy consumption [in the usage phase] of manufacturing facilities can be reduced by either using more efficient technologies and equipment, and/or through improved monitoring and control of energy used in infrastructure and technical services" [10]. In both cases ICT is essential.

ICT has a significant impact in the field of smart motor systems for the intelligent load adjusted control of electrical drives [11], and compressed air systems. Furthermore energy must be taken into account not only within the control of electrical drives but also for the control of the entire machine (e.g. optimized NC programs or the selective switch off of components).

In the field of improved monitoring and control it is first essential to set up a wide network of sensors on machine or even component level, in order to understand where and how much energy is being consumed. ICT can additionally support the analyses and visualization in terms of (automated) operational decision support. A further application is condition based maintenance, whereby the condition of production equipment is monitored in order to launch preventative or even predictive maintenance activities.

Resource and Process Management ICTs

Resource and financial controlling in manufacturing is carried out with the assistance of enterprise resource planning (ERP), PPC Systems or MES. But energy efficiency is not in scope of scheduling or process planning and control yet [12]. ICT should be utilised in a way that takes abroader account of traditional business objectives by including energy efficiency. Energy optimized production schedules impact directly on EE e.g. by reduction of still-stand times with high base load power consumptions, cutting of energy intensive re-tooling, re-arrangements or start-upsor avoidingunproductive consumptions during idle time. Further more energy intensive tasks should be scheduled when the lowest economic and ecological effects are to be expected and macroeconomic energy consumption peak loadsare avoided. Additionally, in terms of intra logistics planning reduced inventory can assist in saving energy by reducing logistical efforts and/or be optimising storage HVAC control. In the wider scope of production networks, supply chain management (SCM) Tools are used for optimizing logistics and the flow of goods, which offers potential to optimize overall energy consumption of production networks.

In terms of knowledge sharing, ICT offers high potentials by providing decision makers with energy relevant information. Current tools for energy auditing assist professional consultants by covering data collection and analysis functions. Further more information platforms for a wider audience are required, which visualize energy consumption of a factory on different levels taking into account energy related KPIs. These KPIs should also be used for benchmarking or even for energy efficiency labels for machines or processes. Guidelines and knowledge repositories are required for assisting in design of energy efficient production equipment as well as processes. In this case especially for manufacturing process a reliable database is required for listing statistical data for energy consumption and CO_2 emissions [13].

Technical integration ICTs and Interoperability

When it comes to the interaction of different ICTs integration and interoperability is the main issue. With regard to energy efficiency in planning and operation of production systems, the integration of energy consumption data in ERP and PLM systems is essential for the realisation of ecological in addition totypical objectives (e.g. cost, time quality) [14]. For this reason interfaces with automation software and sensors are required to feedback energy consumption data from the shop floor into MES as well as back into ERP or PLM. In the design phase the integrated development and simulation of a product and its manufacturing processes has potential for increased energy efficiency in manufacturing [15]. Products can be designed for efficient manufacturing processes, whereas the constraints of the machine tools are taken into account in an early stage. ICT is an enabler to this kind of development and supports understanding with regarding the complex interdependencies between product design and manufacturing processes planning. The integration of shop floor data in planning tools can also be used for real-time simulations of manufacturing factories to predict interdependencies, optimise manufacturing processes and simulate the flexibility of the factory in the usage phase.

Trading/Transactional Management ICTs

Energy management systems are used for managing, monitoring and reducing energy consumption of complex systems [16] and enable the integrated planning, monitoring, control and optimization of energy usage at plant level. The main scope of these systems is the identification of energy loses and the prevention of load peaks. Even though there is a wide range of functionalities, the use of energy management is still not standard in industries. Apart from the independent energy management of production machines and processes other subsystems of the factory building such as heating, lighting and compressed air subsystems need to be integrated into a holistic energy management system, a fact supported by recent research activities [17]. However, holistic energy efficient control of production sites extends beyond facility boarders. It includes traditional factors such as production time, production rate and quality as well as energy efficiency, but it also takes into account the energy market dynamic which is complex due to growing number of deterministic energy sources such as wind turbines. This includes for instance aspects such as shifting workloads of (secondary) processes to avoid energy demand peaks or benefit from temporarily decreasing energy costs.

2.2 Smart Manufacturing: Links to Other Sectors

Within the REViSITE project ‘Smart manufacturing’ is defined as the use of ICT technologies for the efficient and effective use of man, method, machine and material in ensuring the sustainability of the enterprise, its environment and the resources it consumes’. The latter aspect of this definition leads us to discuss a production system in the context of it being a ‘cog’ in a larger energy eco-system. Optimizing the energy usage of a production system requires a holistic approach in terms of its interaction with the infrastructure of that eco-system. What follows briefly outlines the importantrole ICT plays and will play in delivering future energy efficient smart manufacturing facilities through intelligent integration with the other target sectors of the REViSITE project.

Links to Smart Grids Sector

Manufacturing sites are major consumers of energy. Understanding the impact of manufacturing schedules on energy supply and demand will be crucial to the grid. Automated monitoring and control that incorporates energy efficiency logic will be paramount in delivering sustainable smart manufacturing. The individual energy consumption of production equipment, sensors, control units and networking technologies have to be understood and considered in delivering sustainable operation at machine and plant level.

Within the distributed vision of the smart grid, buildings have a unique role to play as prosumers of energy. Manufacturing can be considered a special case of buildings and the sheer volume of energy consumption involved will be crucial to the management of distributed smart grids. Manufacturing facilities also have the potential to operate as middle scale energy producers and to act as storage to the grid via thermal, compressed air and pumped energy storage for example.

Under distributed grid scenarios manufacturing facilities could act as power generators to the grid and the on-site solar and wind capability and patterns need to be integrated with the wider grid. This might not deliver energy efficiency per say but it would positively impact on carbon intensity of the Manufacturing sector and energy efficiency of the wider grid.

Links to the Built Environment

Buildings and the manufacture of building materials/products is the largest contributor to energy consumption and related CO2e within the EU. Manufacturing has an important role to play in reducing the embodied energy of building materials and sub-components that go into the construction and retro-fit of buildings. Also it must be considered that, manufacturing facilities themselves are housed within built environments.

To that point, a significant proportion of energy consumed in manufacturing systems is attributable to supporting infrastructure (HVAC & Lighting etc.) of factory buildings. In fact within service environments the energy footprint of the building essentially constitutes the energy intensity of the product/service offering.

There is considerable cross-over opportunity in terms of holistic echo-design ICTs in the planning phase of production systems and the buildings that house those systems. While in the usage phase automation, operational decision support and control ICTs should prove particularly synergetic. In the usage/operational phase there is also opportunity for reduced maintenance or a move to predictive maintenance models that may deliver energy gains through optimal operation.

The connection between manufacturing facilities and the built environment is apparent, with the number of organisations that actively seek building certification testimony to the competitive advantage efficient buildings hold or are destined to hold in the market place of manufactured products.

Links to Lighting Sector

At a machine level but perhaps beyond the scope of REViSITE the use of photonics in terms of optical control and lasers has had considerable impact on manufacturing and the energy efficiency of same. In an extension of digital-mock-up prototypes can be created directly from the CAD through the use of laser irradiation. When viewed from this perspective the use of light as a tool in manufacturing processes is quite pervasive from the use of laser welding in automotive production to more complicated photolithography in semi-conductor manufacturing.However, in the context of REViSITE the connection between manufacturing and lighting is essentially limited to 'eco-design' and 'automated control', or 'decision support' regarding control, of lighting in production facilities

2.3 ICTs Deemed Most Relevant to Strategic Research Agenda Development

Figures 4.2.3 and 4.2.4 show the results of the REViSITE survey and analysis as they relate to manufacturing,whereby respondents rated current adoption, potential adoption and potential impact. The results were compared against the following key RTDs identified by a manufacturing break-out group—see [17]:

- Energy related methods and functions in planning and design tools for production systems (digital factory).
- Scheduling ICTs (ERP, MES, PPC) with respect to energy efficiency.
- Energy efficiency as an optimization criterion for control systems of machines (e.g. path planning for NC machines or robots, selective switch off of components).
- Decision support tools for designing global value creation networks (logistics).
- Smart motor systems for production equipment.
- Intelligent control of compressed air systems.

These key RTDs were in the main consistent with the qualitative survey answers. However, the trending of Figs. 4.2.3 and 4.2.4 offers greater detail for SRA consideration and some initial observations follow:

Sensing and understanding exactly where energy is consumed within the factory is the prime issue within Manufacturing. This is supported by the fact that four of top five ICTs from Fig. 4.2.3 relate to sensing, monitoring, mining and analysing the energy consumption of the operational phase from process up to plant level. Automation is clearly the category with highest relevance. However, itis the most easily relatable to direct energy impact.

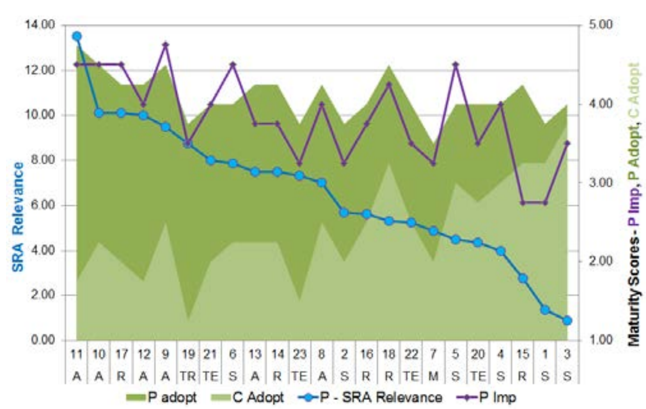

Fig. 4.2.3 Manufacturing ranking graph

MFG : P - SRA [Relevance] = P Imp * (P Adopt - C Adopt)

SMART T cat.	ICT Theme no.	ICT Theme description	Adoption Delta	Highest C Adopt
A	11	Inference sensing Software & algorithms for pattern & signal identification at machine, plant or building level	3.00	Grids
A	10	Software & algorithms for operational monitoring & actuation of devices at machine, plant or building level	2.25	Grids
R	17	ICTs for data mining & analytics in terms of energy consumption & optimisation, pattern identification, predictive diagnostics & analytics at enterprise or network level	2.25	Grids
A	12	Operational decision support ICTs that integrate high level diverse systems such as safety, security, weather and energy etc. at individual, building or district level for near real-time decision making	2.50	Grids
A	9	Embedded intelligent devices (micro architecture)for operational control, sensing & actuation at machine, plant or building level	2.00	Grids
TR	19	Trading & Energy Brokerage ICTs e.g. Consumer/Producer forecasting algorithms, energy source tracking, consumption/price negotiation	2.50	Grids
TE	21	Real-time analytical technologies such as Complex Event Processing and in-memory databases for enhanced operational control and awareness	2.00	Grids
S	6	Product/component specification and selection ICTs E.G. material characteristic database specifying embedded energy, recyclability, thermal performance etc.	1.75	Built E / Grids
A	13	User Centred Data Visualisation ICTs to support system state awareness by human operators / users	2.00	Grids
R	14	Inter-Enterprise ICTs for supporting coordination e.g. contract & supply-network management in the context of reduced energy consumption	2.00	MFG / Grids
TE	23	Use of cloud based services for tasks such as data management, monitoring and analysis	2.25	Grids
A	8	Secure/resilient wired, wireless and optical infrastructure for operational communication, monitoring & control	1.75	Grids
S	2	Human factors Engineering ICTs to gather and model data describing the behaviour of end users/energy consumers	1.75	Grids
R	16	Knowledge sharing ICTs, knowledge management, knowledge repositories, knowledge mining and semantic search, linked data, long-term data archival and recovery at enterprise or inter-enterprise level	1.50	MFG / Grids
R	18	Modelling & simulation ICTs e.g. What-if scenario planning continuous improvement across a sectors life cycle	1.25	MFG
TE	22	Integration technologies / approaches such as service orientation and event driven architectures to facilitate heterogeneous device data interoperability at enterprise, network and environment level	1.50	MFG
M	7	Mobile Decision Support ICTs that utilise real-time communication to facilitate in the field decision making particularly in construction or civil engineering tasks	1.50	Grids
S	5	Simulation ICTs for predicting/estimating the dynamic behaviour of a system as part of the design function E.G. Computational Fluid dynamics, Finite element mode analysis, power system simulation etc.	1.00	MFG / Grid
TE	20	ICT standards and protocols for interoperability across heterogeneous devices at an enterprise, network or environmental level	1.25	Light / Grids
S	4	Causal Modelling ICTs used to describe / predict relationships in physical systems E.G. computer-aided diagramming (e.g. Sankey, Cause and effect, influence diagrams etc.), Life cycle modelling, statistical packages such as JMP & MatLab etc.	1.00	MFG
R	15	Business Process Integration & collaboration ICTs E.g. collaboration support, groupware tools, electronic conferencing, social-media, etc.	1.00	MFG
S	1	Design conceptualisation ICTs for requirement engineering & ideation. E.G. Quality Function Deployment, Mind maps etc.	0.50	MFG
S	3	Visual / spatial design ICTs E.G. CAD (Autodesk, 3D studio max), Multimedia (e.g. Flash, Silverlight), Graphics (e.g. Photoshop, Illustrator) for digital mock-up etc.	0.25	MFG

Fig. 4.2.4 Manufacturing potential SRA ranking

Analysing the top 11 in Fig. 4.2.3, it would seem there is need for strong interoperability with smart grids given the automation focus and real-time decisions that will drive sustainable manufacturing. That relationship will most likely be channelled through the factories building infrastructure. Data visualisation and operational support will be paramount as will energy trading and consumer producer forecasting given the likely volatility of energy markets.

ICTs for design ranked lower than expected given the main aspects of energy consumption are defined in this phase.The reason may be that while recognised as important the design phase is generally already well supported albeit energy is currently only partly taken into account in practice. This interpretation is supported in the figures whereby we have high 'Potential Impact' and 'Potential Adoption' but low SRA relevance given high 'Current Adoption' scores, [S4 & S5 above being examples of this].

3 Summary, Vision and Conclusion

Renewable energy sources (RES) coupled with improved energy efficiency is central to achieving European energy security and sustainability targets [4]. ICT pervasiveness offers unique opportunity to address these challenges by enabling a sustainable cross-sectorial energy network.

Manufacturing, being a vital cog in that network, was studied with respect to sustainable ICT-enabled manufacturing and its integration into a wider energy eco-system. The value of the posited REViSITE framework is that it offers a 'useful lens' into the ICT technologies, practices and research of that eco-system, thus enabling cross-pollination of best practice. The framework in combining 'Life cycle thinking' and an adapted CMF builds an 'informed view' of ICTs best positioned to positively impact on energy efficiency by leveraging part-measurement, secondary data and domain heuristics.

In the context of manufacturing the REViSITE research has identified ICTs both in terms of their potential impact on energy efficiency and relevance to cross sectorial SRA development (Figs. 4.2.3, 4.2.4). The research affirms the important role manufacturing will play in reducing the embodied energy of materials, components and products that permeate our society.

The REViSITE vision sees sustainable manufacturing and its output having immense positive impact on the built environment that houses it and the energy grids that supports it. For example, manufacturing offers the potential to operate as middle scale energy producers and storage to the grid, while energy intensive tasks can be scheduled to optimally balance network load.

But to realise this vision we must adopt a holistic lifecycle approach that leverage the ubiquity of ICT and recognise the dominate theme of interoperability. In conclusion we reiterate some of the more important ICT themes and elements to consider throughout the Manufacturing life cycle:

Full integration and validation of complete production systems and manufacturing process chains need to be achieved, energy performance requirements need to be captured in the specification phase, with energy dependency aspects considered in early design/planning stages. Themes to consider are:

- The concepts of eco-design and the digital factory are paramount.
- ICT for rationalisation/selection of components for better EE.
- Electronic catalogues of resources/processes including relevant attributes of EE.

The importance of ‘automation and operational decision support ICTs’ was perhaps unsurprisingly born-out in the research. Themes to consider are:

- Embedded ICTs for sensing energy consumption of production equipment
- Control units and networking technologies that provide intelligence in terms monitoring and control for sustainable operation at machine and plant level.
- Predictive controls algorithms for solving optimisation problems in real time to gether with energy consumption prediction at each level of a production system.
- Interoperability is crucial for realisation of true sustainable manufacturing.

From a horizontal life cycle perspective three words permeate the REViSITE research—Integration, Interoperability and standards. Themes to consider are:

- Universal control and communication protocol standards for system integration and interoperability need to be agreed and adopted.
- Regulations and market models take into account the environmental aspects and ethical concerns of citizens.
- Energy performance estimation tools.
- Enhanced value-driven business processes and ICT enabled business models.
- ICTs to facilitate virtual enterprise business relationships.
- Enhanced knowledge sharing including: Infrastructure, knowledge mining, semantic mapping, filtering, knowledge consolidation algorithms, distributed data bases, catalogues of re-usable EE solutions etc.
- Green- Product Lifecycle Management and holistic support tools for Optimized production / supply networks and reduced embedded energy product profiles.
- Middleware to facilitate interoperability amongst different devices and systems.

Acknowledegments

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4.3 Energy Consumption: One Criterion for the Sustainable Design of Process Chains

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Abstract
Rising energy costs lead to rising product costs and cause companies to search for methods to reduce energy consumption in production process chains. Therefore, sustainability becomes a matter of competitiveness. Energy consumption in production is determined by the design of parts and the manufacturing process chains. If companies manage to assess and optimize the energy consumption of manufacturing process chains during the design phase, they will be able to reduce energy consumption and to take important competitive advantages. For the decision–making process, it is crucial to know at what point in the planning phase a decision about alternatives in production process chains can be taken. This paper presents an approach to take into account the energy consumption in the early stage of process chain design.

Keywords:
Energy consumption, Energy efficiency, Process chain design

1 Introduction

Today, energy is a demanded, scarce and increasingly expensive resource exerting economic and ecological pressure on manufacturing companies. Electric energy is one of the most commonly used energy sources in industrial production. In Germany, for example, the industrial sector accounts for 43% of the overall electrical energy consumption [1]. A research study estimates a potential for reducing energy consumption in industrial production by 25–30% over the next years [2]. In the context of the discussion on global warming, politics identified the manufacturing industry as one sector in order to achieve their goals in reducing CO_2-emissions. However, the reduction of energy consumption and CO_2-emissions is no longer an issue limited to regulations forced by politics, but rather a high priority issue pursued by companies. This indicates that manufacturing companies take energy consumption into account as one competitive factor.

A lot of research has already been carried out concerning the optimization of existing production systems such as energy recuperation, fixing leakages of compressed air systems and energy efficient retrofitting of production equipment. These measures provide on the one hand a considerable contribution towards energy saving manufacturing while they mostly cause additional investments in existing production systems on the other hand [3]. However, the greatest effect on energy efficiency of production systems can be obtained in the design phase when the opportunities for influencing the energy costs are high and these are not yet determined [4]. The process chain design is one activity within the product engineering process and precedes the planning of the production system. As a consequence, the definition of the process chain sets limits to the further configuration of the production system. Thus, process chain design can be identified as the time to take action in energy efficient design of production systems [5]. Generating and assessing alternative process chains within the product engineering process has been considered, but a comparative assessment of alternatives regarding the energy consumption has not yet been included in these approaches [6, 7]. On the other hand, there are applications of life cycle assessment methods aiming to evaluate the environmental impact of products and processes including energy consumption [8, 9]. Applications of these methods usually require a significant effort for data collection and lack the prospective character needed for the decision-making process in the planning phase.

This paper deals with the assessment and selection of alternative process chains regarding energy consumption. It is explained how a method for prospective assessment needs to be designed with respect to the decision-making situation in the product engineering process. An example process chain is derived and assessed to demonstrate the principle of the proposed method.

2 The Product Engineering Process

The transition of a product idea to the series production is described by the product engineering process. Within this process the product characteristics are specified. Materials, manufacturing processes, machines and tools are selected. Process chains allowing the transition of a defined raw material into the final product are generated. As a result, a great share of the energy needed for the future manufacturing of a product is already determined within this process.

In order to be applicable, a method aiming to predict the energy consumption of alternative process chains has to meet the requirements for decision-making within the product engineering process. Therefore, an analysis of the product engineering process is necessary to answer the following two questions:

- At what point in time should the assessment be available for decision-making?
- How should the method be designed with respect to the limited planning data?

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Being able to answer the first question is very important as the assessment results have to be available when decision-making about alternative process chains is necessary.

Figure 4.3.1 depicts a product-oriented description of the product engineering process. The description is based on a concept that is frequently used in automotive industries. The product and process design is divided into the four phases A to D representing a certain status of the product sample regarding product and process design. Within each sample phase, certain attributes of the product and the process design are defined. In sample phase A, the product is produced as a prototype. A selection of alternative processes is considered to manufacture the product. Materials, machines and tools are not yet finally defined. Subsequently, the B-sample phase is characterized by the use of preliminary machines, tools and processes for manufacturing the samples. In this phase, usually a number of alternative process chains is still considered for evaluation. The selection of one preferred process chain is made at the latest with the end of the B-sample phase. Afterwards, machines, tools and processes close to series production are utilized to manufacture the C-samples. The definition of tools and machines for series production is completed. As a result, the approval of resource procurement is given. Finally, in the D-sample phase, the product is produced the same way as the series product.

The degree of determination of the final process chain increases along the sample phases, while the number of opportunities to influence the future energy consumption decreases. Thus, the energy consumption of the process chain is becoming increasingly determined. Based on the analysis of the product engineering process, answers to the above stated questions can be derived.

According to the above remarks, the definition of the process chain for the series production is finished within the B-sample phase. Hence, it is evident that this is the latest point in time for assessing the energy consumption of alternative process chains. The definition of machine tools starts within the B-sample phase. Here, two scenarios are possible. Either new machines have to be defined and purchased or old machines can be considered for reuse. An approach for reuse including energy consumption as one possible exclusion criterion has been presented in [10]. In both cases no final definition of all machine tools is available before the process chain design is fixed. This indicates that the planning data are not finally determined when the assessment method has to be applied. However, a general specification of both the manufacturing systems and the process parameters is still possible. For instance, technically and economically reasonable process parameters (e.g. cutting speed, depth of cut, feed rate) can be derived from the product description and the manufacturing processes considered for the process chain. Companies maintain such data bases as they represent their manufacturing experience and know-how.

3 Methodology

3.1 Energy Consumption of Process Chains

Process chains are part of a production system and they are the basis for the configuration of the production system. A process chain comprises a number of manufacturing processes that allow the transition of a product from an initial state to a final state. Supporting processes, such as transport, handling or storage operations, interlink the manufacturing processes, as depicted in Fig. 4.3.2. The supporting processes are planned subsequently to the process chains. Thus, at the level of the production system all technologically induced manufacturing processes are included in the energy assessment, disregarding supporting processes.

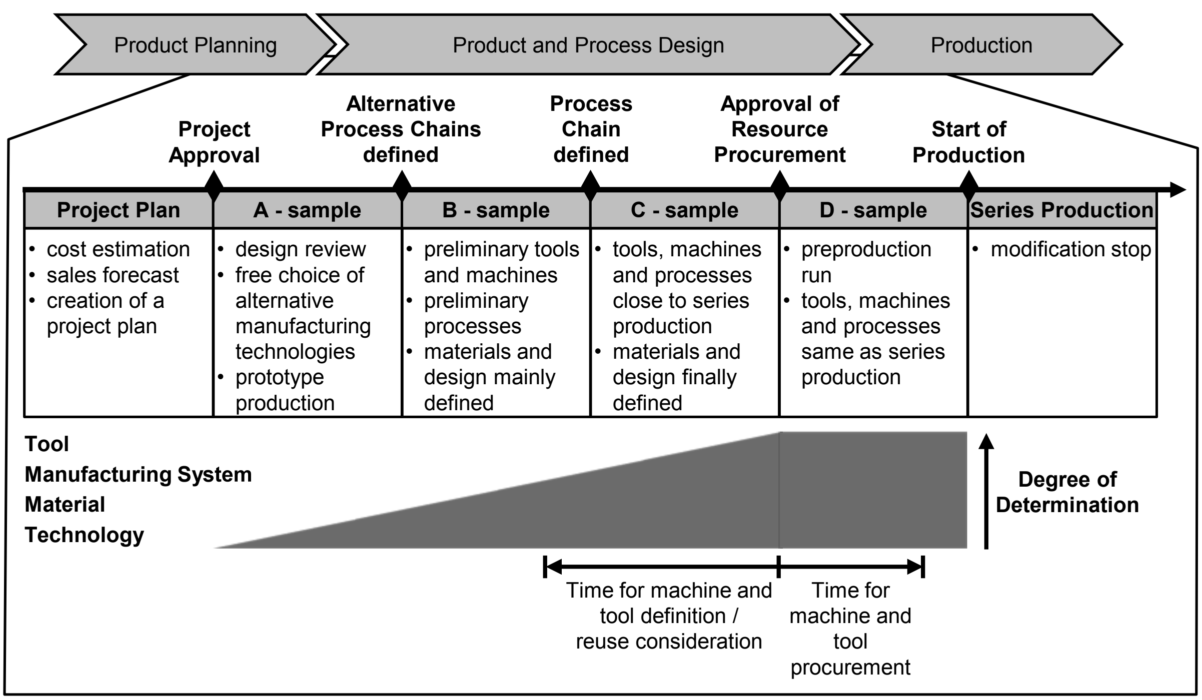

Fig. 4.3.1 Product engineering process

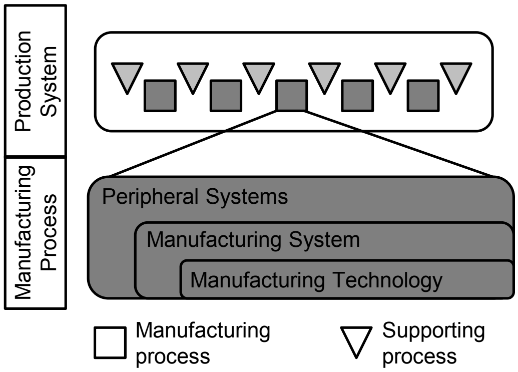

Fig. 4.3.2 System boundaries

Manufacturing processes can be further divided into three scopes: the manufacturing technology, the manufacturing system utilized to perform the process and peripheral consumers supporting the manufacturing system [11]. Each scope accounts for a part of the energy consumed by the process. The amount of energy consumed in the three scopes represents the energy consumption of one manufacturing process.

At the scope of the manufacturing technology the energy consumption can be described as the energy that is physically required to perform the process. For example, the energy consumption required for pressure forming processes can be calculated with regard to geometrical characteristics and empirical material and process parameters [12]. The relationship between the process parameters and the energy consumption of the manufacturing technology and the manufacturing system are not yet well known for a wide range of manufacturing processes. For this reason, empirical investigation of manufacturing processes is currently carried out [13].

The manufacturing system provides the energy for the manufacturing technology and is required to run the process. A manufacturing system comprises a number of components. Besides the energy consumption of the manufacturing technology, it also provides further functionalities like process control and cooling. Investigations of machining processes showed that a significant proportion of the overall energy consumption of the manufacturing system is determined by additional functionalities and not by the manufacturing technology [14].

In order to calculate the energy consumption of the manufacturing system, it needs to be characterized by power consumption parameters. Here, two power consumption parameters shall be considered: the basic power consumption and the average processing power consumption. The basic power consumption (P_{basic}) describes the state in which the manufacturing system is ready for operation but is not processing. The average processing power consumption ($P_{process}$) can be determined when the system is performing an operation that is typical for the manufacturing system. As the power consumption varies due to the use of different functionalities and movements, it is averaged over the processing time of a typical operation. For the average power consumption two cases can occur, depending on whether the power consumption for the technology can be determined and separated from the power consumption of the manufacturing system or not. If the energy consumption of the technology can be separated from the energy consumption of the manufacturing system, it is possible to determine the average power consumption independently from the respective process parameters. This applies for example for machining processes. The average processing power is then measured with regard to the process operation without removing material [15]. For other processes like laser cutting it is not useful to separate the energy consumption of the technology and the manufacturing system. Thus, the measurement of the average processing power consumption also needs to consider the specific process conditions. Either power consumption parameters can be gained by conducting power measurements of the regarding systems. In case that no measurements regarding the concerned system can be conducted, the parameters have to be estimated by using available data of comparable machines. However, a comparable machine must be chosen carefully as even comparably equipped machines performing the same manufacturing process can have a significantly differing energy consumption [16].

After having determined the power consumption parameters, the energy consumption of the manufacturing system can be calculated according to [15]. In Eq. 4.3.1, the process time ($t_{process}$) can either be estimated or calculated based on comparable operations. The basic time (t_{basic}) is based on the process time and considers the time for setup procedures, breaks and additional times when the manufacturing system is ready for operation but is not processing.

$$E_{manufactuing\ system} = P_{process} \cdot t_{process} + P_{basic} \cdot t_{basic} \quad (4.3.1)$$

For peripheral systems, such as the centralized supply of compressed air and cooling lubricant, it is often not possible to allocate the entire energy consumption directly to one process. In this case it is possible to allocate the estimated energy consumption of the peripheral system based on the estimated consumption per period, the energy intensity per product and the quantity of manufactured products per period.

3.2 Applied Data Collection

The data collection procedure is exemplarily applied for the abrasive machining process of honing which is part of the example process chain presented in Sect. 3.3. Honing is a final finishing operation that is typically conducted on the inside surface of a cylinder. A rotation of the honing tool in axial direction is overlaid by a reciprocal stroke movement and feed movements. The main area of application for honing is in the metal working industry, especially for piston running surfaces in combustion engines and hydraulic components.

Due to the undefined cutting edges of the honing tool and the complex process kinematic, there is no model describing the cutting forces with reasonable effort. A description of the energy consumption of the manufacturing technology is not available yet. However, for turning processes the cutting forces are well understood. Material parameters for cutting forces have been determined in empirical studies and are well documented. For that reason an approximation of the energy consumption is developed here, based on a relation between the specific cutting energy of the honing process and the turning process.

Table 4.3.1 Parameter settings

Parameter	Setting	Unit
Workpiece material	16 MnCr 5	[---]
Rotation speed	1,600	[1/min]
Lifting speed	260	[mm/s]
Initial hole diameter	7.95	[mm]
Final hole diameter	7.98	[mm]

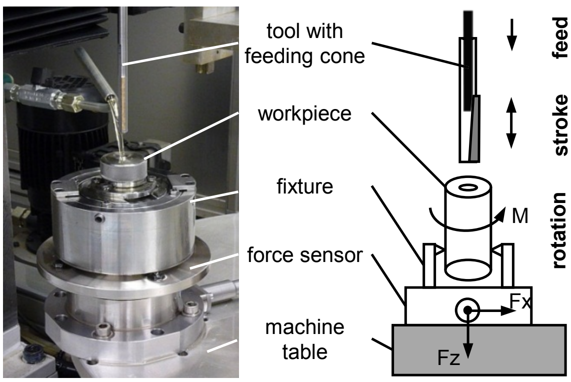

Fig. 4.3.3 Experimental setup [17]

In order to calculate the specific energy consumption of the honing process, an empirical study has been conducted using the experimental setup shown in Fig. 4.3.3. The respective parameter settings are presented in Table 4.3.1. The measured force and moment in the z axis can be averaged and used to approximate the cutting force (F_c), see Eq. 4.3.2. The averaged empirical values that have been determined are given in Table 4.3.2. The specific energy for honing can be calculated by means of Eqs. 4.3.3 and 4.3.4. As a reference value, the specific energy consumption of a turning process can be obtained. As given in Eq. 4.3.5, the value is calculated by using the Kienzle equation [18] with regard to the characteristics of the workpiece material 1.7131 (16 MnCr 5) [19]. Finally, one factor can be determined to approximate the specific cutting energy of honing as thirty times the specific cutting energy of the turning process.

The power consumption parameters of the applied manufacturing system are obtained by measuring the main connection. By using an electronic three-pase power meter, the power consumption is determined to 0.70 kW, when the machine is ready for operation (P_{basic}). When the machine is performing a typical honing procedure, the average power consumption is 1.88 kW ($P_{process}$).

$$F_c = \sqrt{F_{zm}^2 + F_{tm}^2} = \sqrt{F_{zm}^2 + \left(\frac{M_{zm}}{r_m}\right)^2} = 122.9 \; [N] \quad (4.3.2)$$

$$W_{honing} = F_c \cdot s = F_c \cdot S \cdot A_m = 2100 \; [J] \quad (4.3.3)$$

$$E_{spec,honing} = W_{honing} / V_{chip} \approx 110 \; [J/mm^3] \quad (4.3.4)$$

$$E_{spec,turning} = \left|\frac{k_{c1.1}}{h^m}\right| \cdot 10^{-3} \approx 3.8 \; [J/mm^3] \quad (4.3.5)$$

$$f_{honing} = \frac{E_{spec,honing}}{E_{spec,turning}} = \frac{110J/mm^3}{3.8J/mm^3} \approx 30 \quad (4.3.6)$$

Table 4.3.2 Description of symbols

Symbols	Description		Unit
A_m	Mean number of strokes		[---]
$E_{spec, honing}$	Specific cutting energy honing		[J/mm³]
$E_{spec, turning}$	Specific cutting energy drilling		[J/mm³]
F_c	Cutting force	(122.9)	[N]
f_{honing}	Honing factor		[---]
F_{tm}	Mean value of tangential force F_t		[N]
F_{zm}	Mean value of axial force F_z	(41.2)	[N]
h	Cutting depth	(0.1)	[mm]
$k_{c1.1}$	Main value cutting force	(2,100)	[N/mm²]
m	Slope, cutting force function	(0.26)	[---]
M_{zm}	Mean value of moment M_z	(115.8)	[Nm]
r_m	Mean value radius		[mm]
s	Cutting path		[m]
S	Cutting path per stroke		[m]
V_{chip}	Removed chip volume	(18.8)	[mm³]
W_{honing}	Cutting energy honing		[J]

3.3 Example Part and Process Chain

In order to demonstrate the principle of the proposed method, a process chain for an example part is designed and assessed. The defined example process chain consists of the three processes milling, drilling and honing. The example part is produced from a prismatic-shaped blank that measures 100x70x60 mm and is made of the steel 1.0718 (9 SMnPb 28). The example part comprises five geometrical characteristics which are presented in Table 4.3.3.

Table 4.3.3 Geometrical characteristics

	Width [mm]	Depth [mm]	Height [mm]	Diameter [mm]	R_z [µm]
Plane surface	100	70	4		20
Step	30	70	6		20
Blind holes			10	20	80
Groove	12	35	10		80
Clearance holes			50	8	1

Based on the definition of the blank and the description of the geometrical characteristics, a process chain can be designed that allows for the transition of the blank into the final part. To each process a corresponding manufacturing system is referred. The geometrical characteristics are assigned to the three processes as presented in Fig. 4.3.4.

The energy consumption of the manufacturing systems can be calculated with the previously determined power consumption parameters and the corresponding time parameters. The power consumption of the drilling machine that is applied in process 2 is 0 kW when it is ready for operation. Accordingly, this machine does not consume energy when it is waiting for the next operation. For the example processes all additional supplies for the process, like compressed air and lubricant, are provided by the manufacturing systems. Consequently, the energy consumption for the supply of compressed air and lubricant is included in the characteristic power consumption parameters of the manufacturing systems provided in Table 4.3.4.

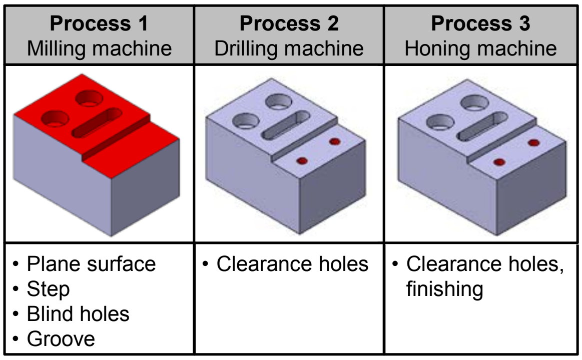

Fig. 4.3.4 Process chain

Table 4.3.4 Energy consumption of the manufacturing systems

		Process 1	Process 2	Process 3
$P_{process}$	[kW]	1.57	0.46	1.88
$t_{process}$	[s]	482	116	81
$E_{process}$	**[kJ]**	**757**	**53**	**152**
P_{basic}	[kW]	0.86	0.00	0.70
t_{basic}	[s]	107	26	19
E_{basic}	**[kJ]**	**92**	**0**	**13**
$E_{manufacturing\ system}$	**[kJ]**	**849**	**53**	**165**

The energy consumption of the manufacturing technology for each process can be calculated according to the Kienzle equation or with the help of the approach presented in Sect. 3.2. In order to calculate the energy consumption of the process chain, the energy consumption of the three processes is added. The consumed energy of the considered process chain is 1,159 kJ per part as displayed in Table 4.3.5.

Table 4.3.5 Energy consumption of the process chain—alternative 1

		Process 1	Process 2	Process 3
Manufact. Techn.	[kJ]	81	10	1
Manufact. System	[kJ]	849	53	165
Sum Process	**[kJ]**	**930**	**63**	**166**
Sum Process Chain	**[kJ]**	**1,159**		

One possible alternative to the presented process chain is to manufacture the clearance holes by also using the milling machine in process 1. By this modification, process 2 is eliminated from the process chain. In this second alternative, the energy consumption of process 1 then rises from 849 kJ to 1,053 kJ due to the extended work content and machining time. As a result, the overall energy consumption of this alternative is 1,310 kJ, compared to 1,159 kJ in alternative 1. This effect is due to the minor energy consumption of the drilling machine used in process 2. Thus, from the perspective of energy consumption, alternative 1 should be preferred over alternative 2. However, further criteria, such as cycle time and investment costs, will have to be included into the assessment of alternative process chains to provide a holistic view.

4 Assessment of Energy Consumption

In business, decision-making is commonly based on key figures. This also applies for the decision about alternative process chains and shows the importance of selecting an appropriate key figure for the decision-making situation. For the energy consumption of alternative process chains, two key figures are often discussed: primary energy consumption and end use energy consumption.

End use energy can be described as the energy content of all traded energy sources. It is used by energy consumers to provide energy services, e.g. the energy consumed by a machine tool in order to perform a process. In contrast, primary energy is defined as the energy content of energy sources that occur in nature and have not yet been technically converted [20]. Based on analyses of the upstream processes a factor can be determined that expresses how much primary energy is needed to generate one unit of end use energy. An equivalent ratio can be derived for materials by analyzing the upstream production processes.

It has been argued to consider the primary energy consumption when assessing alternative process chains in order to ensure a holistic assessment [12]. However, when designing process chains, the planner has a very limited and indirect influence on upstream processes of the consumed materials and energy sources. Furthermore, primary energy consumption is usually neither applied in technical nor in commercial departments in the industry. On the other hand, end use energy consumption is commonly used in the industry. It can be read off from energy bills and is easy to value as energy costs by multiplication with the energy cost ratio. Hence, end use energy consumption will be employed as key figure for assessing the energy consumption of alternative process chains.

In addition to energy consumption, a variety of other decision parameters has to be included when alternative process chains are to be assessed. Criteria such as cycle time, quality, maintenance as well as deployment of machines and personell are frequently expressed in monetary values. These monetary figures are commonly understood and well accepted. Energy consumption can also be represented in monetary values. The energy costs (C_i in [EUR]) for process chain (i) can be obtained by multiplying the determined end use energy consumption (EEC_j in [kWh]) of energy source (j) with the market energy cost rate (r_{mj} in [EUR/kWh]), see Eq. 4.3.7

$$C_i = \sum_{j=1}^{n} EEC_j \cdot r_{mj} \qquad [EUR] \qquad (4.3.7)$$

A recent study clarified that the consumption of a resource is significantly determined by its price [21]. By now, energy consumption has hardly been a substantial decision criterion for alternative process chains. This has been due to a lack of transparency in energy costing and low energy costs. In spite of the still relatively low energy costs, companies have recognized energy consumption as an important factor for sustainable company development.

In order to adequately incorporate energy consumption in decision-making, we propose a corporate weighting factor reflecting the relevance which the company attaches to the consumption of energy. The weighting factor (f_w) can either be an absolute or relative surcharge to the market price of the respective energy source. In Eq. 4.3.9, the corporate cost rate for energy (r_{cj} in [EUR/kWh]) is applied to obtain the weighted energy costs (C_{iw} in [EUR]) of process chain (i).

$$r_{cj} = r_{mj} \cdot f_w \qquad [EUR / kWh] \tag{4.3.8}$$

$$C_{iw} = \sum_{j=1}^{n} EEC_j \cdot r_{cj} \qquad [EUR] \tag{4.3.9}$$

As a consequence, the utilization of a company-wide weighting factor for energy costs ensures transparency in decision-making processes. The incorporation of energy consumption with further criteria for the assessment of alternative process chains is possible. A consistent and objective evaluation is provided.

5 Summary and Outlook

Energy consumption becomes a more and more important issue in the manufacturing industry. In this paper, a methodology has been presented that allows to prospectively consider the energy consumption of alternative process chains within the early planning phase of a product. In this context, it has been worked out at what point in time it is possible and necessary to make a decision about alternative process chains. An example part has been assessed to show the principle of the presented method. It became clear that energy consumption is one important criterion that has to be assessed in the context of additional criteria without extending the decision-making process. For this reason a new approach was presented how companies can incorporate sustainability in their decision-making process.

In a next step, the proposed method will be implemented in a planning software tool in order to put the method into practice. Further framework conditions such as cycle time and production capacities will be taken into account to give a more complete picture.

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4.4 A Method for Evaluating Lean Assembly Process at Design Stage

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Abstract
Lean product design has the potential to reduce the overall product development time and cost and can improve the quality of a product. However, it has been found that no or little work has been carried out to provide an integrated framework of 'lean design' and to quantitatively evaluate the effectiveness of lean practices/principles in product development process. This research proposed an integrated framework for lean design process and developed a dynamic decision making tool based on Methods Time Measurement (MTM) approach for assessing the impact of lean design on the assembly process. The proposed integrated lean framework demonstrates the lean processes to be followed in the product design and assembly process in order to achieve overall leanness. The decision tool consists of a central database, the lean design guidelines, and MTM analysis. Microsoft Access and C# are utilized to develop the user interface to use the MTM analysis as decision making tool. MTM based dynamic tool is capable of estimating the assembly time, costs of parts and labour of various alternatives of a design and hence is able to achieve optimum design. A case study is conducted to test and validate the functionality of the MTM Analysis as well as to verify the lean guidelines proposed for product development.

Keywords:
Manufacturing assembly process, Lean design guidelines, Methods time measurement (MTM), Integrated lean decision tool

1 Introduction

Competitive advantage for many manufacturing companies now lies in their ability to effectively implement on-going product and process innovation, superior manufacturing, continual improvement of quality and reliability (Q&R) of existing products and developing a continual stream of quality new products [1, 2]. Moreover, market pressures have forced companies to emphasise cost, speed, quality, agility, flexibility and most importantly leanness of their manufacturing facilities [2, 3]. These can only be accomplished by developing and producing quality products and bringing them to the market quickly at a reasonable price, in order to meet or exceed customer expectations. As a result, manufacturers' are forced to implement new and efficient strategies in their manufacturing operations. Some of the established strategies in this context are lean practices/principles. Lean strategies/principles in product design have the potential to reduce the overall product development time and cost and can increase the quality of a product. Because "Lean Products start with Lean Design" [4] and design process is the very important part of product development process. According to Shetty [5], at least 75% of the product costs are committed by the end of the conceptual design phase. This means that decisions and changes made after this time can influence only 25% of the product's manufacturing cost. According to Cloke [4]; "Investment on quality and cost reduction at the design stage is 100 times more cost effective than investment after production begins". Keys [6] reported that some 75–90% of opportunity to influence the entire product development cost is gone by the time a design is released to production and assembly. As a result, decisions made during initial concept development can inevitably fix many of the critical cost factors of a product and hard to significantly reduce manufacturing and assembly costs later on. It is also recognized that not paying enough attention to product design early in the product life cycle potentially result in inefficiencies (wastes) throughout the product development (PD) process [7]. In product development, manufacturing and assembly are the major activities that combine the components into final product. Design for Assembly methodologies were developed to help the designer to develop an efficient and economic product so that costs of assembly is reduced. Vincent Chan [8] defined Design for Assembly as "a process for improving product design for easy and low-cost assembly, focusing on functionality and on assemblability concurrently". However, it has been found that no or little work has been carried out to provide an integrated framework of 'lean design' and to quantitatively evaluate the effectiveness of lean practices/principles in product development process. The aim is to concentrate early in the design stage on creating products are easy to assemble, before much effort and cost is expended in pursuing another design, which might be unnecessary expensive. There have several methods to calculate efficiency of Assembly process. The Boothroyd Method [9] is based on parts reduction and handling and insertion improvement. But it is only useful for redesign of existing products, and not to use for conceptual design of new products. The Hitachi Method [10] calculates design efficiency based on the insertion process only, while the Lucas method is focused on a reduction of the number of parts. The most complete calculation of design efficiency is provided by the MTM analysis. It determines design efficiency that takes into account parts reduction and handling, orientation, and insertion improvement. Moreover, it is possible to evaluate the redesign of existing products as well as the conceptual design of new products. For these reasons the MTM analysis is used to implement as a Design for Assembly Method in the Integrated Lean Design Framework.

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Therefore, this research proposed an integrated framework for lean design process and developed a dynamic decision tool based on Methods Time Measurement (MTM) approach for assessing the impact of lean design on the assembly process. A central database, the design for assembly guidelines, MTM analysis and programming language C# are used to generate the integrated lean design framework as a complete user friendly decision tool. The proposed central database includes: list of preferred parts, tools and utilities, reusable design elements, lean design guidelines for assembly and product lifecycle, the effects and benefits of application of design for assembly guidelines as well as how these guidelines influence other parts of the whole product lifecycle. The developed MTM analysis tool is used to estimate the impact of the application of these guidelines on the assembly process concerning time for this assembly process, costs of involved parts and labour costs. MTM analysis tool also showed that the application of ‘Lean Design for Assembly Guidelines’ guides the designer towards a product with an optimum number of parts that requires simple, cost-effective assembly operations and the most appropriate manufacturing processes and materials for its components. Finally, a case study is conducted to test and validate the functionality of the MTM analysis as well as to verify the effect of using the ‘Lean Design for Assembly Guidelines’ on the assembly time and costs.

The rest of the paper is structured as follows: Sect. 2 provides a systematic integrated lean design framework, MTM analysis; a performance evaluation tool is presented in Sect. 3. Research findings are discussed in Sect. 4. Limitations and extensions of this work round out the paper.

2 Integrated Lean Design Framework

A number of models that describe the content of lean production have been evolved; such as the Karlsson and Ahlström model [11]. The most of these models describe the lean thinking in the procurement, manufacturing, and distribution but ignore the product design process. To achieve low-waste and high-velocity new product development process is the most critical step in making a company lean and maximizing their revenue and profit potential. The main aspects of this ‘lean product development process’ are a continuous-flow development process and waste elimination. Figure 4.4.1 shows the proposed integrated lean design framework and method of evaluating the assembly process at design stage.

The first step is to define the new product as clearly as possible the market and customers desire on performance, features, and quality. During this step, Voice-of-the customer tools are applicable. Because, value of a product can only be defined by the ultimate customer, and it’s only meaningful when expressed in terms of a specific product (a good or a service, and often both at once) which meets the customer’s needs at a specific price at a specific time. The next step is to establish the Product Line Optimization Team and the Multi-disciplinary Design Team. The first task of this team is to consider how the new product will fit within existing material inventory, processes, factory layout, core competencies, etc.

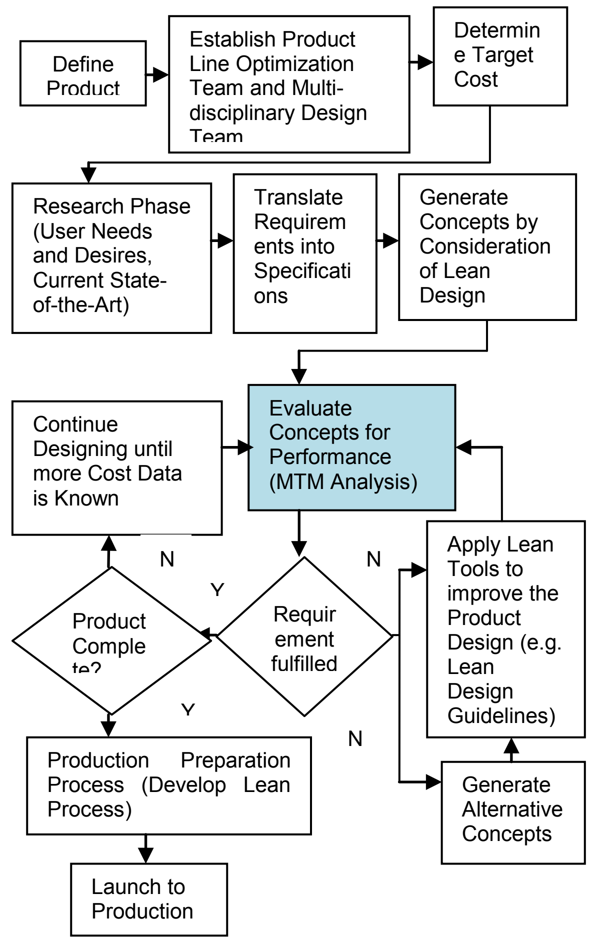

Fig. 4.4.1 Integrated lean design process framework

The design team develops a preliminary cost model to determine the target cost and generates a broad and innovative list of design concepts for the new product. Therefore, the team has to translate the given requirements into product specifications. To evaluate the concepts and to determine which concept has the best combination of production cost and customer value, the design team uses a cost/performance trade-off tool. In this research, MTM analysis is used as the part of this tool and utilized design for assembly method to rate the assembly cost for a product. To optimize design variables, the team uses lean design guidelines such as Lean Design for Life Cycle Guidelines. In addition to the guidelines, designers need to understand more about their own and the suppliers production system in order to develop company unique lean design guidelines to further guides, for example, specific manufacturing processes, capabilities and limitations. All these guidelines are stored in a structured database as a reference work for the design engineers.

Lean design for Life Cycle includes ‘Lean Design for Assembly’, ‘Lean design for Manufacturing’, ‘Lean design for Testability’, Lean design for Safety’, ‘Lean Design for Reliability’, ‘Lean Design for Service and Maintenance’, ‘Lean Design for Environment’, and ‘Lean Design for Disassembly’

[4, 12–14]. The final step in the Lean Design process before product launch is the Production, Preparation, and Process, also called 3P. This process is to ensure a smooth and rapid transition of the new product design into the factory, by consideration of tact time, workplace-layout, process capacity, etc. This 3P will ensure a lean production and incorporate error proofing and Just-in-Time. Moreover, it will guarantee process capabilities and cycle times and build quality into the system.

3 MTM Analysis: A Performance Evaluation Tool for Lean Assembly Process

Methods-Time Measurement (MTM) is a predetermined time and motion system and can be used to suggest what types of parts should not be used and how parts as well as assembly process can be redesigned to reduce assembly time. The time unit for a MTM motion is described as Time Measurement Unit (TMU; 1 TMU = 0.036 sec) [15]. The entire MTM analysis includes eleven different basic motions to describe any manual operation or method [15]. In this research, the seven basic MTM motions are specified, which are necessary for the use of the MTM analysis in the integrated lean design process as a tool to estimate the time and cost for assembly of products. These motions have been simplified and adapted to the requirements of the integrated framework [15]. Time Data Tables and the Decision Models for each kind of motion are taken as the basic framework for the implementation of the MTM analysis [15]. Using the MTM, an electric switch gear design is analysed, and after consideration of the Lean Design for Assembly Guidelines later redesigned. The following steps have to be done to analyse a product with the MTM analysis:

- Select a product to be analysed by MTM analysis tool
- Update the central product development database using the user interface to update the product information
- Start a new or open an existing MTM analysis
- Select the correct Work Station
- Create the Part List
- Create the Tool List
- Edit the Position Matrix
- Edit the Grasp Matrix
- Edit the List with all Performances

4 Demonstration of Proposed Methodology by a Case Example

The case study is a simplified representation of a real situation in a company. The proposed methodology described in Sect. 2 is presented here by a case example. This case example origins from “Design for Product Success” written by Devdas Shetty [5]. It has been used and adapted for the intention to illustrate the functions of the integrated lean design framework and implementation of MTM analysis. Initially, an electric switch has been selected for MTM analysis. A multi-disciplinary design team has been formed and this team includes people from design, production, assembly, and supply chain department. The structure of the switch gear is determined by this team based on the user needs and desires (VOC). Then, these requirements are converted into product specifications. The existing design for the switch contains of 18 parts, as seen in Table 4.4.1. This design uses a lot of different parts, screws and springs. Most of the time screws are used to join parts instead of snap-fit fasteners. Moreover the hand and tool access is not sufficient for joining the parts without a hidden point or a regrasp. The material cost determined by the design team for the original electric switch is altogether 13.82 AUD$. All prices for parts, tools, utilities, and materials are estimated to describe the function of the implemented MTM analysis.

Table 4.4.1 Components of the original electric switch

Part name	Quantity	Thickness [mm]	Size [mm]	Price [AUD$]
Switch base	1	15	29	1.99
Terminals	3	9	8	0.33
Centre terminal contact	1	6	8	0.59
Terminal screw	3	7	7	0.25
Contact rocker	1	4	22	0.49
Base cover	1	3	29	1.19
Switch plunger	1	4	16	1.39
Switch spring	1	3	20	0.99
Switch toggle	1	9	35	1.55
Mounting cover	1	13	19	1.99
Mounting hardware	1	2	16	1.09
Terminal screw short	3	7	4	0.21

4.1 Select or Update Basic Data in the Central database

The first step to analyse a product with MTM is to generate the basics for the object in the program module in Basic Database. These include information about the article categories, work station, parts, and tools, utilities and materials, pay grade (Fig. 4.4.2). In this case, pay grade is the basis for the calculation of the labour costs in the MTM analysis. The electric switch is assembled at the work station 1 with a pay grade of 35 AUD$ per hour. The part number and the part name are the unique identifiers and can only be used for one part, which prevents duplicate identifiers. To define a new tool an article category, 5-digit part number and name are necessary. For additional information, it is possible to add the price, weight and dimensions, as well as a specific description. For the analysis of the original switch two types of containers and one assembly jig (mechanical stop) are determined.

4.2 Start a New or Open an Existing MTM Analysis

After the completion of all appending basic data, the analysis of the product with the MTM method can begin. The first step is to identify a product and define the assembly process to be analysed by developed MTM analysis tool. In the developed MTM tool, one can start a new MTM analysis by entering the name in the appropriate text box. In this module, it is also possible to open an existing analysis or to delete a no longer needed analysis (Fig. 4.4.3).

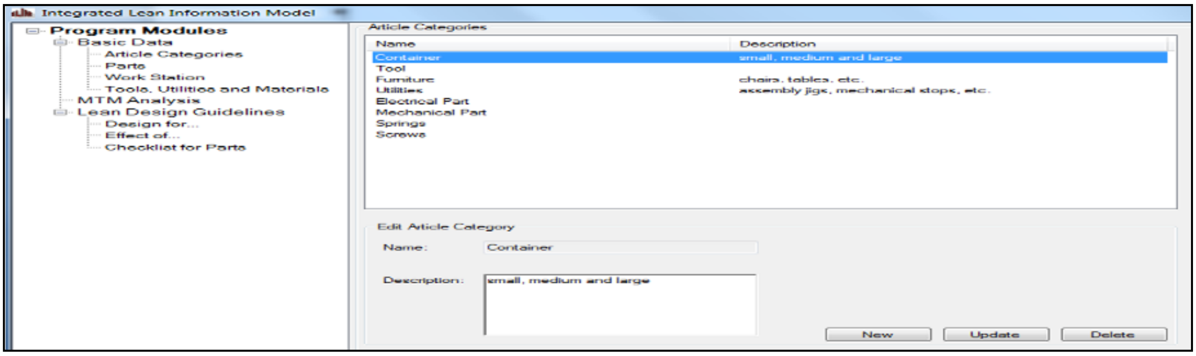

Fig. 4.4.2 MTM analysis for original electric switch

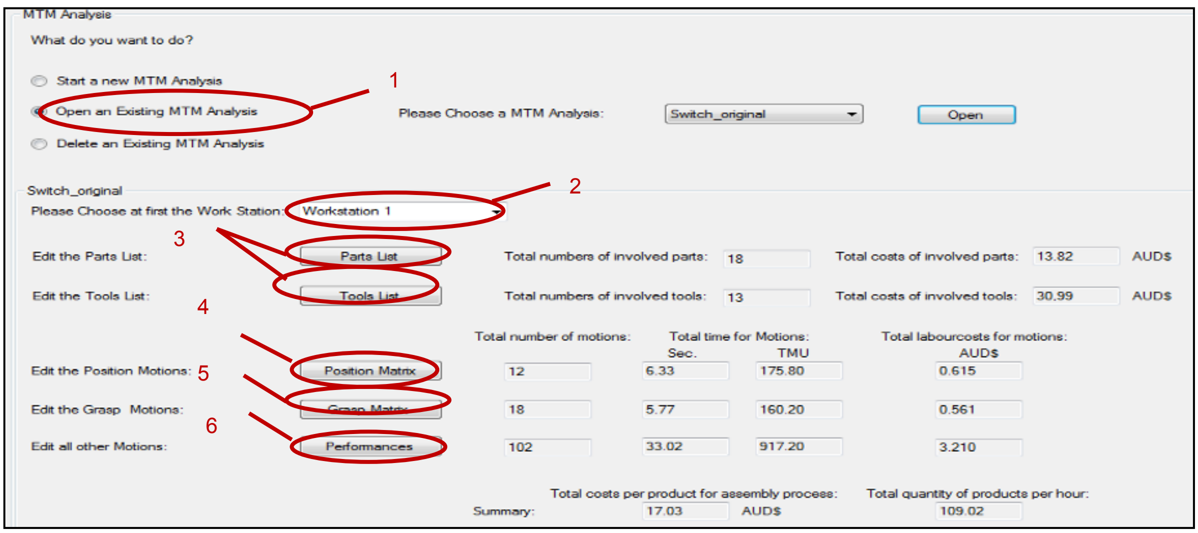

Fig. 4.4.3 MTM analysis of original electric switch

4.3 Select the Correct Work Station

Every MTM analysis should start with the selection of the correct work station for producing a product, because this will be the basis for the calculation of the product and labour costs of a product (Fig. 4.4.3). Assemble of different parts of a product can be done in the several workstation and labour cost of these work station may not be same. By clicking in the combo box a context menu will open with the defined work station in the basic database. In this case, work station 1 is selected for performance analysis of the original electric switch.

4.4 Create the Part and Tool List

The compilations of the necessary parts and tools list are the next steps in the analysis. Therefore, just click on the appropriate button for selecting defined parts or tools for making the specific product. If an item is necessary then checked by clicking the item, the program will add this article to the part or tool list. To remove items out of the list just uncheck these in the lower list view. Moreover, the total number of involved parts and tools as well as their total costs will be on display in the MTM main window. In this case, the total number of involved parts for making the original electric switch are 18 and their material costs per product are 13.82 AUD$. The tools include eight small containers and four medium containers as storage areas for the parts as well as one assembly jig (Fig. 4.4.3).

4.5 Edit the Position Matrix

After creating the parts and tools list, the real analysis of the product starts with the first matrix 'Position Matrix' (Fig. 4.4.3). This matrix describes all position motions are conducted in the assembly process. If the user clicks on the button Position Matrix a separate window with a matrix consisting of all included parts will appear. A click with the right mouse button in the appropriate cell will open a context menu with the menu items:

- Add Position Motion—Add a new motion
- Delete Position Motion—Delete an existing motion
- Disable Position Motion—Disable a no longer needed motion, the cell colour will be grey
- Enable Position Motion—Enable a disabled motion

There will be several position positions in the database. From these position motions, user has to select the appropriate case for the position motion which includes 'Case of Symmetry', 'Class of Fit', 'Design for Shaft and Hole', and the number of motions. With all these information, the program will calculate the time for this position process on the basis of the time data described by [15] and write this time in TMU in the selected cell in the position matrix. After the completion of all necessary position, the program summates all position motions and their times and shows these in the main form to the right of the button Position Matrix. To assemble the original electric switch, twelve position motions are needed with a total time of 175.80 TMU or 6.33 sec. Moreover, the program calculates the labour costs for these motions about 0.615 AUD$.

4.6 Edit the Grasp Matrix

The analysis with the Grasp Matrix runs similar to the Position Matrix (Fig. 4.4.3). A separate window with a matrix consisting of the tools in the rows and the parts in the columns will be open. After the selection of the type of grasp the cases for every type will be displayed, for example the cases for the type select and the program summates all grasp motions and their times as well. For the assembling of the original electric switch 18 grasp motions has to be needed with a total time of 160.20 TMU or 5.77 sec. The total labour costs for these motions amounts to 0.561 AUD$ per product.

4.7 Edit the List with all Performances

In the Performance List, all motions included in the assembly process will be described with their time and labour costs (Fig. 4.4.3). The program automatically will transfer the determined position and grasp motions matrix into the performance list. The user has to put these motions in the right order. Additional motions can be added to this list by clicking the right mouse button in a cell. After this action a context menu will open with the following menu items:

- Add Motion—Add new disengage, grasp, move, reach, release, or turn motion
- Delete Row—Delete a complete row from list
- Disable Motion—Disable a no longer needed motion; the cell colour will be grey
- Enable Motion—Enable a disabled motion
- Add new Row—Add a new empty row to the list
- Add Parts/Container/Tools—Add in this special process included parts, tools, or utilities to the list

If the user wants to append in the process included parts or tools, in the lower part of the form will display two list views with all defined parts, tools, utilities, and materials. Similar to the part or tool list it is possible to add or delete these articles in the concerning cells by checking and un-checking respectively. The user has to select the appropriate types and classes and press the button Analyse. The program will calculate according to the time data tables the time in TMU and the labour costs in AUD$.

4.8 MTM Analysis Results of Original Electric Switch

The assumptions for the analysis of the original electric switch are that the average distances to the containers are determined as 20 cm and that the parts are jumbled with other objects in a group so that search and select occur. The screw movement is simply described as two 180 degree turn motions separated by a regrasp. The assembly process of the original electric switch consists of 102 separate operations and according to the MTM analysis takes 917.20 TMU or 33.02 sec. By selecting the Workstation 1 with a pay grade of 35.00 AUD$ per hour the total labour costs for all motions are 3.210 AUD$. All involved times, costs, and counts as well as the improvements are shown in Table 4.4.2.

5 Proposed Redesign of Electric Switch

The goals of redesigning the switch are to minimize the number of parts, reducing the time for assembly process and increasing the safety and ergonomics for the work people during the assembly process, while maintaining the functionality of the original design. The electric switch has been redesigned based on the proposed integrated lean design framework. As a result, following design changes have been occurred on the electric switch.

First: The switch base was modified to incorporate a snap-fit into the switch cover. This eliminated the existing bent tabs used on the metal switch cover to attach it to the plastic switch base. Moreover, there are snap-fit sockets to hold two metal wire clinch terminals and the centre terminal / rocker in place. All these modifications will not cause additional fabrication charges for this piece because a new plastic mold has to be created.

Second: The wire clinch terminals replace the terminals, terminals screws short and terminal screws of the original switch. They perform the dual function of holding the stranded wires and providing contact points for the centre terminal/rocker. Wires are held in place within terminals by a metal-locking spring action. The two wire clinch terminals are formed from rolled brass sheets and they snap into the plastic switch base. Additional tooling and fabrication charges are incurred to create these specialized parts.

Third: The centre terminal/rocker replaces the centre terminal contact, centre terminal screw short, contact rocker and switch spring of the original design. This piece snaps into the plastic switch base, like the wire clinch terminals. It is formed out of brass and sheet metal and provides a flexible interface at the switch toggle. This part incurs extra tooling and fabrication charges.

Fourth: The plastic switch toggle was modified extensively from the original design. A molded plastic piece with snap-fit posts replaced the cast aluminium piece. The plastic design of the new toggle incorporates the original switch plunger piece into the toggle itself. No extensive charges are foreseen in fabrication of this new part because a plastic-mold part simply replaces the casting process.

Fifth: The switch cover underwent an extensive redesign. It replaces the base cover, mounting threads, and mounting cover of the original design. This piece undergoes a complicated fabrication process. The overall shape is a metal casting, and several machining operations are performed to finish the part. This makes the switch cover one of the most expensive parts in the new design. But the new design allows a snap-fit at the switch base interface, and posts on the toggle snap into the inner diameter of the threaded portion.

Sixth: The mounting hardware is not changed from the original design. The switch assembly is redesigned to keep the same functionality as the original design. This includes the way that it is mounted to the electrical panel, chassis, etc.

5.1 MTM Analysis for the Redesigned Electric Switch

To compare these two design proposal of the electric switch and to estimate the better design concerning costs and assembly time a MTM analysis has been conducted for the redesigned product. The selected work station is also Workstation 1 with a wage per hour of 35 AUD$. Thus, these two design principles can be evaluate about the same basics. The proceeding is equivalent to the analysis of the original switch. The user has to enter the position operations are involved in this assembly process. In this analysis, manufacturer needs to edit the part and tool list, position matrix, grasp matrix, and the list with all performances. The following table displays the complete MTM analysis for the redesigned electric switch. The similar assumptions of original electric switch are also considered for this analysis. After analysing by MTM tool, it has been found that the assembly process of the redesigned electric switch consists of 42 separate operations and takes according to the MTM analysis 435.60 TMU or 15.68 sec. All involved times, costs, and counts as well as the improvements are shown in Table 4.4.2.

Table 4.4.2 Comparison of two electric switches

Performances	Original electric switch	Redesigned electric switch	Impro vement [%]
Part count	18	7	61.1
Costs of involved parts [AUD$]	13.82	11.55	16.4
Tool Count	13.00	6.00	53.8
Costs of involved tools [AUD$]	30.99	10.00	67.7
Position operations count	12	6	50.0
Position operations time [sec]	6.33	5.68	10.3
Labor costs of position operations [AUD$]	0.615	0.552	10.2
Grasp operations count	18	7	61.1
Grasp operations time [sec]	5.77	2.1	63.6
Labor costs of grasp operations [AUD$]	0.561	0.204	63.6
All performances count	102	42	58.8
All performances time [sec]	33.02	15.68	52.5
Labor costs of all performances [AUD$]	3.21	1.524	52.5
Total cost per product [AUD$]	17.03	13.07	23.3
Products per hour	109.02	229.59	110.0

6 Conclusion

The lean design guidelines for product life cycle have been developed to support engineers/designers in designing easy, sustainable and cost-effective products. These guidelines consolidate manufacturing knowledge and present them to the designer in the form of simple rules to be followed when designing a product. All these guidelines are stored in a structured central database as a reference work for the design engineers. The developed MTM analysis tool demonstrated that the application of these guidelines during an early stage of the design process reduce the time to market, reduction in part counts and costs, improvements in quality and reliability, reduction in assembly time, as well as reduction in manufacturing cycle time. The design changes in the case example 'original electric switch' showed that application of lean design guidelines lead to a faster and more efficient assembly of the electric switch. Further analysis of this research may find benefit in a more in-depth study of guidelines across several industry types, using this research as background. It is expected that the proposed integrated lean design framework and developed MTM analysis would make a significant contribution to sustainable lean product development process of any manufacturing organization.

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4.5 Mini Factories for Cocoa Paste Production

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Abstract

This paper introduces a concept for decentralized value creation instantiated in mini factories for cocoa paste production. Mini factories can be located at strategic places for local income generation and to support regional development. Potentials and challenges of cocoa processing will be discussed. The impact of mini factories in the value creation process of cocoa will be outlined. It will be introduced the first mini factory for cocoa paste production that has been build up by "BEAR Holding" and is operated by "Pt. JavaCocoa" in Bali.

Keywords:

Sustainable value creation, Cocoa paste production, Decentralised production

1 Introduction

In September 2000 the United Nations passed ambitious aims to handle major action fields of the 21th century together on a coordinated international level. At the end they focused on eight goals to be reach by the international community until 2015. The "Millennium Development Goals" (MDGs) [1] among others aim to halve the number of people living in poverty (MDG 1), to promote the gender equalization (MDG 3) and to promote a worldwide developing partnership (MDG 8).

Today, in 2011, major steps have been made in some areas to reach the target, in others the development remains static or is even regressive. The global economic crisis at the beginning of this century may be one reason for this. Between 1990 and 2005 the rate of those, who have less than 1 USD per day, fell from 46 to 27 percent. The success is based on the economic growth in China and other Asian states. In Africa however, in the south of Sarah, cumulated nearly 70% of the poorest people of the world live. Especially alarming is, that more than halve of the working population lives in poverty. They were called the "working poor". The impact of the global crises is not included in the calculation of these numbers, and this suggests that the number continues to rise [2].

To reach the ambitious goals, the German development cooperation is undergoing a change: Help for self-help is the new topic. Two of the six core areas of the German ministry are: "Fighting poverty sustainably" and "to make greater developmental use of the economic engagement" [3]. Micro credits are a famous example, how financing tools can be useed to relieve the poverty. *Now the question is what kinds of tools do exist in production technology and factory management to help reaching the MDGs?*

One possible way is a *value creation network*. A Value creation network takes the three parts of sustainability into consideration. The economic motivation is based on a flexible production (variants, quantity). Economic-ecological reasons are shorter ways of transportation and so related reduction of cost and environmental impact. The ability for independent value creation, even in socially and geographically isolated regions, added by higher teaching productivity and new perspectives can lead to an actively designed, independent life for humans in developing countries by income generation.

A tool to realize value creation networks is a *mini factory for micro entrepreneurship***.** The systematic approach of mini factories is based on the following points:

- reconfigurability, mobility and reusability of the modules in the factory
- can be integrated in different communities
- customizable product- and material cycles
- promotion of skills

The approach will be shown exemplarily in the case of value creation networks for cocoa beans. The situation of the global market for cocoa will be briefly introduced and the actual situation of the African state Sierra Leone. How mini factories can be used in the cocoa value chain and other transfer scenarios for mini factories will be shown.

2 Value Adding Process and Cocoa Market

3.4 million tonnes of cocoa beans per year are produced worldwide. More than 90% of the total amount is produced by about 14 million workers at three million small holdings in ten countries (Ivory Coast, Indonesia, Ghana, Nigeria, Brazil, Cameroon, Ecuador, Dominican Republic, Malaysia and Colombia) [4]. In West-Africa alone 10.5 million farmers work at 3–5 hectare large plantations and produce almost 70% of the entire annual production (Fig. 4.5.1) [5]. Cocoa bean production is very labour-intensive. In comparison to that the daily revenue of 1.25 USD per farmer is very low. Furthermore it is dependent on fluctuations of the world market. As the cultivation of cocoa is often the only source of income for a family they are not able to live an independent and stable life.

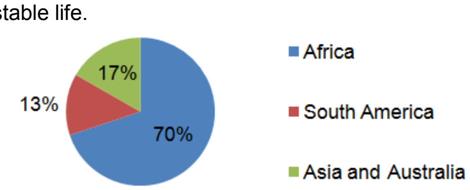

Fig. 4.5.1 Share of worldwide cocoa bean production 2008–2009 [5]

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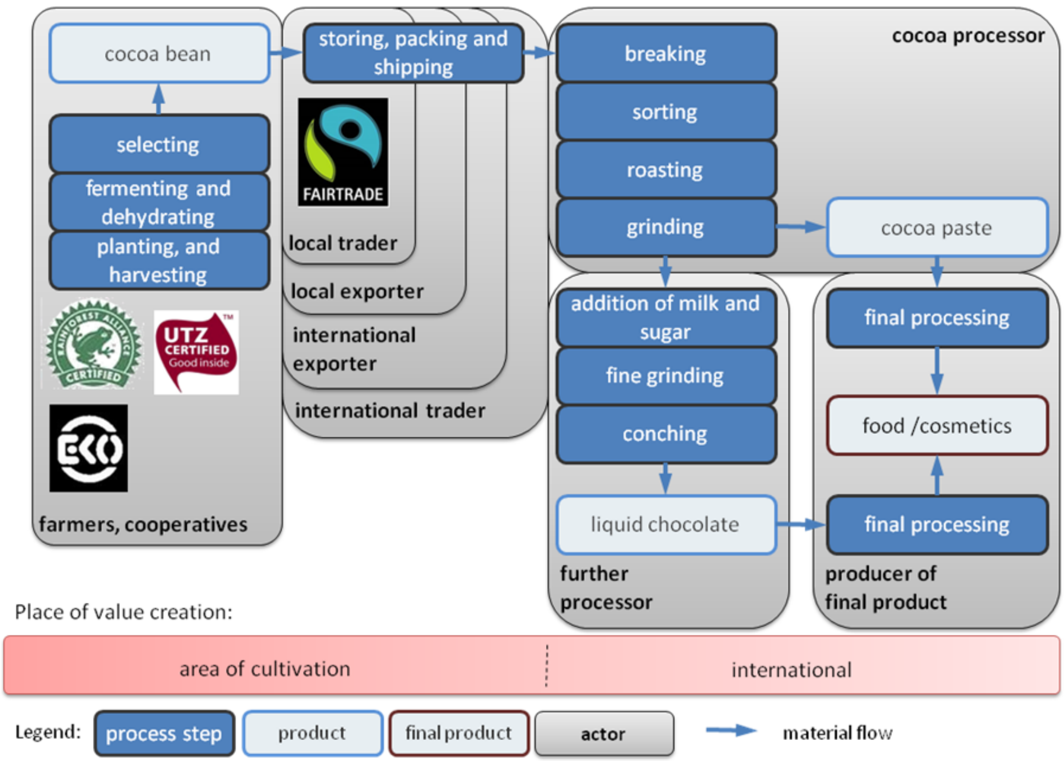

Fig. 4.5.2 Current situation of value adding process of cocoa (after [4])

To improve their life standards and also to increase their income one approach is to place farmers nearer to the market. To do so the governmental development organizations (GIZ), various non government organizations and fair trade cachets are founding production cooperation, teaching of price mechanism and training “of sustainable agricultural practices according to an internationally accepted standard” [6].

A farmer—possibly organized in cooperation—harvests the cocoa pod from the cocoa tree. He or her opens the pod and dries the cocoa beans. The beans will be sold ether on the local market or to an intermediary or trader. The local trader sells the beans to a local/international exporter or to a local cocoa processor, the grinder.

The first technical value adding process is grinding. The grinding process could be placed in the area of cultivation. By-products of the grinding process like husks and shells could be used as organic mulch, soil conditioners and poultry feed. But in most cases (66%), the beans were shipped out to foreign countries, where further processing takes place. Many players exist in the grinder market, but only a few big ones hold more than 50% of the market (Cargill, ADM, etc.). The growth rate of the market is about 25% [4].

The grinder produces cocoa paste and sells it to an international exporter. International trader brings the beans or the butter to further processing steps. The cocoa butter is used in the cosmetic and food industry. The value adding process is often not in the growing region, but in foreign countries, as shown in Fig. 4.5.2 [4].

The situation on the chocolate manufacturing market is analogical: the market is highly concentrated, and dominated by a few producers, have nearly half of the market volume.

Consequently the market can be described as follows:

14 million farmers, who live with 1.25 USD per day closely above the poverty level, produce approximately 3 million tonnes cocoa beans, which are exported to nearly two-thirds. The five major producers (ADM, Cargill, Barry Callebaut, Petra Foods and Blommer) of semi-finished cocoa products, the grinders, cover more than the half of the market and produce together 1.7 million tonnes, with an increasing trend. The number of grinders and chocolate manufactures is declining and the remaining companies collaborate more and more in the last years [4]. Between 2008 and 2011 the world market price for cocoa beans rose by 83% to nearly 3000 USD per tonne [7], because of price speculations, significantly increased demand and reduction of production.

3 Cocoa Market in Sierra Leone

Sierra Leone has nearly 5.8 million inhabitants, two thirds of the population practice agriculture; approximately half of the gross domestic product is generated here. From 1991 to 2001 the civil war destroyed most of infrastructure and production systems. The rice of production now is on an equal level to the situation before the civil war. Also in the cocoa branch a recovery takes place, as shown in Fig. 4.5.3. 74 percent of the total area of the country (72.300 km²) is considered arable land, but only less than 15 percent is currently cropped [8]. A further development of the country is urgently necessary: In 2010 the country was number 161 of 172 at the Human Development Index, over 70% of the population lives under the poverty limit, the infant mortality rate is 89 per 1000 births and life expectancy at birth is 47 years [9, 10].

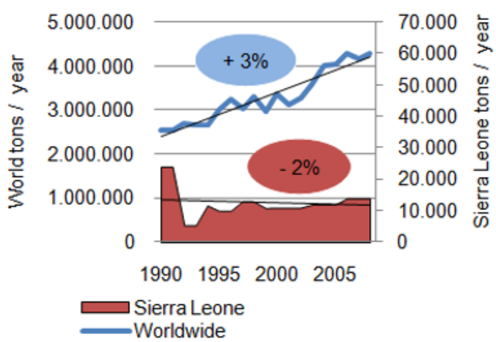

Fig. 4.5.3 Cocoa Crops in Tonnes 1990–2008; world production compared to Sierra Leone [5]

Sierra Leones produce 14.000 tonnes of cocoa beans per year; this is just a share of 0.56% of the production in Africa. In Sierra Leone the production and export of cocoa is one of the greatest opportunities for the future. High prices on the world market and instable social and political situations at the Ivory Coast let the demand for Sierra Leones cocoa beans rise. The decrease in production since 1990 is due to the civil war, and the following wildness of cocoa plantations.

The largest plantations were in the east, where the civil war was particularly bad. Many families had to take refuge and those who return to rural areas, now often work as miners. “The lack of manpower in agriculture, is problematic for the reconstruction and food security of the county”, explains Franz Möstl, project manager for the German agro action in Sierra Leone [11]. Further more women are not involved in the cacao production.

Not only in quantity also in quality has Sierra Leone had weaknesses. On the world market beans from Sierra Leone considered to be from miner value, and so their price is 15% under market level [12]. Regional farmers organise themselves in cooperatives to set quality standards and to reach certifications in order to enforce higher prices for their products. Further the expansion of the agricultural sector, particularly cocoa production is one of the priorities of the development agenda in the country [13]. Because of the cooperatives the price for dried beans per pound has already increased from 1500 Leone to 3500 Leone (approx. 0.45 USD). Farmers benefit from the cooperatives profits directly. They help to secure their livelihood [14]. The difference of 2000 Leone is a success, but it is still far away from the goal to defeat poverty and its consequences. Another step for the farmers in Sierra Leone could be the further processing of beans and selling of the semi-final product.

The cacao market in Sierra Leone would be an excellent application field for a mini factory network because of the unexploited potentials regarding quality and quantity of the beans, the political background, and the great social and economical impact.

4 Concept Description

4.1 Decentralized Value Creation in a Mini Factory

A mini factory is a micro enterprise performing at least one designated technical process out of a value adding chain, as part of a value creation net. All equipment needed to perform the process is located in a container. It can be moved from one strategic place to another for local value creation to create local income generation and to support regional development [15].

According to the United Nations Environment Programme, many micro enterprises, especially in developing countries, suffer from relative lack of training, know-how, appropriate technology, and money. This can lead to a high degree of resources used in production and depending on performed production processes, to polluting emissions with a negative impact to human and environment as well. Micro enterprises fall into the grey area known as the “informal sector”, what makes it more difficult to support them with information regarding their sustainability and how to achieve higher performances. Many of them are not covered by occupational health and safety laws and unaware of the consequences [16].

Mini factories in a flexible value creation net can be accumulated decentralised. In this paper the decentralisation of mini factories aims to have a positive social and environmental impact. It becomes more important to follow development principles such as

- First time users: Customers lack technological intuition
- Development and alternative uses: Local ingenuity can adapt products to unimagined uses
- Local production: Creating local jobs, service and support structures as well as acceptance
- Local/sustainable materials: Ensuring a low ecological footprint
- Energetic sustainability: Don’t rely on non renewable fuels
- Multiple purposes: Multiple uses reduce the need for several machines
- Durability: Durability is a strong lever in resource efficiency
- Repair: Weak support infrastructure demands products to be serviced by the consumer

for establishing or providing micro enterprises with triple-bottom-line tools and approaches [17]. The here presented concept and implementation of a mini factory has not reached these principles completely but first steps have been done in the right direction.

4.2 Mini Factories for Cacao Paste Production

As described earlier most of the value adding steps of cocoa are not performed in the area of cultivation, but in industry regions with large technical equipment. Using a mini factory, we want to enable small scale production and value creation in the area of cultivation to promote incomes of local population.

The technical challenge of such a small scale production is the development of adapted technology that can include the miniaturization and simplification of existing production equipment. Figure 4.5.5 shows the CAD-model of a mini factory. Equipment included in the mini factory are a roll crusher, a upstream sorter, a roaster, a stone grinder, 5 ball mill, a agitator tank, a diesel tank and generator. Before processing, the cacao beans will be selected from pollutions (e.g. Sand, Metal, woods) and dried in the sun. The process steps to be performed in the mini factory are breaking of beans into nibs; sorting with an upstream to remove the shells that can be used as organic mulch soil conditioners and poultry feed; roasting of nibs and three staged of grinding to get the cocoa paste as shown in Fig. 4.5.4.

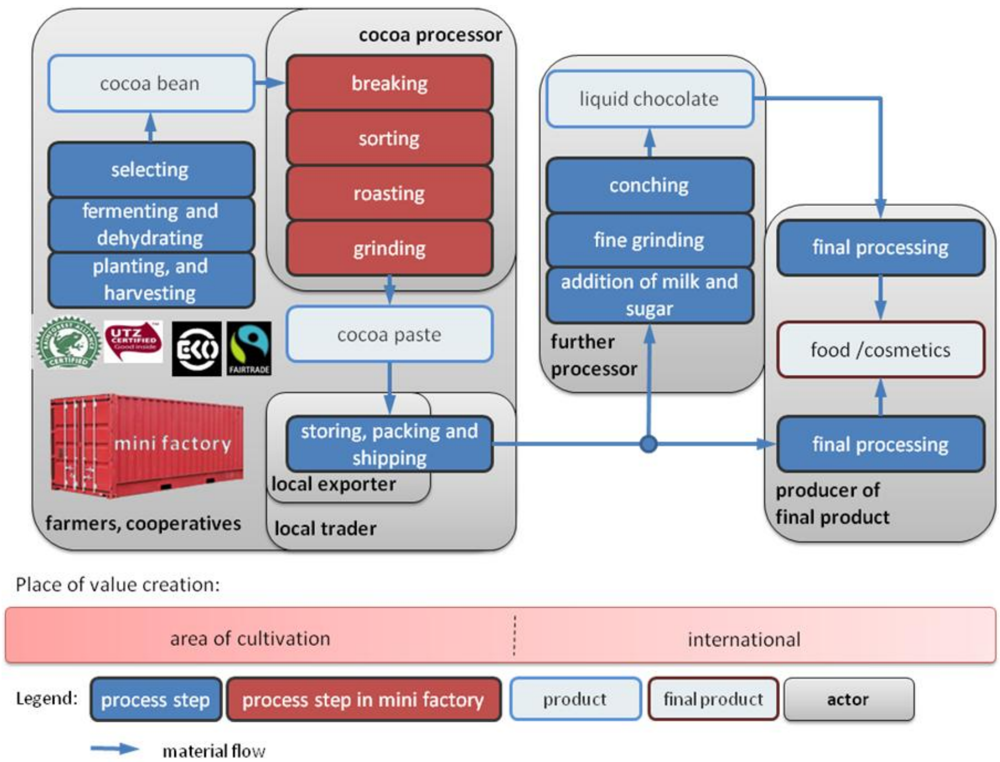

Fig. 4.5.4 Possible situation including mini factories for cocoa paste production (after [4])

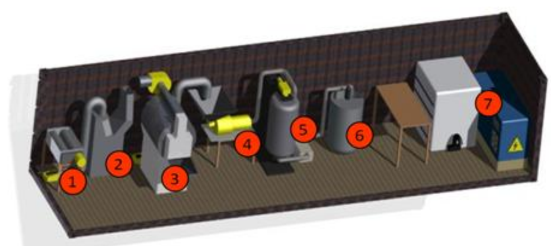

Fig. 4.5.5 Current 3D-model of a mini factory for cocoa paste production (*1* roll crusher, *2* upstream sorter, *3* roaster, *4* stone grinder, *5* ball mill, *6* agitator tank, diesel tank and generator)

The roasting process has two different functions, the first leads to the typical aroma and second all germs are killed. Now the paste can be packed and delivered.

The educational challenge is how to build capacity to run, maintain and repair such a production system. Another challenge is the organizational structure as one mini factory needs seed money as well as a certain amount and quality of raw material to work productive and for amortization.

One tonne cacao beans yield 830 kg cacao paste. The beans alone have a market price of 3.000 USD per tonne in other countries, but in Sierra Leone just of 2.250 USD [18]. Cocoa paste has a sale price of 4.000 USD per tonne [19]. The share of value adding per tonne cocoa paste is 1.367 USD, calculated with the lower Sierra Leone prices.

The mini factory introduced in this paper is capable of a cocoa paste flow of 50 kg/h. One sack/h filled with 60 kg cocoa beans is required. Working 24 h and 365 days with a distribution time of up to 5% the factory can produce approx. 415 t cocoa paste out of approx. 8.322 sacks cocoa beans (500 t beans) per year. With a value adding factor of 1.367 USD per tonne a yearly turnover of approx. 514.000 USD could be reached (Table 4.5.1).

Table 4.5.1 Production data and turn over cocoa paste, first year

	Beans	Paste	
Yield	1.17	1	$y_{b/p}$ = [kg]
Price	2.250	4.000	$P_{b/p}$ = [USD/t]
Value adding		1.367	$V_p = P_p - (P_b \cdot y_b/y_p)$ = [USD/t]
Processing per hour	60	50	$h_{b/p}$ = [kg/h]
Processing per year	450	376	$p_{b/p} = T_a \cdot h_{b/p}$ = [t/a]
Time per day		24	t_d = [h]
Working days per year		330	t_a = [d]
Distribution time		5	t_{dis} = [%]
Production time per day		22.8	T_d = [h/d] = $t_d \cdot (1-t_{dis})$
Production time per year		7.524	$T_a = t_d \cdot t_a \cdot (1-t_{dis})$ = [h/a]
Turnover paste	513.992		$T_p = p_p \cdot V_p$ = [USD/year]

Subtracting the running costs, labour costs and the sale tax, we get the profit after tax. In the first year the profit is nearly 270.000 USD (Table 4.5.2).

Table 4.5.2 Assumed data for amortisation, first year

	Expense	Revenue	
Running costs	180.000		400 USD/t for 450 t
Labour costs	14.850		3 employees * 330 days * 15 USD/day
Value adding		513.992	USD
Profit before taxes		319.142	USD
Sale tax	47.872		15% [20]
Profit after taxes		271.270	USD

Table 4.5.3 Assumed turnover and profit development [USD]

Year	Sierra Leone beans/ tonne	Paste/ tonne	Turnover	Profit after taxes
1	2.250	4.000	513.992	271.270
2	2.475	4.400	723.800	449.607
3	2.700	4.800	789.600	505.537
4	2.925	5.200	855.400	561467
5	3.140	5.600	924.960	620.593

The growing demand on the world market and the increasing quality of the cocoa products in Sierra Leone to be assured lead to an amortization of the investment of 500.000 USD in under two years (Table 4.5.3).

Assuming that one farmer in Sierra Leone can produce 1.5t cocoa beans per year (25 sacks filled with 60 kg beans per year) on 1.5 ha of land; the mini factory could supply 300 farmers with additional income.

If the beans would be bought for world market prices a farmer would get 2.250 USD/t, in total 3.375 USD per year or 9.2 USD per day. In the first year already their income would be 7 times higher than it is today. Allocating the mini factories in form of a net across Sierra Leone and not only along the coast the cocoa paste production could lead to a better infrastructure, as more and better roads would be required (Fig. 4.5.6).

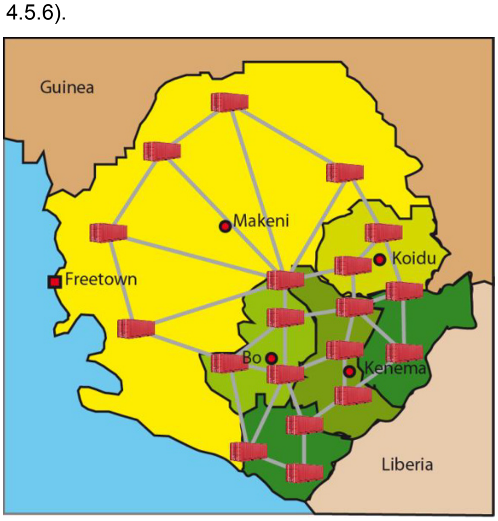

Fig. 4.5.6 Network structure of mini factories in Sierra Leone

14.000 tonnes of cacao beans are harvested and exported from Sierra Leone per year. With half of the volume (7.000 tonnes) 15 mini factories could produce cacao paste with a valuation of over 4 million USD in the first year. The earnings would promote the incomes of all members along the value chain in Sierra Leone and increase the tax sum of the highly indebted state by 718.080 USD in year one.

4.3 Effects of a Mini Factory to Achieve the Millennium Development Goals

The beginning question was: "*What kinds of tools do exist in production technology and factory management to help reaching the MDGs?*"

The Millennium Development Goals are subdivided into targets which are evaluated on the basis of measurable indicators.

The mini factory promotes the local income; this will work to target A of the MDG 1: *"Halve, between 1990 and 2015, the proportion of people whose income is less than $1 a day."*

A safe and fair workspace in the mini factory, adequate for women and men, and aspects of job enlargement tools aim at target MDG 1.B: *"Achieve full and productive employment and decent work for all, including women and young people."*

Because of a problematic lack of manpower in agriculture, gender equality and empowerment of woman (MDG 3) is necessary. Training of female staff to operate the technical equipments reduces the number of woman in informal employment.

Supplementary certification leads to the development of *"further an open, rule-based, predictable, non-discriminatory trading and financial systems"* (MDG 8.A).

Through cooperation with the private sector MDG 8.B can be reached *"Develop a global partnership for development": "make available benefits of new technologies"* (this topic will be further discussed in the next chapter).

The insurance of environmental sustainability (MDG 7) is also part of the mini factory concept: reduced transport weight due to 20% percent weight loss during the production process, leads to reduced greenhouse gas emissions.

In summary, a mini factory affects the three pillars of sustainability: Economy, Society and Environment. Furthermore it is an enabler for help for self-help.

5 Implementation

The company *BEAR Mühlen & Behälter* (www.bear-gmbh.de) has extensive experience in design, manufacturing and installation of machinery and equipment for industrial cocoa processing. Normally offering production systems with an output capacity of up to 4.500 kg cocoa paste per hour, the company builds up a mini factory for cacao paste production with a flow rate of 50 kg/h cocoa paste. The production process will be located in a 40 feet high cube container (ISO quota 668). The container will be completed and tested in Berlin and than shipped to Bali the place of production. Here the production line will be mocked up by "BEAR Holding" and operated by "Pt. JavaCocoa". The mini factory will be allocated in between of cocoa plantations. The estimated date for the start of production is the end of October 2011.

The processing of beans starts with a manual pre-sorting, cleaning and drying process. After that the cocoa beans are deposited in a large hopper located on the roof of the container. They undergo a second drying process in a silo for about one hour. A heat exchanger is planned here to use the waste heat of the generator for the drying process. The beans are transported by means of a conveyer screw to a crusher having a performance of approx. 60 kg per hour. The remaining shells are extracted by an aspirator and stored outside in a little tank. A second screw carries the nibs to the roaster where two roasting cycles take place, each one with approx. 25–30 kg per hour. During roasting the nibs are sterilized. The fine grinding of nibs is carried out in a stone mill and two mini ball mills in order to achieve the required fineness. Finally, the cocoa paste is cooled down in a stirred tank and is then tempered by batch of 200 kg. The packing of the final product is carried out manually (approx. 8 cartons per batch). The cartons can be stored on shelves where the mass continues to solidify. The technical data of the container follows [21]:

- 50 KVA generator
- Complete infrastructure encompassing rooms with doors and windows, electrics, ventilation, etc.
- Air-conditioning in the blocking room
- Electric roaster 5 kW
- Stone mill 6.5 kW
- Two ball mills 2 kW, filled with 25 kg of balls
- Power requirement: 10–15 l of diesel per hour for the diesel generator
- Staff: 2–3 workers during production process
- 500 l of cooling water for the machines

Fig. 4.5.7 3D-model, exterior view of a mini factory for cocoa paste production

6 Transfer Scenarios

Table 4.5.4 Production data and turn over peanut oil

	Nuts	Oil	
Yield	1	0.4	$y_{n/o}$ = [kg]
Price	282	1.493	$P_{n/o}$ = [USD/t]
Value adding		788	$V_o = P_o - (P_n \cdot y_n/y_o)$ = [USD/t]
Processing per hour	130	52	$h_{n/o}$ = [kg/h]
Processing per year	978	391	$p_{n/o} = T_a \cdot h_{n/o}$ = [t/a]
Turnover oil	308.108		$T_o = p_o \cdot V_o$ = [USD/year]

Table 4.5.5 Assumed data for amortisation, peanut oil

	Expense	Revenue	
Running costs	97.800		100 USD/t for 978 t
Labour costs	14.850		3 employees
Value adding		308.108	USD
Profit before taxes		195.458	USD
Sale tax	29.319		15% [20]
Profit after taxes		166.139	USD

Based on the mini factory concept, other scenarios have been created. Factors like product and region have been changed. Regarding the factor product two possible transfer scenarios with a nearly similar production process have been looked at: the peanut and the Shea nut.

The peanut for instance is used as food, but also in industry, for manufacturing of pesticides and lubricating oils [22]. The traditional Shea nut is used as cooking oil and wax in Africa. Industrially, it is also used in cosmetics and food [23].

Both nuts grow in different regions. The peanut grows worldwide for instance in South- and Central America, China, India and Central Africa. The Shea nut grows only in Central Africa. Countries were both plants can be found are Niger, Mali and Congo.

Similar machine requirements of the three products open the opportunity to produce several products in one mini factory, depending on season and demand.

The process steps for the peanut are harvesting, dehydration, sorting, breaking and roasting to produce peanut butter and flour. To produce oil, a press is needed additionally. One tonne peanuts yield 400 kg oil. The price difference between untreated nuts and peanut oil is nearly 788 USD per tonne oil. At a throughput of 52 kg per hour, 978 tonnes peanuts are needed yearly to add a value of approx. 308 thousand USD (Table 4.5.4) with a final income of approx. 166 thousand USD (Table 4.5.5) [24]. As peanuts are much softer than cocoa beans, the running costs will be reduced due to a lower abrasion of the grinders. The amortisation time for a peanut mini factory accounts three years.

The production process of Shea butter is very similar to the cacao paste process. After harvesting, dehydration, sorting and breaking, the nut gets roasted and grinded. Adding of water and separation from oil and solid butter are the last steps. Only 200 kg butter result from one tonne Shea nuts. The world market price for Shea butter is by 1.750 USD per tonne, for dried nuts 213 USD. At a throughput of 25 kg per hour, 978 tonnes Shea nuts are needed yearly add a value of 564 thousand USD (Table 4.5.4) with a final income of approx. 307 thousand USD (Table 4.5.5) [25]. As Shea nuts are much softer than cocoa beans, the running costs will be reduced again due to a lower abrasion of the grinders. The Shea nut mini factory would amortise after less than two year.

The knowledge about Shea nut processing is based on traditional production techniques, so that additional training to use the machines in a mini factory can be done easier.

Table 4.5.6 Production data and turn over shea butter

	Nuts	Oil	
Yield	1	0.2	$y_{n/b}$ = [kg]
Price	250	1.750	$P_{n/b}$ = [USD/t]
Value adding		1.500	$V_b = P_b - (P_n \cdot y_n/y_b)$ = [USD/t]
Processing	250	50	$h_{n/b}$ = [kg/h]

per hour			
Processing per year	1.881	376	$p_{n/b} = T_a \cdot h_{n/b} = [t/a]$
Turnover oil	564.000	$T_b = p_p \cdot V_b = [USD/year]$	

Table 4.5.7 Assumed data for amortisation, Shea butter

	Expense	Revenue	
Running costs	188.100		100 USD/t for 940 t
Labour costs	14.850		3 employees
Value adding		564.000	USD
Profit before taxes		361.050	USD
Sale tax	54.157		15% [20]
Profit after taxes		306.892	USD

7 Conclusion and Prospect

The cocoa paste example illustrates that the implementation of a mini factory can be a powerful tool to keep value adding processes in areas of cultivation. Governments and non government organizations can use this production technology tool to fight poverty and its consequences in a sustainable way and to reach the MDGs. Challenging is to guaranty a good quality of the raw material and final product for certification, to qualify the factory operators, and the integration of the mini factory in a value creation network.

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4.6 Design of Energy Efficient Hydraulic Units for Machine Tools

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Abstract

Within the research project EWOTeK—Enhancing the efficiency of machine tools by optimising the technologies for operating components—that is funded by the German Federal Ministry of Education and Research (BMBF) amongst others energy efficient hydraulic ancillary units for machine tools are designed. Hydraulic is used in machine tools e. g. for the clamping of the tool in the spindle, for the change of tools, for the clamping of the workpiece, for the change of palettes that serve for the allocation of workpieces, for hydrostatic guidings or for the hydraulic weight compensation of vertical axes. This paper compares different hydraulic ancillary units of machine tools with regard to their energy consumption for an exemplary machining centre.

Keywords:

Energy efficiency, Hydraulic, Machine tools, Sustainable manufacturing

1 Introduction

The results presented in this paper are taken from the research project EWOTeK—"enhancing the efficiency of machine tools by optimising the technologies for operating components". This co-operative project is sponsored by the Federal Ministry of Education and Research (BMBF). The partners in the co-operative project, which is scheduled to last three years from July 2009 to June 2012, are the two machine tool manufacturers HELLER and INDEX, the component manufacturers Siemens, KNOLL, BKW and Bosch Rexroth and the Laboratory for Machine Tools and Production Engineering (WZL) at RWTH Aachen. To permit findings to be of importance for industry, the co-operative project is complemented by a group of users. As in lots of fields of the industrial production sector, significant potential for increasing energy efficiency also exists in the machine tool sector [1].

The aim of the co-operative project EWOTeK is to reduce the energy consumption of machine tools and their ancillary components, i.e. hydraulic unit, cooling system and cooling lubricant supply. Thus within the co-operative project EWOTeK concepts are drawn up for more efficient use of the entire machine. At the same time, individual components of the machine are optimised technologically. This involves, for instance, requirement-oriented cooling concepts, requirement-based use of cooling lubricants, enhanced control in asynchronous drives for machine spindles and energy-saving hydraulic concepts.

2 Distribution of Energy Consumption of Machine Tools: Focus Hydraulic Units

Hydraulic components belong to the ancillary components of machine tools. Collectively, the ancillary components hydraulics, cooling and cooling lubricant supply are often the most significant consumers of energy of machine tools. There are a variety of known studies on the energy consumption of ancillary components of machine tools [2–9]. These studies base on research on various machines. These machines differ e.g. according to their machine principle, equipment and degree of automation. In addition, these various studies take into consideration different machining scenarios, in other words, processes with different materials and tools as well as cutting speeds, depths and widths. Furthermore, different measuring equipment is utilised and different study methodologies are applied. Despite the described differences one finding common to all of these studies is that ancillary components account for a large share of the energy consumption of machine tools. The energy required for the actual machining itself is significantly less than the energy consumed by the ancillary components.

Studies on the amount of energy consumed by machine tools for machining high-strength materials prove an exception. These studies show that the share of power drawn by the spindle increases significantly due to greater process forces. [2–9].

Going more into detail there are also a variety of studies known on energy consumption of, and in particular, hydraulic components of machine tools [3–5, 10–15]. They show that the energy consumption of the hydraulic components for the respectively described machine conditions and described processes amount to between 0.9 and 32.4% of the total energy consumption of the machine tools under study. In absolute figures the active power input of the hydraulic components of machine tools range between 0.1 and 7.5 kW for the studies considered. Figure 4.6.1 depicts in percentage terms for the studies being considered the distribution of active power input for the individual electrical consumers of machine tools, and in particular of the ancillary components hydraulics, cooling and cooling lubricant supply. [3–5, 10–15].

G. Seliger (Ed.), *Sustainable Manufacturing*,

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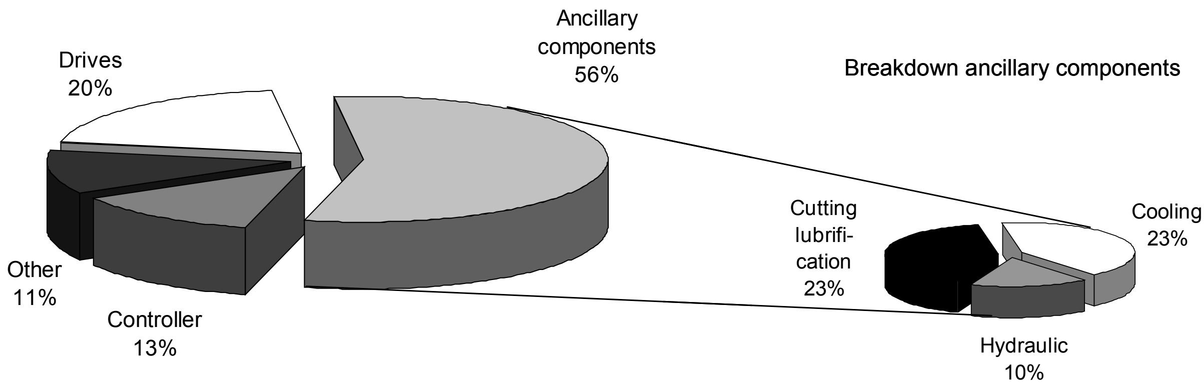

Fig. 4.6.1 Distribution of active power input for various studies [3–5, 10–15]

3 Technologies for Energy Efficient Hydraulic Units

With their high force density hydraulics fulfil a variety of tasks in cutting machine tools. These tasks include releasing and clamping of tools in the spindle, changing tools, opening and clamping the chuck, operating the revolver head clamping system, hydraulic weight compensation, operating protective doors, workpiece clamping and tracking, changing and transporting pallets, supplying power to hydrostatic guidance systems and traversing hydraulic axes [16–18].

Different approaches exist to make the ancillary component make hydraulics of machine tools more energy efficient. The approaches described in literature as well as those already implemented by companies to increase energy efficiency in the field of hydraulics in machine tools can be summarised as follows [19]:

- Energy efficient pumps
  - Increased degree of efficiency
  - Variable speed pump drives controlled by means of frequency conversion
- Accumulator charging circuit
- Optimised hydraulic consumers, for example workpiece clamping systems with minimised leakage
- Directional seat valves

Variable speed pump drives controlled by means of frequency conversion are used to adapt the speed of the motor according to the volume flow rate requirement. In so doing, the energy efficiency of the hydraulic system can be improved. The accumulator charging circuit solution sees the hydraulic system supplemented with a hydraulic accumulator. The pump is activated only when the hydraulic pressure of the hydraulic system falls below a defined value. The hydraulic accumulator serves to ensure rapid reaction to fluctuating volume flow rate requirements and compensate for leakages. After the motor has been turned on the pump requires a short time until the necessary pressure is built up. The hydraulic accumulator compensates for the lack of pressure during this time [20].

4 Analysis of the Energy Consumption of Different Hydraulic Units

4.1 Measuring Setup

The studies of energy efficiency of different hydraulic units described in this article are performed on a Heller H2000 machining centre. This machining centre is suitable for both series production and job-shop operations. The hydraulics in this machining centre serve to fulfil the functions changing pallets, clamping and releasing work pieces as well as changing tools. Changing tools encompasses the hydraulic functions clamping and releasing the tool in the spindle as well as actuating the tool carrier system that transfers the tool from the tool magazine to the tool changer and back again. To accomplish the functions described above requires a pressure of 60 bar with a maximum volume flow rate of 25 l/min when changing pallets and tools. To clamp workpieces requires a pressure of 200 bar with a maximum volumetric flow rate of 14 l/min.

For the purpose of these studies two different hydraulic units are compared. On the one hand a unit is analysed that from the point of view of energy efficiency represents state-of-the-art technology. And on the other hand a unit is examined whose energy consumption has been optimised. The unit corresponding to state-of-the-art technology is equipped with two variable-displacement axial piston pumps. One pump, referred to in the following as low-pressure pump, delivers a pressure of 60 bar. The other pump, referred to in the following as high-pressure pump, delivers a pressure of 200 bar. Both pumps are mounted on a shaft and are driven by an induction motor with a connected load of 4 kW. The high-pressure pump on the unit with optimised energy consumption characteristics is replaced with a booster. This pressure intensifier is fed via the low-pressure pump and generates the high-pressure required for workpiece clamping with a fixed compression ratio, Fig. 4.6.2. The hydraulic system of the investigated machine has especially to cope with contamination as with each pallet change the hydraulic system is open for a few seconds. The machine tool manufacturer of the machine tool that is investigated already tested pressure boosters that are available in the market. Yet they all failed because of contamination. This prototypic booster is unsusceptible against contamination.

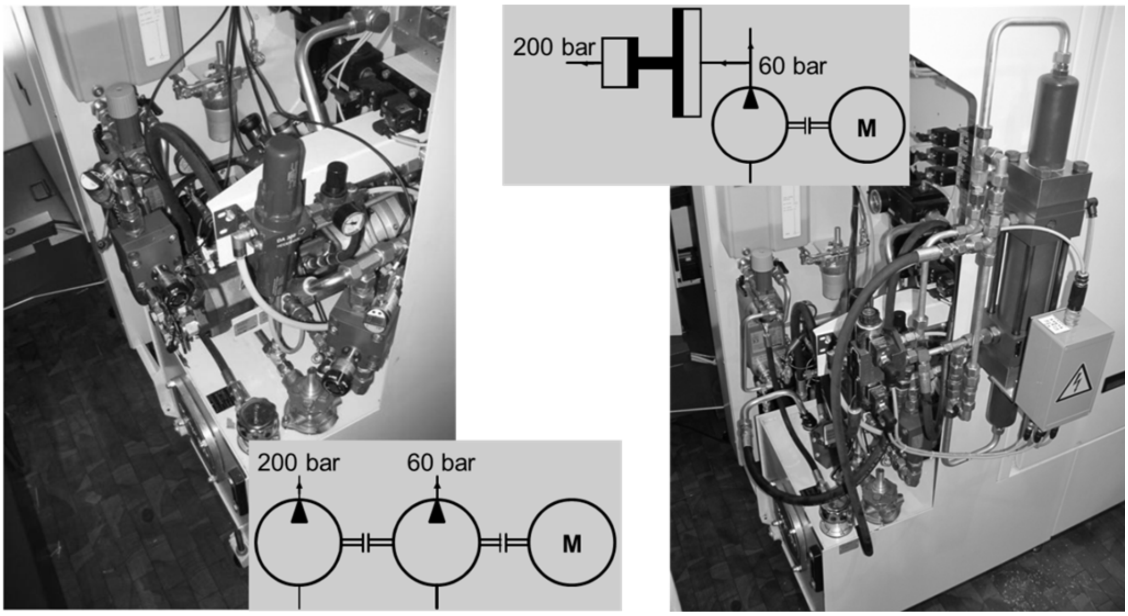

Fig. 4.6.2 Hydraulic unit with two pumps and with a pump including booster

To compare the two hydraulic units under study the following variables were measured:

- Pressure
- Volume flow
- Temperature
- Active power
- Reactive power
- Apparent power

Figure 4.6.3 depicts the measurement setupfor the hydraulics of the state-of-the-art and for the hydraulic unit whose energy consumption has been optimised. All measured signals are triggered and measured and recorded via a common dSpace system.

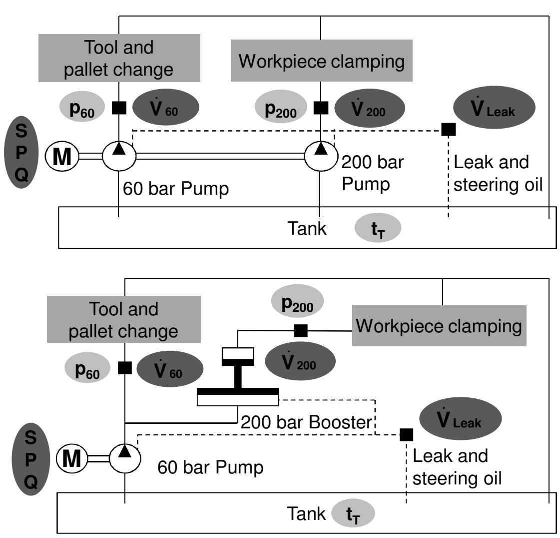

Fig. 4.6.3 Measurement setup of the two hydraulic systems.

A Norma 5000 high precision power analyser from Fluke with 1 MHz bandwidth and 0.5 % accuracy was used to measure the power components. The pressure and volume flow are measured separately on each pump on the unit corresponding to state-of-the-art technology. The pressure and volume flow of both the low-pressure pump and the booster are measured separately on the optimised unit. In addition, the volume flow of the leak and steering oil are measured together for both of the pumps of the state-of-the-art unit as well as for both the low-pressure pump and the booster of the optimised unit.The temperature in the hydraulic tank is also measured.

4.2 Experimental Procedure

To analyse both hydraulic units all three hydraulic functions pallet change, tool change and workpiece clamping are taken into consideration. At the same time the power components pressure and volume flow rate are examined for times in which no hydraulic functions are carried out. With that, all possible conditions of both hydraulic units are covered for the machining centre under study. With the aid of the data obtained it is possible to depict the energy consumption of any possible scenario or any workpiece for the purpose of calculating pay-back periods.

4.3 Evaluation of the Test

Figure 4.6.4 depicts the volume flow curve for the three hydraulic functions pallet change, tool change and workpiece clamping of the hydraulics of the state-of-the-art unit. The share of leak and steering oil is clearly visible for times in which no hydraulic function is being performed. All told, both pumps exhibit a leak and steering oil volume flow of 3.8 l/min for times in which no hydraulic function is being performed. Further measurements found that 0.5 l/min of this figure can be attributed to the low-pressure pump and 3.3 l/min to the high-pressure pump. The maximum volume flow rate of the low-pressure pump of 25 l/min is required when the hydraulic functions clamping and releasing tools as well as changing pallets are performed.

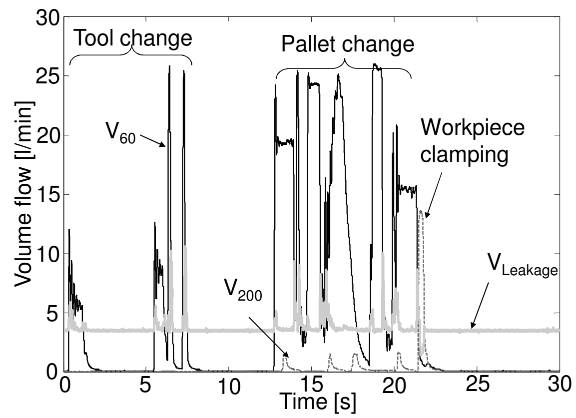

Fig. 4.6.4 Volume flow curve for the hydraulic unit equipped with two pumps

Figure 4.6.5 depicts the volume flow curve for the three hydraulic functions pallet change, tool change and workpiece clamping of the hydraulic unit whose energy consumption has been optimised. It becomes clear that by replacing the high-pressure pump with the booster it is possible to reduce the leak and steering oil volume flow to approx. 0.7 l/min for times in which no hydraulic function is being performed. At the same time all of the functions of the hydraulic unit are retained.

Figure 4.6.6 compares the pressure curves of the different hydraulic functions of the machining centre for both the state-of-the art unit and hydraulic unit whose energy consumption has been optimised. As expected the pressure curves are very similar for the 60 bar pump. The pressure spikes in the high-pressure circuit of the hydraulic unit whose energy consumption has been optimised are particularly conspicuous.

These result on the one hand from pressure fluctuations in the low-pressure circuit when hydraulic functions are being carried out in the low-pressure range and the coupling of both circuits that now exists. On the other hand they result from the change of direction of the piston of the Booster in both reversal points. It is possible to counteract these pressure spikes by introducing a diaphragm accumulator. In addition, the high pressure of the booster is still somewhat less than

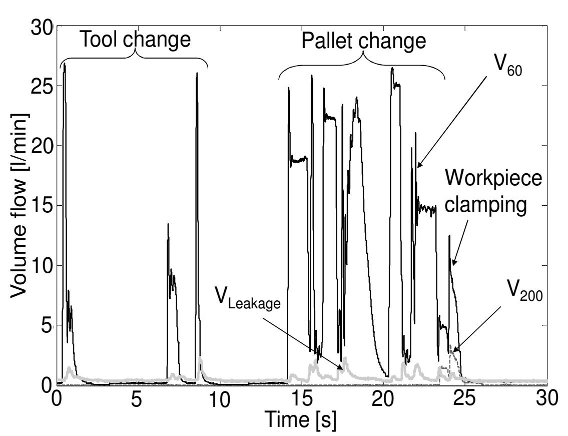

Fig. 4.6.5 Volume flow curve for the hydraulic unit equipped with a pump and booster

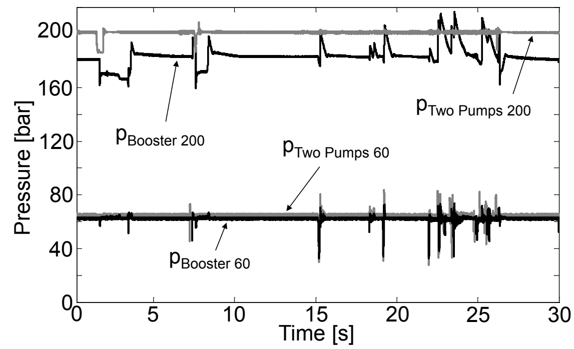

Fig. 4.6.6 Pressure curve for both hydraulic units

the high pressure of the state-of-the-art unit. This is attributable to the fixed compression ratio between the low-pressure and high-pressure of the hydraulic unit whose energy consumption has been optimised. Yet a pressure of 200 bar is needed for workpiece clamping. To correct this it is necessary to slightly increase the pressure of the low-pressure pump. This will also result in a slight increase in power consumption.

Figures 4.6.7 and 4.6.8 depict the curves of the power components active, reactive and apparent power for the two units.

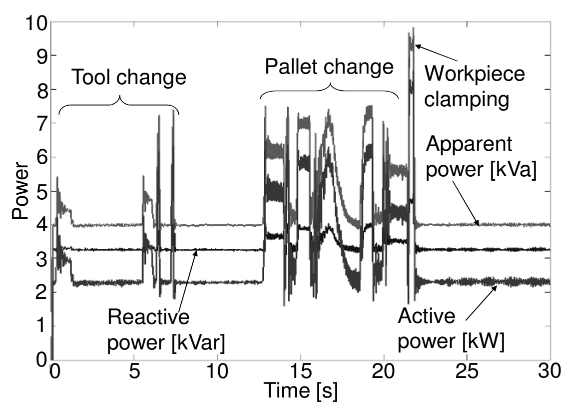

Fig. 4.6.7 Characteristics of the power consumption for the hydraulic unit with two pumps

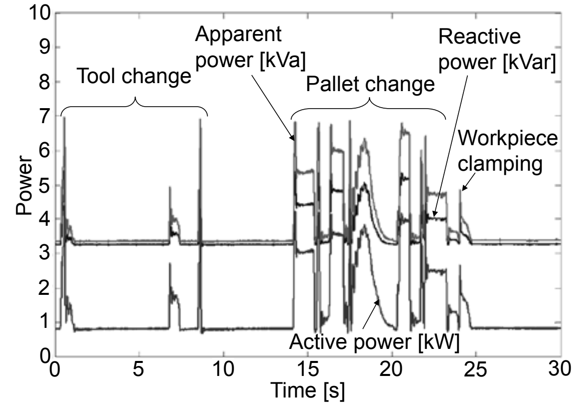

Fig. 4.6.8 Characteristics of the power consumption for the hydraulic unit equipped with a pump and booster

Particularly conspicuous is the reduction in the active power input for the optimised unit. The state-of-the-art unit has an active power input of 2.3 kW during those times in which no hydraulic function is being performed. The hydraulic unit whose energy consumption has been optimised requires only 0.9 kW for times in which no hydraulic function is being performed.

The apparent power is reduced accordingly. The reactive power component is practically unchanged. Above and beyond the savings described the hydraulic unit whose energy consumption has been optimised is significantly quieter in comparison with the state-of-the-art unit.

5 Summary and Outlook

This article compares a hydraulic unit, which from the point of view of energy efficiency corresponds to state-of-the-art technology, with a hydraulic unit with optimised energy consumption. Both units were studied on the same representative machining centre. The unit that corresponds to state-of-the-art technology is equipped with two variable-displacement axial piston pumps delivering 60 and 200 bar pressure respectively. Both pumps are driven by a common induction motor. The different hydraulic functions changing tools, pallets and workpieces on the machining centre are fulfilled with the aid of these pressure circuits. The 200 bar high-pressure pump on the hydraulic unit with optimised energy consumption characteristics is replaced with a booster. The measurement results show that in contrast to the hydraulic unit, which from the point of view of energy efficiency corresponds to state-of-the-art technology, it is possible to reduce the active power input of the hydraulic unit with optimised energy consumption characteristics in the machine condition “motors on” i.e. for times in which no hydraulic function is being performed by some 60 %. In addition, it is possible to reduce the leak and steering volume flow by 3.1 l/min for this machine condition.

In future, the studies described above will be continued and extended to other hydraulic units with optimised energy consumption characteristics. Future research will also focus on the comparison with an accumulator system.

6 Acknowledgments

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4.7 Business Models for Product-Service Systems (PSS): An Exploratory Study in a Machine Tool Manufacturer

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Abstract
Product-Service System (PSS) is an innovative business strategy that shifts the traditional way of doing business based on designing and selling only physical products to a new approach focused on delivering a combination of products and services. To perform this shift, changes in the way of doing business and delivering value to the users are necessary, resulting in changes in the company's business model. In this sense, this study aims to identify and classify the main PSS characteristics according to the elements of a business model. This is the basic information to carry out a case study to propose a business model based on the PSS strategy for a machine tool manufacturer. The main contribution of this work is to support companies on the first steps of defining a PSS strategy by demonstrating the design of a PSS business model.

Keywords:
Business model, Characteristics, Product-service system

1 Introduction

The product-service system (PSS) offers opportunities for companies interested in gaining a competitive advantage in today's marketplace by introducing new ways of dealing with businesses, customers value chain. The PSS shifts the traditional business approach based on designing and selling physical products to a approach focused on delivering products and services that can meet user needs [1].

Despite its foreseen potential, the PSS requires substantial changes in business operations. Some open issues in this context are: How does a company create value for its customers? How can this value be produced and delivered? How can interaction take place with customers and suppliers? [2] Therefore, business model characteristics must be redefined to support the effective implementation of PSS [3, 4]. In this sense, it should be noted that the main contribution of a business model is to understand, design, analyze, and change their business logic [5].

However, the current literature offers little information about business models suitable for the PSS approach, thus affording an opportunity for investigation. The purpose of this study, therefore, is to identify and classify key PSS characteristics according to the elements of business models and to propose a business model based on the PSS strategy for a machine tool manufacturer.

In order to identify the main PSS concepts and characteristics a literature review was carried out. In addition, the theory of business models was investigated, which enabled the definition of the business model to be used in this research, proposed by Osterwalder and Pigneur [5].

Finally, an exploratory case study of a machine tool manufacturer was performed to identify characteristics for the definition of its business model based on PSS approach. Additionally, the case study highlighted some of the challenges related to PSS business model design. These challenges were classified into Service Offer, Product Leasing, Financial Information and Culture.

The next sections of this paper describe the research methodology adopted for this study; the literature review, including a description of PSS characteristics; the case study results; the challenges for PSS implementation; and the conclusions. The findings are pointed out in terms of their practical and theoretical contribution.

2 Methodology

This research involved a literature review on the subject of PSS. The concepts and characteristics of PSS were thoroughly studied, as well as practical cases reported in the literature that describe the implementation and use of PSS. A review of the literature on business models was also carried out to identify the elements of a business model and to select a specific model for this research. Later on, the PSS characteristics were classified according to the elements of the business model.

To complement the list of characteristics and propose a business model for the practical implementation of the PSS, a case study of a machine tool manufacturer was made. The case study method was chosen since it allows an intense analysis of a particular situation [6], which is the case of this work. Therefore, the aim of the case study was to describe and analyze a PSS business model for a particular company. To this end, it was conducted workshops with company's top management. The method used to perform the workshop was based on Canvas [5], which describes five stages for the construction of a business model, to wit: mobilize, understand, design, implement and manage.

Section 3 describes the bibliographic review on PSS and business models.

3 Literature Review

3.1 Product-Service System (PSS)

The PSS consists of tangible products and intangible services designed and combined so that they are jointly capable of fulfilling specific customers' needs [7]. Goedkoop et al [8] defined the PSS concept as a system of products, services, infrastructure and network support that continually strives to be competitive, satisfy customer needs and can result in less environmental impact than traditional business models.

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In traditional business models, the customer purchases a product and becomes responsible for monitoring its performance, maintenance and adequate disposal. In contrast, according to the PSS concept, the manufacturer earns revenue from the customer for providing a function. Thus the ownership of the product is not necessarily transferred to the customer. The manufacturer remains responsible for maintaining the product along its life cycle and for discarding it [9].

The PSS concept has the potential to benefit both companies and customers. According to Baines et al. [9], the main advantages for the customers are: more customized supply and higher quality; new functionalities and combinations of products and services to better suit customers' needs and; responsibility for monitoring and end-of-life tasks transferred to the manufacturer. For companies, some advantages are: new market opportunities and competitive advantages; alternative to standardization and mass production; higher total value delivered to the customer by increasing service elements and; access to information about product's performance during its use.

The PSS may also result in a number of environmental benefits. As companies become responsible for the entire life cycle of their products, they are encouraged to take them back at their end of life, reuse or remanufacture them, and place them on the market again. Therefore, less waste is discarded, thereby reducing the consumption of raw materials and energy [1]. These practices leads to a more sustainable production system.

Notwithstanding the above cited benefits, the adoption of a PSS-based strategy involves major challenges for companies since it requires changes such as the development of new relationships with stakeholders [1]. Such requirements should be considered in a company's business model.

the next section presents business models concepts and the specific business model selected to conduct the case study.

3.2 Business Model

Shafer et al. [10] define business model concept as a representation of a company's underlying core logic. Thus, it is considered a powerful tool to communicate strategic choices. According to Elbers [11], business models represent how a company creates, delivers and captures value based on its strategic choices and in accordance with its net value.

Hence, it gives the organization a holistic view of the business, clarifying important issues and relationships. The business model can be also considered an abstract representation of the business strategy [12].

Based on an intensive review of the literature on business model concepts, attributes and their relationships, Osterwalder et al. [13] defined the business model as a conceptual tool composed of objects, characteristics and their relationships, which provides a simplified description of a company's business logic.

Canvas Business Model

Osterwalder and Pigneur [5] developed the Canvas Business Model, which is a tool for describing, analyzing and designing business models and which was chosen for this research to visualize PSS business models.

This approach is used as a reference in this paper for two main reasons: (i) the elements that compose this model were defined after a detailed bibliographic review of business model elements, which are described in detail; (ii) the model has been applied and tested successfully in many organizations (e.g., IBM and Ericsson).

Defining the elements (also referred to as building blocks) that comprise a business model is the first step involved in planning business and in helping companies understand and describe their business logic [12]. In this context, the Canvas Business Model is used to describe clearly and to manipulate business models to create new strategic alternatives. The nine elements of the Canvas Business Model are cited in Fig. 4.7.1.

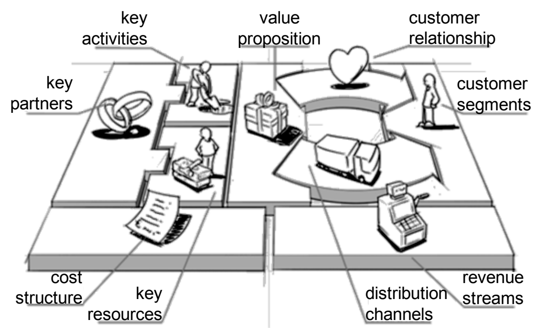

Fig. 4.7.1 Elements of the canvas business model osterwalder and pigneur [5]

The next item describes the nine elements considering the main characteristics of a PSS business.

4 PSS Elements for a Business Model

Because of the differences between the PSS and the traditional way of doing business (product selling), one of the main challenges faced by companies that adopt the PSS is to identify specific requirements in the business model. Thus, based on our literature review, we describe below some of the main characteristics of the PSS business model, which are showed according to the elements of the Canvas business model:

1. Value Propositions: These are related to the value provided by a PSS though the integration of products and services. Examples of value proposed in a PSS are: function guarantee [14]; cost reduction in manufacturing operation, since services such as maintenance and repair are responsibility of the PSS provider [15].

2. Customer Segments: It is important to consider the kind of opinions specific target group has about products ownership, since in some of the PSS types this ownership will not be transferred to the client, keeping with the producer [16]. In a PSS, a good way to define the customer segment is to consider the different types of user behavior, since PSS involves changes in ownership, responsibility, availability and cost [17].

3. Distribution Channels: Sales and retail departments should define how the PSS should be offered to make it more attractive than buying a product-based option. Another important aspect is to sell the PSS concept through marketing campaigns [16].

4. Customer Relationships: This element involves the creation of added value and its delivery through direct relations and intensified contacts and detailed contracts with customers [18], which enables the development of long-term

relationships [18, 19]. The "relational" path can be achieved through increased operational links, information exchange, legal ties and cooperative rules [20].

5. Revenue Streams: The PSS also offers opportunities for augmenting revenue by improving the function offered by the PSS provider [21]. Payments may be based on the availability of the PSS, frequency of use or final results [22].

6. Key Resources: New competencies to deal with customers must be developed, people trained and in some cases additional personnel recruited [18]. A fundamental shift in corporate culture and market engagement is also needed, to incorporate the new PSS aspects in the whole organization, which requires time and resources [22, 23].

7. Key Activities: Instead of focusing on activities related to a physical product, PSS providers must focus on the Key Activities of their customers. Even when the product provides a core function, essential activities occur during the entire product lifecycle [22, 23]. An example of a Key Activity is the integration of product and service development processes [14].

8. Partnership Network: Due to the complex nature of the value proposition and the mix of competencies required to implement a PSS, a Partnership Network is essential. Structuring a PSS network involves identifying the necessary core competencies and the actors that possess those competencies [24]. In the PSS business model, the relationship between producer and stakeholder is recognized with a wide scope and has a considerable impact on the design of the supply chain structure [18].

9. Cost Structure: this element and the PSS pricing is one of the challenges of the PSS [25]. The practices of financial and accounting functions may have to be adapted since the time scale of financial flows changes from an almost immediate return of capital to an extended use period [18]. Therefore, when the function of products is sold, cost structures may need to be restructured to support different cash-flow requirements.

The identification of PSS characteristics according to the elements of business models reveals some differences between them and the traditional business models. Thus, a case study of a machine tool manufacturer was made in order to examine how the design of a PSS business model would look like for companies which currently handle their business in the traditional way and seek to adopt the PSS. The second purpose of the case study was to give a first orientation for companies in the initial phase of design of their PSS-oriented business. The following list summarizes several important points.

5 Investigation of the Characteristics of a PSS Business Model for a Machine Tool Manufacturer

The company studied on this research has been in the machine tool market for over 48 years. The principal business unit, which is the most interested in applying PPS, manufactures and sells thermoforming machines. Their customers are companies which produces and sells traditional and biodegradable plastic bags using the thermoforming machines.

The company's current business model is based on the sale of machines and the supply of maintenance and technical assistance services. This interest on PSS adoption emerged mainly in response to the market opportunities that the company envisages.

The new business model was created using the business model design method (Canvas) proposed by Osterwalder and Pigneur [5], which is composed of five stages:

• Mobilize: Present the objectives of the case study;

• Understand: Collect the information necessary to create the business model;

• Design: Define a business model for the company;

• Implement: Implement the newly developed model in the company;

• Manage: Adapt the business model to the characteristics of the company and the market.

Only the first three aforementioned stages were carried out in the present study, since the objective here was to investigate and identify the characteristics of a PSS oriented business model for a machine manufacturer. The implementation and management of the model lie outside the scope of this study.

These three stages were carried out during a 6-hour workshop attended by representatives of the company's sales, engineering, and production departments. These representatives are also the owners of the company, which gives them a good understanding of the business. This also increases the commitment with new developments since they can make strategic decisions towards adopting a new business model that can function along with the existing one.

The next subsections describe the results achieved in each of these stages.

Mobilize: The first stage involved a description of the objectives of the study, a presentation of the main PSS concepts, the advantages for clients and companies, and the methodology employed in the development of the Canvas business model. Some of the characteristics of companies that have implemented PSS successfully were also presented.

Although the company's representatives know how PSS works, particularly because the company's main competitors already use this concept, they were unfamiliar with the expression "Product-Service System" and with how the concept could be adopted and work on their business.

Understand: This stage involved a description of the information required to create the business model for PSS by means of brainstorming with the company's representatives. Information was gathered about the company's general characteristics for the construction of the business model.

As mentioned, their current business model is based on the sale of machines and supply of services. However, these services account for only 5% of the company's revenue. The company's representatives mentioned that the services provided cover only their operational costs. The company considers that the only advantage in providing assistance lies in obtaining the customer's fidelity, which is a market strategy used by them.

The company is currently not responsible for the disposal of the sold machines at their end of life. However, growing concerns about product end of life, along with the recent approval of the solid waste disposal law in Brazil and the increase of market pressures, have led the company to rethink this issue. In this sense, a few attempts have been made to recondition the machines, but the time and resources spent in doing so were higher than those involved in manufacturing a new machine. However, the company sometimes purchases used machines from clients and resells them at substantially lower prices. In some cases, the client himself reconditions his machines, aiming to extend their service life.

Another determining factor for the company is its concern about government measures, since its currently main products are machines that produce plastic supermarket bags, which are being phased out in most developed countries. Because of factors like the one mentioned, the company are beginning to think about the implementation of new business alternatives.

Design: After becoming aware of the current company's business, it was noticed that radical changes in its current business practices would be required in order to shift to PSS. Therefore, the findings previously discussed oriented the decision to develop a new business based on a PSS concept.

Among various opportunities, the company discussed the option of commercializing a new machine for producing packaging to replace glass and aluminum containers. Thus, considering the PSS concept for this business, instead of developing machines, the proposal would be to purchase machines produced in China at a lower price and lease them under the company's quality brand and warranty.

The discussion with the company's representatives then focused on how a business model for this case would look like, and what characteristics each element of the PSS-based business model should consider. To analyze and understand the proposed PSS-based business model, the next section describes the discussion of characteristics of each business model element.

1. Customer Segment

Following the strategy of leasing low-cost machines, the company decided to target small firms and new entrants.

2. Value Proposition

The value to be delivered to clients through this PSS were identified and described:

• Customization: The PSS options could be customized according to each client's needs, considering, for instance, the frequency in which the machine would be used.

• Training: A training course on the use of the machine could be offered to the client, who would benefit from its better performance and operation.

• Quality: The value provided to the client could be increased by integrating products and services, thus increasing the client's perception of quality.

• Lower initial investment: The fact that the client would not purchase the machine, but rather pay for its use, reduces its initial costs of investment and also spreads these costs over the time the machine is used. A lower initial investment clearly attracts the client segment for this business, which consists of small companies and new entrants, most of which would find it difficult to make heavy investments.

• Lower operational cost: The PSS provider is responsible for the machine during its entire life cycle, thus reducing the client's costs in contracting maintenance and technical assistance services.

• Co-development of solutions: The greater proximity between the PSS provider and the client increases their contact and communication, making it easier for the PSS provider to participate in the client's processes. This also makes it easier to develop joint solutions, so that the customer has a solution that increasingly approaches what he seeks.

3. Customer Relationship

The company aims to establish long-term relationships through formal agreements, seeking close relationships with its clients and also supporting them to deliver the proposed value to their customers. To achieve that, co-development of solution and training programs are the main ideas.

4. Distribution Channel

The element distribution and communication channel aims to define how value can be delivered and communicated to the client. To this end, it was decided that a Customer Assistance Service (CAS), trained to assist this new market segment, would be developed, as well as a new sales channel qualified to show the benefits of the PSS offer. In addition, the company intends to use its website as a tool for constant communication with the client.

5. Revenue Model

Revenue would be generated by means of a fixed amount paid by each client. The idea would be to charge a monthly fee, which would cover both the product and the services that would be made available throughout the machine's life cycle.

6. Key Resources

The key resources considered by the company in this new offer are human resources and financial resources. It should involve qualified staff to handle the machines during their use, and to provide technical, mechanical, electrical and electronic support services. In addition, training for sales staff should be considered, as well as the definition of staff and of people directly responsible for managing contracts.

The financial resources involve the investment required to acquire this new offer, i.e., the resources for purchasing the Chinese machines and the cost of maintaining them during their life cycle, using the periodic revenue paid by clients.

7. Key Activities

The key activities were defined as follows:

• Support the development of the customer's business model: Small firms and new entrants are rarely aware of how PSS works. Given that the company aims to create closer relationships with its clients and to develop co-solutions with them, it would be interesting to help these clients in the development of a business model according to the PSS concept.

• Prepare the machine to be monitored (product development): The company should consider the use of software programs to monitor the machine during its use, to perform maintenance when necessary, to monitor the performance of the machine and to be aware of its end of life.

• Management of partners: The greater number of partners needed for the implementation of a PSS strategy may increase the complexity in managing the network. Development of techniques and tools to support the communication between partners are required.

• Performance measures: A new set of performance measures should be established to keep track of the results of this new strategy. These new measures should demonstrate the performance of the whole system. Therefore, measurements have to be created for all the elements of the business model, expanding the focus beyond the value proposition.

8. Partner Network

One of the most relevant elements for a PSS-oriented business is the network of partners needed for its development. Considering the value proposition and the targeted clients, the company identified some partnerships that it would have to develop, namely:

• New company/business unit: For this new business, the company intends to develop a new business unit or company, which will be responsible for the PSS of the new machines.

• Machine supplier: Because the machines will not be manufactured by the company itself, a partnership should be established with a Chinese supplier to acquire the new machines.

• Transportation services: These services need to be outsourced to deliver the machines to clients and. In the final stages of the lifecycle, these services are necessary to remove for maintenance or dispose of the machine;

• Technical assistance: It will be necessary to create a technical assistance infrastructure to attend machines located in different regions.

• Law firm: Due to the new types of agreements signed with partners and clients, it will be necessary to have people responsible for contract management.

• Software developer: To increase customer satisfaction and monitor the machines during use, the company intends to install software to monitor the performance of the machines bought from China. This will require the development of specific software.

9. Cost Structure

Some of the costs involved in this PSS differ from the usual ones pertaining to product sales. The increase in the number of partners means that there will be an additional cost to pay them. Moreover, unlike the sale of a product, the entire revenue will not be made at the moment the offer is delivered to the client, since the latter will make monthly payments. This means the company will have to make a large initial investment. Moreover, because the company retains property of the machine, it will have to bear not only the costs involved in buying the machines from Chinese producers, but also the costs involved in the use of the PSS (maintenance services, upgrades, replacement parts and shipping of same, the cost of maintaining the property of the product) and its end of life and/or disposal costs (reverse logistics, end of life alternatives).

6 PSS Implementation Challenges

Some challenges related to PSS business model design arise during the case study. The challenges are related not only with the company studied but also with its environment and market demand.

In the case of the company, it was found that the collaborators do not yet consider services as a differentiator or value adder, and would therefore not make full use of some supply opportunities, e.g., increase its revenue by supplying services, monitor the product’s performance during its use, increase the value delivered to and perceived by the client, effectively use the information from the client about the product. Some important aspects raised by the participating company concerned the structuring of a new services development process, as well as employee training both to improve the services currently provided by the company and to render new services.

With respect to leasing of the product, an important point to consider is the easy financing of machines that can be obtained in the Brazilian market, since the government, through the BNDES (Brazilian National Development Bank), reduced the interest rate for the acquisition of machine tools, giving clients a period of 10 years to pay back. Due to this incentive, most of the clients who were purchasing maintenance services decided to purchase new machines instead. These incentives for purchasing new machines hinder the implementation of the proposed PSS strategy.

The financial aspect also gave rise to many doubts for the company, e.g., how much time would be required to amortize the initial investment, since the client would no longer pay for the acquisition of the machine but would, instead, make periodic payments for the right to its use. Another question that was brought up and has been mentioned in many studies about PSS is how to define its price, given the difficulty of pricing the intangibility of the services, which would be one of the results provided to the client.

The company also had several questions related to taxation, which is an extremely important point to consider in the adoption of PSS by companies that only sell products. What are the existing taxes for companies that lease but do not sell machines? If the company has many assets used as services, what taxes would it have to pay?

Finally, the company also believes that it would encounter internal resistance to change to a PSS, because of its culture. It was considered more advantageous to create another company or a new business unit to develop this offer, so that the company would lower the risks of losing its focus on its current business.

7 Conclusions and Managerial Implications

The proposed business model has characteristics of business models for PSS reported in the literature as well as characteristics required for a PSS-oriented business model of a company aiming to adopt this concept. The model provides an initial vision for companies about the application of PSS, viewing the business from a holistic standpoint. It provides an idea of what should be considered in this new offer, according to the new characteristics that will be required.

From the academic standpoint, this work contributes to the current body of knowledge on PSS. This approach herein described differs from the majority of approaches found in the literature, which focus on PSS design issues or on specific elements of business for PSS, e.g., customer relationship, managing PSS costs, or the importance of partnerships for the PSS offer. Such approaches examine these elements separately, making it difficult to obtain a complete vision of the PSS business as a whole.

Additionally, some interesting information arises as challenges that the company studied faces to implement the PSS business model designed. These challenges, classified into Service Offer, Product Leasing, Financial Information and Culture, can be used by other companies that aim to implement PSS, to reduce risk and plan the resources required for the shift towards PSS.

The company didn´t mention about challenges or even benefits related to the environments issues. Probably these benefits are not known for the company and not analysed during the study. Considering the fact mentioned and the characteristics of a PSS, it was noted the necessity to consider the environmental element in the business model structure. The sustainable aspect of PSS is one of the main areas that should be explored by companies that uses this concept.

The idea of the Canvas method is to provide an overall view of what the business would look like, which was the objective of this study. A more detailed vision would fall outside the scope of this work and of the objective of creating a business model. Additionally, the study of solely one company enabled a deeper investigation of what could be considered in the PSS business model.

Considering the methodology employed for the development of this case study, the next stage is the implementation of the defined business model. This stage has not been started, because the company in question is studying the feasibility to put the proposed business into practice.

It should be noted that this study has limitations, first due to the fact that only one case study was conducted, which prevents the generalization of the results and its robustness. Another limitation is the lack of scientific publications and knowledge related to the economic factors involved in the development of the PSS, particularly the difficulty in pricing the offer. The lack of this type of information complicates the decision making during the development of the PSS-based business model.

The authors suggest that future studies should involve new case studies, especially of companies operating on other industries, in order to augment the robustness of the findings and delve deeper into the theme under study.

8 Acknowledgments

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Chapter 5:

Innovative Energy Conversion

5.1. New Aspects of Energy Consumption Analysis in Assembly Processes and Equipment

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Abstract

Multi-material use and large scale functionality of products as well as cost targets in many cases lead to part design principles that use "assembled components". Advanced lightweight design often requires the combination of different substructures and the synthesis of different manufacturing technologies, including a wide range of known, as well as new assembly approaches. As other manufacturing processes too, assembly operations normally include value creating, primary process sequences but in addition also secondary, just supporting and/or auxiliary operational steps—with the target to maximize value creation. Looking from the point of energy or resource efficiency related to those applied technological process chains, analysis and decision making recently is mostly still hindered by the lack of data or even a methodology of consolidated benchmarks. The paper deals with new approaches to analyse and to optimize energy consumption in processes that include assembly operations. As part of this, results of a case study defining preferential working spaces for assembly systems are presented.

Keywords:

Assembly, Robot, Energy optimization

1 Motivation and Target

In practice, the task of optimizing singular parts of complex products in terms of both cost and functionality leads from monolithic modules more and more to pre-assembled sub-modules. Examples can be found in the power train of vehicles, including e.g. camshafts or crankshafts [1, 2]. Such concepts make it possible—in particular through the use of different materials—to adapt different areas of the concerned component to the specific load properties or other functionalities later in use in the individual part.

In this context, joining and assembly tasks are given new significance from both, engineering and economic point of view. All of this is also happening under the auspices of energy efficiency, which is currently receiving increasing attention and ever-greater value in production. Initial comparative case studies of classical and assembly-oriented production process chains, for what are essentially analog components, show that in this case more attention should be paid to the non-value adding, supporting and/or auxiliary operational steps and processes.

Weinert et al. [3] developed a concept of 'energy blocks' to be used in a planning method to forecast energy consumption in production systems.

Especially for the manufacturers of assembly equipment, such as robots, and systems suppliers such as plant manufacturers and installers, the knowledge of the associated relationships is of particular importance as a competitive factor.

One approach for achieving higher energy efficiency in production engineering lies in the analysis and subsequent utilization of potentials within the process chain itself, especially for component handling and in assembly processes. Individual single handling and assembly operations in production do mostly not, from a technological perspective, have singular very high energy consumption and therefore, at present, are not usually the focus of the energy considerations made by plant engineers. Owing to the frequency of individual handling and assembly processes within an overall process, however, an integrated energy consumption analysis should be nevertheless worthwhile. In addition to taking into account the individual process step, including how this is linked to the upstream and downstream production steps, a holistic view of the total process chain by this could offer a particularly high, still unexploited savings potential. Through the spatial combination of various processes, the direct physical effects can be used for an energy reduction, among other uses.

The purpose of the work presented in this paper was to develop new methods which can, in terms of the energy required, be used to detect and analyze whole process chains for the manufacture of a part, including all primary and secondary processes up until the point when it is mounted in an assembly. In particular, these energy values should also be visualized to increase the energy-based process understanding when such methods are used in practice by engineers and technicians. Finally it needs new technical knowledge and methodology to optimize and to use potentials for energy and resource saving.

2 Process Versus Auxiliary Energy Analysis (PAEA)

As a starting point for the energy consumption detection, analysis and visualization of a process chain, the primary-secondary-analysis based on economic considerations developed by Lotter was used [4], and adapted to the energy consumption approach. Based on Lotter, each assembly process is divided into primary and secondary actions and their duration is determined as a percentage of the total. Here, all value-adding actions are termed 'primary', and all actions which have a purpose other than being value-adding are referred to as 'secondary'. Extending this approach and with reference to this 'P–S-analysis', a splitting and specific assignment of the determined value-adding and non-value-adding energy consumptions were carried out. Since the term "primary energy" is already used otherwise the energy used directly in the manufacture of products and creating

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value is redefined as ‘process-energy’, based on the definitions according to Lotter. This is in contrast with the ‘auxiliary-energy’ needed indirectly for the process, e.g. additional manufacturing supplies which are not value-adding. A similar approach has been shown by Rahimifard et al. [5].

The classification of a process step is based on criteria specific to the process, defined in advance on the basis of technical considerations or estimates made by engineers. For visualization, the vector representation developed by Lotter and Wiendahl [6] is also adapted to the requirements of the energy consumption approach. Figure 5.1.1 shows an example of the energy consumption analysis of a joining process typical in car body manufacturing—spot welding—including the differentiation of the different forms of energy to be taken into account.

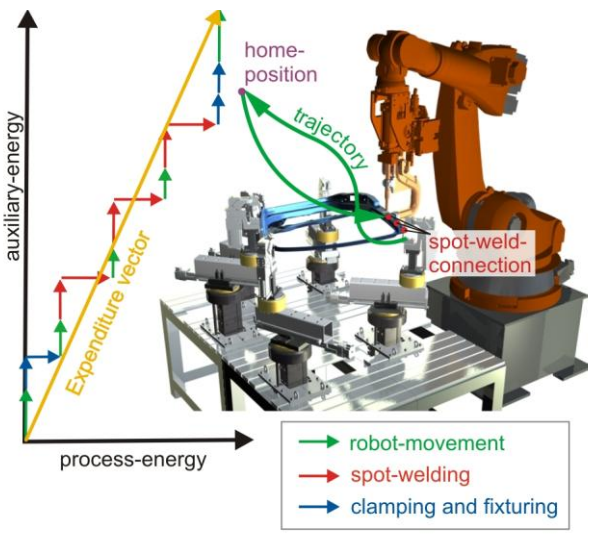

Fig. 5.1.1 Assembly cycle during spot welding of a car body part

The purpose of process optimization would be to achieve as short and shallow a process vector as possible for each manufacturing process step. The graph clearly shows the relatively high number of non-value-adding sub-processes, which are needed and link the value-adding processes to each other. In particular, these are the feed movements of the gripper and clamping systems as well as the direct adjustment and clamping processes. The total process chain expenditure vector is produced for all stages of the individual processes. In the same way as the single process vector, the aim here is to reduce this vector and to render as flat as possible. Taking as an example this spot welding process the combination of several individual processes needed is shown as a sub-process chain, see Fig. 5.1.2.

Such a chart can help visually represent the actual energy consumption state of a process chain. This forms the basis for subsequent process optimization. To achieve this goal, several approaches and new optimization methods have been developed and analyzed specifically for assembly. A first selection of those approaches is going to be presented in the following sections of this paper.

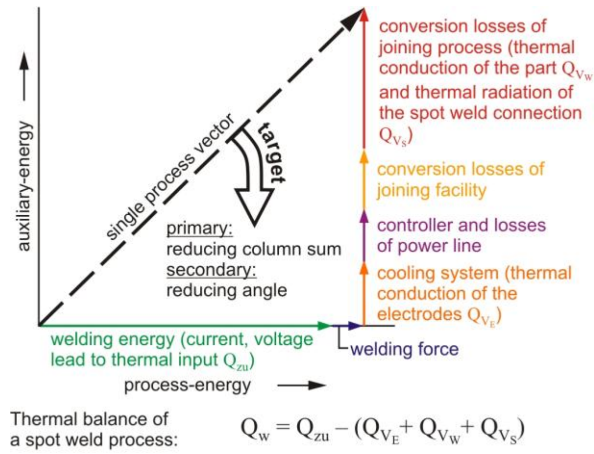

Fig. 5.1.2 Qualitative process-auxiliary-energy-analysis of a spot welding process

3 Methods to Optimize Energy Consumption

3.1 Workspace Energy Consumption Analysis (WECA)

Results achieved in a pilot study [7] show that a major aspect especially for multi-axes handling systems is their optimized location and energy optimized assignment of all motions during manufacturing and handling.

A specific workspace energy consumption analysis can be used to determine such favorable locations in terms of energy consumption, e.g. the positioning of robots and other handling equipment or devices in relation to the single part or component or the complete assembly line. As a result, the non-value-adding energy—the auxiliary-energy—of the assembly system can be minimized. The proposed procedure is as follows: In the initial step, the workspace of the assembly components subject to testing is examined in terms of its power consumption while acting. On base of this it will be divided into different energy levels in a schematic (Cartesian or polar) grid. To create an initial database with specific characteristics available, tests were carried out on various handling systems and literature data have been analyzed. E. g. Raza et al. [8] recently carried out studies on the optimal positioning of a milling workpiece in the work envelope of a 3-axes machine tool. Special problems of processing a great amount of measured energy data of complex machine systems has been investigated by Vijayaraghavan and Dornfeld [9].

A similar example of a 6-axes industrial robot, which is applied for component handling and for the joining process of the assembly process shown in Fig. 5.1.3, is used to explain this kind of method in greater detail in the following section of this paper. To simplify matters, it has been assumed that the robot's workspace is a sphere and is divided into several levels. These levels have in turn been divided into a grid of channels at right angles to one another. When traveling along these trajectories in a measurement pass, the robot's current power consumption was measured and the work carried out was subsequently calculated. The results of the experiment are shown in Fig. 5.1.3.

For trajectories parallel to the x-axis the curves diverge at the outer limits of the workspace. The energy required for the movement of the robot flange along the trajectory towards the robot's base is significantly lower than for a movement of the robot flange in an outward direction, i.e. away from the robots base. This effect can be attributed to the weight compensation system of the analyzed robot, which is located at the end of the rocker of axis 2. In conclusion, when using the robot as a transport system from the perspective of energy consumption, movements under load should predominately be made in the direction of the robot's base, while load-free movements are being made in the opposite direction. The energy consumption for trajectories parallel to the y-direction was also recorded (see Fig. 5.1.3b). The chart shows how energy consumption decreases as the distance of the individual trajectories from the robot's base increases, rising again only when the trajectories get close to the outer area of the workspace. Due to the symmetrical arrangement, the energy consumption is approximately the same for both the positive

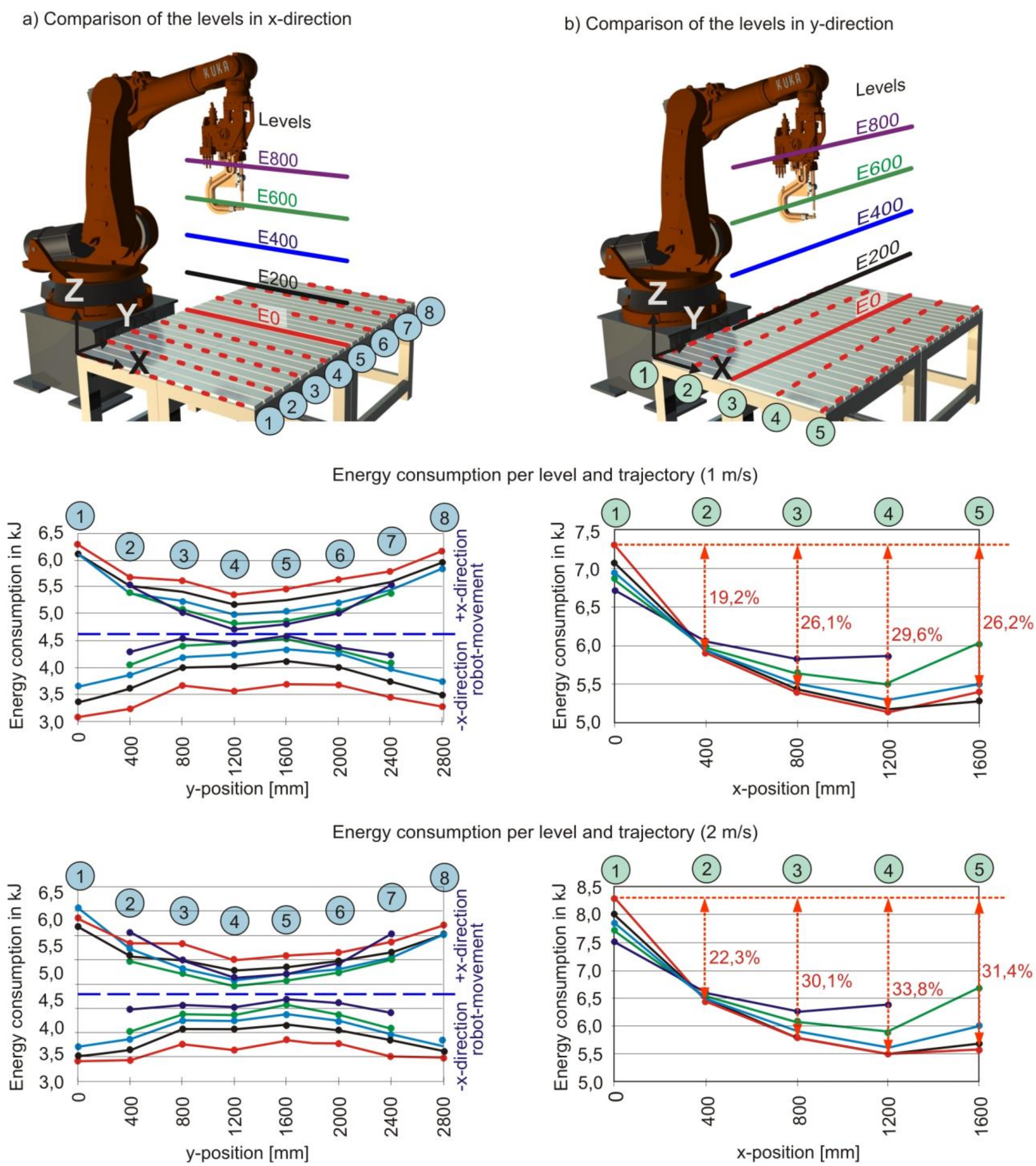

Fig. 5.1.3 Workspace-energy-consumption-analysis—WECA of a 6-axes robot
a Energy consumption analysis of levels for the movement of the robot in the X-direction
b Energy consumption analysis of levels for the movement of the robot in the Y-direction

and negative y-direction. In the example presented here, the energy expenditure for a linear trajectory can be reduced by about 30% (see Fig. 5.1.3b), if this trajectory is relocated from the energy-intensive work zone close to the robot base to the low energy work zone.

In summary, based on the above results, the conclusion can be drawn that the described effects can be usefully integrated as a method into an overall assembly system design by, for example, choosing a direction for component handling as well as a position for the mounting device which is favorable in terms of energy consumption.

3.2 Workspace Intersection Analysis (WIA)

Another approach was used and is proposed for the optimization of the actual state of complex systems, consisting of singular, interconnected assembly sub-systems. Such interlinked systems usually comprise several machines and handling systems. Often, several cooperating robots work on an assembly line or within an assembly cell. Each of the handling systems have their own specific optimal energy areas based on the WECA (Sect. 3.1).

This new approach of intersection analysis presented in the following section gives the opportunity for holistic optimization of such complex systems. During this analysis, all cooperating handling systems are examined in relation to each other, and the intersection set with the best energy consumption properties is established from all of the systems in the network during an assembly process. A varying amount of handling movements of individual components served as a factor on the assembly device, to weigh up its influence. Therefore, it is possible that in the result, an assembly device may have a very significant impact on the overall system due to a large number of movements, despite having relatively small single energy consumption. Therefore this device is given a high priority in the overall rating. By taking several boundary conditions into account, such as the number of movement cycles, the transport weight or cycle time, the goal is to find an optimum balance of time, costs and energy.

For example, in order to allow for comparison, each area can be assigned a specific energy value on a scale of 1–10. The minimum and maximum value of the area is also considered in the calculation. Reference should also be made concerning the type of production involved, e.g. assembly line or nest production.

In assembly line production, continuous transport of the workpiece must be assured so that, in this case, a part of the overall workspace is not available for the observations. The space still available in the overall workspace is further limited by additional other criteria. The following evaluation criteria must also be used for the evaluation:

- number of handling steps per handling system,
- cycle time,
- energy value of each handling system
- handling weight (component and/or tool).

Constant, i.e. non-changing, boundary conditions, such as spot welding position or the quantity of parts, must also be taken into account. In contrast, parameters marked as 'variable' in the system are those that can be changed for optimization, such as transport routes and speeds. The spatial arrangement of such a system can be 2- or 3-dimensional, as shown in Fig. 5.1.4.

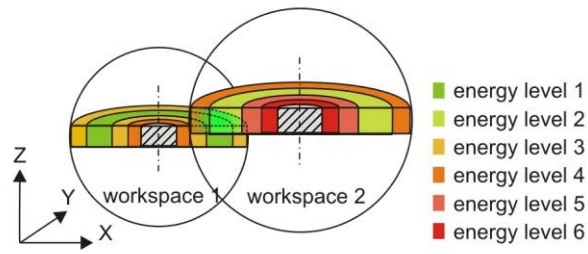

Fig. 5.1.4 3-dimensional intersection representing the energetically optimal workspace of an optimized arrangement in an assembly system

3.3 Process and Technology Substitutions

Besides the spatial assembly planning system, it is still an option and possibility to achieve energy efficiency through optimizing the technical systems itself, see Fig. 5.1.5. Several products are often produced by the same assembly machine due to small or varying batch sizes. Often these require diverse devices and gripper systems, which are adapted to the different part geometries. These may need to be replaced after each production cycle, i.e. after each product change. Flexible devices represent an alternative whereby the respective holding and gripping systems automatically adapt to the particular product [10]. Such systems, however, typically have a variety of motors and sensors and as a result of this normally higher energy consumption.

The clamping modules used in the analyzed assembly-setup (see Fig. 5.1.1), have a flexible arrangement. A conventional clamping technique can be used as an alternative. The difference in terms of energy consumption is significant, but the flexible system offers the advantage that it can cover several different types of product during production. Despite the increased energy consumption, the flexible system offers added value when compared to the conventional technique. In the holistic approach, this added value must be included in the calculation as a value-adding criterion. An attempt to do so is shown in Fig. 5.1.5 as well.

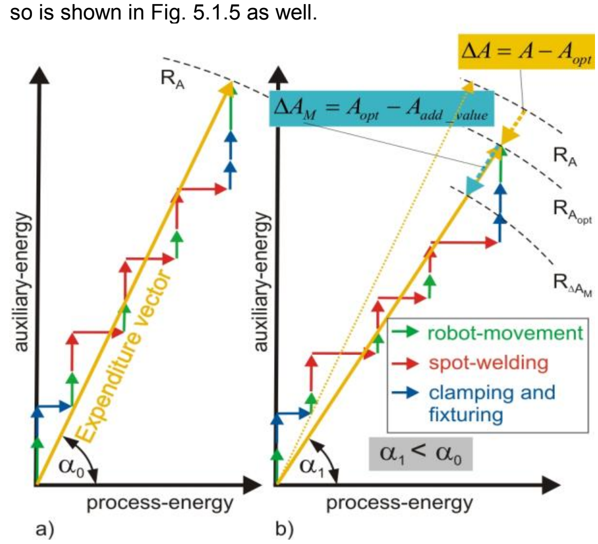

Fig. 5.1.5 Comparison of **a** actual status with **b** variant optimized using WECA

4 Conclusion and Summary

The analysis of the energy consumption of complex, automated assembly systems requires a thorough understanding of the process. Alongside the actual, technological process steps, the interaction between the individual workstations must also be analyzed and optimized. The process steps can be classified based on the added value attained for the product. The steps in the chain are mainly non-value-adding, while the technological steps, due to the direct influence on the product, provide a large proportion of the added value. However, there is often optimization potential within these processes, e.g. with regards to the auxiliary materials used.

On this basis, an optimization in terms of energy consumption can be carried out on the individual process through sub-division into a (value-adding) process and a (non-value-adding) auxiliary-energy. To do so, the PAEA method might be useful to be applied. This method divides and visualizes the necessary volume of energy in a step diagram. Such sub-process steps, with high energy consumption and, in particular, a high non-value-adding part can be filtered out for closer further consideration. An expenditure vector can also be derived which is to be used to compare and evaluate different process chains. In addition, a value-adding criterion can be applied for specific process chain variants, which considers special effects on the manufactured product. This value-adding criterion leads to a direct decrease of the expenditure vector. As a result of the analysis and optimization, a comparison can be then made with the actual state of the process chain or other alternatives.

Besides the optimization or substitution of individual technologies with unfavorable energy consumption properties, workspace energy consumption analysis (WECA method) can also be used to achieve an optimization of the handling processes in automated systems. Due to this analysis, the workspace of the handling system is analyzed systematically in terms of energy consumption, enabling areas that are favorable in terms of low energy consumption to be identified. On this basis, all equipment in the system can be arranged in the assembly line in such a way, that handling movements require as low energy as possible.

A comprehensive evaluation and optimization of a complex assembly system is, however, not possible unless all the cooperating handling systems have first been considered. To this end, a workspace intersection analysis (WIA method) can be performed, which results in an optimal arrangement of all machines and components along an assembly line, in terms of energy consumption and economy for the entire assembly system.

During this analysis, actual user-specific values are required to enable the methods to be adapted to the particular manufacturing and assembly process. A feasible plan would be to create a global database for a range of different systems, including assembly, in which data can be entered by the suppliers of handling systems, and which serves as the basis for the choice of systems already in the planning stage of assembly systems.

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5.2 Evaluation of the Energy Consumption of a Directed Lubricoolant Supply with Variable Pressures and Flow Rates in Cutting Processes

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Abstract
Despite of considerable improvements in the area of cutting materials and tool coatings, the use of cutting fluid is still essential for the machining of difficult to cut materials like high alloyed steels, titanium or nickel based alloys. However it has to be a major task to set up the application of lubricoolant as effectively as possible. In this context, the high-pressure lubricoolant supply is rendered as a modern technology with a great capability to increase the productivity and process stability in machining difficult to cut materials. In this paper supply pressures up to 300 bar are considered. In terms of sustainable manufacturing it is the aim to minimise the overall energy consumption per part by carefully adjusting and coordinating setting parameters like supply pressure, flow rate, cutting parameters and tool design. In this paper the energy consumption of a machine tool used with a conventional low-pressure flood cooling is compared to the external high-pressure lubricoolant supply. With reference to the applicable cutting parameters depending on the lubricoolant supply strategy and setting parameters, the power consumption, tool wear and chip forms are examined in order to identify the most economical process design. Furthermore the real energy consumption of the lubricoolant supply unit is compared with the theoretically required fluid hydraulic power and an efficiency value is generated. The paper shows that the use of an external high-pressure lubricoolant supply is capable to reduce the overall process energy consumption through a significant increase of the material removal rate while improving the process stability at the same time.

Keywords:
High-pressure lubricoolant supply, Jet assisted cutting, Manufacturing process evaluation, Sustainable manufacturing, Energy efficiency

1 Introduction

Besides the positive effects that can easily be achieved with high-pressure lubricoolant supply in the machining of difficult to cut materials, a profound lack of knowledge exists concerning the economical and energy-efficient use of this technology. Since industry is aware of their responsibility to achieve a more sustainable manufacturing especially machine tools and manufacturing processes are analysed in terms of energy consumption [1]. For the use of high-pressure lubrication it is necessary to understand the fundamental acting mechanisms and the impact of the jet setting parameters (e.g. pressure and flow rate) in order to increase its performance and energy efficiency [2]. The power consumption of the high-pressure equipment directly depends on the lubricoolant supply pressure and flow rate.

In this paper turning of the high alloyed steel X5CrNi18-10 by using the directed high-pressure lubricoolant supply on the rake face of the cutting tool is investigated in comparison to the conventional flood cooling. Within the experiments, pressure and flow rate are varied independently from each other. The used flow rate amounts between 8 and 54 l/min while the pressure is varied in the range from 70 to 300 bar. Beside the examination of tool wear behaviour and chip breakage, the evaluation of the lubricoolant supply focuses on the required energy consumption correlated to the removed material.

2 State of the Art

2.1 Conventional Machining of Difficult to Cut Materials

The machining of difficult to cut materials like titanium or nickel based alloys but also high alloyed steels is characterised by low productivity and process stability due to their physical and mechanical properties [3]. Major problems during machining of these materials are low applicable cutting speeds due to excessive tool wear, long machining times and thus high manufacturing costs as well as the formation of ribbon and snarled chips in continuous cutting [4]. Under these conditions the automation of the production process is limited [5]. Despite considerable improvements in the area of cutting materials and tool coatings, the use of cutting fluid is still necessary when machining difficult to cut materials, even though it is linked with considerable costs. Therefore it has to be a major task to set up the application of lubricoolants as effectively as possible [2, 6]. In conventional machining processes the area of chip formation is most commonly flooded with lubricoolant. In this way the lubricoolant does not penetrate to the cutting edge and secondary shear zone, the most thermally stressed areas of the cutting tool in machining, because the lubricoolant uncontrollably flows around the cutting zone and preliminary impinges the chip top side.

2.2 Advances of High-Pressure Lubricoolant Supply

In this context, the high-pressure lubricoolant supply is a modern technology with a great capability that is increasingly in demand in industry. By using the rake-face sided high-pressure lubricoolant supply, a focussed and targeted

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lubricoolant free jet is directed into the wedge between chip bottom side and tool rake face [7]. A liquid wedge is formed which effectively cools and lubricates the cutting site leading to reduced tool wear, the optimum prerequisite to increase the cutting speed.

Sharman has shown that the conventional flood cooling is effective to extend tool life when cutting at low speed and easy to machine materials. In machining difficult to cut materials with increased cutting speed, higher cutting temperatures are generated [8]. Some researchers report that the high temperatures at the cutting site cause the lubricoolant to vaporise and to generate a vapour barrier which, during conventional lubricoolant supply, prevents effective cooling of the tool in the region of the cutting edge. By using high-pressure lubricoolant supply, the vapour barrier may be broken through or pressed in, enabling the lubricoolant to penetrate closer to the cutting edge, thus leading to enhanced cooling of the tool [6, 9–11].

Furthermore, the mechanical jet force acting on the chip underside acts as a liquid chip former reducing the upward bending radius of the chip. As a result, the tool chip contact zone is reduced by up to 50% in comparison to the conventional flood cooling, [6–10, 12]. The chip bending can be influenced by the hydraulic jet force which firstly depends on the lubricoolant supply pressure and flow rate [7, 13–16]. In dependence of the predominant conditions it must paid attention that the flowing chip respectively chip fragments captured by the high-pressure jet do not conflict with the newly generated workpiece surface that may be damaged in this way. This undesirable effect can be influenced by the geometrical jet alignment and the jet force point of attack [6, 7]. Crafoord et al. assume a Gaussian distribution of the pressure distribution on the chip.

Dahlman und Kaminski have shown that a reduction of the tool temperature of about 40% is possible to reach with high-pressure lubricoolant supply in comparison to the conventional flood cooling [6, 8]. The shorter contact length and reduced friction in this area also result in a larger shear plane angle and reduced chip compression, approving that chip formation is significantly influenced by the high-pressure lubricoolant supply [6]. Moreover Palanisamy et al. [17] detected that the application of coolant under a pressure of 90 bar in turning titanium alloys results in increased frequency of chip serration, shear-band thickness and average chip thickness compared to a pressure of 6 bar.

Dahlman investigated the performance of a rake face sided high-pressure lubricoolant supply in longitudinal external turning of two different steels ((34CrNiMo6 (SS 2541) and 100Cr6 (SS 2258)). He has shown that the natural contact length of a workpiece material is a significant indicator if a high lubricoolant supply pressure or the lubricoolant flow rate has the main effect on the resulting cutting temperature. Dahlman figured out that for materials that have a large tool-chip contact length (e.g. 100Cr6) a large flow rate combined with low pressure shows the best cooling effect. According to Dahlman, a larger tool-chip contact area in which heat is generated needs more flow rate for heat dissipation. In cutting materials with a naturally small contact length (e.g. 34CrNiMo6) a larger supply pressure is needed instead of a high flow rate, since less heat is generated and small amounts of lubricoolant are sufficient for heat dissipation [8].

Detailed investigations regarding the influence of of high-pressure lubricoolant supply on chip formation have been carried out by Crafoord et al. in external longitudinal turning of 100Cr6 (SS 2258) with cemented carbide. Crafoord states that in the case of rake face sided lubricoolant supply the chip upward bending radius is reduced more efficiently at constand hydraulic jet power when increasing the flow rate and decreasing the lubricoolant pressure [7].

Beside the positive effects and studies performed in the past, the scientific relations of the high pressure lubricoolant supply are not yet completely analysed and requires further research [4, 18]. The understanding of the fundamental mechanisms is necessary to improve the systematic use of the high-pressure lubricoolant supply and its optimal adjustments against the background of profitability and energy efficiency [4, 19]. It must be the goal to achieve maximum productivity and process reliability gains with minimum pressure and flow rate (= low pump power required) and, above all, with the appropriate ratio of pressure and flow rate that is carefully coordinated with the cutting parameters and the tool design.

2.3 Influence of the Use of Lubricoolants on Energy Efficiency

In the last years several studies have been conducted on power consumption of manufacturing and especially machining processes. Electrical energy is the main power source for machine tools and causes the main environmental impact of machining processes [20]. Within former studies main consumers of electrical power in machine tools were identified. Dietmair showed in his investigations for the complete machining of a reference workpiece that the coolant supply was responsible for more than 30% of the total consumed electrical energy. The second largest consumer was the process with the spindle with around 15% [21, 22]. Beside others also Brecher et al. obtained comparable results within their study in the German EWOTeK project. In the production state of a five axis machine tool the main consumers were the coolant supply and hydraulic power unit prior the main drives [23]. Further studies identified a high optimisation potential in the use of cutting fluids for energy and health aspects [20].

For the description of the power consumption of machine tools different complex models were established with up to 9 different machine tool operational states as well as up to 8 power consumers and consumer groups [20–22].

Beside these complex models simplified models were derived with only three states and three process periods due to the fast passing of some states and the parallel starting of different consumers [20, 24, 25].

Figure 5.2.1 displays the composition of the power demands, forming the overall energy per part depending on the process periods. During one machining cycle the three machine tool states operational readiness (base load), idle mode and process mode can be distinguished. The variable portion (idle and process load) mainly depends on the actual process as well as on auxiliary and feed movements [20].

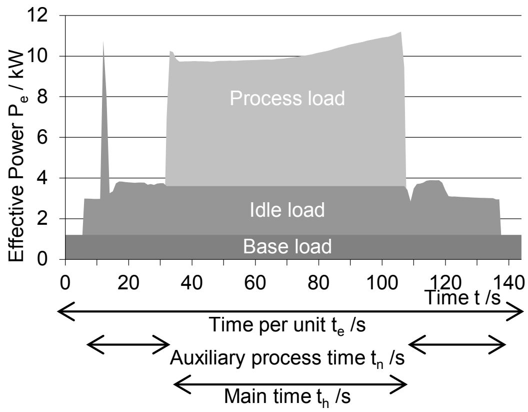

Fig. 5.2.1 Energy model of machining processes

3 Experimental Setup

In this study the effects of a high-pressure lubricoolant supply on tool wear, chip forms, cutting temperature and power consumption of machine tool and high-pressure unit were investigated in a longitudinal external turning process. All experiments were carried out under roughing conditions on a CNC-lathe type Monforts RNC 400*plus*. The supply of lubricoolant with high pressure was performed by an external unit type ChipBLASTER CV16-5000 with a maximum pressure of 350 bar (continuously adjustable) and a maximum flow rate of 65 l/min. The conventional 6 bar flood cooling (flow rate about 10 l/min) was used as a reference.

The high alloy austenitic stainless steel X5CrNi18-10 was machined using coated cemented carbide cutting inserts. When the lubricoolant was supplied with high-pressure, three jets were directed straight onto the rake face of the tool. In this case, the internal pump of the lathe was switched off. The influences of the lubricoolant supply pressure and flow rate were analysed independently from each other by using a custom made tool holder from ISCAR with internal lubricoolant supply and variable orifice diameter. In this way it was possible to change each parameter—pressure and flow rate—separately. The flow rate could be varied in three steps from low to medium to high volume. In case of conventional flood cooling the external high-pressure pump was switched off and the lubricoolant supply was performed by the internal low-pressure pump of the machine tool. By using a two-colour pyrometer the temperature during turning was measured within the cutting tool very close to the cutting edge. Therefore flat cutting inserts had to be employed. An emulsion with a concentration of about 7% of type Fuchs Ecocool TN2525HP was used as cutting fluid. The test conditions are summarised in Table 5.2.1.

For the evaluation of the turning processes it was essential to collect beside the electrical energy, which is directly consumed by the machine tool, also the electrical energy from the external lubricoolant supply system to generate the required energy per part or per removed material. Therefore the balance shells for the evaluation are drawn for the two systems as shown in Fig. 5.2.2.

The power consumption of both systems was therefore captured at the main power supply of the machine tool and the external ChipBLASTER lubricoolant supply unit with Chauvin Arnoux C.A 8335 power and quality analysers.

Table 5.2.1 Test conditions

Machine tool	Monforts RNC 400*plus*
High-pressure supply	ChipBLASTER CV16-5000
Workpiece Material	Stainless Steel X5CrNi18-10
Process	Longitudinal external turning
Tool holder	Iscar DCLNL-25-UHP-12
Tool geometry	CNMA 120408
Cutting material	HC-M05/M20 (Iscar IC907)
Cutting parameters	v_c = 200; 400 m/min f = 0.15 mm a_p = 2.5 mm
Lubricoolant supply pressure	Conventional flood cooling: 6 bar High-pressure: 70–300 bar
Evaluation criteria	Tool wear Chip form Tool temperature Energy consumption (machine tool, ChipBLASTER)
Emulsion	Fuchs Ecocool TN2525HP, 7%

Power quality analysers are generally used for long term power quality measurements of power grids. They have sample rates of 128–512 samples per cycle, resulting in a sample frequency of 6.4–25.6 kHz for 50Hz grids [27].

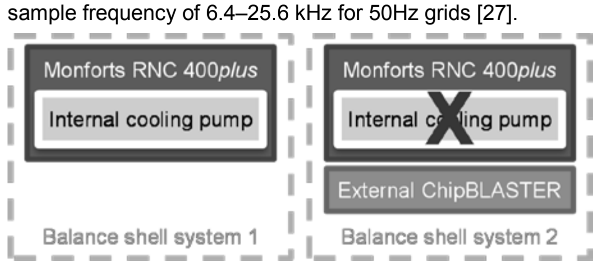

Fig. 5.2.2 Balance shells for the evaluation of the lubricoolant supply

Figure 5.2.3 shows the effect of lubricoolant supply pressure and flow rate on tool temperature. The cutting tool temperature was measured in the cutting insert at a distance of 0.15 mm below the rake face and a distance of 0.37 mm parallel to the main flank face. It is conspicuous that for both cutting speeds, 200 and 400 m/min, the tool temperature decreases with increasing supply pressure. The maximum measured temperature reduction of about 30% could be observed at a cutting speed of 400 m/min and a lubricoolant supply pressure of 300 bar with medium flow rate (31 l/min) in comparison to the conventional flood cooling. In most cases the variation of the flow rate from low to medium volume at constant pressure resulted in a minimal decrease of tool temperature, while a further increase of the flow rate from medium to high volume even showed a marginal increase of the cutting tool temperature. It can be stated that the lubricoolant supply pressure is the dominant setting parameter. Medium flow rates showed the best results while an increasing pressure up to 300 bar continuously improved the tool cooling.

4 Technical Results

4.1 Variation of Supply Pressure and Flow Rate

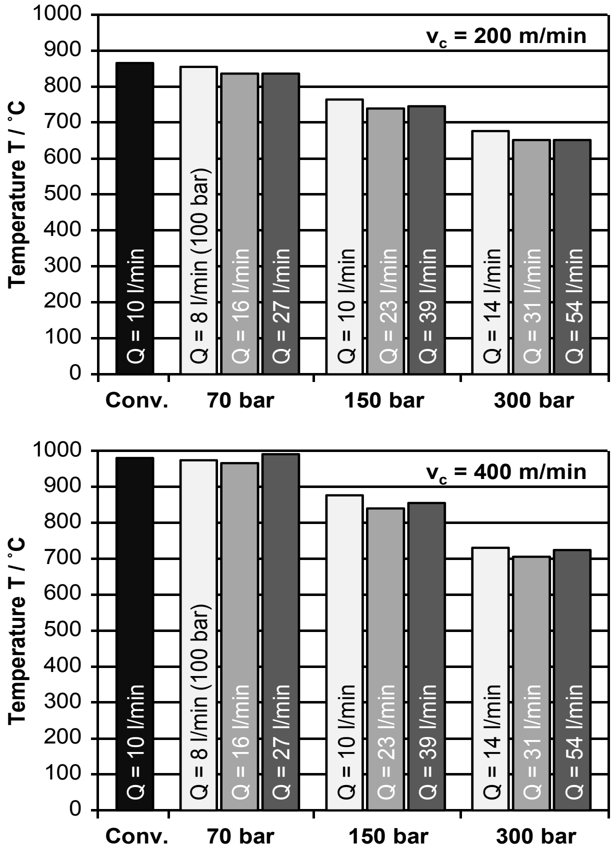

Fig. 5.2.3 Tool temperature in dependence of supply pressure and flow rate for cutting speeds 200 m/min (*top*) and 400 m/min (*bottom*)

4.2 Tool Wear Analysis

It is assumed that the tool temperature reduction correlates to the increase of the tool lifetime. Since the cutting tool temperature at a cutting speed of 200 m/min with conventional flood cooling was in the same order of magnitude as the temperature at a cutting speed of 400 m/min with 150 bar and medium flow rate high-pressure lubricoolant supply, these two parameter setting were analysed in terms of tool wear. Figure 5.2.4 shows a comparison of the width of flank wear land depending on the cutting volume for both parameter settings. Uniform abrasive flank wear was the dominant wear form. It can be seen that the flank wear land is similar in scale for both 200 m/min cutting speed with conventional flood cooling and for the doubled cutting speed 400 m/min with high-pressure lubricoolant supply up to a cutting volume of 650 cm³. In the further course the tool wear land rises significantly in the case of lower cutting speed and conventional flood cooling. At this point it may be summarised that the cutting speed can be doubled from 200 to 400 m/min at more or less the same level of tool wear by using the high-pressure lubricoolant supply in comparison to the conventional flood cooling in turning the austenitic steel X5CrNi18-10. Furthermore the tool wear analysis showed a distinctive chipping and built up edges when using the conventional flood cooling, while no chipping and built up edges could be observed in the case of high-pressure lubricoolant supply. This in fact demonstrates the huge potential of a high-pressure lubricoolant supply in terms of the increase of productivity.

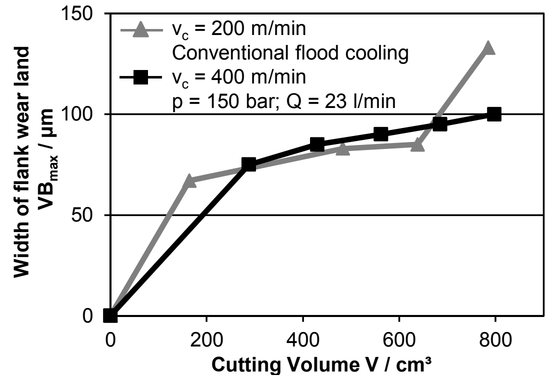

Fig. 5.2.4 Tool wear analysis

4.3 Process Stability

When using the conventional flood cooling ribbon chips were formed for both cutting speeds, 200 and 400 m/min. The chips wrapped round the workpiece and tool holder and thus causes a danger either by means of total tool failure or the formation of damaged surfaces. Moreover the accumulation of chips leads to long process down-times, since the chips have to be removed manually by the machine tool operator. In the case of high-pressure lubricoolant supply with 150 bar supply pressure defined chip breakage occurred as shown in Fig. 5.2.5. Short chips with a length of 3–5 cm were formed that are easily evacuated from the cutting zone and machine tool.

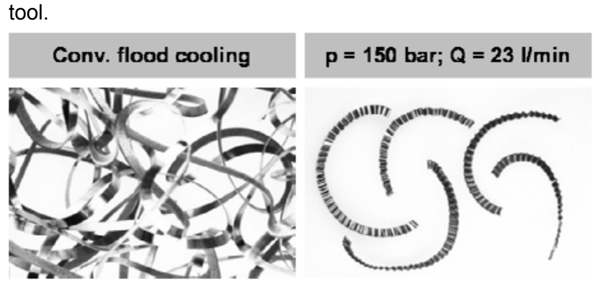

Fig. 5.2.5 Resulting chip forms at a cutting speed of vc = 400 m/min

Beside the enhanced tool cooling chip control is a further significant improvement achieved through high-pressure lubricoolant supply leading to a substantial improvement of process stability and productivity, too.

5 Evaluation of Energy Consumption of the Different Lubricoolant Supply Systems

Within this chapter the power consumption of the two subsystems Monforts RNC 400*plus* and ChipBLASTER is shown and the total energy per removed material is evaluated.

5.1 Power Consumption of the External Lubricoolant Supply

An exemplary power consumption of the external lubricoolant supply unit is plotted in Fig. 5.2.6. The power consumption can be allocated to four consumer groups. First there is the base load which is considered to be constant. The second consumer is the skimmer, which cleans the lubricoolant periodically. A retraction pump is the third consumer and refills the ChipBLASTER on demand. The last consumer group is directly responsible for the generation of the high-pressure lubrication. Although the retraction pump and skimmer are not working constantly it is possible to distribute it evenly to the base load.

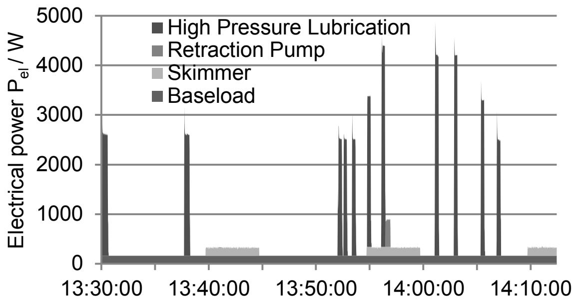

Fig. 5.2.6 Power consumption and responsible power consumers in the ChipBLASTER lubricoolant supply system

As described in chapter 3 the pressure and the flow rate were varied separately to investigate the technological effects of the high-pressure lubricoolant supply. The real electrical power consumption of the ChipBLASTER was captured and plotted as a surface depending on flow rate and pressure in Fig. 5.2.7

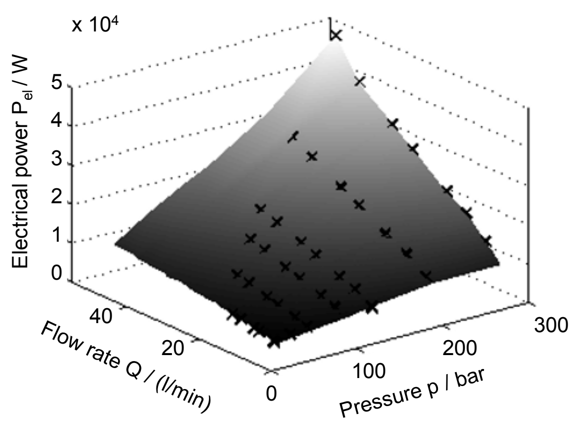

Fig. 5.2.7 Electrical power consumption dependent on the generated pressure and flow rate

The calculated hydraulic power is plotted in comparison to the electrical consumed power in Fig. 5.2.8. It is calculated as the product of pressure and flow rate.

5.2 Efficiency Value for the External Lubricoolant Supply

As a first evaluation approach for the external lubricoolant supply the efficiency value is generated as the quotient of the hydraulic power divided by the required electrical power depending on flow rate and pressure.

$$\eta(Q,p) = \frac{P_h(Q,p)}{P_{el}(Q,p)} \tag{5.2.1}$$

The efficiency value in Eq. 5.2.1 is plotted in Fig. 5.2.9 depending on flow rate and pressure. The efficiency value is rising with the pressure and flow rate. Although the efficiency of the sub system lubricoolant supply unit is increasing with higher pressure and higher flow rates, the technical evaluation has demonstrated that the increase of the flow rate above the medium flow rate does not achieve any benefit in turning of X5CrNi18-10.

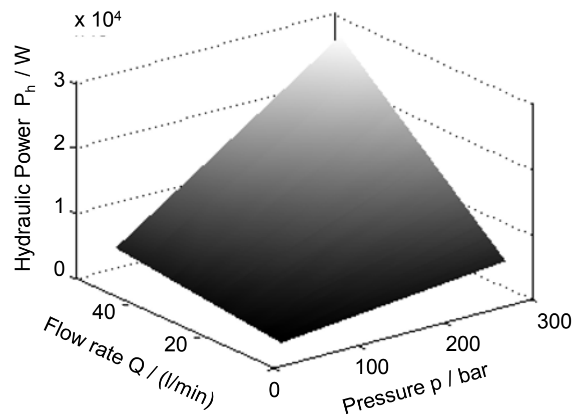

Fig. 5.2.8 Calculated hydraulic power

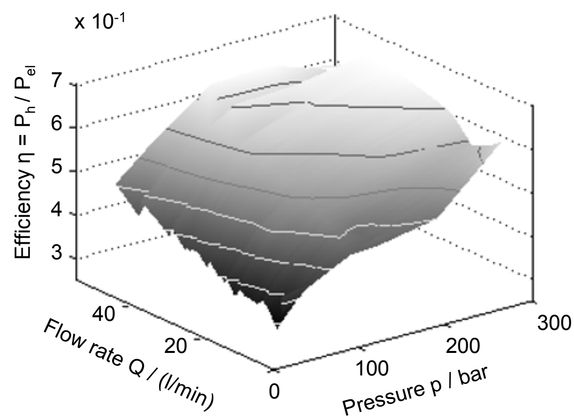

Fig. 5.2.9 Calculated total efficiency values for the ChipBLASTER lubricoolant supply system

5.3 Power Consumption of the CNC-Lathe

The power consumption of the investigated CNC-Lathe Monforts RNC 400*plus* corresponds to the plot in Fig. 5.2.1. The base load is constant for both investigated balance shells while the idle load indicates a difference of 1.25 kW, which is caused by the internal lubricoolant pump in the balance shell 1. The effect of the two different ways of lubricoolant supply on the process power consumption was very small and thus will be neglected in the further discussion. Furthermore it will be assumed that the auxiliary process time and its power consumption is constant.

5.4 Specific Cutting Energy

As already explained in the Chaps. 1.1 and 5.2 it is not sufficient to compare the absolute power or the efficiency values of subsystems for a total evaluation of cutting processes under the life cycle assessment perspective. In fact it is essential to establish a relationship to the product or the removed material. In the view of the life cycle perspective the specific cutting energy as the quotient of the used energy and the removed material has been established as the relevant ratio for machining operations. [1, 20]

$$E_{el,spec} = \frac{\sum E_{el}}{V} \tag{5.2.2}$$

For a comprehensive life cycle analysis of the machining process also the primary energy in the tool has to be taken into account. Only for the case that almost the same amount of material can be removed with different process parameters it is possible to make a direct comparable evaluation. Due to the fact, that the productivity could be raised by an increase of the cutting speed from 200 to 400 m/min two scenarios with the same amount of removed material can be directly compared as shown in Table 5.2.2.

Table 5.2.2 Comparison of the two lubricoolant supply strategies

	Balance Shell 1	Balance Shell 2
Cutting speed v_c/(m/min)	200	400
Feed f/mm	0.15	0.15
Depth of cut a_p/mm	2.5	2.5
Lubricoolant supply strategy	Internal	External
Lubricoolant supply pressure p/bar	6	150
Average power consumption Monforts RNC 400*plus* during machining $P_{el,Mon}$/W	10 341	9 073
Average power consumption ChipBLASTER during machining $P_{el,CB}$/W	0	3373
Average total power consumption	10 341	12 446
Tool life criteria VB_{max}/µm	100	100
Tool lifetime T/min	9	5,3
Removed material V/cm³	675	795
Total energy during machining E/J	93 069	65 963.8
Specific energy $E_{el,spec}$/(J/cm³)	8272.8	4978.4

The investigation showed a reduction of the specific electrical energy during machining of the high alloyed steel X5CrNi18-10 of about 40% by using high-pressure lubricoolant supply in contrast to conventional flood cooling. Therefore the results can object the prejudice of the high energy consumption of high-pressure pumps since, in terms of a life cycle assessment of the cutting process, the increase in productivity leading to a shorter process main time compensates the larger amount of required power.

As the paper investigation focused on the main time analysis, the total effect for the specific energy per removed material might be influenced in a different amount due to auxiliary process times.

6 Summary

In this paper turning tests in stainless steel X5CrNi18-10 were carried out with the use of a high-pressure lubricoolant supply in comparison to the conventional flood cooling. As a first conclusion it is drawn that the directed supply of lubricoolant leads to significant reduction of tool temperature up to 30% compared to the conventional flood cooling. The cutting tests have demonstrated that the lubricoolant supply pressure is the dominant setting parameter while the flow rate has a minor influence on the process performance. In summary the cutting speed could be doubled from 200 to 400 m/min through the use of the high-pressure lubricoolant supply leading to a significant increase of productivity. At the same time, the process stability could be enhanced since defined chip breakage and chip evacuation could be reached with high-pressure lubricoolant supply, while ribbon chips were formed in the case of conventional flood cooling. In a second step the process energy consumption was analysed for both cases, cutting speed 200 m/min with conventional flood cooling (internal machine pump) on the one hand and an increased cutting speed of 400 m/min with high-pressure lubricoolant supply (external pump) on the other hand side.

Although the total power consumption as sum of machine tool and external high-pressure unit raised about 20% in the case of high-pressure lubricoolant supply in comparison to the conventional flood cooling, a reduction of 50% in the main process time could be reached reducing the specific electrical energy during machining about 40%. However the estimation done for the electrical energy consumed in the main time does not include the influence of enhanced process stability on the auxiliary process time so far. With the use of the high-pressure lubricoolant supply it is possible to reduce process down-times and the scrap rate due to process failures by controlled chip breakage and safe chip removal.

7 Acknowledgments

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5.3 Energy-Aware Production Planning Based on EnergyBlocks in a Siemens AG Generator Plant

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Abstract

The constant cost saving pressure in industrial production is more and more complemented by environmental requirements. Thus, increasing energy efficiency and effectiveness in industrial production systems moves into the attention of factory and production planners. Evaluating and selecting alternative energy saving measures, like energy efficient electrical actuators or energy load management systems are gaining increasing importance in production. To enable this evaluation during the factory and production planning phase an accurate prediction of the expected energy consumption is necessary. The EnergyBlocks methodology introduced in this paper meets this purpose.

To demonstrate the EnergyBlocks methodology, production processes of a generator plant of the Siemens AG have been acquired and analyzed in terms of their material flow data and corresponding electrical energy profiles, measured over a period of three months. The EnergyBlocks created are used to support the energy optimal production planning.

Keywords:

Energy efficiency, Production planning, EnergyBlocks, Material flow and energy profiles

1 Introduction

At the 2010 United Nations Climate Change Conference in Cancún, Mexico, the parties agreed on limiting the anthropogenic-caused global warming to 2°C [1], thus preserving today's living conditions for humanity on earth.

The largest contributor for the global warming is Carbon Dioxide (CO_2), which is responsible for about 64% of the effect. Its climate impact relevance is underlined by the time span of up to 200 years that it remains in the atmosphere. This stands in contrast exemplarily to Methane (CH_4), which only remains up to 15 years in the atmosphere and is responsible for about 20% of the global warming effect [2]. One of the main CO_2 emission sources is the energy generation from fossil fuels like coal, gas, and oil.

Approximately 390 parts per million (ppm) CO_2 is currently concentrated in the earth's atmosphere. Limiting the global warming to 2 C could be achieved with a probability of 75%, if the CO_2 concentration of 400 ppm is not exceeded [3]. However, since the annual growth rate of the concentration is approximately 2 ppm this goal is in danger [4].

Siemens wants to help maintaining a healthy world, one in which natural resources are protected and the needs of future generations are respected by environmental conservation [5]. As one of the important factors for achieving these targets energy consumption and energy efficiency are identified.

The energy consumption of the developed civilizations and the new emerging populations in Asia and South America is one of the main threats for functioning ecosystems globally. Not only green house gas emissions as a consequence of fossil combustion has to be named but also the environmental impairment raised by the extraction of natural resources. Consequently, the excessive use of energy not only threatens the environment but strongly influences the social dimension of the human existence and thus the ability to increase the global living standards. Unfortunately, growing prosperity of societies has always been linked to increased energy consumption. At the same time, the economical challenges due to the increased worldwide demand of the limited available resources become observable.

In 2007, 457 EJ (1 Exa Joule = 10^{18} Joule) of primary energy were consumed worldwide, the share of final energy used for industrial applications have been 195 EJ. About two fifth of the total primary energy are converted into electrical energy, with an increasing share. The required energy is estimated to double globally until 2050, while the electrical energy demand will already be doubled in 2030 [6, 7].

Overall, the primary energy carriers used in the industry are fossil fuels. Regarding the manufacturing industry, a different distribution is given: Taking the German manufacturing industry as an example, about 55% of the consumed energy is electrical energy [8]. Two third of this are converted into mechanical energy [9].

Industrial companies are at the same time designers and manufacturers of products, which require energy during their usage phase. Thus, reducing the energy consumption for the manufacturing is as necessary as the development and the production of products using energy efficiently. As a prerequisite, a detailed analysis of the energy consumption of the product but also of the production phases is necessary. This analysis has to be carried out as early as possible during the process of the product and the production system development as well as the production planning to achieve maximum effects. The energy consumption has to be modeled for the required analysis prior to the system realization or the production start.

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2 Energy Modelling Requirements

2.1 Energy Efficiency Opportunities

Physically, the energy consumed in a production process is represented by the power consumed at each time the process is running, integrated over the duration of the process and evaluated for each energy carrier involved, like electricity, pressurized air, heating and cooling. Thus, raising the efficiency could be achieved by minimizing the power required for the process, or by minimizing the duration of the process itself. While the first option could be achieved by technical improvements like applying more efficient actuators and drives, the latter is realized by organizational means.

Organizational means for raising energy efficiency are heavily effected by the technical or technological properties of the applied equipment. One of the most common examples for this is the energy required by equipment during stand by, which in most cases represents a notable share of the total consumption and thus raises efforts for developing sleep modes or fast shut-down and start-up modes. Improving machine utilization would significantly reduce the consumption during non working machine states. One common approach for achieving this aim would be setting up buffers, so that the processing rate of each process could be directly adapted to its duration. Thus, the objective of avoiding stand by times stands in conflict with the objective of the most common method of lean production with the principle of one piece flow, which tends to result in longer stand by times as a consequence of uneven distributed process times at different stations of one manufacturing system.

Regarding the energy consumption of a whole production system enlarges the degrees of freedom for improving energy efficiency. Since processes are mostly executed in parallel, the whole consumption profile of the concerned production represents the sum of all single processes. Thus, besides the amount of energy required for one process, the time the energy is required becomes relevant in terms of peak load management and energy recovery possibilities.

Furthermore, increasing the energy efficiency of a production system can be accomplished by alternative process chains within the framework of lean production, allowing a holistic optimization through the design of process chains instead of single processes.

2.2 Energy Modelling Requirements

As discussed above, increasing the energy efficiency of a production system involves technical and organizational aspects that depend on each other. As a consequence, the energy consumption of different production machines have to be adjusted in terms of the process chain-wide required energy as well as the specific time the consumption takes place. This requires a consumption forecast, which is based on each single process and the time the process is executed.

Further requirements can be derived from the information of such a consumption forecast system. This requires a quick and easy modelling of the consumption itself as well as the possibility to adapt to new process technologies with a reasonable workload. The EnergyBlocks methodology presented in the next chapter aims to meet these requirements.

3 EnergyBlocks-Methodology

3.1 Approach

Production equipment, like machining centers, handling and transport systems have various operating modes that exhibit different resource consumption behaviors: turned-off, starting/warm-up, stand-by, operating, or stopping. The observable time spans of each operational mode can be separated in constant and variable times. For example, the time necessary for processing a work item will differ from item to item, while the time required for starting controls and machines will be approximately the same every time they occur, especially when the technically feasible minimal time span is achieved [10].

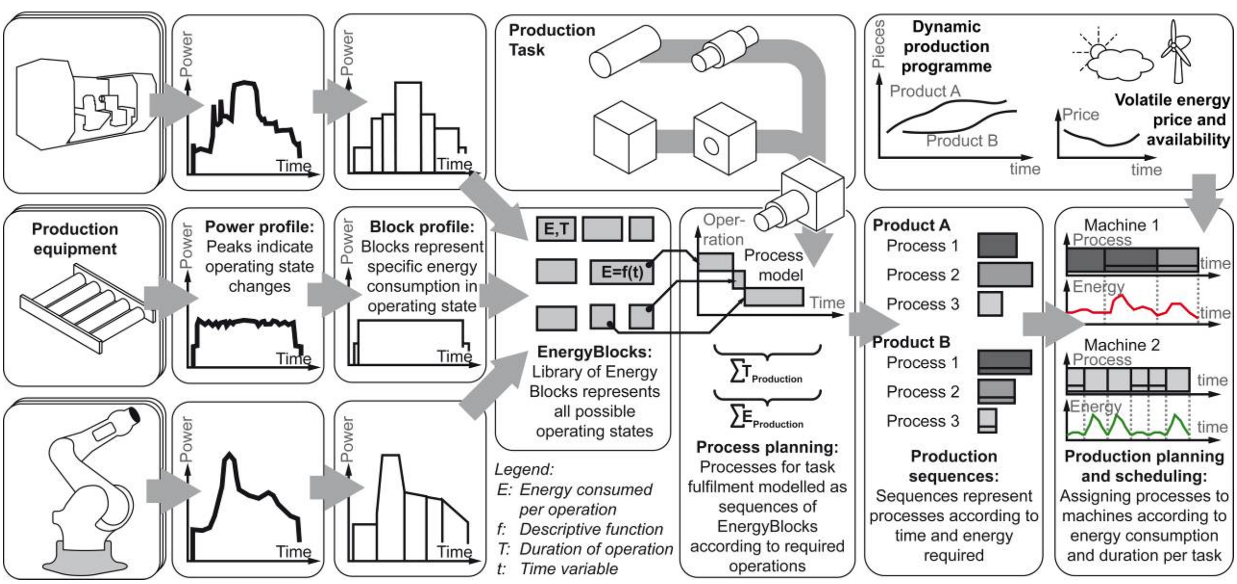

Fig. 5.3.1 EnergyBlocks methodology [10]

Production equipment (Fig. 5.3.1, left column) is assumed to show similar resource requirements for similar machine types within comparable performance classes and comparable production tasks, enabling the clustering of energy consumptions according to the operational state of the production equipment and the targeted production processes (Fig. 5.3.1, middle columns). As a result, a two-dimensional clustering according to resource consumption and process time becomes possible for each energy carrier, and each operational state is defined as an EnergyBlock representing the duration as well as the energy required during each operational state. Thus, production sequences can be modeled and represented by easily arranging these blocks in a Gantt-chart manner with a minimum effort of setting up parameters (i.e. setting up the duration of time-variable blocks). This approach is carried out for every energy form used by the considered machine.

3.2 Mathematical Representation

The amount of energy required in a specific operational state can be constant, but in many cases is not. An example is given in Fig. 5.3.2, where the different operational states for a roll balancing process of a generator rotor can be observed. While the energy amount required during stand-by is constant, the acceleration as well as the braking operations requires a time dependant amount of energy.

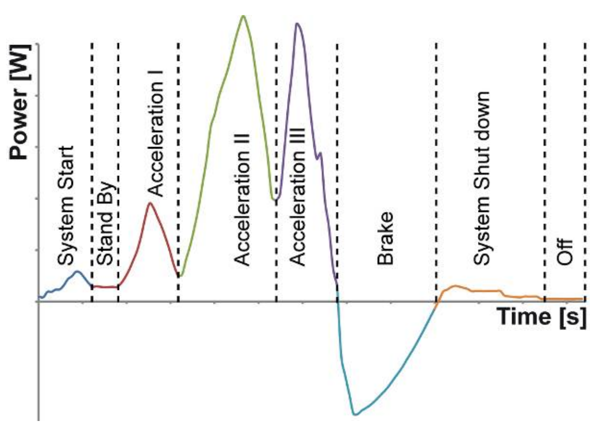

Fig. 5.3.2 Electric Power profile of a roll balancing process

The required power $P(t)$ can be described as a series of functions $f_i(t)$. Since each operational state occurs only for a specific period of time, the function is only defined within an interval $\left[T_{i,0}, T_{i,1}\right]$, so that the power profile of one single operational state could be described as:

$$P_i(t) = f_i(t), \forall t \in \left[T_{i,0}, T_{i,1}\right] \quad (5.3.1)$$

The time dependent representation of the power can be expressed as a polynomial and hence as a power series around any center t_0:

$$f_i(t) = \sum_{j=0}^{\infty} a_j (t - t_0)^2 \, , \quad (5.3.2)$$

where a_j is a coefficient of the j th term.

Production sequences can be described as a series of different blocks, i.e. as a series of functions each defined in a specific time interval:

$$P(t) = \begin{bmatrix} f_{i,1}(t), \forall t \in \left[T_{i,1}, T_{i,1}\right] \\ \vdots \\ f_{i,n}(t), \forall t \in \left[T_{i,n}, T_{i,n}\right] \end{bmatrix} . \quad (5.3.3)$$

The total energy consumed during the process then is:

$$E_{Process} = F(t) = \int_{T_{Start}}^{T_{End}} P(t) \cdot dt \, . \quad (5.3.4)$$

Depending on the planning task the concept of EnergyBlocks is applied for, one must decide if the total amount $E_{Process}$ or the time dependant functional description $P(t)$ is more appropriate.

3.3 Software Architecture

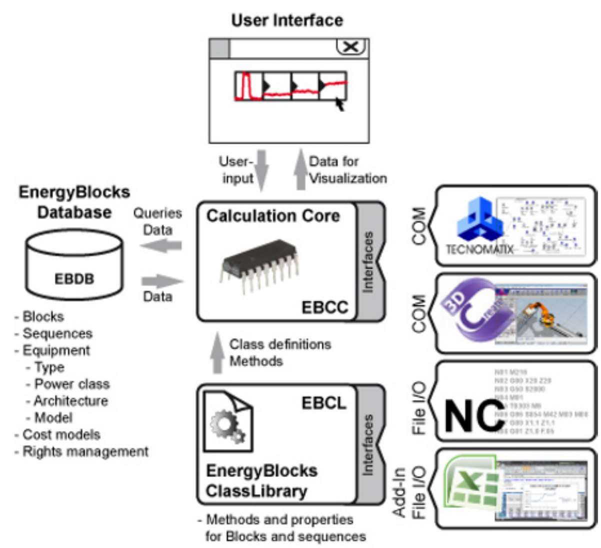

Fig. 5.3.3 EnergyBlocks software framework [11]

The concept of EnergyBlocks has been implemented as a software plug-in system for existing tools which are applied in the different areas of production planning and control. An example is Siemens Plant Simulation, but also interfaces to general software like Microsoft Excel or Project are available, as well are importers for generating consumption models from e.g. NC code (Fig. 5.3.3).

The EnergyBlocks Software itself consist of the class prototypes for representing EnergyBlocks and EnergyBlock-Sequences as well as for providing file or database access for data saving. It also provides a computational core for calculating the energy consumed per energy carrier and machine. Further, user interfaces and dialogues for importing energy consumption data are provided.

3.4 Fields of Application

The strategic aspect of planning a production area, e.g. the manufacturing area or the assembly area within a factory, according to energy efficiency objectives relates to the dimensioning of the production lines and cells. When conducting capacity management and layout planning, one should take the energy consumption profile of the system to be implemented into account. This means that an evaluation of the various alternatives for designing a production line/cell according to its energy efficiency must take place. During the design phase of the line/cell, the planner can evaluate the various alternatives for each process step by using information stored in the EnergyBlocks-Database (EBDB) and derive the optimal system configuration.

On the operational level the approach can be applied to determine the exact energy requirements of a production line/cell when executing a production program. By simulating the behavior of the system and correlating the simulation results, e.g. the processing, start-up and waiting times of each system element, with the energy consumption profiles, the planner can accurately determine the production's energy requirements. Different material flow strategies can be tested and new energy efficient production control strategies developed. The results of such studies can act as an accurate cost calculation tool. The presented approach is also applicable in the design phase of equipment. The energy blocks can be used to represent the energy consumption of single actuators and other machine components and thus determine the energy consumption of the production equipment. Another field of application is the product development itself. By determining the energy required for the production of products one can favor energy efficient designs.

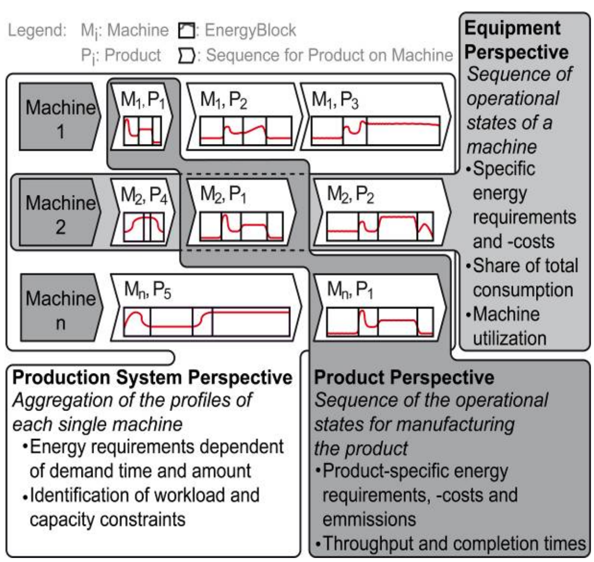

Fig. 5.3.4 Result types of the EnergyBlocks Planning Methodology [10]

As shown in Fig. 5.3.4, the results of modelling the energy consumption of a production system using EnergyBlocks provides three different views: Each process is described as an EnergyBlocks sequence. For each machine, a series of sequences describes the machine's production program and thus the energy consumption of the machine throughout the whole production can be determined. Related indicators, like machine specific energy costs, become available. Further, the time-based modelling eases the integration of the EnergyBlocks methodology in existing scheduling methods. Based on the aggregation of all machine consumptions, a prediction of how much energy is required at which time becomes possible. As with a single machine, related information like energy costs, emissions or bottleneck machines become easily accessible and visible system-wide due to the time based modelling.

From the product perspective, by evaluating all product specific work processes, the embodied energy for each product can be calculated. Not only primary production processes are considered, but also secondary operations like machine loading and set-up. Furthermore, not only the theoretical processing energies are considered, but all part specific consumptions of all subsystems, e.g. the main spindle, axle drives, coolant pumps or tool changers. Thus, the overall consumption calculation is more accurate than e.g. dividing the total energy consumed in secondary operations by the number of produced parts or elapsed production times.

4 Use Case

The methodology described above is used to investigate and improve the energy consumption of a generator plant of the Siemens AG. The application is aiming at a better adjustment of the processes requiring the highest amounts of electrical energy in this plant. Under certain conditions peak loads exceed the targeted electrical limits. As a consequence, the peak load is controlled by an energy management system. The system is able to throw-off and interrupt certain production processes, which causes extra effort for process restarts. Additionally, limiting the maximum load limits production costs due to the energy contract conditions.

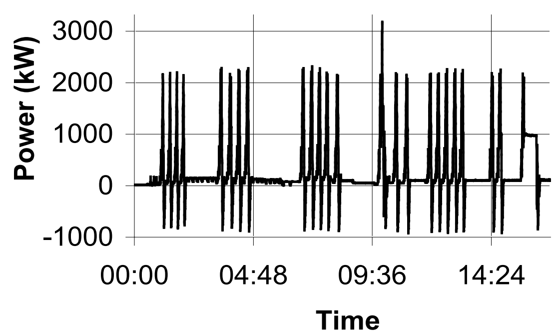

Fig. 5.3.5 Exemplary energy power profile of the roll balancing process

The main electricity consumers regarded in this use case are the processes roll balancing and testing. In both processes, generator rotors are accelerated to high revolutions, requiring high amounts of electrical energy for the drives. The rotors then have to be kept in certain rotation patterns for process stabilization and measurements, and are decelerated after each process. While decelerating, energy is recovered by running the electrical motors as generators. Further electrical energy for other electrical tests is required, especially for the testing processes. In the roll balancing process, the main energy share is used for the acceleration of the rotors, which is executed iteratively with a deceleration and weight balance placement phase until the desired mechanical running smoothness is achieved. Figure 5.3.5 displays a consumption profile of this process.

The electrical energy consumptions of the roll balancing and testing processes have been measured over a period of three months with a process adequate fine sampling rate of one second. The electrical consumption data was then correlated with the material flow data of this three months period. The material flow data was retrieved from the process control logs, the planning data, the logged expert reports of the process operators, and the overall machine log files with one second resolution. In addition to these measurements over the observed three months period the products have been grouped in terms of their physical properties into four classes. This classification has been verified by two independent process experts of the plant. Respective EnergyBlocks were defined (comp. Fig. 5.3.2) for all machine states of the two processes. The number of different blocks has been limited to a necessary minimum for all product classes. The power profiles of the processes were simulated using Siemens Plant Simulation, extended with the EnergyBlocks software plugin, thus being able to investigate different strategies, for example by adjusting the product class sequencing or starting times of processes.

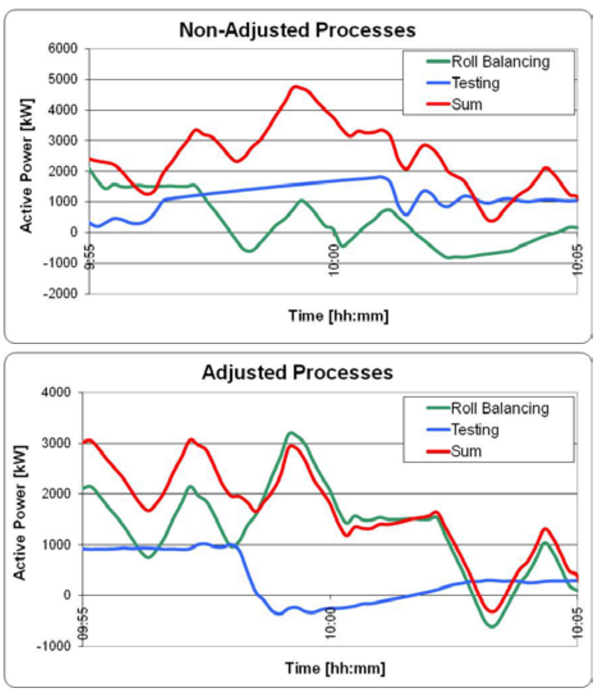

Fig. 5.3.6 Consumption profile of the initial (top) and final (bottom) process adjustment

In Fig. 5.3.6, an exemplary result of this investigation is depicted. The upper diagram shows a common initial state of the power consumption of the two main processes testing and roll balancing, leading to a peak load of about 5000 kW. The lower diagram displays the final state after adapting the production schedule, limiting the peak load to 3000 kW. Beside the avoidance of an electrical load excess and the reuse of a reasonable amount of energy during the deceleration phase, the peak load limitation saves about € 30.000 demand charge per year. Furthermore, energy is saved by avoiding process interruptions, since no energy is wasted for unfinished processes or process restarts.

With this use case, examples from an ongoing project have been presented. Until now, this project focuses on the investigation of the energy and the material flow data acquisition and on the possibilities for improving the energy consumption. In the further course of the project the EnergyBlocks methodology will be integrated in the production planning system of the concerned generator plant, thus allowing an easily integration of economical and ecological objectives in the production planning.

5 Summary

CO_2 is the larges contributor to the greenhouse effect. Reducing the energy required for production processes is an important contributor for avoiding CO_2 emissions. Siemens, as a manufacturer of a large variety of products, has committed itself to improve the energy efficiency of their production processes and thus to contribute to CO_2 savings.

Increasing the energy efficiency in a production environment requires a detailed knowledge of the consumption behaviour of the investigated production system, prior to the system realization and to execution of the production. The EnergyBlocks methodology adopts this requirement and provides a possibility for predicting the energy consumption of production systems of any kind. The method is based on the segmentation of power profiles of production equipment according to the possible operational status, and on modelling any production process by arranging these segments, the EnergyBlocks. According to the occurrence of the equipments operational states in the investigated process, the EnergyBlocks are arranged for modelling the power profile.

For demonstrating the application and the operational benefit of the methodology, preliminary results from an ongoing project concerning the production planning and scheduling at a generator plant of the Siemens AG have been presented. The results indicate promising chances for both, consumption reduction and cost savings, thus contributing to the economical and ecological dimension of the Siemens sustainability definition [5].

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5.4 Optimization of Energy Production under the View of Technical, Economic and Environmental Conditions

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Abstract

The global growing of electricity production and consumption increase the pollution of the biosphere. In the conventional generation of electricity with coal, oil and gas the emissions of carbon dioxide to the atmosphere increase. According to the actual technical state of the art in the production of nuclear electricity, the waste disposal of dangerous radioactive materials is not clear. The generation of electricity with nuclear power is a technology with incalculable economic and ecological risks to people and the environment. In the future globally considered the production of nuclear and conventional power is not economically and ecologically. For these reasons, the production of electricity from renewable energy sources has to be enlarged and realized consequently. In this paper, the concept of the described model can be used to represent the technological, economic and environmental conditions for regions or countries to optimize the energy production. From this model, then a global representation can be developed. The aim of the model is to minimize the energy production on the base of coal, oil, gas, to optimize the production of electricity by renewable energy sources and stop the generation of nuclear power under technical, economic and environmental point of views.

Keywords

CIRP International Conference; Economic Conditions, Energy Production, Environmental Conditions, Optimization, Technical Conditions

Introduction

The increasing energy demand in the global economy has to be covered by environmentally friendly sources of energy. For the optimization of electric energy production the safe, timely, environmentally friendly and future-oriented power supply to all industries and all regions must be considered.

Our planet is being significantly impacted by environmental influences. The number of oncological diseases is increasing. Each year, the problems of climate change through emissions from the production and living activities of people become larger. The growing global production and consumption levels of energy increase the burden on the biosphere, mainly by emissions of CO_2 by the use of fossil fuels to generate electricity. In 2008, the CO_2 emissions increased by 34.1% compared to 1995, in 2009 the emissions increased on all continents, even in the global financial crisis, by 32,3% compared to the values 1995. In 2010, the growth rate of CO_2 emissions was 41.,1% compared to 1995 [1].

Nuclear and Wind Power

Since the accident at the Chernobyl nuclear power plant in Ukraine 25 years have passed. The accident is the worst nuclear disaster of humanity in times of peace. More than 2,2 million people are affected, of which 255 thousand people were engaged to eliminate the catastrophic consequences. In the atmosphere 190 tons of radioactive material was distributed, an area of more than 145,000 km^2 was in Ukraine, Belarus and Russia contaminated by radionuclides. The damage and the elimination of the consequences of the Chernobyl disaster in Belarus are estimated for a period of 30 years to 235 billion Dollars [2].

The risk of contamination by nuclear power plants is high not only because of the human factor (control error, power off, plane crash, terrorist attack). The risk of contamination caused by possible natural disasters with force majeure (earthquake, flood, tornado, hurricane, volcanic eruption) is very high. Proof of this result is the disaster at the nuclear power plant in Fukushima 1 in Japan, a country with highly developed economy and advanced technologies. Japanese and foreign experts estimate the cost of the disaster at minimum 125 billion Dollars [3]. The events in Japan have influenced the energy policy of many countries in the world. The plans to build new nuclear power plants are delayed.

After the disaster at the Japanese nuclear power plant in Fukushima 1 in March 2011 in Germany seven nuclear power plants were shut down for three months. In June 2011 the decision was fixed to take this nuclear power plants not running again. On 30 June 2011 the German parliament decided the Thirteenth Law amending the Atomic Energy Act [4]. Of the 17 existing nuclear power plants in Germany today, nine nuclear plants are still in operation. According to law, all nuclear power plants in Germany will be shut down step by step until 2023.

On 6 June 2011 from the federal government of Germany's energy policy, "The way the energy of the future - safe, affordable and environmentally friendly" was accepted. As the main aim of this concept, to increase the share of electricity produced from renewable energy sources, was fixed from 17% to 35% in 2020 [5]. As part of this energy strategy, a special program "Offshore wind energy" was developed to support the implementation of the first ten offshore wind parks with a financing volume of 5 billion EUR.

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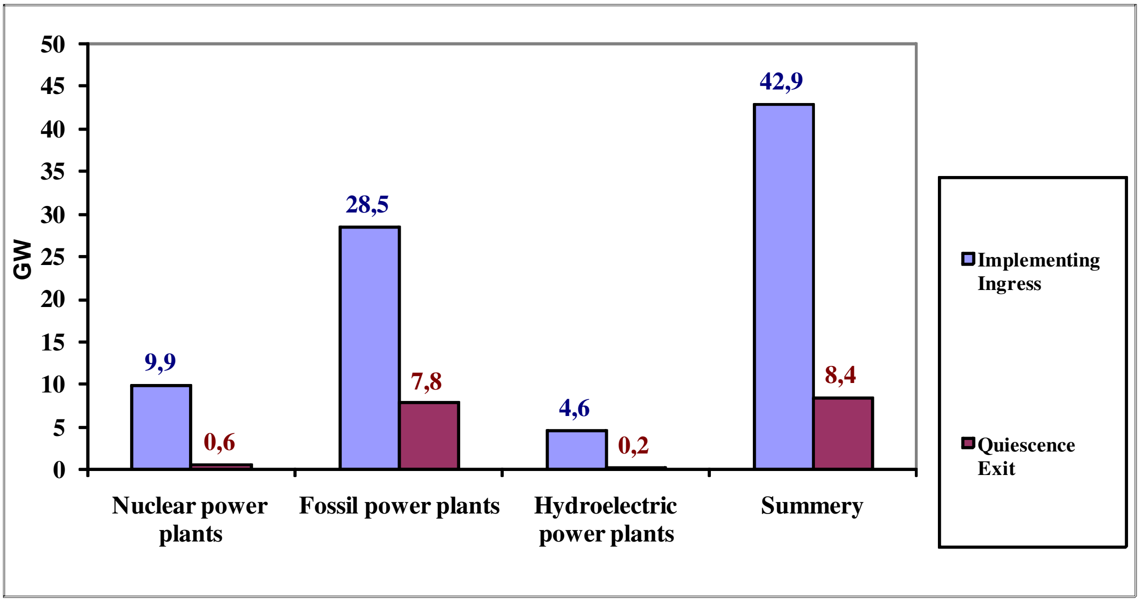

Figure 1:Commissioning and decommissioning of Russia's electricity generation capacity in the period 2010 – 2016

Pro-nuclear arguments	Contra-nuclear arguments
Coverage of needed power generation capacity	Construction of nuclear power plants is not economically (see Table 4)
Improving the CO_2 balance	The use of wind energy is more useful to reduce CO_2, emissions from electricity generation in nuclear power plants amounted to 32 g/kWh, in wind turbines 24 g/kWh [8]
Possibility of reusing nuclear fuel	For the reprocessing of nuclear fuel very expensive technologies are required.
High continuous power from nuclear power plants	Nuclear energy is required only for the cities and regions with high energy consumption for production and infrastructure
Lower energy costs, especially heat energy costs	High costs for the decommissioning of reactors and the disposal of radioactive waste (see Table 4)
Reduced dependence on fossil fuels, Save fossil fuels for other economic uses, Possibility of built up nuclear power plants in regions that have no large energy resources	Wind turbines are more economical

Table 1: Pro and contra for the development of atomic energy in Russia

Since 1995 also by the government of the Russian Federation the nuclear industry was new realigned, which indicates a high degree of attention for the development of nuclear power in Russia. In the year 2010, the volume of the investment program of OAO "Group Rosenergoatom" amounts to 163,3 billion Rubles (4,1 billion EUR). For 2011, investments amounting to 220 billion Rubles (5,5 billion EUR) are planned, which is 34,7% over the planning for the year 2010. For housing the total investment in 2011 amounts to 654,5 million Rubles (16,4 million EUR) [6].

In 2011, by OAO "Group Rosenergoatom" ten nuclear power plant units built in Russia. Five power plant units of these will be built new. The other five nuclear plants are continuing built up after a long interruption. Commissioning and decommissioning of power generation capacity in different power plants in Russia in the period 2010 - 2016 are shown in Figure 1 [7].

Water power plants and water-storage power plants are shown separately in Figure 1. The chart shows, that it is

Parameter	Units	Windturbine	Nuclear power station
Electrical power	GW	0,005	1,0
Availability/year	%	40,0	90,0
Energy production/year	GWh/year	17,5	7.884,0

Table 2: Comparison of annual electricity production from wind turbines and nuclear power plants, depending on the availability

Parameter	Units	Values for	
		Windturbines	Nuclear power plants
Planned electrical power per year	GWh/year	100.000	100.000
Demand of units for the planned output per year	Number	5.707,80	12,7
Investment costs	EUR/KW	1.800	3.437
Investment costs	Mrd. EUR/GW	1,8	3,437
Total investment costs	Mrd. EUR	57,1	43,6

Table 3: Need for equipment and investments

Costs of investments	Share of investment costs for			
	Windturbines		Nuclear power plants	
	% of total investment costs	Mrd. EUR	% of total investment costs	Mrd. EUR
Operating costs, maintenance costs and costs for the actuel state of the art	10	142,7	20	218
Disposal costs after the end-of-life	30	17,1	100	43,6
Investment riscs	0	0	50	152,6
Total investment over 25 years		216,9		457,7

Table 4: Costs for 25-year operation time of wind turbines and nuclear power plants

scheduled to take during the period of seven years, new nuclear power plants with a capacity of 9,9 GW and fossil power plants with a capacity of 28,5 GW in operation. The energy supply from renewable sources, primarily wind energy, is given not enough attention in Russia at our opinion.

The Government of the Russian Federation and the participating organizations promote the development of nuclear energy as an ideal energy source. They prove the usefulness of the power supply by nuclear power. Arguments and counter arguments have been analyzed and summarized in Table 1.

In Tables 2 through 4 is shown that the use of wind energy is more economical than the use of nuclear energy. Table 2 lists the calculation results for the annual electricity production, taking into account the given availability.The need for equipment and capital investment for power generation of 100.000 GWh per year is shown in Table 3.

Table 4 shows the economic comparison of costs for wind turbines and nuclear power stations during a using time of 25 years.

According to Table 4, the cost for the operation of nuclear power plants with investment risk is 2,1 times higher than the costs for wind turbines. The preparation and assembly of wind turbines to operation is possible within three to ten days, the foundations take two weeks to a month. The shorter times for the approval and construction of wind turbines are an important argument for investments in wind turbines.

Summery

The investigation of wind energy concepts for Russia permits the following conclusions [9]:

- Energy demand will rise in Russia, which increases the amount of CO_2 emissions using the electrical supply by fossil-fired power plants (lignite, coal, petroleum and natural gas),
- the use of wind energy is developing rapidly worldwide and has a great potential in the future,
- negative influences on the operation of wind facilities are minimal,
- the available wind resources on the territory of Russia are far above the demand for electricity,
- the wind resources in Russia can be used in all areas for decentralized electricity supply,
- the sectors of the Russian energy sector have great potentials and resources in personnel, engineering knowledge and production for the use of wind energy and other renewable energies.

The results of our work, we can point out that electricity generation from nuclear energy is a technology which has unpredictable ecological risks to humans and the natural environment. The problem of disposal of radioactive waste, produced by the electric production in nuclear power plants, has not been solved. The calculations confirm that the generation of electricity from nuclear energy is not economical. Many arguments speak in Russia for the economic use of wind energy. The paper shows that the technologies for generating electricity by wind energy and other renewable energy sources in Russia should be future-oriented developed and implemented.

The technical, economic and ecological conditions for the optimization of electricity generation in Russia are a good basis to reduce the use of nuclear energy and to use more the potential of wind energy and renewable energies.

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5.5 Microalgae as Source of Energy: Current Situation and Perspectives of Use

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Abstract

The report is devoted to alternative crude for bioenergy—microalgae as source of biofuels (methane, biohydrogen, biodiesel and liquid hydrocarbons). There were considered advantage of microalgae as biofuels-2 generation, its high productivity and energy content bring up these organisms to extensive research activities focus. As demonstrated here, oil productivity of many microalgae greatly exceeds the oil productivity of the best producing oil crops, so replacement of plants by microalgae will allow to reduce cropland aimed for energy plantations by a factor of 50–100, at that there will be possible to use land resources, unsuitable for plant cultivation. An important avenue of works is seen in conducting further studies and developments obtaining commercial strains of lipid producing microalgae, including those tolerant to low cultivation temperatures, as well as studies on using heterotrophic strains of microalgae taking into account the great experience that has been gained in the microbiological industry of Russia.

Keywords:

Bioenergy, Biotechnology, Biofuels, Biodiesel, Carbohydrates, Lipids, Microalgae biomass, Photosynthesis

1 Introduction

Until recently, production of liquid fuel around the world has been limited mainly by production of bioethanol and biodiesel fuel, for which grain and oil cultures were used as raw material. This gave rise to a contradictory attitude to biopower engineering as a large-scale consumer of food resources and stimulated development of technologies for obtaining biofuel from nonfood raw material, primarily from the lignocellulose contained in waste wood, agricultural wastes, etc. However, according to the data of the U.N.O.'s Food and Agriculture Organization, the increase in the price for food was largely due to other factors: a low level of crops in countries exporting agricultural products, growing demand for food in rapidly developing countries of Southeast Asia, and a growth of prices for energy carriers. An analysis of the ratio of prices for petroleum shows that there is no relation between the production of biofuel and the growth of prices for food products. In 2008–2009, the prices for grain dropped in step with the prices for petroleum despite the rapidly increasing production of biofuel around the world [1].

2 First, Second and Third-Generation Biofuels

At present, the term "biofuel" is understood to mean fuel produced from any kind of biomass (organic substances of vegetable and animal origins) that can be converted into thermal energy. The existing classifications of biofuel are based on the type of used raw material. Thus, first-generation biofuel encompasses biofuel produced from food raw materials, and second-generation biofuel includes biofuel obtained from various wastes (like wastes from food, wood and wood working industries, and agriculture). In our opinion, it is advisable to introduce the term third-generation biofuel produced from the biomass of microalgae, because microalgae are cultivated especially for power-generating purposes and are not a traditional food and feed raw material. At the same time, the biomass of microalgae does not fall under the category of wastes, i.e., the category of second-generation biofuel. In addition, biomass of microalgae contains many valuable accompanying substances, the cost of which is frequently higher than the target power-generating product, due to which the produced biofuel becomes cheaper.

A more detailed analysis and classification of methods for producing energy from biomass, as well as technologies for processing it, are given in [2–4].

3 Importance of Algal Biomass for Fuels

Biofuels made from algal biomass are being considered as the most suitable alternative energy in current global and economical scenario. Such interest in algae stems from the fact that their biomass has many attractive properties and meets the majority of requirements imposed on vegetable raw materials for power generating purposes. Below, these advantages are considered.

- Algae are photoautotrophs; that is, they need sunlight, CO_2, and water with a small quantity of mineral salts for their growth.
- Similar to other biomass resources algal biofuel is also a carbon neutral energy source. Withdrawal of the cultivated microalgae biomass for power generating purposes does not upset the natural conservation of organic substances in the biosphere. In addition, plantations of microalgae serve as an efficient short term sink for manmade CO_2, converting it into high density energy.
- The second biological mitigation strategy still being given some attention is the possibility of stimulating oceanic primary production by the addition of iron. The LONAFEX (LONA is Hindi for iron, F stands for Fertilization EXperiment) an Indo-German iron fertilization experiment in the Southwest Atlantic Sector of the Southern Ocean conducted for rapid growth of the minute, unicellular algae that not only provide the food, sustaining all oceanic life, but also play a key role in regulating concentration of the CO_2 in the atmosphere. The development of such algal bloom on its environment and the fate of carbon sinking out of it the deep ocean might play a crucial role in popularization of algal biofuels [5].

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- Algae require much less water than the traditional cereals; algae can be grown in salt water and in sewage water, which makes it possible to use smaller amounts of pure water.
- Microalgae do not belong to the category of traditional raw food and feed materials.
- By natural yield of bioproduct and content of energy, microalgae are several tens of times more efficient than traditional biomass as raw material for producing liquid biofuel. Many scientific technological centers around the world are constantly working on improving technologies for producing and reprocessing the biomass of microalgae, thus creating a basis for making a shift in the next few years from research and experimental design works to commercial production of liquid fuel from microalgae. One of the possible ways in which the cost of microalgae biofuel can be reduced consists of using them simultaneously to obtain valuable products for the chemical, pharmaceutical, medicine, food, and fodder industries (beta-carotene, astaxanthine, phycocyanine, chlorophyll, glycerin, etc.) and using for cultivating wastes from other production processes.
- With the technologies now available around the world, it becomes possible to cultivate the biomass of algae year- round on a large scale, not only under the conditions of tropical and subtropical climate, but also in zones with moderate climate, even at negative temperatures of outdoor air in winter [6].

4 Methods for Analysis of Algal Lipids

The research studies and engineering developments aimed at producing microalgae biofuel are focused on the culture of microalgae that should feature the ability to rapidly grow, and synthesize and accumulate considerable quantities of lipids in the form of triacylglycerides and liquid hydrocarbons. In this point of view, microalgae satisfying such requirements are being searched for in natural populations. It is very important to utilize species that have a suitable lipid profile for biodiesel production [7]. There are many analysis tools that can be adapted to evaluate algal cultures, algal lipids, or fatty acid methyl esters, and each tool provides a unique set of information. Two of the most common algal lipid analysis methods are solvent extraction for gravimetric lipid quantification and fluorescence microscopy using a lipid stain such as Nile Red of BODIPY. Chromatography [high-pressure liquid chromatography (HPLC)], gas chromatography coupled with mass spectrometry (GC–MS), thin layer chromatography (TLC), has been used to separate, identify, and in some cases quantify lipid extracts. Several forms of spectroscopy have also been applied to analyze algal lipids. Now liquid state NMR was included in this analysis toolbox [8].

Apart from active search for natural microalgae producing lipids, work is being carried out—by means of mutagenesis and using gene engineering methods—on creating new strains of microalgae featuring high output of biomass and target product, which is one of the main requirements of commercial production.

5 Areas of Research: "Biomass of Microalgae as a Source of Energy" in Renewable Energy Sources Laboratory, Moscow State University

For the past two decades, specialists of the Moscow State University's Renewable Energy Sources Laboratory have been conducting investigations for biomass of microalgae large-scale cultivation in open planar photocultivators both for power engineering purposes and for integrated use as fodder and food products.

To fix the effectiveness of CO_2-utilization during the cultivating of lipide's microalgae-producers in laboratory experiments, we have chosen following microalgae: *Arhtrospira* (*Spirulina*) *platensis*, *Dunaliella salina*, *Haematococcus pluvialis*. For that purposes we constructed and installed laboratory sterile bioreactor for microalgae's cultivating. It is showed that barbotage with gas mixture where concentration of CO_2 equal to 1.5 and 3.0% and with intensivity 0,7 vvm raised productivity and accumulation of lipides in biomass of mentioned above microalgues. While for *Arhtrospira* (*Spirulina*) *platensis* it strongly reduced threshold toxic effect from the heightened pH of medium over a long period of cultivating (2–3 points of pH reduction was reached). These findings allowed to make preliminary estimates of absorbing CO_2 during microalgae's cultivating, and also to make an analysis of power input's structure for it's cultivating. Control of parameters of gas–air mixture, which conducted the bubbling culture medium was carried out by using gas analyzer included in the experimental set-up. It allows provide measurement of CO_2 concentration in a continuous or discrete mode. The gas supply system maintains a constant environment for the entire period of the experiment.

6 LED Lighting Systems for the Cultivation of Microalgae

Achieving more efficient photosynthesis and optimizing the biosynthesis of lipids are the tasks pursued by many research programs. The intensity of photosynthesis is determined by the quanta with a wavelength of 400–700 nm. This spectral range is called Photosynthetically Active Radiation (PAR). But even in the range of photosynthetically active radiation microalgae are not equally perceive quanta with different spectrum. This is due to specific absorption of different pigment types; the most famous one is chlorophyll. Laboratory tests showed that the sensitivity curve (the algae to the photon flux) [9] has two peaks—450 and 650 nm (blue and red spectrum) and less efficient photosynthesis in the region around 550 nm (green spectrum). However, as a result of the studies there is an evidence of a regulatory role of green light. Thus, all quanta in PAR range are important in varying degrees, for the life of microalgae. So investigation of the optimum ratio of these quanta in the general stream of light for different types of algae is the subject to research.

Based on analyzes of the above characteristics of photosynthesis and experience in development of LED lighting, it is concluded that microalgae can be very efficient lightened by using modern LED lighting systems. LEDs emit up to 100% of light falling in the range of photosynthetically active radiation. Semiconductor light sources consume less power than traditional lamps (light emitting diodes have the efficiency to 200 lm/W and incandescent bulbs—20 lm/W

[10]). So these light sources do not heat the air as do the incandescent lamps or gas discharge lamps. LEDs retain body condition over longer period of time (about 100,000 h). The phase of short bursts is easy to implement and has no harmful effects on the longevity of the light sources. This phase required for the dark phase of photosynthesis.

This study describes the LED lighting system of algae, developed for research with various lighting options, as the spectral composition and intensity. The composition of the lighting system includes lamps with white, red and blue LEDs. White LEDs firm Edison Opto EDEW-3LS6-FR has a color temperature of 6000 K and the order of intensity up to 180 lumens. Red LEDs ARPL-3W RED and blue LXHL-PB09 Blue have radiation intensity of about 80 and 40 lm, respectively. Each cell of photobioreactor illuminate by two round lamps. Each lamp has 9 LEDs. Also each lamp has its own adjustment of light intensity from zero to maximum and the ability to switch to flash with adjustable frequency. LED lamps are located at the height of 70 cm above the surface of the cell. To collect the maximum light output within the area of the cell, the lamps used lenses 9B30DF Turlens with the viewing 30°angle. With help of Quantum Flux Apogee (MQ-200) the measurements of the surface of light cells have been carried out. As well recorded the following maximum values: white light—250 μE/(m^2 × c) or μmol/(m^2 × s), the red—270 μE/(m^2 × c) and the blue—180 μE/(m^2 × c). Narrowly focused spectra of red and blue can conduct research of the impact on the development of algal cells of different quanta.

7 Heterotrophic Algae

To avoid difficulties in cultivating microalgae on a commercial scale due to inadequate illuminance, researchers took the path of creating heterotrophic strains of algae from obligate photoautotrophs. After a gene responsible for transportation of glucose had been entered into *Phaeodactylym tricornitum* microalgae, this culture became able to utilize exogenous organic carbon and grow independently of light. This was the first successful trophic conversion of an obligate photoautotroph carried out using metabolic engineering; it has shown that the cell feeding method can be changed fundamentally by introducing one gene [11]. A method has been patented according to which diesel fuel is obtained using the Chlorella kessleri strain of heterotrophic *chlorella* that allows to obtaine output equal to 108 g/l of biomass and 52% of oil per dry mass [12]. Specialists of Solazyme (the United States) also work on obtaining genetically modified strains of algae with a heterotrophic type of feeding with the purpose of reducing the cost of producing biodiesel fuel from algae through reducing the infrastructure of production facilities and simplifying the work on harvesting the biomass of algae and separating oil from it. By cultivating such microalgae it becomes possible to remove problems of ensuring a certain level of illuminance and use the welldeveloped infrastructure of the microbiological industry; as it regards the necessary carbohydrates, sugars from cellulose can serve as sources of these substances [13].

It is our opinion that we have to mark out following basic technologies of getting biofuel of third generation from the products of microalgae's biosynthesis: (1) microalgae's biosynthesis of ethanol and hydrogen; (2) microalgae's biosynthesis of: (a) carbohydrates (with the following spiritual or acetone-buthyric fermentation up to bioethanol or biobutanol), (b) hydrocarbons (with the following hydrocracking up to kerosene, gasoline, diesel, mazut, etc.), (c) triglyceride (with getting biodiesel by transesterification and aircraft oil by hydroprocessing), etc. At the same time the microalgae's biomass itself or the wastes of its processing can be used for biofuel's production (methane, bio-oil, liquid biofuel) using the technologies of second generation.

In view of the back ground of scientific and research works that is available in Russia, an important avenue of works is seen in conducting further studies and developments on obtaining commercial strains of lipid producing microalgae.

8 Conclusion

Use of biomass for producing liquid biofuel is becoming a rapidly developing industry that requires innovations for accelerated commercialization. The amount of money that has been invested, the technologies that have been developed, and the production facilities that have been constructed are such that the so-called return point has been passed.

Further research and development are necessary to establish an economical industrial scale production of algal biofuels.

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5.6 Development of the Geographic Information System "Renewable Energy Sources in Russia"

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Abstract
In this report the state of development of the GIS "Renewable Energy Sources of Russia" is being analyzed. The architecture and the structure of GIS were prepared. Information on the resources of biomass, solar and wind energy in Russia was gathered and submitted in the form of a database. The part of GIS resources, solar and wind energy was developed, based on two approaches: use of the open mapping service "Yandex.Maps" presented at the developed site http://gis.vov.ru and the use of standard GIS packages. The initial version of the admin interface and user of GIS was created.

Keywords:
Geographic information system, Database, Renewable energy sources, Solar and wind energy

1 Introduction

Implementation of renewable energy projects (RE) in Russia in addition to solving technological and engineering problems raises the problem of assessing the possibility and efficiency of renewable energy for the regions. Obviously, on the one hand this requires a vast array of data on all aspects of renewable energy, which covers both the natural resources of the territory, and economic characteristics of the region. On the other hand it is necessary to attract such analysis tools that allow to collect, rapidly modernize and convert these data files, display them, through a comprehensive analysis based on them to get reasonable estimates and do the calculations. Due to the complexity of this problem, as well as the famous "regional" demand for renewable energy, it is possible and desirable to use the tools of geographic information technologies: creating geographic information systems (GIS) with the appropriate thematic focus. In this case it is possible to successfully work with large sets of information, using GIS modularity, connecting together the industry information resources of municipalities, villages, regions and federal districts. The main steps of creation of the GIS "Renewable Energy Sources in Russia" are following:

- choice of the architecture of the GIS and development of its structure;
- choice of the DBMS;
- development of the formats of the information massifs;
- collection, analysis of data, filling in of the information geographically-associated data massifs;
- development of the visualization of the data and the user interface;
- development of the admin interface;
- development of the mathematical models of energy plants on RE;
- mathematical modeling, calculation of efficiency figures;
- processing and generalization of the results of the modeling.

2 Analysis of Foreign GIS in Renewable Energy

The analysis of thematically similar geographic information resources allows to differentiate the following types of GIS depending on their coverage area:

- local (eg, The Los Angeles Solar Portal);
- regional (eg, Atlas of Renewable Energy Vermont [2]);
- national (GIS NREL Energy [3]);
- global (3TIER Renewable Energy [4]; Solar & wind energy resource assessment (SWERA) [5]).

Renewable energy sources vary greatly from location to location in their cost-effectiveness, availability, and impact on the environment. The National Renewable Energy Laboratory (NREL) in USA updated wind resource maps using ArcGIS Desktop. The NREL staff created wind resource models that estimated the wind potential at 200 m for many areas in the United States. The maps produced showed the most favorable locations for wind farms based not only on quality and availability of wind resources but also on transmission costs and the layout of the electrical grid.

The Renewable Energy Atlas of Vermont makes extensive use of GIS to enable and encourage the use of renewable sources for commercial and private energy generation. Potential and existing sources for energy generation from wind, solar, hydro, geothermal, and biomass can be assessed by county or town, by a user-defined area, or using the current map extent displayed (www.vtenergyatlas.com).

The LA Solar Portal (lacounty.solarmap.org) is a Web site that lets the 10.5 million residents and business owners in Los Angeles, California, quickly and accurately estimate the potential energy generation for solar photovoltaic systems on individual buildings. Launched in 2009, this ambitious project mapped more than 3,000 square miles and incorporated the effects of shade from nearby trees, buildings, and mountains as well as using the pitch and slope of the roof to estimate the amount of incoming sunlight every 5 feet.

GIS-creating problem has particular complexity in the connect of recourses of small hydropower resource because of necessity in a broad spectrum of hydrologic data, rivers-bed and drainage area characteristics, as well design water yield data. In the absence of observational data it is

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necessary to choice well-founded analytical method of estimation. In the U.S., the assessment of small hydropower resource of the country on the basis of GIS technologies for the Department of Energy was carried out in IDAHO National Laboratory [6]. In the course of this work the GIS “Virtual Hydropower Prospector” (VHP) was employed on the basis of the software of the company ESRI. This GIS is a tool that allows users to evaluate the hydropower resources of streams in the U.S. in a certain area and to compare the options for the possible deployment of small hydropower plants.

International databases (DB) which were developed in the last two decades can be seen as the products that perform similar functions with GIS, however, provide only the information base for further analysis (a kind of “pre-GIS”), covering the territory of various sizes (NASA SSE [7], WRDC [8], SOLARGIS [9], METEONORM [10], etc.). They are either accessible via the Internet or are a commercial product. Being as a matter of fact databases of climate information, these databases offer the original arrays that allow for quantitative assessment (or quality characteristic) only for solar and wind energy, and modeling of appropriate facilities and systems. Several databases includes maps of the terrain and landscape types. As an information base for these data serve ground-based measurements and the results of satellite monitoring and modeling (models of the atmospheric general circulation and distribution of solar radiation in the atmosphere).

3 The Structure of the GIS

The aim of the geographic information system “RES Russia” defines its primary structure. The GIS "RES Russia" base is forming by:

- arrays of spatial information on the resources of renewable energy sources in the Russian regions;
- climatic data required for simulation and calculation;
- information on existing renewable energy power plants;
- additional datasets, thematically related to renewable energy and have a value for projects in the field of renewable energy (scientific, technical and educational organizations specializing in renewable energy, equipment manufacturers, design organizations; regional program and regional legislation in the field of renewable energy, etc.).

In addition to the above mentioned information and analysis unit the GIS will provide the user with the necessary data for computational and theoretical studies. In particular, it will include the original data, the results of dynamic simulation of power plants and renewable energy performance indicators of using in different climatic and geographical conditions. Visualization of information is proposed in the form of maps, tables, graphs, drawings and photographs.

As a basic digital terrain models in GIS "RES Russia" are used:

- for the Russian Federation—digital topographic map scale of 1:1000000;
- for the regions—a digital topographical map of scale 1:50000–1:200000.

4 Part of the GIS Resources of Solar and Wind Energy: Data Sources

On the base of standard GIS-program package MapInfo Professional the part of GIS resources of solar and wind energy was developed, which contains a topographic base and information on two topics: the resources of solar energy and wind energy. At this stage the geographic base contains the following layers: the boundaries of subjects and the federal districts of Russia, degree grid with the possibility of its completion.

To create a “Resources” section in the blocks, “Wind Energy” and “Solar Energy” GIS “RES” requires a fairly extensive and detailed data sets of meteorological and solar radiation parameters. As a source of background information climatic database (NASA SSE) and surface meteorological data and solar radiation observations were used. The option for the user to create a query and get a sample from the database in both digital and in chart form was developed. Modern data base (DB), derived from satellite observations and mathematical modeling, for example, the NASA Surface meteorology and Solar Energy database are widely used in renewable energy. Such arrays of information are increasingly being used, because they are based on parameters derived from long-term observations (for NASA SSE—this period 1983–2005 gg.). This data as a result of mathematical modeling, is an almost continuous field values (resolution: 1 ˚ ˚ x1 or less in latitude and longitude), and thus make it possible to overcome the problem of lack of meteorological stations and their distance from each other.

Weather station data are characterized by wide spacing and low altitude of wind speed measuring (in respect to modern wind farm), which do not allows to determine wind and solar energy characteristics with high accuracy. On the other hand they may be the base of detailed verification (error analysis) of the data massifs received with the help of mediated methods.

In connection with the use of wind and solar energy data based on the results of mathematical modeling and satellite observations (database NASA SSE), a detailed verification (error analysis) of this data was performed. Verification was conducted by comparing the array NASA SSE for the RF and of ground meteorological stations of Russia, and the comparative analysis was carried out in three directions: a comparison of large arrays covering a large territory of the Russian Federation, regional analysis, point analysis (for selected weather stations). Relative deviations (data NASA SSE—ground-based measurements) for the monthly sums of solar radiation and for the majority of its secured months and the Russian regions did not exceed 10–15%, which is quite acceptable for engineering calculations of the efficiency of solar installations. This error value enables to determine pitch isoline 0.5 kWh/(m^2 day) in the construction of maps of the distribution of incident solar radiation on the territory of Russia according to the NASA SSE.

Based on the analysis of all possible modern methods of wind speed measurements there was proposed a hierarchy of data on the completeness and adequacy of the resulting estimates of wind power capacity in Russia (Table 5.6.1)

Table 5.6.1 Hierarchy of data to calculate the wind power potential

The quality of the ratings list of data sources	List of data sources
The maximum total score of area windpotential	- Wind data monitoring for sites within the region - The weather stations data in the region (average long-term, and data for selected years) - NASA SSE data
Intermediate evaluation of data	- Data of meteorological stations in the region (available detail) - NASA SSE data
The most common assessment	- NASA SSE data or other global databases

5 The User Interface and the Administrator of GIS-Based Yandex.Maps

To select the tools when create a thematic GIS it is important to consider also the possibility of map servers, for example, Google Earth and Yandex.Maps. In addition to satellite data and the earth's surface constructed on the basis of their maps both services allow the user to place maps on one’s website and apply them to a variety of point and distributed in space objects, and create map layers that contain user-provided graphics. Thus such service provides with everything needed for the creation, maintenance and operation of the online version of GIS “Renewable Energy of Russia”.

User access to the system Yandex.Maps through web-based interface can be used with any web browser, which provides screening of the site including some mobile phones. So for the user the system is cross-platform. In accordance with the Service User Agreement “API Yandex.Maps” [11] the user of GIS, built on the basis of service, is provided with free public access to the system. The need to register is not considered as an access limit. Because the GIS is based on interactive maps implemented by means of JavaScript, the browser must be able to run Java-scripts, and this possibility should not be disabled by programs blocking inappropriate content.

The administrative interface of GIS consists of access control systems (registration) of the user, the service ftp-server to retrieve data and tools Yandex.Maps—Application Programming Interface (API) Yandex.Maps [12–14]. Yandex.Maps API allows to create on the basis of the user map information layers line maps. To do this tiles are prepared from the original graphic material, gridded layer are made, add the necessary controls are added.

Managing imaging facilities at the map can be performed using an external menu which allows you to add and hide groups of objects. Thus the available tools Yandex.Maps API allows you to display on the map and manage the process of graphic object visualization and can be the basis of GIS Renewable Energy of Russia online version. At present online version of GIS contains 17 maps of average daily total solar radiation incident on different orientation surfaces (for summer, hot and cold 6 months, year); four maps of average daily direct normal solar radiation (for summer, hot and cold 6 months, year); 2 maps of average annual wind speed; 4 maps of solar collector effectiveness characteristics (for summer and hot 6 months). The maps are presented at the developed site http://gis.vov.ru.

6 Conclusion

- Development of architecture and structure of geographic information system “Renewable Energy in Russia” was completed;
- There was developed a part of GIS resources of solar and wind energy, which contains a topographic base and information on two topics: the resources of solar energy and wind energy resources. This part of “Renewable Energy of Russia” was created with two approaches: the first—using open mapping service “Yandex.Maps”, the second—the use of standard GIS packages;
- Amounts of information on the resources of biomass, solar, wind and geothermal energy in Russia were prepared and submitted in the form of the database;
- Data hierarchy to calculate the wind power potential and its representation in GIS is based on the initial attempt of analysis of such a large amount of verification studies of errors in climate research databases for resources of solar and wind power;
- Developed and offered initial version of the admin and user interface of GIS “Renewable Energy of Russia”, including the website http://gis.vov.ru, which presents the results of cartographic processing data sets of the potentials of solar and wind power for the territory of RF.

7 Acknowledgments

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5.7 Resources, Energy Efficiency and Energy Development Ways of Karelia Region Energy

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Abstract

Republic of Karelia is a typical energy deficit region. The analysis of renewable energy sources of Karelia region is given. With help of software ENERGOM renewable energy sources estimation of have been received. As a result of studying of Karelian hydro resources the hydro-energetic cadastres for approximately 500 rivers were developed. Research of regional bioenergy resources has been executed. The rational variant for energy development Republic of Karelia is proposed.

Keywords:

Renewable resources, Energy efficiency, Carbon balance, Software ENERGOM, Computer model

1 Introduction

Republic of Karelia is a typical energy deficit region of Russia with only local and renewable sources of energy. In such a regions an increasing usage of renewable sources of energy corresponds to all highest priorities of Russian Power Engineering Strategy. In created and accepted by Karelia Republic Government «Strategy of the social and economic development of the Republic of Karelia» (2007), development of the regional power systems was mentioned as one of the major points.

Energy production systems grow out of a long-term technical development. Modification of these systems requires a lot of time. That's why it is important to plan the future Power-engineering system in the long-term power policy. Main objectives of Karelia power policy are:

- Increase of Karelia maintenance reliability with fuel and energy.
- Increase of the renewable energy sources usage efficiency in the economical and social fields.
- Substantial environmental improvement.

Oil and natural gas are the currency reserves of the country. Maintenance of the fuel–energy complex export potential demands first of all a rational usage of the natural gas in the country. A high deficiency in the fuel and energy balance of the Republic of Karelia is caused by following things: lack of the Republic's own deposits of traditional mineral fuel (oil, gas, coal), the priority development of energy—intensive industrial enterprises producing raw materials, slow putting into operation generating capacities on the basis of local energy sources. According to a new concept of Russia's energy policy, "the region should form it's own programs of economic development, combining possibilities of the local energy sources usage and economically justified participation in creating inter-regional fuel and energy complexes and energy carriers transportation systems on cooperative principle". Taking into consideration the prospects of the Shtockmanovsky natural gas deposit development, a long-term concept of the development of energy for Karelia's conditions should be orientated towards natural gas usage and maximum involvement of the local renewable energy sources into the fuel and energy balance. Partly therefore the long-term concept of Karelia energy development is defined as "rational usage of natural gas with economically, socially and ecologically well-founded involving of the local renewable energy sources into fuel and energy balance".

The Republic of Karelia is situated in the northwest part of Russia, far from the main fuel bases of the country. Karelia has a long boundary with Finland in the west. Republic receives more than 50% of the consumed electric energy from neighbouring regions (the Leningrad and Murmansk districts). Karelia has poor supplies of it's own traditional fuel and energy resources. That is why non-traditional energy, and wind energy in particular, can become one of the promising lines in the development of energy in Karelia.

In outlook for the future the Republic economy will be focused on requirements of the internal and external markets with a priority for profound wood processing products, nonmetallic building materials, iron ore semi-finished products, special fish and seafood. Preconditions for the fast development of agriculture and tourism infrastructure will be generated the same time. Development of the specified directions will require power support, which can be provided by the technologies of the renewable energy.

Republic of Karelia is in advantage with a geopolitical position on the border with Scandinavian countries. The economy of Karelia is focused on extraction and primary processing of wooden and mineral natural resources. Region of Karelia has focal type of industry positioning. Specific character of economy (presence of energy-consuming industries) and a north climate have predetermined the raised consumption of fuel and energy in the region. With a predicted rise of prices for energy sources, the expenses on the fuel and energy arriving from other Russian regions will also grow. It will lead to decrease of goods competitiveness and regress of Karelia's economic situation.

There is also a row of problems connected with social-economic development. First of all it is a usage of the old equipment and technologies, low innovation level, growing wood-industrial sources deficit, high level of unemployment in the northern areas of Karelia.

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2 Contemporary State of Energetics

Karelia's fuel-energy complex includes hydropower plants (with total power 632, 8 MW), heat power plants (478 MW total), and big amount of the boiler plants. All the heat power plants use imported fuel.

In the structure of the fuel-energy resources consumption there were essential changes connected with coal and black oil replacement with natural gas and biofuel. During last 8 years there was some increase of used fuel-energy resources. The volume of fuel-energy resources consumption in Karelia is not so high. Fuel-energy resources expense in housing and communal services on the person makes nearby 1.2 tons of coal equivalent (t.c.e.) per person. The Republic of Karelia is at the level of Germany on fuel-energy resources expense per capita—approximately 6.7 t.c.e./person in a year (2000). By 2008 this expense has increased to 7.1 t.c.e./person in a year, it is caused by decrease in a population to 670,000 persons.

One of the major indicators of power efficiency is fuel-energy resources expense on 1000$ of Gross Regional Product (GRP) production. The comparative characteristic of the regions of North-West Federal District of Russian Federation under the charge fuel and energy resources is given. For Karelia it is 1.3 t.c.e./1000$ GRP (2000) and 1.5 t.c.e./1000$ GRP (2008). This value is much bigger than average value in North-West Federal District and 4 times bigger, than in the USA. Certainly, it is partly caused by presence of power-consuming industries and a frigid climate.

For an estimation of a perspective current consumption at level of 2020 the approach within the model [1] is used. Particularly, in one of scenarios development of the Pudozhsky mega-project focused on extraction of ores of nonferrous metals is supposed. By 2020 only electric power requirement for this project is estimated by 2020 in 4 TW h.

Substantially volume of local and renewable energy sources usage will depend on predicted volumes of fuel and energy consumption in Republic. Conformability of forecasts and an actual current consumption for 1993–2009 are shown on Fig. 5.7.1.

The real current consumption mostly corresponds to the moderate development scenario. By 2020 the current consumption in Karelia can reach 16.7 TW h. The current consumption gain in comparison with 1990 will make 90 %.

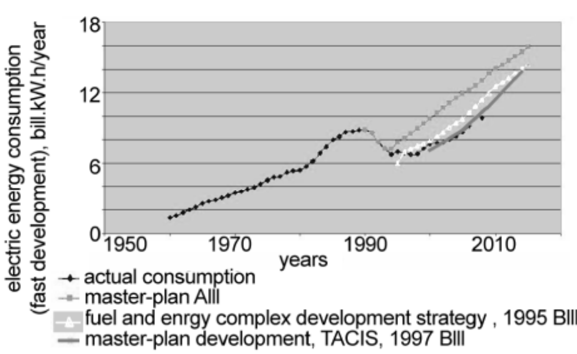


Fig. 5.7.1 Comparison of the forecast electricity consumption with actual

3 Renewable Energy Resources

In Karelia the further development of hydroenergy, windenergy and bioenergy is the most perspective. Which resources has the Republic for this purpose? For renewable resources estimation the special software (ENERGOM) was used.

The analyses of energy potential of hydro, wind and bio resources of Karelia region is given. With the help of the ENERGOM software the renewable energy sources estimation was received. The study of spatial-time distribution of renewable energy sources demands regular and prolonged observations. We replenished, systematized and treated the observations on the basis of contemporary informational know-how, including the databases of wind energy resources and software for observations treatment. In accordance with these techniques two groups of databases, “Wind Energy Resources” and “Observations”, were developed.

New fundamental results are received at studying of hydro resources of Karelia. The main result is developing of hydro-energetic cadastres for approximately 500 rivers (Fig. 5.7.2). As a result of these researches estimations of hydro resources of the rivers of Karelia have been received. In a year only 2300–3300 GWh from this potential is used. Estimations of drain and hydro resources changes on prospect are received. The problem of positioning of hydro power plants ranges on a waterway taking into account ecological and social restrictions [4] is solved. The scheme of hydro power plants positioning in Karelia is developed.

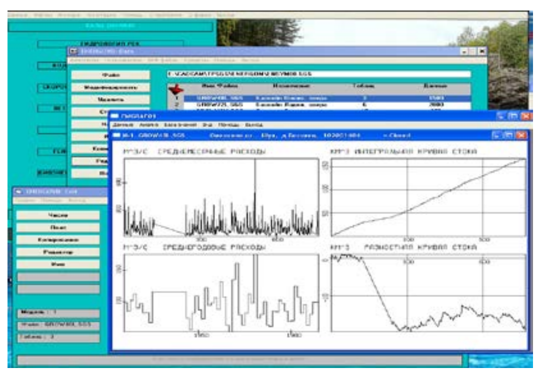


Fig. 5.7.2 Results of hydro energy investigations (Software ENERGOM)

The same system has been used also for wind energy research. New results in wind energy resources research of Karelia are received. In particular, on Fig. 5.7.3 the distribution of the wind maximum speeds for every day in a long-term period is shown. As a result of wind resources study the new results and estimations of economic potential of wind energy resources for Karelia are received. Economic potential of Karelia makes 0.7 million t.c.e. The real potential, that can be conversed by 2020, is estimated in 0.18–0.44 million t.c.e.

Fig. 5.7.3 Results of wind energy investigations (Software ENERGOM)

The bioenergy resources are investigated and the estimations of biomass usage for energy production in Republic were executed. Total renewable energy sources potential is estimated approximately in 6.3 million t.c.e (Fig. 5.7.4). Some additional results are shown in paper [2].

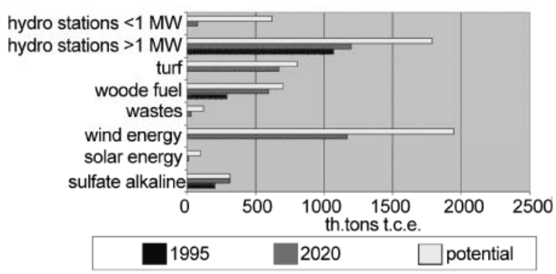


Fig. 5.7.4 The estimations of renewable energy resources of the Republic of Karelia

4 Carbon Balance of Republic of Karelia

The carbon balance of the region has got great value for ecologically well-founded energy development of the Republic of Karelia [3]. The estimation of carbon fluxes (the basic anthropogenic source of greenhouse gases) allows defining the contribution of various facilities to carbon balance of the certain territory, and also is a substantiation of wider renewable energy sources usage. The estimations of direct and indirect fluxes of carbon in territory of republic Karelia are given. Correlation of carbon fluxes with various sources of a power biomass formation is shown. Carrying out of actions on gathering and power use of allocated biogas allows influencing carbon balance considerably.

4.1 Fuel and Energy Complex of Karelia and its Contribution to the Carbon Balance

At the level of 1990 carbon emissions in atmosphere from fuel burning in thermal power station of Karelia have made—4 36 mln. tons in a year; and from burning only fossil fuel—3.5 mln. tons in a year. Besides the carbon received by burning fuel directly in the Republic, the compensation for electric power that comes to Karelia from other power systems is also considered. Estimations of indirect emissions are received in [3] and have made 0.15–1.67 mln. tons. Thus, emissions from the heat power plants of Karelia in 1990 have made 4510.1 ÷ 6026.9 th. tons of carbon.

4.2 Carbon Balance Estimation in a Forest Sector

In 1990 from Karelia's wood cutting areas there were exported 10.766 mln. m3 of wood. The quantity of carbon in the removed from cutting areas steam wood has made 2.605 mln. tons. There are 0.825 mln. tons of carbon that remains in logging waste. Losses at tree hauling are estimated at 0.156 mln. tons of carbon. Taking into account losses there are 0.981 mln. tons carbon left in logging wastes. The carbon content in the cutted down biomass makes 3.43 mln. tons of carbon. The volume of the carbon which has arrived in a wood complex for processing is estimated and has made 1.88 mln. tons of carbon or 7.766 mln. m3. This volume of carbon in a biomass goes into production, escapes to the atmosphere during combustion, escapes to the atmosphere during wastes aerobic decomposition, deposits at wood waste dumps, The value is defined on the basis of wood complex production volume in Karelia and equals 1.451 mln. tons of carbon. Carbon consumption for the power generation from the black liquor and wood wastes combustion equals 472.8 th. tons of carbon.

Wood complex final output contains in total 1450.8 th. tons of carbon. 762.0 th. tons of carbon are removed from the Republic. With a glance of timber wood this value equals 942.9 th. tons of carbon. It is also required to exclude carbon contained in timber and woodwork wastes, which are formed during production of goods to be exported from Karelia region. Carbon emission through wood complex output consumption and wastes fallen to the share of this output equals 1492 th. tons of carbon. On Fig. 5.7.5 the scheme of carbon fluxes in a forest sector is given.

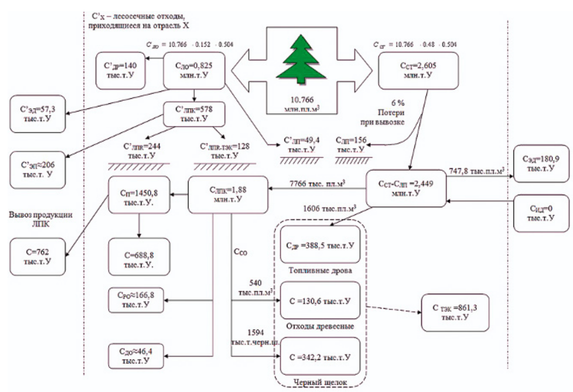


Fig. 5.7.5 Scheme of carbon flux in forest sector

4.3 Public Activity and Agriculture Contribution to Carbon Balance

The total annual volume of animal husbandry wastes in Karelia makes 876 th. tons. Main waste amount is concentrated in southern regions of Karelia. The greenhouses gas emission by stock-farms in these areas is defined: carbon emission—47.6 th. tons, methane emission—103.2 th. tons. Total equivalent carbon output equals 604 th. tons.

Carbon emission significant decrease in an animal husbandry is possible at the expense of collection and power utilization of biogas. In this case carbon emission can make 13 th. tons, and volume of power contained in evolved methane equals 1221.2 th. Gcal. This power will make possible to replace 174.5 t.c.e. in fuel and energy complex.

Carbon emission quantity as a result of public activity can be defined according to foodstuff volume consumption (fabricated in the region and imported from without). In 1990 it made 36.4 t.c.e. Total carbon stream from the animal husbandry wastes decompositions as well as from water-borne wastes made 640.4 t.c.e. in 1990. Biogas utilization will enable to decrease carbon stream quantity (as a CO2 equivalent) till 49.4 th. tons per year.

4.4 Estimation of Carbon Fluxes in Bog Biogeocenosis of Karelia

Peat resources in the borders of a commercial pool are estimated at 13.7 billions m3 or 2 billion tons. Marshes produce 170 mln. m3 of biogas annually. Quantity of methane and carbon emission is estimated at 132.6 th. tons per year and 61.2 th. tons per year appropriately. Carbon equivalent output equals 776.1 th. tons. Carbon fixation in the bogs biogeocenosis will make 1.08 mln. tons per year. Carbon balance in the bogs biogeocenosis is estimated at 303.9 th. tons of carbon per year.

4.5 Carbon Exchange (Transmission) in the Forest and Bogs Biogeocenosis of Karelia

Total atmosphere carbon absorption by forest ecosystems estimated 15541.1 th. tons in 1990. From them in a pure gain of forest stands it is fixed 4190 th. tons of carbon. 11351 th. tons of carbon came with tree wastes to forest floor. In addition 981 th. tons of carbon, contained in wood wastes and losses, came to the forest floor. Around 12332 th. tons of carbon left forest floor. This amount equals to it average annual income during past 15 years [3].

In the natural forests 10% of the quitting forest floor carbon transforms as an organic substance to the humus and soil turf. Left 90% escapes to the atmosphere in the form of CO2. However natural state of Karelia's forests is disturbed by cutting and forest hydroreclamation. In accordance with it real carbon transformation to ground equals 1148 th. tons, emission to the atmosphere—11184 th. tons.

Carbon emission to the atmosphere by forest ground amounted 1140 th. tons. As a result of drained area growth the value rises to 1159 th. tons. Total carbon emission to the atmosphere by forest ecosystems made 12343 th. tons. Though this value should be reduced by size 981 th. tons, that is already taken into account in the forest complex balance, as being extracted during wood wastes and losses decomposition.

Total carbon balance in the forest ecosystems of Karelia at 01.01.1991 equals 15541 – 12343 + 981 = 4179 th. tons. Carbon balance in the bogs biogeocenosis is estimated at 304 th. tons.

4.6 Summary Carbon Balance in the Region of Karelia

Carbon emission into the atmosphere by fuel and energy complex made 4510.1 ÷ 6026.9 th. tons in 1990.

1492 th. tons were added by forest complex (without registering carbon contained in wood and wastes, used as fuel). Equivalent carbon emission quantity by animal husbandry wastes and water-borne makes 640.4 th. tons.

Total anthropogenic carbon emission made 6642.5 ÷ 8159.3 th. tons. Carbon fixation in the bogs biogeocenosis made 4179 + 304 = 4483 . Summarized carbon balance:

4483 - (6642.5 ÷ 8159.3)= (-2159.5) ÷ (-3676.3) th. tons.

Energy sector development should follow the way, in which certain carbon emission limiting value won't be exceeded. Thereby some compromise option of Power engineering development should be found. It should be relatively cheap from one side and ecologically acceptable from another.

5 Large Wind Power Station

For large-scale wind power engineering development in Karelia coastal areas of the White sea, the Onega and Ladoga lakes are optimum. Besides, the Karelian coast of the White sea possesses moderate and uniform winds, without strong and heavy impulses within a year. These are the areas authors offer to build large Wind power plant.

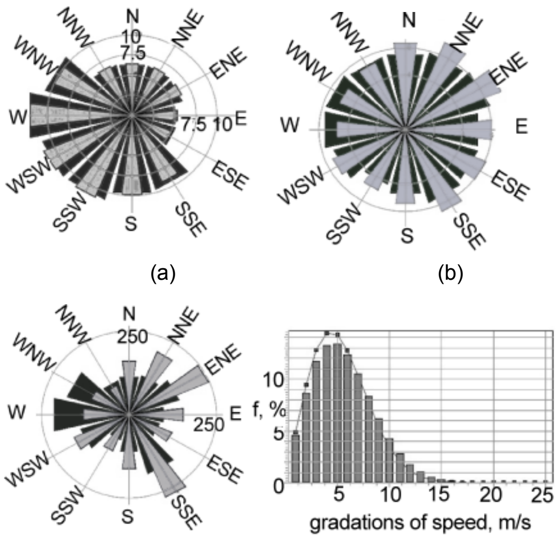
There was considered step-by-step wind power development with large wind power plants construction in the area of White Sea seashore, notably near city Kem. Wind resources of this district are examined rather good at the aspect of climate and wind power conditions [5]. The wind directions that contain largest power are determined. These are south-southeast and east-southeast directions. Thus east-southeast occupies one of last positions on frequency number. That's why it is more reasonable to array wind power station perpendicularly to the south-southeast—west—northwest direction.

As a platform of possible construction field the suburb of Kem, Puh Navolok cape, an island Popov and Goreliha Mountain have been considered. There are power lines 110 and 330 kV in close proximity to the city of Kem. Area of Kem obtains enough territory for placing wind power station. In addition power line presence close to the city makes it easier to connect future power station to regional network. As a part of Kemskaya power station it is supposed to establish MW wind turbines. Such decision was accepted on the basis of comparison of turbines with various capacities.

All the calculations were made taking into account cold climate of the region. By this time world practice of wind power engineering development has stored sufficient experience of building of stations in regions with a frigid climate. Similar complexes are established in the countries of Europe, North America, Russia and China. By the end of 2008 the total established capacity of stations in which wind turbines work at temperatures below the temperatures corresponding to a normal operating mode of installation, has reached practically 3000 MW. It has allowed to generate standard requirements to wind turbines, placed in areas with a cold or polar climate.

At the estimation of economic efficiency of wind power station project in the areas with cold climate to which Kem concerns as well there have been considered the losses of energy connected with an ice formation on blades and negative temperatures of air.

Around Kem the risk of rime on wind turbine elements makes 32 days in a year [5].



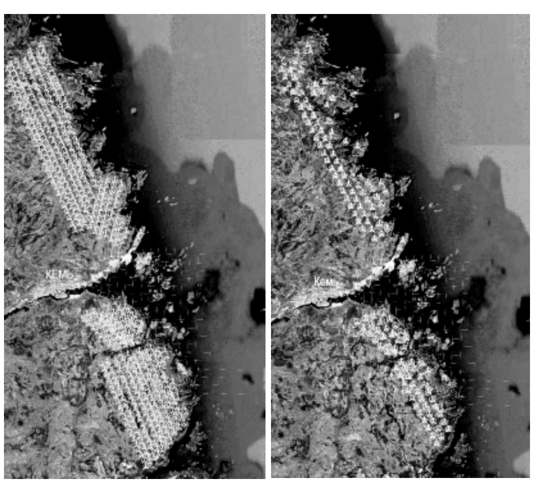
(a) (b)

(c) (d)

Fig. 5.7.6 Results of investigation wind velocity structure in place Kem. **a** prevailing direction of wind; **b** directions appropriate to the greatest speeds of wind; **c** directions greatest on a wind energy; **d** distribution of speeds of wind on gradation

Wind turbines and area selection for the 1000 MW wind power plant

At the analysis and choice of wind turbines there were considered following wind turbines: Enercon E 82 and Enercon E 126. Areas that shown the biggest level of electric output are shown at the Fig. 5.7.7.



(a) (b)

Fig. 5.7.7 **a** Positioning scheme of Enercon E 82 wind turbines. **b** Positioning scheme of Enercon E 126 wind turbines

Results of WPP electricity production and capacity factor calculation are given in the Table 5.7.1.

Table 5.7.1

Value	Enercon E82	Enercon E126
Electricity production, TWh	2.44	1.83
Hours of plant's installed capacity utilization, h	2710	2037
Capacity factor, %	27.8	20.9

Wind power plant (WPP) with Enercon E126 wind turbines occupies 2.5 times smaller area than WPP that includes Enercon E82 wind turbines. These are additional expenses on roads, foundations, electrical part, land rent. At the same time wind turbines Enercon E82 show higher output and capacity factor. Moreover generating cost in the case of Enercon E82 and Enercon E126 turbines make respectively 7.7 c€/kW h and 8.7 c€/ kW h (for effective rate r = 12%). Therefore the basic variant is considered to be the WPP including wind turbines Enercon E82 as an optimum for this region.

6 Rational Variant of Energy Development for Republic of Karelia

Thus, wind energy sector development in Karelia is proved and expediently. To search a rational way of development it is important to take into account changes in carbon balance of region. The estimation of Karelia's carbon balance is received. One of the rational ways of Karelia's development in view of resource, economic and ecological aspects (carbon balance) and restrictions is found.

In this variant further development of the large-scale and small hydro energetics and wind energetics are supposed. The balance is covered by input of heat power plant on natural gas with total power 500–1000 MW in Medvejegorsk. Also it is necessary to build heat power plant on natural gas with total power 180 MW in Petrozavodsk and power plants on biomass.

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Chapter 6:

Green Supply Chain and Transportation

6.1 Supply Chain Constraints in Practising Material Efficiency Strategies: Evidence from UK Companies

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Abstract

Manufacturers could play a major role in influencing decisions upstream and downstream in their material supply chain, which includes influencing suppliers and customers to reduce materials and waste. Manufacturers could influence both suppliers' and customers' practices through their own eco-design and sustainable manufacturing strategies. This paper presents the supplier and supply chain constraints experienced by several manufacturers in the UK. This investigation uses semi-structured interviews in 9 manufacturers and 1 retailer, analysed using thematic analysis with the assistance of qualitative software, nVivo. It is found from this study that the supplier and supply chain practices are among the top constraints experienced by UK companies. This exploratory study provides insight into one of the main challenges in implementing Material Efficiency element of a sustainable manufacturing strategy.

Keywords:

Material efficiency, Sustainable manufacturing, Supply chain

1 Introduction

Natural resources such as materials are not available in abundance, and therefore efficient use of such materials is a method to reduce decline in resources for future generations. Sustainable manufacturing is, without a doubt, an unavoidable aspect for manufacturers at present and in the near future. There are many external and internal pressures which drive companies to subscribe to sustainable manufacturing strategies.

There are many techniques and concepts proposed to support movement towards sustainable development (see [1]) and specifically towards sustainable manufacturing (such as local manufacturing, low carbon manufacturing, low temperature processing, etc). Although there are numerous pressures and drivers for companies to adopt sustainable manufacturing strategies, there are also many constraints and difficulties experienced by companies. According to Simpson et al. [2], much research has been devoted on the external pressures which caused companies to embrace environmental responsibilities. However, the amount of research which explored the implications of the nature of the customer-supplier relationships on the uptake and effectiveness of these environmentally-relevant supply requirements was small [2].

2 Supply Chain Barriers of Material Efficiency

Material Efficiency is one of strategies which is important for manufacturers to practise sustainable manufacturing. The efficient use of materials is not limited within the company itself, but involves the material supply chain upstream and downstream. This forms a question of how the suppliers and supply chain support the companies which have the intention to employ tactics and strategies to achieve Material Efficiency. In order for manufacturers to practise Material Efficiency and sustainable manufacturing, the company requires support from suppliers. Supply chain is a crucial element to ensure that the company could work towards attaining sustainable manufacturing. Abdul Rashid et al. [3], Abdul Rashid and Evans [4], and Abdul Rashid [5] debated that Material Efficiency strategy is an important element of Sustainable Manufacturing strategy. Material Efficiency in industrial production is defined by Peck and Chipman [6] as the amount of a particular material needed to produce a particular product.

In this paper, the working definition of Material Efficiency is proposed by the authors as manufacturing practices which are actively coordinated and implemented with the aim to:

- Use less materials per product made, and/or;
- Generate less waste per product, and/or;
- Use less energy to make each product, and/or;
- Select materials which reduce impact on the environment (e.g. less toxic, recoverable, recyclable, and disposable).

There are many barriers related to the implementation of environmental strategies, as discussed by Post and Altman [7], Shi et al. [8], Walker et al. [9] and Murillo-Luna et al. [10]. However, with regards to the environmental practice constraints of suppliers and the supply chain, the authors found that the supplier's commitment and size of the company are among the barriers in implementing sustainable manufacturing and environmental strategies. Walker et al. [9] found that poor supplier commitment such as lack of information due to confidentiality concerns or fear of poor environmental performance practice and low level of trust is the barrier for organisations to implement green supply chain initiatives. In terms of company size, the SMEs would experience greater challenge to influence their suppliers to change in order to improve environmental practices [11].

In this paper, the investigation is limited to Material Efficiency strategies which emphasise primarily on material waste reduction and the efficient use of materials. In this investigation, the sustainable supply chain is not explored. Rather, this investigation is focused on the issues related to supplier and supply chain constraints experienced by UK companies in order to implement Material Efficiency strategies. This research is aimed towards theory building, and therefore qualitative methods are chosen for data collection, data analysis, validation, synthesis and theorising the findings. The supply chain constraints experienced by

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several companies in practising sustainable manufacturing, in particular, Material Efficiency strategies are presented in this paper.

3 Data Collection and Analysis Methods

Since this research is of an exploratory type, the study is driven by phenomenological inquiries and methodologies. This is a multiple-case study [12], which adopts grounded theory research commonly used in theory building. In this approach, it's the findings are grounded from data. The companies interviewed comprise of large and small international and national companies. A description of each company interviewed is listed in Table 6.1.1.

In this study, several qualitative methods are used to collect and analyse the data, namely, case studies, semi-structured interviews, thematic analysis and causal analysis. For data collection, semi-structured interviews are carried out primarily with the personnel responsible for the implementation of sustainable manufacturing strategies. The interviews are carried out from year 2007 to 2008, and involve 17 top personnel. Table 6.1.1 shows descriptions of the companies and interviewees. The interviews are aimed to discover constraints limited to supply chain and supplier issues experienced by companies in implementing sustainable manufacturing strategies, specifically Material Efficiency strategy.

The semi-structured interviews are specifically focused on the implementation of Material Efficiency in the companies. There are a number of questions asked regarding the barriers of implementing material efficiency and material waste reduction due to suppliers and supply chain constraints. The interviews are recorded and transcribed prior to uploading into a qualitative software, nVivo version 8. The software facilitates researchers with the coding. Coding is the first step in thematic analysis technique. According to Collis and Hussey [13], codes are labels which enable qualitative data to be separated, compiled and organised. Coding is carried out for within-cases analysis. The researchers also search for consistency in the interpretation of codes across the cases. Finally, the codes are reduced into higher themes using dendogram analysis. Through dendogram analysis, the final themes are finalised.

Table 6.1.1 Descriptions of companies and interviewees

Company 1	**Company 2**
A global provider of power systems and services. 2 operation managers and 2 value engineers	A manufacturer of safety equipment for aviation industry. 1 site manager
Company 3	**Company 4**
A European furniture company, which has produced universal shelving systems for European and American markets. 1 managing director, 1 head of sustainability and 1 design engineer	A global IT company, which sells office equipment technology. 1 environmental engineer, 1 operation manager of company's recycling facility
Company 5	**Company 6**
An automobile manufacturer with a global market 1 European environmental engineer	A designer and manufacturer of industrial engines. 1 environmental manager and 1 personal assistant to environmental manager
Company 7	**Company 8**
Manufactures and supplies CNC machines, Machine Centres and Manufacturing Systems for global market. 1 health and safety engineer (ISO-coordinator), 1 production manager and 1 quality and technical support manager	A UK corrugated manufacturer. 1 safety, health, environment and quality manager
Company 9	**Company 10**
One of the largest producers of polythene film products in Europe. 1 operations director	The UK-leading home and general merchandise retailer. 1 group sustainability manager 1 packaging development engineer

A number of methods are employed to ensure the quality of research results. Transcriptions of interviews are stored in soft and hard copies for records, peer review is carried out and a qualitative software nVivo 8 is utilized to facilitate the coding processes and data management during thematic analysis. Synthesis of data is enhanced by examination of secondary documents and through field observations during company visits. The research findings are validated using high-quality secondary data from House of Lords inquiry evidence [14]. The data from House of Lords are not in report form; rather, they are raw versions of interviews and memoranda in 499 pages. Hence, nVivo software is required for thematic analysis. Both themes grounded from companies' practices and House of Lords' interviews are compared, resulting in additions and rejections of themes.

After validation analysis, the authors perform synthesis and theorising stages. This is when the Causal analysis is carried out to interpret and model the findings into causal relationships. A Causal model is a network of variables with causal connections among them, drawn from multiple-case analyses. Causal modelling can take many forms; however, the essence of causal modelling is the focus on cause-effect relationships [15]. This is an early stage of theory building and is one of the methods towards theory building [16].

4 Findings

In this paper, the authors present findings on the constraints experienced by manufacturers and 1 retailer. It is found that there are four (4) significant constraints which can affect the implementation of Material Efficiency strategies. The evidence obtained from the companies' practices is supported by pieces of evidence found in secondary data. Table 6.1.2 shows the quotes extracted from the interviews, which support the findings.

In this study, "constraints" are the difficulties or barriers faced by companies prior to and during the implementation of Material Efficiency strategies. The significant constraints experienced by the participating companies are listed as follows:

1. Uncooperative supplier
2. Supply specifications
3. Company size
4. Supply chain constraint

4.1 Constraints

Uncooperative Supplier

Reducing waste and materials is not limited to activities within manufacturing facilities in companies, but involves suppliers and customers. Involving suppliers upstream is important in order to ensure that the incoming materials are not wasted. The Four (4) companies interviewed reported that they encountered problems with uncooperative suppliers and experienced constraints in the supply chain. Uncooperative suppliers are suppliers who refuse to listen or refuse to entertain requests from the company in terms of supplying the amounts of materials as needed and over-pack the materials and products.

Supply Specifications

From the study, it is found that the companies encountered several problems with supply, pertaining to virgin or secondary materials. The problem with virgin materials is highlighted as difficulties to acquire supplies as specified. For example, to use the materials efficiently, the company wants the approximate size of materials; however, this sometimes is not possible.

Although secondary or recycled materials promote Material Efficiency and sustainable strategy, secondary materials exhibit several constraints. The evidence gathered from the investigation show that the manufacturers suffer from secondary material supply fluctuations, which can comprise product quality. There are many factors which could contribute to this shortage such as quantity of demanded specified grade of material, inconsistent supply from recyclers which could cause the material fluctuations.

Company Size

Small companies may experience problems in a long supply chain. Company 9 provides evidence that they faced difficulties influencing suppliers due to the type of products produced and due to the size of the company, which is small, which made them less significant in the long supply chain. Smaller companies also experience difficulties in getting material and processes specifications fulfilled by suppliers.

Supply Chain Constraint

Supply chain constraint pertains to overseas suppliers involving contractual issues such as overseas suppliers which do not comply by the same regulations, companies which do not possess control over packaging, and inability to control sourcing. Logistic issue is also involved such as difficulties to return defect goods and communications.

4.2 Causal Model

The findings show that the companies experiencing difficulties in implementing Material Efficiency strategies in the context of supply and supply chain are mainly due to uncooperative supply and difficulties in obtaining material supply in desired specifications. Figure 6.1.1 shows the causal relationship of factors which constraints the implementation of Material Efficiency strategy in UK companies.

Fig. 6.1.1 Causal model for supply chain constraints

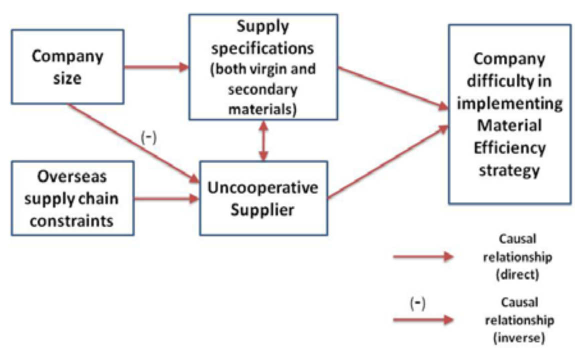

Table 6.1.2 Primary and secondary evidence for findings

Constraints	Primary evidence	Secondary evidence [14]
Uncooperative supplier	… £800 is an awful a lot of money but for that to work for us to have a strapping bench here, to be able to strap them, we have to get the supplier to supply them to the same way. So they had to have the strapping bench so… I can't remember how many phone calls and time I had spent on the phone to managing director of that supplier to persuade them to buy £800 strapping bench *"Ohhh can we do it this way"*…because they just don't want to spend £800 on the bench dedicated just to our business. (Company 3)	In other sectors where materials may be used in a very wide range of applications, the supply chains have been less closely linked and there has been less involvement by suppliers in innovations of the customer. (Memorandum by Chemistry Innovation Knowledge Transfer Network and the Chemical Industries Association)

Supply specifications	(for virgin materials); ….we were going to the mill and saying *"we want two and the sixteenth square bar two foot long just for our short quantities"* and they were laughing and putting us on the tail and back burner and saying *"we will deliver it to you in 4 months time"*. …. Well it was not worth their while to produce it, more important customers with much larger quantities material to produce so therefore they push our products until the back burner. (Company 2) (for secondary materials); Yes and of course in that respect we are somewhat hampered by a couple of things, one is consistency of material supplies. So for example it's not so easy for a manufacturing environment to manage a wildly fluctuating recycled content of a plastic material. It's OK if its fixed at 7%, 10% whatever it is and its stable at that then you can do high volume manufacture with that material you can set all your parameters on your die maker or your injection machine and yes we have a good condition. (Company 5)	(for secondary materials);…. the problem we have is that the materials available from the recycling stream are not in high enough quantities to make it viable for us to use. We are trying at this moment to clarify a stream of plastic that is useable. Obviously when we make a mould, that mould is designed for a specific plastic requirement and specific plastic properties—melt-flow index, and all that sort of thing. (Peter Evans, Senior Management Environment, Sony UK)
Size of company	I said it was a lot that has been said then about a decline of British manufacturing in the early 1990s recession. So, in response to an article in FT, and letters that followed from it, I wrote a letter following that letter in that article talking about the problems that we had getting suppliers to take us seriously in this country because we wanted decent quality and we are small and all of those things. (Company 3)	SMEs typically have little influence on the supply chain, up or down. They can rarely improve their market potential by being actively "green". (Supplementary memorandum by Dr Claire Barlow, Senior Lecturer, Institute for Manufacturing, University of Cambridge)
Supply chain constraint	So you get a box this size with 5 MP3 players, you open up a box and throw away the box, you get 5 MP3 players and plastic tote and was kind arghhh!. Why can't you just send a tote to China, pack directly into a tote, there is never any need for any secondary packaging. But in order to ship, because there is load of empty containers going back to China, in order to ship those back to China …they…import tax you has to pay is prohibited. It's make it very…very expensive. Even though you never imported product into China, you're actually renting it rather than importing it. (Company 10)	Question: ….There is a good deal of evidence we are getting about the complexity of supply chains and the EEF and your evidence referred to the international aspect of supply chains, some of them coming from countries where the standards dealing with these matters are perhaps less effective than they are here. What advice would you have about how you affect supply chains? How does an individual company hope to influence a complex and international supply chain? Answer: It is a very difficult situation because that supply chain can be very long and you could be a very small part of that. (Mr Gareth Stace, Head of Environment Affairs, EEF, the manufacturer's organization)

Uncooperative supplier can be attributed to several other factors such as overseas supply chain constraint, the size of company, and supply specifications (this includes deadline, order volume, and expected quality). Supply specifications can influence suppliers to become cooperative or uncooperative. This can also work the other way around, whereby uncooperative supplier tends to refuse meeting the specifications. Both virgin material supply and secondary materials supply could affect the materials' specifications. The problem with secondary materials is the quantity and quality fluctuations, which is a big problem to attain products with consistent quantity and quality. The size of the company can also influence the suppliers' behaviour. The company size has an inverse relationship with uncooperativeness of suppliers. The larger the company (which the authors assume bigger material orders) the less uncooperative the suppliers will be. For smaller companies, such companies may order small quantities of materials, which cause suppliers to become uncooperative.

5 Discussions

The supply chain and suppliers can constrain the companies' efforts to practise Material Efficiency strategies. Based on evidence, there are many difficulties faced by companies; among them are uncooperative suppliers and supply specifications. Uncooperative suppliers can cause real problems if they refuse to cooperate in supplying the materials as needed. Supply chain constraints such as overseas suppliers and company size also sometimes contribute to suppliers being uncooperative. Small companies complained that they are too small and insignificant in the long supply chain and that their requests are usually un-entertained. This problem becomes worse when dealing with overseas suppliers in which standards and practices are different. It is not difficult to request a supplier to comply with certain environmental standards within the UK, but this poses a problem overseas suppliers are involved, particularly in lengthy supply chains. The companies also sometimes have no control over packaging as packaging decisions are not included during purchasing. Large companies can usually impose greater pressure on suppliers to comply with their requests. Large companies are capable of managing environmental audits and tracking sources; however, this is not easy for small companies. What matters to suppliers is the profit, and hence, they are often unwilling to comply with small companies as the profit from them is small.

6 Conclusions

Sustainable manufacturing is important towards achieving sustainable development. Inefficient use of resources such as energy and materials could deter the progress to reduce environmental impact regardless how efficiently resources are recycled. Compared to energy, material is complicated as there are thousand types of materials, which would give different environmental impacts. This makes Material Efficiency strategy an important element in sustainable manufacturing. However, practicing these strategies could not be limited to one company to attain the desired effect. Upstream suppliers and downstream customers' practices and policies could affect the company's own practices' effectiveness. This study is aimed to investigate what companies experienced in terms of supply chain constraints. This study provides good insight on real experiences of manufacturers in the context of materials supply. A causal model is built from the grounded findings which could be used as theoretical framework for further studies.

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6.2 Improving Forecasts for a Higher Sustainability in Spare Parts Logistics

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Abstract

Timely, reliable supply of customers with spare parts is becoming a key factor for business success in many branches. Therefore many manufacturing companies try to optimize their spare parts logistics to satisfy the customer demands. Due to the large differences between the logistics for serial production and spare parts logistics during planning and operating, unique processes are necessary. The unpredictable demand of spare parts requires often the transport by air freight or courier services, thus increasing negative environmental impact additionally. The paper describes the main characteristics of spare parts logistics and the resulting disadvantages in terms of environmental sustainability. Furthermore a control loop for the demand forecast is presented.

Keywords:

Spare parts logistics, Spare parts management, Supply chain, Control loop

1 Introduction

The purpose of spare parts logistic is to combine the required type of spare parts with defective primary parts temporally and quantitatively aligned [1]. Thus the spare parts logistics is a part of the spare parts management. The spare parts management is becoming increasingly important for many manufacturers [2]. On the one hand exists the opportunity to keep contact to the customer even after the purchase of the primary product and to increase and achieve customer satisfaction [3]. On the other hand the spare part business is also very margin-strong and independent of economic situation [4–6].

The specification of spare parts logistics is challenging in many branches and different to those of the source and distribution process for series products [5, 7]. If a high priced machine, e.g. a printing machine or an airplane, is not applicable due to an unforeseeable defect, every hour can cost several thousand Euros. The operator has to provide the required spare parts as quickly as possible. Thus costs of transportation are only secondary and their share in regard to the product costs is quite high in spare parts logistics. The demanded and required high availability of spare parts in industrial practice often leads to high inventories at the manufacturer of the primary product [2, 7]. For example, in the aviation industry the value of spare parts in inventory is more than 40 billion dollars [8].

Also for foreseeable requirements of spare parts e.g. due to overhaul and scheduled repair the requirements of spare parts logistics differs from those of series production. It is necessary to pack small numbers of items in order to deliver direct to the customers. This has also effects on the environmental sustainability of the processes. As the sustainable design of logistics networks is becoming more and more important due to pressure from customers and legislation, the sustainability of spare parts logistics has to be improved [9, 10]. Therefore the source and distribution process of spare parts logistics are examined in this paper. Based on this analysis the main deficits are identified and a control loop is derived to establish better forecasts and thus to reduce the environmental impact of spare parts logistics.

2 Analysis of the Spare Parts Logistics

To analyse the processes of spare parts logistics the supply chain operations reference models (SCOR) of the supply chain council version 10.0 is used. It was developed to describe all processes which are conducted in order to satisfy the wishes of customers [11]. It is used to link process elements, metrics and best practices and is based on four levels [12].

2.1 SCOR Model

At the top level the process types are defined. These are plan, source, make, deliver and return. According to the selection of the scope and content the performance targets are set. The second level is the configuration level, where the company's supply chain can be configured according to the requirements. In the third level the process elements are selected. Furthermore the information inputs and outputs, the performance metrics and system capabilities are chosen. The fourth level describes the implementation and is not in scope of the model [12, 13].

The performance of a business process is measured by performance attributes, which contains several metrics. The performance attributes are reliability, responsiveness, agility, costs and asset management efficiency. The metrics have also a hierarchical structure. E.g. for the first level the perfect order fulfilment is the metric to evaluate the process. This metric can be divided in the second level in documentation accuracy, perfect condition, percentage of orders delivered in full and delivery performance to customer commit date. In the third level these metrics are detailed, e.g. the percentage of orders delivered in full may be divided into delivery item accuracy and delivery quantity accuracy [12].

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2.2 Model for the Source Process

The source process according to the SCOR 10 model consists of five process steps as shown in Fig. 6.2.1. These steps are valid for the process of spare parts logistics and can be specified on the underlying layer.

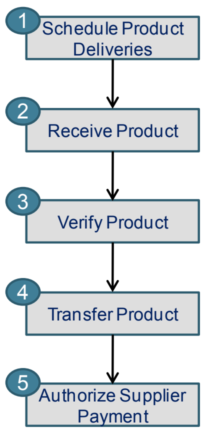

Fig. 6.2.1 Source process [12]

In the first step product deliveries are scheduled. Whereas the logistics for serial production can schedule the material acquisition in long term, the spare parts logistics has often to act on short term notice. The deliveries for serial production are based on detailed sourcing plans which are continuously updated and rely on existing contracts where the supplier has a fix and dependable base for planning. In contrast for spare parts logistics a long-term dependable planning base does not exist in general. Scheduling is done on a short term basis and often cannot rely on existing contracts which provide delivery times and prices [7].

The second step of the source process includes activities for receiving products. In the standard process the delivery is not at the point of use but at the incoming goods department of the enterprise. In serial production potentials can be used due to larger lot sizes. Transports of different products from one supplier can be put together and basic approaches for optimization like vendor managed inventory can be carried out. Due to the considerable smaller lot sizes and higher product variance in spare parts logistics many approaches for optimization cannot be taken.

In the third step the control of the delivered products takes place in form of a receiving inspection if applicable. It is examined whether the delivered product is the one desired and whether it is in the right quality, the right quantity, at the right place, at the right time and for the right costs. For series products several best practices can be identified due to the frequency and continuity of this kind of production. For spare parts the receiving inspection constitutes a special challenge because the processes are less standardized. Furthermore the number of different parts is in the spare parts business very high, due to the variety of primary products in conjunction with a long supply period.

Following the inspection of received goods the transfer of the products to either an interim storage or to the production follows. Additional sub-processes can be repackaging in other carriers or installing of additional identifications like a barcode or a RFID tag. The source process ends with the payment instruction. This process constitutes the interface to accounting and controlling.

2.3 Model for the Delivery Process

The delivery process can be split in 15 steps according to the SCOR model as shown in Fig. 6.2.2. The first step is process inquiry and quote. Thereby a general customer request is received and a price is quoted.

Fig. 6.2.2 Delivery process [12]

The second, third and fourth steps are the internal procedures of the customer order handling process. They do not influence the ecological impact of logistics hence they will not be considered in detail.

A fundamental difference between spare parts logistics and logistics for serial production emerges in the fifth step. While the shipping of the primary products can be planned long term due to fixed delivery dates and a determined processing time, it is necessary to react fast in spare parts logistics. The distribution networks are often structured in several steps thus at least fixed routine transfers to the distribution centres can be scheduled [14]. For markets with a high penetration further transfers e.g. to maintenance stations are scheduled. But if spare parts are needed in less penetrated markets without a distribution centre or in case a spare part is only available in stock in a faraway storage, it is necessary to deviate from planed routines and the parts must be delivered individually. These routines and the transport mode are determined in the sixth step depending on requirements of cost and time. In the seventh step carriers or couriers are selected, who conduct the delivery.

The eighth step is the interface to the production or to the procurement, depending on the chosen supply strategy [15]. The received goods are collected, assigned to a storage location and stored. If necessary, a quality inspection is conducted. The supply of the products takes place in the ninth step of the reference process. In the spare parts logistics required parts are picked according to the order, commissioned and brought to the packing area. In the tenth step, the commissioned products are packaged. Due to the high variety of spare parts already in one enterprise the packaging process needs a high flexibility. E.g. in the automobile industry a spare part may be a small sealing ring or a huge gear drive, which can just be handled with support of a crane.

The eleventh step includes loading and the generation of shipping documents, followed by the physical transportation of the product, the receipt and the installation on the customer's site. The process is completed with step fifteen the creation and sending of the invoice.

2.4 Summarization of Requirements of Spare Parts Logistics

From the detailed description of the processes in spare parts logistics the following key differentiating features can be extracted:

Low planning security: Due to often short-term needs, long-term forecasts based purely on historical consumption data, are afflicted with high uncertainty [15].

Customer demand for fast delivery: Particularly high-loaded facilities or linked production lines downtime will result in high costs. Primary requirements of most customers are a high service level and short delivery times [6].

Small lot sizes: Only in rare cases, replacement parts are ordered in large quantities. Instead, an order will include several different positions in small numbers.

High number of different parts: The increasing variety of primary products and more possibilities to customize the product according to the customer's wishes in conjunction with a long supply period lead to an increase in the number of parts regarding the spare parts management [16, 17].

High variety in dimensions and weight of parts: The variety of parts in spare parts management is very high. The processes must be flexible to handle and package these different parts [16].

3 Demand for Better Forecasts

Describing the logistics processes it turns out that a large part of the additional effort in spare parts logistics is the result of uncertain forecasts. This causes short-term needs of spare parts that must be satisfied within the shortest time. Results are courier trips or even transportation by helicopters or by plane. Setting up more accurate forecasts, not just about the exact number of material requirements but also the place of the requirement, may significantly improve the environmental sustainability of the spare parts logistics. Herewith a change from the current pull method to a push method is initiated. For this purpose in the context of a research project a continuous control loop should be developed and implemented.

3.1 Dynamic Control Loops for the Forecast of Spare Parts Demand

In the past the spare parts management was selected as a central theme in numerous research projects [17]. However, this was mostly an isolated view of individual approaches. Indeed these approaches are suitable for many applications, but a combination of different approaches to an integrated control loop has not yet been performed.

Currently in industrial practice used approaches, methods and IT tools for demand planning of decentralized distribution centres cover the needs of the spare parts logistics only insufficiency. Investigations show that the predictability of Maintenance, Repair and Operation (MRO) expenses and demand is subject to considerable uncertainty. Approaches of advance planning of part demand in form of condition monitoring are not applicable for not signal-based assessable parts. Furthermore, a variety of mathematical methods exist for calculation the maintenance and part requirements [2, 18]. Nevertheless, a pure inventory planning based on calculated probabilities of failure and maintenance intervals does not have the required accuracy. In industrial practice, normal inventory control models are transferred on the spare part management without considering the special demands. Furthermore, the optimization is often performed only locally and does not consider the entire supply chain [7]. In conclusion it becomes clear that an isolated application of forecasts is not useful. Therefore a combination of different procedure should be applied. Moreover, the regarded research project should not consider the evaluation of just a single component, but an aggregation of all parts in the inventory.

An essential factor for the success of an optimal inventory planning is the quality of the used input parameters, in particular the calculation of the actual material requirements of each customer. In the research project a control loop should be developed which calculates the demand of spare parts continuously. This control loop is based on the control loop of production planning and control according to Wiendahl [19]. For the correct projection of these parameters the historic demand needs to be matched constantly with actual developments and simultaneously adjusting the forecast parameters optimally.

Running through the control loop according to Fig. 6.2.3 the reliability of planning increases significantly. In particular by the identification and integration of new influential factors, the forecast method can be improved successively. In contrast to the today's static planning, which runs through only once and is checked only during acute emergencies, needs for action should be indicated quickly and uncomplicated through the continuous identification of demands.

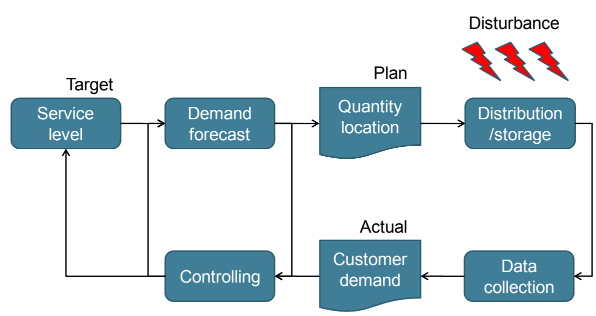

Fig. 6.2.3 Control loop for spare parts management

The input values for the control loop form the target for the service level to be reached. The service level is defined differently depending on the regarded industry and varies in its dimension. For instance, because of a clearly higher expectation of failure costs in aviation industries than in the automotive industry a much higher level of service standard is required. Often these service levels are also specified by contract bilaterally between customers and manufacturers and are assigned with penalties. With the definition of service levels, the company strategically positions itself relative to other companies.

In the second step a demand forecast is provided on the basis of the service level. In general these are deduced from the total requirement and can be further specified. At this level of detail, the overall requirements are broken down to the different places of requirement. For example, in the automotive industry these are the service branches. For the forecast different procedures can be used which are generally based on historical data.

The next step is the operational distribution and storage of products according to the determined plan demands. In this step, also the actual customer orders are served. Thereby it is assumed that there will be deviations from the predicted value. The deviations may be lead back to unpredictable disturbances. For example, the planning for the demand of spare parts in the automotive industry was affected since old cars were scrapped in high numbers due to state subsidies ("cash for clunkers"). These deviations from the planned values will be identified through data collections and finally leads to the real customer demand.

The controlling is the last step and completes the control loop for spare parts management. By comparing the demand forecast and actual demand the deviations are determined. These need to be analysed to define measures to improve the reaching of the service level [19]. In addition, this knowledge can be used to adapt and improve the forecasting process.

3.2 Influence Parameters of Demand Forecasts

In advance of the research project several influence parameters of the control loops were identified, which are described below Fig. 6.2.4.

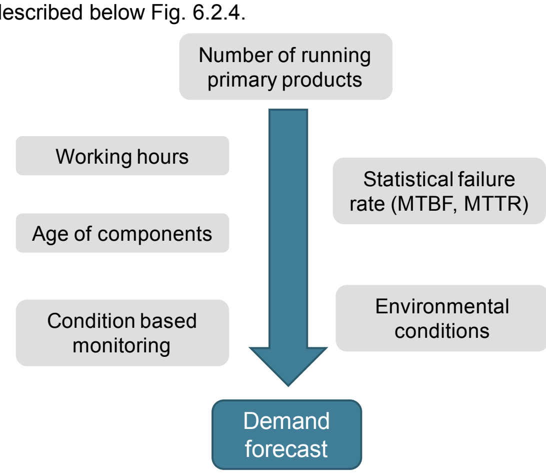

Fig. 6.2.4 Input of the demand forecast

Base of the control loop must be the number of all running primary products. This number will decrease continuously after the end of serial production. Depending on the industry, there are several ways to obtain this number. Often, these data are recorded by governmental institutions, such as vehicle registration offices. In industries with high customer loyalty, like in aviation industry or plant engineering, an up-to-date data base is ensured by an intensive cooperation with the customer.

A decisive factor is the performance of the observed technical system. Depending on the primary product, this can be for example driving hours for automobiles, trains or commercial vehicles, flight hours for planes or working hours for technical installations such as wind power plants or production lines. If necessary, special impacts that were not covered with the work performance will be considered separately. For example the landing of an aircraft has a particular impact so that their number also has to be considered.

In addition to the period of use the age of the components is important because failures are not just lead back to abrasion but also to aging. Thus, materials such as rubber can become brittle for instance or plastics discolour and become fragile.

Statistical values of the failure behaviour for the components contained in the primary product, such as mean time between failure (MTBF) or mean time to repair (MTTR) can be obtained from historical data. If a component is new and there are currently no data available, analogies to already used components have to be done or forecasts can be developed which need to be deposited as quickly as possible with real data.

Another alternative to increase the forecast accuracy is the usage of condition monitoring systems, which are also integrated into the control loop. These systems allow an optimized maintenance strategy with the aim to minimize the total costs of the repair process including failure costs as well as repair costs [20]. They can either record the abrasion, such as the abrasion of brakes and clutch plates, or show early failures by detecting and analysing vibrations, noises or operating temperatures. Furthermore also lubricants or coolants can be analysed regarding the soiling [8, 20]. Ideally, the degradation process i.e. when the resistance to failure has started to decrease should be recorded and reported. If the replacement time of the components is less than the time until the actual occurrence of the error, a precautionary repair can be carried out without risking a defect of the machine during running operations [21]. Because of the associated costs and the increased complexity of products naturally the condition monitoring systems cannot be used for all components. At this place a risk analysis need to be performed and the components with a high probability of failure or rather with high follow-up costs resulting in a failure need to be identified [22]. The combination of condition based monitoring systems with decisions on inventory management has not been achieved acceptance so far [8].

In some applications, the environmental conditions for the replacement of abrasion are also decisive. If substantial differences exist between the considered primary products, for instance operating at high as well as very low temperatures, parameters must be used to improve the forecasts.

4 Conclusion

The spare parts logistics is becoming increasingly important in many branches. In particular, the high margins and the independence of economic cycles are factors for this change in mind. However, herewith major challenges are associated concerning the short delivery time expected from the customers and a high service degree. Main cause of the turbulence in the illustrated reference process of spare parts logistics is the lacking quality of the forecasts, which leads to unexpected short-term needs and unexpected high expenses. As a solution a current research project is implementing a dynamic control loop that allows a constant comparison between actual and set value. Furthermore this control loop is using a variety of data sources to generate the forecasts. In addition to mathematical procedures which are based to historical data monitoring control system are used. The exact design and development in a software prototype and the technical integration of this software with existing systems in order to be able to use already existing data should be analysed in the research project.

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6.3 Modeling of the Optimum Logistic Systems for Shipment by Land Types of Transport with Respect to Risk Drawings of Harm to Environment

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Abstract
This paper is result of research worries environmental pollution during transportation of cargoes by land types of transport. The basic idea of the project consists in calculating the damage put to ecology by the specified kind of transportation, and also try to diversify the risks connected with this process, optimizing a damage put to environment. For object in view achievement tools of the theory of games, namely criteria of definition of optimum strategy, both classical, and modified, the risk theory, construction of models of a diversification of risk and damage calculation, and also simulation modeling, construction of simulation model of transportation of cargoes, taking into account quantity of consumed fuel have been used. The imitating model of transportation of cargoes has been as a result constructed, the matrix of effectiveness which has been checked up by means of criteria of definition of optimum strategy is constructed, and after the specified procedures the damage from the given kind of transportations has been counted up.

Keywords:
Theory of games, Matrix of usefulness, Models of a diversification of risk, Imitating model of transportation of cargoes

In the literature for today statement of problems of storekeeping and models of optimisation taking into account harm put to environment, for such systems do not allow the manager to consider rather important attribute of the corresponding analysis caused by necessity of decision-making in the conditions of uncertainty on logistics. At the same time development of new technologies in the conditions of market economy promotes a wide circulation of models of decision-making in the conditions of uncertainty [1]. In particular, for problems and models of optimisation of control systems of stocks such situations take place, when values of some parametres of model and laws of distribution of probabilities of such parametres are unknown. To provide the specified feature at a choice of the best alternative variant for storekeeping strategy, the manager on logistics faces with new statements of problems of optimisation within the limits of such systems and according to new approaches to their decision. Namely, realisation of corresponding optimising models of decision-making in the conditions of uncertainty with reference to concrete situations of business for control systems of stocks, as a rule, demands:

• corresponding formalisation or updating of concrete model of a control system by stocks which should consider specificity of its practical use;

• in particular, within the limits of such formalisation or updating concrete scenarios of development of "external" events which represent possible combinations in practice of realised values for the unknown parametres of model influencing on final economic result should be proved/are stipulated;

• the additional efforts of the manager caused by necessity of special updatings of corresponding models of optimisation of decisions in the conditions of uncertainty, and with reference to specificity of a problem of optimisation.

Methods and models of decision-making in the conditions of uncertainty will be used for the decision of a problem of optimisation of work of a control system by stocks. Thus a number of parametres of model (such parametres as annual consumption of the goods, the price of its realisation etc.) are in advance unknown: they are accepted as uncertain parametres. The problem of optimisation of strategy of storekeeping is considered as a problem of maximisation of profit at the minimum damage put to environment.

The structure of a corresponding problem of optimisation of storekeeping as problems of decision-making in the conditions of uncertainty is analyzed and formalized. Alternative decisions from which it is required to choose the best / optimum, are formalized so that to consider possibility of minimisation of risk to cause a damage of ecology, types of transport for transportation. Such analysis is necessary for an estimation of expediency of a diversification of risks of decrease in profitability (because of possible failures of deliveries) at storekeeping.

• Algorithms of a finding of the best decision with reference to various criteria (both classical, and to derivative criteria) relations LPR to possible losses of profit are presented.

• Within the limits of the theory of decision-making in the conditions of uncertainty the problem of a choice of the best decisions is formalized with reference to a so-called matrix of usefulness. Elements of such matrix are indicators of final economic result (a gain / profits) with reference to concrete analyzed decisions and the possible casual events influencing on specified result. Therefore the store keepings of statement of problems of optimisation standard in the theory as problems of minimisation of the general annual costs at first are necessary to formalize in the form of

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problems of maximisation of a gain or profit at the minimum harm put to ecology.

Let's note corresponding basic concepts and designations within the limits of analyzed model:

D —annual consumption of production;

C_h —expenses for storage of a unit of production;

C_0 —an overhead charge for each delivery;

q —quantity of the units in order

$C_П$ —the price of purchase of a unit of production

C_s —the price of realization of a unit of production;

$C_г$ —the general annual charges;

$P_г$ —the general annual profit (before taxes).

Let's remind that the general annual charges Cr considered as function from q (the size of the order), with reference to classical model of storekeeping are defined by a parity:

$$C_г = C_г(q) = C_0 D / q + C_h q / 2 + C_П D$$

Thus the problem of maximization of the general annual profit $P_г$ can be presented in a kind.

$$P_г(q) = C_s D - C_0 D / q - C_h q / 2 - C_П D \rightarrow \max_{q>0},$$

And, as it is visible, it is easily reduced (taking into account that the composed $C_s D$ does not depend on the optimizing parameter q) to a classical problem of minimization of the general annual charges

$$C_г(q) \rightarrow \min_{q>0}$$

Hence, by optimization of profit for the determined model if all its parameters are known, it is possible to find the optimum size of the order under formulas which define the economic size of the order in a format of traditional models of minimization of costs at storekeeping:

$$q^* = \sqrt{2C_0 D / C_h}$$

In other words, for LPR the specified size of the order q is optimum not only at minimization of the general annual charges, but also for achievement of a maximum of the general profit (it is natural, with reference to noted determined case of corresponding classical model of storekeeping) [2].

Let's underline that at formalization of model LPR can set corresponding scenarios, generally speaking, arbitrarily, considering demanded accuracy or carefulness of such formalization. Further for definiteness and conveniences of a statement (to avoid unduly bulky constructions) at formalization of considered model for each of the specified parameters two scenarios will be considered only. Thus formalization of full group of the events influencing on economic result, will demand consideration (as it will be presented lower) of sixteen casual various events that will naturally be reflected in a format of a matrix of utility.

Namely, for annual consumption and with reference to the price of realization of a unit of production the following scenarios are accepted further.

Demand for production for a year can be:

- low-scenario D (1), that is $D \in [D_1, D_3)$;
- high-scenario D (2), that is $D \in [D_3, D_5)$;

Besides, the price of realization of a unit of production can be:

- low-scenario Cs (1), that is $C_s \in [C_{s1}, C_{s3})$;
- high-scenario Cs (1), that is $C_s \in [C_{s3}, C_{s5})$

Besides, at formalization of optimizing model transportation possibility by various types of transport, and on different delivery terms and with the different price of a unit of production is considered. Thus also the possible various losses of profit caused by claims on environmental contamination, and, as well as for other parameters of model, conformably only to two scenarios are considered:

(1) the scenario (+), corresponding to a favorable outcome of formation of profit; (2) the scenario (−), corresponding to a failure of formation of profit. Namely the specified losses of profit are considered by introduction of the "lowering" factor α for value of an analyzed gain. Corresponding designations are presented in Table 6.3.1.

Table 6.3.1 Model parameters at realization of scenarios (+) and (−) losses of profit for each supplier

Parameters of Model	**Desigtions**	
	Supplier I	Supplier II
The price of purchase of a unit of production	$C_{\Pi 1}$	$C_{\Pi 2}$
Overhead charge for each delivery	C_{o1}	C_{o2}
The lowering factor α for a gain at a favorable outcome of formation of profit	The scenario I (−) $\alpha = \alpha_{I+} = 1$	The scenario II (−) $\alpha = \alpha_{II-} = 1$
The lowering factor α for a gain at a failure of formation of profit	The scenario I (−) $\alpha = \alpha_{I-}$ $0 < \alpha_{I-} < 1$	The scenario II (−) $\alpha = \alpha_{II-}$ $0 < \alpha_{II-} < 1$

Thus, as it is visible, at realization of a concrete outcome we have:

- for a favorable outcome the gain size does not go down (α =1);
- for a failure the gain size goes down ($0 < \alpha_I < 1$).

Let's underline the following feature. Introduction of factor α for the account of the losses caused by claims on environmental contamination, will be reflected in formal representation of criterion function. Namely, the corresponding problem of optimization will be presented as follows:

$$P_z(q) = \alpha \cdot C_s D - C_0 D / q - C_h q / 2 - C_{\Pi} D \rightarrow \max_{q>0}$$

Full Group of Events

For acceptance of optimum decisions in the conditions of uncertainty on the first step of corresponding procedures it is required to formalize full group of events for considered model of storekeeping in the conditions of uncertainty. With reference to an analyzed situation, it will contain sixteen casual events $\{\theta_1, \theta_2, \ldots, \theta_{16}\}$, which are resulted more low:

Table 6.3.2 Full group of events and parameters of model for each of this events

Event	**Combination of scenario in case of event**	**Variants of realization of parameters of model**	**Mark of event**
θ_1	D(1),C_s(1), I(+), II(+)	$D \in [D_1, D_3), C_s \in [C_{s1}, C_{s3}), \alpha_{I+} = 1; \alpha_{II+} = 1$	**(н,н,+,+)**
θ_2	D(2),C_s(1), I(+), II(+)	$D \in [D_3, D_5), C_s \in [C_{s1}, C_{s3}), \alpha_{I+} = 1; \alpha_{II+} = 1$	**(в,н,+,+)**;
θ_3	D(1),C_s(2), I(+), II(+)	$D \in [D_1, D_3), C_s \in [C_{s3}, C_{s5}), \alpha_{I+} = 1; \alpha_{II+} = 1$	**(н,в,+,+)**

...	...	...	...
θ_{14}	D(2),Cs(1), I(-), II(-)	$D \in [D_3, D_5), C_s \in [C_{s1}, C_{s3}), 0 < \alpha_{I-} < 1; 0 < \alpha_{II-} < 1$	(В,Н,-,-);
θ_{15}	D(1),Cs(2), I(-), II(-)	$D \in [D_1, D_3), C_s \in [C_{s3}, C_{s5}), 0 < \alpha_{I-} < 1; 0 < \alpha_{II-} < 1$	**(Н,В,-,-)**;
θ_{16}	D(2),Cs(2), I(-), II(-)	$D \in [D_3, D_5), C_s \in [C_{s3}, C_{s5}), 0 < \alpha_{I-} < 1; 0 < \alpha_{II-} < 1$	**(В,В,-,-)**

The list of analyzed alternative decisions. For a finding of the best decision in the conditions of uncertainty on the second step of procedures of optimization needs to formalize the list of analyzed alternative decisions. Corresponding alternative decisions are set directly for Person who Make Decision (PMD). It is clear that in frameworks of considered model of storekeeping the decision for PMD means: (1) a choice of the supplier/suppliers; definition of the size of the order/orders. Thus, if the supplier is known, annual consumption and an overhead charge for each delivery is known, within the limits of determined model PMD as the decision, naturally, chooses the economic size of the order q defined by resulted at the beginning of this chapter a parity . Therefore for formalization of various alternative decisions for PMD within the limits of considered model further it is natural to arrive as follows. Namely, further we consider that such decisions are defined:

• on the one hand—a choice of various variants for shares of delivered production from considered suppliers;

• and on the other hand—various values for possible realization of size of annual consumption (D) values of an overhead charge for each delivery (C_{o1}) and (C_{o2}) depending on what share of corresponding consumption will be provided which of suppliers.

The choice of possible distribution of shares of the delivered goods between analyzed suppliers can be, generally speaking, any. In considered model LPR at formation of the list of decisions wishes to consider in addition possibility of a diversification of risk of the losses caused by claims to quality of the goods, only at the expense of goods purchase by equal shares at both suppliers. In this case the list of analyzed alternative decisions includes six decisions: $\{X_1, X_2, \ldots, X_6\}$ Thus, they are formalized as follows.

Matrix of Usefulness

For a finding of the best decision in the conditions of uncertainty on the third step of corresponding procedures of optimization is required to formalize already mentioned matrix of usefulness. Such matrix represents final economic result (a gain or profit) with reference to each analyzed decision and each casual event of the constructed full group of events. The specified matrix we will define with reference to profit indicators.

Thus, at matrix formalization of usefulness for its each cell is required to define the corresponding size of expected annual profit P_{ij} as element of such matrix for a case when the decision will be accepted X_j (From set specified above analyzed alternative decisions), and the situation will develop θ_i (from set of the situations influencing economic result).

Further for definiteness naturally we accept that at calculations of profit which is expected at realization any of events of full group $\{\theta_1, \theta_2, \ldots, \theta_{16}\}$,

it is supposed to use the middle of intervals for respective alteration of parameters of model of storekeeping within the limits of considered scenarios. Therefore with reference to each of the specified events we will present in addition corresponding indicators of annual consumption and the price of realization of production which should be used in calculations of expected profit P_{ij} at formalization of elements of a matrix of usefulness. Namely, for situations interesting us "external" factors cause following values for indicators of annual consumption and the price of sale of goods:

Sizes of expected annual profit with reference to each decision for PMD and each casual event (from analyzed full group of events) will be presented a corresponding matrix of usefulness A=(P_{ij}).Its structure is resulted in Table 6.3.3.

Let's underline corresponding features of procedures of formalization of this matrix [3].

For definition of expected profit P_{ij} we will use equality

$$P_{ij} = C_s D - C_0 D / q - C_h q / 2 - C_\Pi D \qquad (6.3.1)$$

If there comes event θ_1 (i.e. the event presented by a situation

$D \in [D_1, D_3), C_s [C_{s1}, C_{s3}), \alpha_{I+} = 1; \alpha_{II+} = 1$,

Table 6.3.3 The structure of matrix of usefulness

	X_1	…	X_j	…	X_6
θ_1	P_{11}	…	P_{1j}	…	P_{16}
…	…	….	…	…	…
θ_i	P_{i1}	….	P_{ij}	…	P_{i6}
…	…	….		…	
θ_{16}	$P_{16,1}$	…	$P_{16,j}$	…	$P_{16,6}$

when annual consumption is low at the low price of realization of a unit of production, and the additional losses of profit, caused by claims to quality is guided by prospective annual consumption D_2, and deliveries are assumed only from the first supplier by volume parties of production of both suppliers are absent),then at decision X_1 (in which frameworks PMD orientate itself on expected annual consumption D_2, deliveries are expected only from the first supplier by batches of volume $q_1^* = \sqrt{\frac{2C_{01}D_2}{C_h}}$,

for the corresponding size of expected annual profit P_{11} on a basis Eq. (6.3.1) we receive equality:

$$P_{11} = (\alpha_{I+})C_{s2}D_2 - C_{01}D_2 / q_1^* - C_h q_1^* / 2 - C_{\Pi 1}D_2$$

Similarly for an element P_{12} of this line of a matrix of usefulness we have following equality:

$$P_{12} = (\alpha_{II+})C_{s2}D_2 - C_{02}D_2 / q_2^* - C_h q_2^* / 2 - C_{\Pi 2}D_2$$

At element definition P_{13} it is necessary to consider that in considered model the decision X_3 provides a diversification of deliveries of the goods in equal shares between suppliers I and II. Therefore it is convenient to represent this element in the form of two components: $P_{13} = P_{13}(I) + P_{13}(II)$, where the component P 13(I)corresponds to expected annual profit with reference to deliveries from the first supplier, and a component P 13(II) - from the second. These components is defined under the formula (*) with reference to "the" parametres:

$$P_{13}(I) = \frac{\alpha_{I+}}{2 \cdot C_{s2}D_2} - \frac{C_{01}D_2}{2q_{3a}^*} - \frac{C_h(q_{3a}^*)}{2} - \frac{C_{\Pi 1}}{2 \cdot D_2};$$

$$P_{13}(II) = \frac{\alpha_{II+}}{2 \cdot C_{s2}D_2} - \frac{C_{02}D_2}{2q_{3б}^*} - \frac{C_h(q_{3б}^*)}{2} - \frac{C_{\Pi 2}}{2 \cdot D_2};$$

Similarly we define other elements of the first line with reference to decisions X_4, X_5, X_6:

Choice on a Basis of Maximin Criterion (MM-Criterion). Criterion Function of Maximin Criterion:

$$Z_{MM} = \max_j \{K_j\}, K_j = \min_j \{a_{ij}\}$$

(here is considered that for considered model the matrix of usefulness is transposed).

Corresponding procedures of optimisation of the decision within the limits of this criterion assume:

- introduction of an additional line for a matrix of usefulness;
- its elements (on columns) are filled with the worst indicator (the smallest value of profit for the corresponding decision);
- from all such indicators of an additional line the best is defined (the biggest on profit size);
- the corresponding decision is accepted as best/optimum

Choice on the Basis of Optimistic Criterion (N-Criterion). Criterion function of optimistic criterion:

$$Z_H = \max_j \{K_j\}, \; K_j = \max_i \{a_{ij}\}$$

Choice on the basis of neutral criterion (N-criterion).

Criterion function of neutral criterion:

$$Z_N = \max_j \{K_j\},\ K_j = \frac{1}{n}\sum_{i=1}^{n} a_{ij}$$

Choice on the Basis of Savage, S Criterion(S-criterion).

Criterion function of Sevidzh, s criterion:

$$Z_s = \min_j \{K_j\},\ K_j = \max_i \{l_{ij}\},$$

a $l_{ij} = \max_j \{a_{ij}\} - a_{ij}$;

(here is considered that the matrix of usefulness for analyzed model is transposed).

Choice on the Basis of Hurwicz's Criterion (HW-Criterion). Criterion function of criterion of Hurwicz:

$$Z_{HW} = \max_j \{K_j\},$$

$$K_j = c \cdot \min_i \{a_{ij}\} + (1-c) \cdot \max_i \{a_{ij}\}$$

c —the corresponding "weight" factor, accepting values c={0:1}, and a factor choice c realizes PMD.

After using of the presented criteria of optimization, it is possible to say that for minimization of risk of drawing of harm to environment, it is necessary to diversify transportations on the basis of a type of transport.

In further practical apply the manager on logistics can use any software on purpose to construct imitating model of a warehouse and system of the organization of transportations of stocks on this warehouse taking into account the diversification offered in given work. And also to create so-called fund of losses, in a case if certain harm to environment has been put.

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6.4 Eco-Efficiency Within Extended Supply Chain as Product Life Cycle Management

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Abstract

Designers make decisions that ultimately impact on both the economic and environmental performance of the products, and many of these costs and impacts occur across the supply chain. This paper proposes an eco-efficiency model for product life cycle management within the extended supply chain (ESC) for food industry. Eco-efficiency (EE) has the potential to incorporate both environmental and economic improvement by companies of ESC, and we explore the use of EE in the design process. It is noteworthy that it is an imperative in the current competitive market that companies must be able to manage their entire production chain taking into account environmental issues as an important factor in their decision-making processes. Therefore, it is believed that EE can integrate and strengthen a company's functions and assist its decision-making processes as well as implement improvements within its ESC. In this context, it is expected that the proposed model will be able to deliver a validation process based on EE strategies as well as map environmental aspects and its impacts. In addition, the proposed model aims to consider economic aspects along the product ESC and to present elements which can help companies to promote improvements within its supply chain by considering a more environmentally friendly perspective.

Keywords:

Food industry, Eco-efficiency, Extended supply chain, Life cycle management

1 Introduction

Many businesses seek to understand, improve and demonstrate an appropriate environmental performance in response to stricter demands from various sectors of society, namely: NGO's (e.g. Greenpeace), government (environmental legislation, e.g. electro-electronics waste disposal in Europe and the new solid waste policy from Brazil), international treaties (e.g. Rio Submit and Kyoto Protocol), and market demands for improving their environmental, social and ethical performance.

In addition, businesses have been challenging to recognise that the ecological footprint of their products and services is not limited to the production stage of the final product manufacturer [1]. In fact, all stages of the product life cycle have influenced on the environmental burden of a supply chain, including resource extraction, manufacturing, use, reuse, recycling or final disposal [2].

In this context, it is important to emphasize the extended supply chain (ESC) in product design decisions, where the ESC is defined as a network of organizations that are involved, through upstream and downstream linkages, in the different process and activities that produce value in the form of products and services to the final consumer, including use and final disposal of materials [3]. In other words, the ESC encompasses the full product lifecycle perspective and not only contemplates the cradle to grave vision but also includes the potential for cradle to cradle, as it considers the material returning to its full use using reverse flow which is possible by recycle, re-use and remanufacture.

According to the literature, researchers have observed that the management of the product life cycle has historically been driven most intensively by organizations known as "focal company" [1]. The "focal company" can positively influence the entire production chain, requiring suppliers and service providers to establish environmental practices and procedures which ranges from reactive behaviors (e.g. attention to legal, operational adjustments, elimination or decreasing the concentration of hazardous substances, etc.) to proactive practices (e.g. implementing certifiable Management Systems, such as Environmental—ISO 14001 and Social—SA 8000, environmental labeling of materials and products, sustainability reports, etc.) [4, 5]. Focal companies often take the original equipment manufacturer (OEM) position in most sectors and offer the chance to influence both suppliers and customers/users. Roberts [6] states that the non-governmental organization (NGO) actions

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[1] It is called "Focal company", companies which usually rule their supply chain, providing direct contact with customers and designing products and services (HANDFIELD, NICHOLS, 1999* *APUD* SEURING, MULLER, 2008). That is, they are the most important organizations in the production chain, having purchasing power or holding direct contact with customers and having the project's products and / or services required control, or to establish environmental standards and features for the chain.

* HANDFIELD RB, NICHOLS EL. Introduction to supply chain management. NewJersey: Prentice-Hall; 1999.

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can also influence the reputation of "focal company", demanding responsibilities in the upstream and downstream production. For example, Nike, Disney, Levi Strauss, Benetton, Adidas and C&A in recently years have been criticised for problems that occurred during their suppliers production stages such as environmental contamination and inhumane working conditions [7].

As a consequence, managing the product's supply chain based on a life cycle perspective can be beneficial for the organizations. For instance, it is possible to identify and prioritize the stages with higher pollution burden and environmental risk as well as to avoid pollution transferring from one stage to another. In addition, it helps to promote the competitiveness in the chain, reducing costs and strengthening the image before the society [8–10].

However, to develop individual actions in the extended supply chain does not mean that the organization has total control over its product chain. It is necessary to consider the production chain within all organizational and functions levels. Thus, at the strategic level it is expected that OEMs will continue their investment in resources and use of techniques to support continuous improvement of products and services offered as well as to support the decision-making process of supply chain management. For example, the manufacturing sector will be increasingly pressured to adopt environmental tools to optimize the use of its materials and to present environmental criteria for materials purchasing sector. So there must be a strong association of what is defined at the strategic, tactical and operational levels. The changes of decisions on these three levels should happen smoothly and naturally such that environmental issues can permeate the entire company.

Eco-efficiency has been recognized as an important tool to integrate and strengthen various functions of a company as well as to assist its decision-making process and to improve ESC by using environmental, economic and performance information [11–14]. In addition, the EE is seen both as a concept and as a tool where the basic idea is to produce more with less impact on nature. Thus, we can see that EE involves both environmental and economical issues which can be used in order to promote improvements in the products, processes and services. For instance, in the food industry, the implementation of EE in their various supply chains would be extremely important. It is noteworthy that the main environmental aspects and impacts are: the use of resources (water, soil, energy, materials packaging) and generation of water waste, air emissions, organic waste and packaging waste, contributing mainly to environmental phenomena such as eutrophication of water resource and global warming [15]. Maxime, Marcott and Arcand [16] highlight that the food and beverage industry is responsible for processing 80% of primary agricultural production.

In Brazil, the food industry during 2009 had a turnover of 291.6 billion Reais, up 50% over the past nine years, which shows a big picture of continued growth. In relation to Brazilian GDP, it was responsible for almost 10% in 2009. This typology industry employed more than 1.4 million workers in 2009 [17]. In the Rio Grande do Norte State, the productive chain of the food industry represents over 70% of exports, mainly through fish and shellfish, fruits, sugar, chocolates and candies and marine salt (In 2004, exports accounted for R$ 413.3 million) [18]. Hence, approaching the productive chain of the food industry with emphasis on EE means to reduce drastically the waste which is generated throughout their extended supply chain, and to minimize the associated environmental impacts, and to make this sector more competitive in international market.

Thus, this paper aims to show initials elements in order to propose an Eco-efficiency model for product life cycle management focusing on the extended supply chain of the food industry in order to facilitate the incorporation of environmental and economic improvement by companies of ESC in their business procedure.

2 Product Life Cycle Management and Eco-Efficiency

2.1 Product Life Cycle Management

The life cycle management of products (LCM) is an approach which supports the management and integration of business processes and life cycle information in order to increase productivity and improve the effectiveness of business processes regarding planning, development, manufacturing, maintenance and removal of products [19]. This is an vast theme that involves a variety of views that is meant to solve different problems such as marketing (optimize sales curve), the engineering product development (developing products that consider performance requirements, impact on environment and subsequent costs of the life cycle), environmental management (to measure and reduce environmental impacts throughout the life cycle) cost management (providing cost information to direct the engineering decisions) and data management product (to support the creation, management and dissemination and use of information throughout the product life cycle).

According to UNEP / SECTA [20], the LCM is a business management approach that can be used by all business sizes and types to improve the sustainability performance of the product. Thus, the LCM can be used to organize, analyze and manage information and activities for continuous improvement of products throughout the life cycle.

It is noteworthy that the life cycle of a product is characterized by a succession of stages of production, covering since the extraction of raw materials for their production, until the application of reverse logistic concepts for the gathering of product at the end of their use [21].

To carry out these processes, the extended supply chain can be mapped and managed, involving control of the organizations responsible for the extraction, processing and supplying of raw materials, developing and producing the final product and product distribution, purchasing, and supply chain issues reverse as the dismantling of products, cleaning and / or treatment, reuse, remanufacture and / or recycling of components.

Thus, the investigation of improvement opportunities in the product would be from an integration of the organizations of the ESC. In this context, "Focal company" would lead an investigation of the life cycle of its products through other companies comprising its ESC. Competitiveness gains, to avoid passing on costs to other link chain as well as the elimination of waste and increased use of quality criteria and increased reliability, and adds value to the product in this process are feasible consequences of the management of the lifecycle from the extended supply chain.

The closer relationship between suppliers and service providers and focal company can rise gradually the chances for mutual benefit, as well as to enable improvements in product design, value engineering practices of components, etc. It is also emphasized that many focal companies are finding that by maintaining its suppliers involved in product development process can achieve innovative solutions [22].

In accordance with Michelsen, Fet and Dashlsrud [23], companies which are unable to provide information on their environmental performance and costs associated with its lifecycle can have some difficulties in getting contracts with the public sector in the future. Equally importantly, they claim that companies cannot be considered as the only element of the chain, they become more competitive when they work in an integrated manner with their associated supply chain as a single unit. Therefore, it is an imperative in the current competitive market, that companies are able to manage their entire production chain, considering environmental issues as important factors in the decision-making process.

There are several reasons to develop production chain management practices based on a product lifecycle perspective. For example, a study carried out by Zhun, Sarkis and Lai [24] within 77 companies across the automobile industry has showed that certain laws influenced the adoption of environmental practices to improve operational adequacy, such as eco-design and implementation of investment for improvements from suppliers. The pressure from customers and NGOs resulted in the adoption of green purchasing (materials produced with less environmental impacts).

However, unfortunately, these practices have not been fully implemented yet within Brazilian companies. Jabbour and Jabbour [25] have conducted a study examining the establishment of environmental practices in the selection of suppliers of five major companies in the Sao Paulo State, certified by ISO 14001. They found that only one company influenced their suppliers across the wide range of criteria. It is noteworthy that this particular company had carried out a Life Cycle Analysis (LCA) for its main products which resulted in significant improvements within the company and its production chain, indicating a stronger than normal interest in environmental performance. In addition, another two companies had strict criteria with no practical effect on the suppliers while in two others considerations were not systematic in their suppliers. Also, the authors stated that the environmental management maturity level of companies was a driving force for the establishment of criteria to select their suppliers.

Thus, it is observed that when the "focal company" is pressed by external factors and when it has a high maturity level of management practices, it requires an appropriate environmental stance within its suppliers and it more proactively manages its supply chain.

According to this, a series of strategies and tools have been adopted by the "focal company" in order to introduce environmental improvements across its extended supply chain. Haes and Rooijen [26] suggest some approaches to product life cycle that can be incorporated across a chain, namely: Industrial Ecology (multidisciplinary study of industrial systems and economic activities and their relationship to the natural system); Dematerialization (substantial reduction in the volume of materials and energy usage by products and services), Life Cycle Assessment (designed to assess the consequences of a product or service from cradle to grave), and Eco-efficiency (management philosophy for sustainable development, meaning produce more with less). While these are not alternatives to choose from, and can be implemented together, these models are used in order to support the "focal company" and other members to promote a more efficient environmental aspects management.

In accordance with Michelsen, Fet and Dashlsrud [27], companies which are unable to provide information on their environmental performance and costs associated with its lifecycle can have some difficulties in getting contracts with the public sector in the future. Equally importantly, they claim that companies cannot be considered as the only element of the chain, they become more competitive when they work in an integrated manner with their associated supply chain as a single unit. Therefore, it is an imperative in the current competitive market, that companies are able to manage their entire production chain, considering environmental issues as important factors in the decision-making process.

Thus, one approach which can be used to manage the ESC focusing on life cycle of product or service is Eco-efficency which will be discussed in the next section.

2.2 Eco-Efficiency Applied Within ESC

Historically, the term eco-efficiency was established by the World Business Council for Sustainable Development (WBCSD) in 1991 as the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the Earth's carrying capacity [28].

According to Verfaillie and Bidwell [29] EE is a philosophy of management that challenges organizations to get more value for products and services by reducing the quantities of materials, energy and emissions, i.e. producing more with less. To this end, organizations have to be creative and innovative, for example, establishing more efficient practices in the chain of supply and improved products.

Eco-efficiency is a practical approach that has economic and environmental issues integrated into a single path [30], promoting a link between ambitious environmental goals and increasing business opportunities. Accordingly, EE allows an organization to strengthen its competitiveness, implementing marketing activities, improving the corporate image and to implement actions to recycle waste in supply chains [31].

Saling et. al. [32] state that EE identifies weaknesses in global processes and systems throughout the product life cycle, making it possible to prepare and support the development of new processes, accelerate their releases and decrease costs.

Lehni [33] emphasizes that EE has three overall objectives: reducing the consumption of resource (this objective includes minimizing the use of energy, materials, water, enhancing recyclability and product durability, and closing material loops); reducing the impact on nature (this covers the minimization of air emissions, water discharges, waste disposal and the dispersion of toxic substances, as well as, fostering the sustainable use of renewable resources) and increasing product and service value (this means providing more benefits to customers through product functionality, flexibility and modularity).

The implementation of EE within productive chains related to the development of strategies to optimize resource usage and the environmental performance measurement and economic system, covers all the stages from the extraction of raw materials to the materials disposal. It is proposed as win-win strategy, where all involved can have environmental and economic benefits. For instance, the focal company can lead an integrated survey on environmental and economic performance of their suppliers and service providers, pointing out critical points and assisting in establishing improvement opportunities, encouraging their partners to become more eco-efficient.

Also, EE can be a guide for business decisions (e.g. establishment of criteria to promote improvements in production supply, selection of suppliers and service providers), market (e.g. shareholders—new acquisitions), government (e.g. development of public policies). It is noteworthy that many managers, consumers, and even politicians are interested in environmentally friendly decisions, but there is still a lack of clear and precise information [34].

It is noteworthy that the EE, both in Brazil and abroad, is being traditionally worked as the performance evaluation process of economic activities, although, in an isolated manner. Usually, these applications follow the traditional measurement proposal of EE developed by the WBCSD [35], in which the EE is calculated as the ratio between the value of the product or service (mass or volume, monetary value or function) and the environmental influences of the product or service creation or use (energy consumption, material consumption, consumption of natural resources, generation of waste ; characteristics of products / services, generation of packaging waste, energy consumption and emissions during use and disposal).

It must be emphasized that only with the calculation of the EE indicators of a production process it is not possible to obtain conclusive data for decision making and improvement of a product or service. Nevertheless, other stages is also taken into account in this calculation in order to have a satisfactory degree of comparability between possibility of changing a process, product or service.

The strength of a life cycle perspective leads to the identification of trade-offs between production, use and handling of end of life and prevent various types of environmental impacts, especially the transfer of pollution for the next stage of the extended chain [36].

This knowledge is critical in the design phase of the product since often the choices of alternatives occurred early in the development cycle are responsible for about 85% of the cost of the final product. That is, all other definitions and decisions to be taken throughout the development cycle, after the initial stages, determine 15% of the cost. In other words, after the definition of materials, technology, manufacturing process and key construction solutions, the development team remains: to determine the tolerances of the pieces and build and test the prototype, defining the suppliers, the arrangement of supply chain partners and physical arrangement of production, the marketing campaign, technical assistance etc. And these settings, when compared with the previous, smaller influence on the final cost of the product [37].

3 Theorical Model of Eco Efficiency Applied Within ESC

It is noteworthy that the EE, both in Brazil and abroad, is being applied as a performance evaluation process of economic activities, although, in an isolated manner. Usually, these applications follow the traditional measurement proposal of EE developed by the WBCSD [38], in which the EE is calculated as the ratio between the value of the product or service (mass or volume, monetary value or function) and the environmental influences of the product or service creation or use (energy consumption, material consumption, consumption of natural resources, generation of waste; characteristics of products / services, generation of packaging waste, energy consumption and emissions during use and disposal).

These calculations of the EE indicators are usually focused on OEM productive process and cannot be conclusive for decision-making and improvement of a product or service when other stages are considered or even a degree of comparability between satisfactory possibility of change of a process, product or service. In addition, each company can use different methods for collecting information which may lead to misunderstandings and a lack of standardization.

It is necessary to emphasize that the EE calculation of a single production process cannot be conclusive for decision-making for product or service improvement when considering a product lifecycle approach. In other words, EE calculation of a single process is not able to understand all environmental performance of a product or operation, neither global impacts. In the food sector, for example, in the processing of beef, which the stage that offers the best efficiency with regard to emissions of greenhouse gases? It is interesting that all stages have specifics environmental goals, it is not enough the process of creating the animal has the eco-efficiency if there is not concrete actions to reduce emissions in the slaughter and processing of meat.

Thus, it is imperative to seek new management models that integrate and focus the following aspects:

(1) the product lifecycle thinking considered across the extended supply chain,

(2) the access and manipulation of environmental and economic information in a clear and standardized way to improve the relationship between service providers versus suppliers versus focal company versus market, based on an eco-efficiency perspective. This innovative approach may contribute to the reduction of pollution and optimization of resource across the production chain as well as promoting quality of life within the limits of the planet.

3.1 The Proposed Model

The proposed model of eco-efficiency for the extended supply chain of the food sector focuses on establishing a classification system for the maturity level of eco-efficiency (diagnosis of maturity of practices both within the "focal company" and the other organizations of the chain) as well as assessing the environmental and economic performance identifying practices to adopt such as a Cleaner Production programme and could support the formulation of public policies. Figure 6.4.1 presents details of this approach.

The first innovative aspect of this model is characterized by the Eco-efficiency application within extended supply chain of the food sector presenting a cross-efficiency between the economic-environmental elements and environmental issues along the extended chain. This trend of research has been arising in the scientific world, especially in Europe [39].

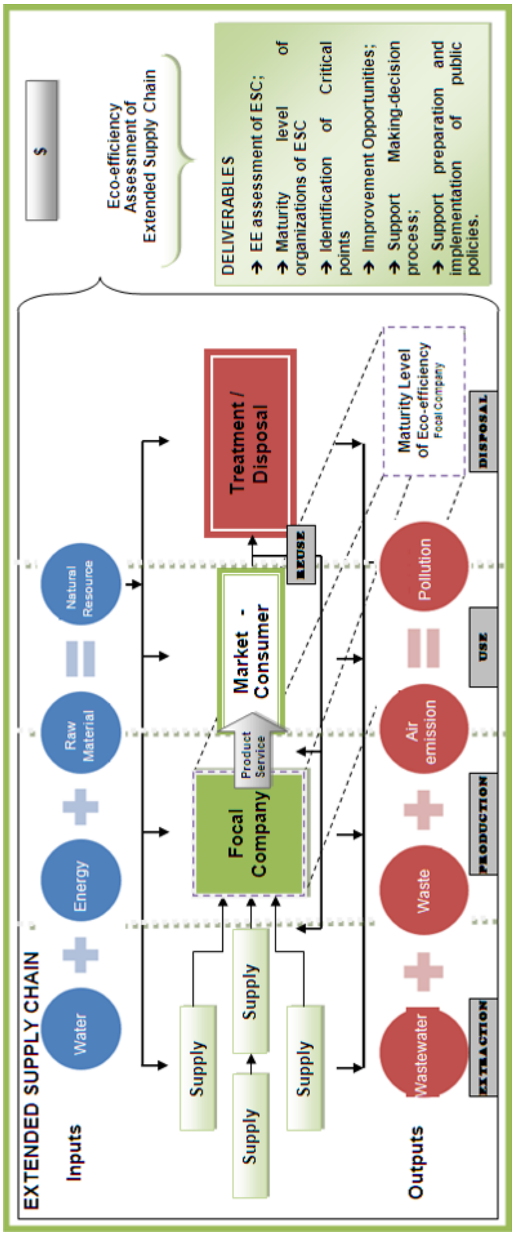

Fig. 6.4.1 Initial aspects of EE model to ESC

It is emphasized that the EE is explained as having a link to sustainability [40]. In this context, we can recall the report "Our Common Future" prepared by the UN in 1987, where it was argued that the promotion of sustainable development using, renewable resources should be explored with the premise that the utilization rate is within the limits of regeneration and natural growth. But the use of nonrenewable resources must take into account the criticality of these resources, the availability of technologies to minimize the depletion and the likelihood of substitutes. Still, the report shall highlight that the accumulation of knowledge and technologies that can improve the recharge capacity of resources.

Moreover, it is known that the natural resources usage for productive activities is not efficient. For instance, in the U.S. economy, only 7% of natural resource extracted becomes product. Out of the 7%, only 1% becomes durable and 6% will become waste in the first use by customers. In addition, by considering these 1% of durable materials, only 0.02% of them are recycled or remanufactured [41].

As a consequence, product life cycle management through eco-efficient supply chains can be a key factor for promoting sustainability by reducing resource extraction in nature as well as reducing the pollution burden and strengthening the remanufacturing process and recycling of materials. In this context, the support of public policies development can be based in applying this model.

Ekins [42] states that the main objective of public policies with respect to the increase in EE is the public social benefits gained. For example, introducing tax in order to reduce the resource usage or pollution generated.

In Brazil, a new legislation called Solid Waste National Policy [43] is an example of how public policy can promote the EE within ESC. This law stimulates, among other objectives, no waste generation, waste reduction, product reuse and recycling as well as waste treatment. In addition, it also stimulates the adoption, development and improvement of clean technologies to minimize environmental impacts. In fact, EE appears as one of the principles of this legislation, embodied mainly on the establishment of a waste integrated and shared management by all social actors and forces the execution of reverse logistics programme on the part of manufacturers, importers, distributors and marketers of pesticides, batteries, lubricants, fluorescent tubes and electronic products.

As a consequence, this model can have a positive impact for Brazilian economy. For example, in the productive chain of the food industry, it can help by identifying companies that generate hazardous waste and how these companies are managing them and help to establish better mechanisms that specify quantitative parameters and guidelines on how to perform reverse logistics.

Therefore, the use of this model of EE in order to support the development of public policies to promote the sustainability through public-private partnership is considered as the second innovative aspect of this model.

With regard to business, it is observed that similar organizations which manufacture similar products can have different environmental performances. Therefore, it is intended with this proposal to evaluate the maturity level of eco-efficiency performance in Brazilian food supply chains. This assessment is important not only to better inform public policy of incentives to adopt for environmentally friendly strategies as well as a self-assessment of organizations and the consequent definition of directions to pursue. Therefore, this analysis characterizes the third innovate aspect of this model.

This dynamic will challenge organizations to operate in a more transparent manner, requiring communication and co-operation between sectors and partners of the extended chain. In addition, assessing the EE maturity level will make it possible to understand how the organization levels and functions interact with environmental and economic issues.

It is believed that the final outcome of this model will be two main elements :

- the development of a validation process of Eco-Efficiency strategies and mapping of environmental aspects and impacts as well as economic aspects along ESC,
- the presentation of elements that can help companies to promote changes within their supply chain, contemplating a more environmentally friendly view, and creating conditions for meeting and exceeding the EE goals along a supply chain.

Therefore, an investigation on how natural resource is usage such as water, energy and raw material, as well as, waste is generated, for example, how greenhouse gas and wastewater can be released revel the stage of an unsatisfactory performance of the process. This analysis will companies to review their production system, improve their products, upgrade the environmental performance of ESC companies as well as define their level of eco-efficiency.

3.2 The Proposed Model and Product Development

In general, developing products consists of a set of activities by which the identification of market demands and technological constraints are considered, as well as the competitive company strategies. In addition, it is intended to come up with suitable product specifications and its production requirements. Moreover, the product development process also generates follow up activities after product launch in order to perform improvements over the product life cycle [44].

Normally, it is argued that the decision making processes occurring in the early stages of the product development cycle are responsible for 85% of the cost of the final product. The same argument can be used when considering product environmental impact over its life cycle [45]. For instance, product development affects significantly the use of materials in the short term as well as their recycling the long run [46]. Also, this phase influences how much energy will be used by the product as well as its generation of waste production (e.g. materials and packaging).

Therefore, there is a strong relation between product development and sustainability by which plays a potentially important role in reducing environmental burden, pollution prevention and rational use of raw materials and natural resources.

As a consequence, planning the product development process must be carried out in a manner which involves some strategies such as the use of environmentally friendly materials and low energy consumption, improving the efficiency of operation and serviceability of a product as well as its potential for reuse and recycling after disposal.

In fact, various tools, methods and methodologies have been developed to help designers to perform this difficult task. However, some of these procedures are laborious which makes it difficult to apply in practice. Many authors recommend that these procedures should have a simple format, and be easy to use and understood by the designers [47–49].

Therefore, the proposed model seeks to lead a reflection from designers when considering environmental variables along the product development process throughout its lifecycle. By considering these variables, the designer can eliminate possible negative environmental effects, without neglecting product's functionality. It has to be stressed that at this moment of reflection and decision-making it is possible that the goals related to environmental concerns and product efficiency can be similar. For example, by adopting strategies such as use of less polluting materials and low energy consumption, optimizing the use and less waste, potential for reuse and recycling after disposal. In this sense, the model proposes the use of certain environmental variables which can be addressed in the Product Development (PD) process, considering the whole life cycle of a product.

It is observed that the proposed model can influence the process of product development "independently" and/or "dependently" of the production chain. It is called "independently" when one supplier uses its supply chain information regarding their level of eco-efficiency (e.g. environmental burdens) to find opportunities for improving product development performance. On the order hand, it is called "dependently" when the focal company coordinates its product development performance based on supply chain information from all of its suppliers. Moreover, the focal company can lead to environmental improvements throughout the chain, neutralizing negative environmental effects, without neglecting product functionality.

In this context, it is expected that the product life cycle management based on eco-efficiency measurement in extended supply chain to promote environmental improvements in products and services can be carried out by actions such as:

twofold:

- searching for less harmful materials to the environment during its extraction and processing (deforestation, contamination of water resources, soil and air pollution, depletion of natural resources) including harm to the health of anyone at manufacturing and use stages;
- packaging optimization through the envisioning of possibilities of how the product will be transported, commercialized and distributed in order to optimize its logistics along its life cycle as well as to consider less waste generation.
- adopting techniques and production technologies with less environmental impact. For example, products with low energy consumption, optimizing the use of materials as well as less polluting materials and consequently lower charges of environmental pollutants.
- optimizing transport. In other words, efficient freight by any mode of transportation used while efficient logistics can also reduce the environmental impact.
- extending product life (period over which the product works well) and its aesthetics (period over which the user perceives the product as attractive).
- facilitating maintenance and repairs: products which are difficult or expensive to maintain can be easily replaced by new products.

4 Concluding Remarks

This article discusses the potential application of Eco-efficiency across the extended supply chain as an alternative form of life cycle management. This research based model will have as deliverables the development of a validation process for Eco-Efficiency strategies and a mapping of environmental impacts as well as economic aspects along

ESC; it includes the presentation of elements that can help companies to promote changes within the chain contemplating a more environmentally friendly view, creating conditions for meeting and exceeding the EE goals along a supply chain.

We believe that this research could be very important for Brazilian reality, it can encourage the organization to further sustainable actions, strengthen supply chains, support environmental life cycle management of products, and improve the decision-making processes in organizations and in public policy development. It is observed that the proposed model can influence the process of product development "independently" and/or "dependently" over the production chain. It is "independent" when one supplier uses its supply chain information regarding their level of eco-efficiency (e.g. environmental burdens) to find opportunities for improving product development performance. On the order hand, it is called "dependent" when the focal company coordinates its product development performance based on supply chain information from all of its suppliers. Moreover, the focal company can lead to environmental improvements throughout the chain, reducing negative environmental effects, without neglecting product functionality.

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6.5 Information Sharing and Utilization for Environmental Loads in Disassembly System Design with PLM

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Abstract

Nowadays products and their product lifecycle design are required for lower environmental loads throughout the whole of the closed-loop supply chains, and reuse and recycling are well known for reducing the environmental loads in view of resource circulation. For promoting the resource circulation for assembly products with the supply chains, disassembly systems for the reuse and recycling should be designed economically for not only recovering product values but also reducing operating costs. However, the recovered parts/materials by the disassembly also have the environmental loads, and this information can be shared with the product design phase as the bill of materials (BOM) by utilizing recent Product Lifecycle Management (PLM) tools such as a 3D-CAD. This study considers the environmental loads for the recovered parts/materials as well as the product recovery values and the system efficiency in the disassembly system design, and proposes the information sharing and utilization for lower environmental loads in the disassembly system design with PLM.

Keywords:

CO_2 emissions, Reuse and recycling, Product recevery values, Environmentally conscious manufacturing, Sustainable manufacturing, Closed-loop supply chains

1 Introduction

Nowadays products and their product lifecycle design are required for lower environmental loads throughout the whole of the closed-loop supply chains [1]. Reuse and recycling are well known for reducing the environmental loads in view of resource circulation [2, 3]. For promoting the resource circulation for assembly products with the closed-supply chains, disassembly systems [4, 5] for the reuse and recycling should be designed economically [6] for not only recovering product values but also reducing operating costs [7]. However, the recovered parts/materials by the disassembly also have the environmental loads [3], and this information can be shared with the product design phase as the bill of materials (BOM) by utilizing recent Product Lifecycle Management (PLM) tools such as a 3D-CAD [7, 8].

This study considers the environmental loads for the recovered parts/materials as well as the product recovery values and the system efficiency in the disassembly system design, and proposes the information sharing and utilization for lower environmental loads in the disassembly system design with PLM.

2 Ecologic and Economic Design for Disassembly System

2.1 Purpose of Ecologic and Economic Disassembly Design by Product Recovery Values

For promoting the material circulation of the assembly products, the closed-loop supply chains should be designed ecologically and economically. For the disassembly in the closed-loop supply chains, it is necessary to pursue an economic design with higher recovered materials values and shorter disassembly time [7, 8]. However, some of disassembly parts have higher environmental loads with the CO_2 emissions, and these parts should be disassembled and recycled instead of the destructive disassembly.

In view of economics, total profit in the disassembly system is calculated by a difference between reward and cost. The total reward is obtained with the material recovery values in the disassembly systems [7]. The material recovery values in the disassembly systems are calculated by the second hand material prices [9] and the recovered material weights. On the other hand, the cost of the system includes the expensive manual disassembly. Therefore, the disassembly cost is improved by pursuing the shorter disassembly times.

The purpose of this study is to design the economic disassembly system by maintaining the limited environmental impacts of the End-of-Life (EOL) parts in terms of the CO_2 volumes by information sharing and utilization of the product recovery values with the environmental loads.

2.2 Information Sharing and Utilization of Environmental Loads by SolidWorks

To describe the environmental impacts of each part on the bill of materials (BOM) and share this information between product and system design, a PLM tool, SolidWorks [8] provided by SolidWorks Japan K.K., is used in this study.

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Figure 6.5.1 shows a calculation example of environmental impacts for an assembly product by SolidWorks Sustainability. The SolidWorks Sustainability is embedded in SolidWorks 3D-CAD, where the values of the environmental impacts are automatically calculated based on a LCA database by PE international and GaBi software. In this study, the CO_2 volumes are used within 4 types of the environmental impacts shown by the SolidWorks Sustainability.

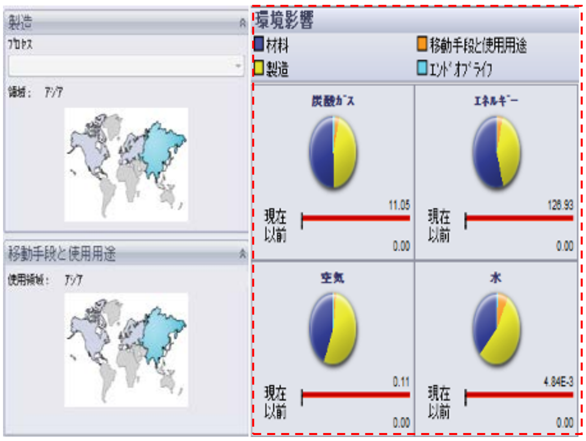

Fig. 6.5.1 A calculation example of environmental impacts for an assembly product by SolidWorks sustainability

3 Disassembly Design Procedure with Information Sharing and Utilization by Environmental Loads

3.1 Overview

Figure 6.5.2 shows the disassembly system design with the information utilization by the environmental loads. The disassembly design with the PLM [7] is applied to this design procedure with the environmental loads.

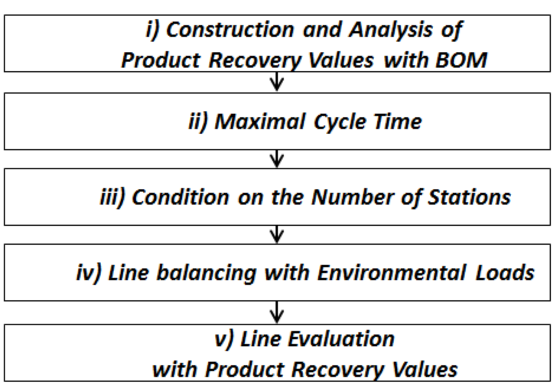

Fig. 6.5.2 Disassembly system design with the information utilization by the environmental loads

3.2 Design procedures with BOM for product recovery values

Based on the design procedure for a disassembly line in Section 3.1, a disassembly system design with the information sharing and utilization using BOM by a PLM tool is developed to consider product recovery values and environmental loads at the same time. The details of the steps are as follows:

(i) Construction and analysis of product recovery values with BOM

Collected EOL products are first referred to the BOM for their product recovery values and the environmental loads. Their disassembly process such as product refurbish, spare parts reuse or material recycling is diagnosed and decided based on the values and the environmental loads. Therefore, it is necessary to construct the Bill of Materials (BOM) and add that information to the BOM by using 3D-CAD as a PLM tool. In the BOM, a product/part structure is shown, and each part has a part number, part name, recovered price of reused parts/materials, disassembly time and his environmental loads at the same time. By including material and their weighs, the environmental loads of each part are obtained.

(ii) Maximal cycle time

The maximal cycle time is obtained by dividing the production planning quantity by the production planning period as well as the assembly/disassembly line designs.

(iii) Condition on the number of stations

The number of necessary stations is calculated by dividing the mean of total disassembly time by the maximal cycle time, and is rounded to the nearest minimal integer above.

(iv) Line balancing with environmental loads

Under the maximal cycle time, the disassembly element tasks satisfying the disassembly precedence relation are assigned to each station. To decide the assignments, 2 types of pitch diagram are made by total disassembly time and environmental loads at each station. The alternative assignments are considered in view of the disassembly times, recovered material prices and the environmental loads.

(v) Line evaluation with product recovery values

By calculating the balance delay, smoothness index, the disassembly line is evaluated whether the service times among stations have a good balance or not. In addition, the total recovery values at each recovered EOL product is shown by disassembly times, recovered material prices.

4 Design Example of Disassembly System with the Information Utilization by the Environmental Loads

4.1 Construction of Product Recovery Values with BOM

Based on the design procedure of the disassembly system with the information utilization by the environmental loads in Sect. 3.2, a design example of the disassembly system with the information sharing and utilization using BOM by a PLM tool is developed. A product example for computer and cell phone is assumed and set to valid the proposed design procedure in this study.

(1) 3D-CAD model and bill of materials (BOM)

By using SolidWorks as a PLM tool, a 3D-CAD model is first drawn, and a product/part structure table is also prepared. In the table, each part has a part number, part name, recovered price of reused parts/materials, disassembly time and his environmental loads at the same time.

(2) Material recovery values

Based on the surveyed market prices for the metal and non-metal in Japan [9], the material recovery values for each part is obtained from the weight of each part. The obtained material recovery values per product for each part are added to the product/part structure table in the SolidWorks. It is assumed that glasses and plastics have no values of the market (Table 6.5.1).

Table 6.5.1 Example of material recovery values: case of cell phone

Part name	Materials	Material prices (yen/ton)	Weight (g)	Material prices (yen/product)
Camera	Zink alloy	153,000	5.28	0.81
Speaker	Stainless steel	350,000	0.56	0.20
Battery	Nickel	20,000	58.14	1.16
Microphone	Stainless steel	350,000	0.50	0.18
Circuit board	Copper	-	85.44	120.00
Junction	Stainless steel	350,000	47.46	16.61

(3) Environmental loads

By included material and their weighs, the environmental loads of each part are obtained. In this study, the CO_2 volumes are automatically calculated by the SolidWorks Sustainability.

4.2 Analysis of Material Recovery Values with BOM

By the Step (1–3), 3 types of part information is added to the BOM for the material recovery values as shown in Table 6.5.2, environmental loads and disassembly times at the same time. By this information with the BOM, product/part lifecycle options are considered visually. Also, the cobweb chart (Fig. 6.5.3) and correlation chart (Fig. 6.5.4) are prepared for the 3 types of the material recovery values in order to make a decision in terms of the material recovery prices, environmental loads and disassembly times at the same time.

Table 6.5.2 Example of 3 types of material recovery values: case of cell phone

	Environmental loads (CO_2e)	Disassembly time (sec)	Material prices (yen/product)
Camera	0.04	7.80	0.81
Speaker	4.86	2.00	0.20
Backcase	0.25	5.00	0.00
Battery	1.01	2.00	1.16
Battery cover	0.21	1.00	0.00
Front case	0.39	3.00	0.00
Main button	0.19	3.00	0.00
Number buttons	0.20	2.00	0.00
Microphone	3.00E-03	2.00	0.15
LCD	0.03	2.00	0.00
Circuit board	0.51	10.20	120.00
Junction	0.20	7.60	0.31
Average	0.66	3.97	10.22

Figure 6.5.3 shows the analysis of the material recovery values by cobweb chart in the case of the cell phone. By each type of the material recovery values, the relative evaluations among all parts are carried out in terms of the material prices, disassembly times and the environmental loads. First, the average values among all parts by each type of the material recovery value are calculated and set as the impact 5. Next, the impacts of the material recovery values for each part are relatively evaluated as the impact values from 0 to 10. For example, it is seen that the part "camera" has the highest impact 10 for the disassembly time but the lower impact 4 for material prices and the impact 1 for the environmental loads among the parts within the cell phone.

Figure 6.5.4 shows the analysis of the material recovery values by the correlation chart between disassembly times and environmental loads in the case of the cell phone. For example, the part "Speaker" is plotted on a zone in the top and left side, which is positioned as higher environmental loads but shorter disassembly times. Therefore, this part may be disassembled due to the high environmental load but with

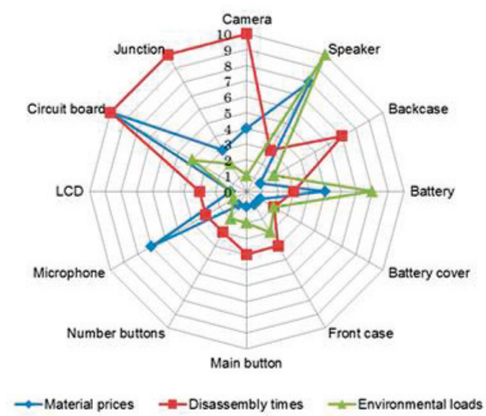

Fig. 6.5.3 Analysis of material recovery values by cobweb chart: case of cell phone

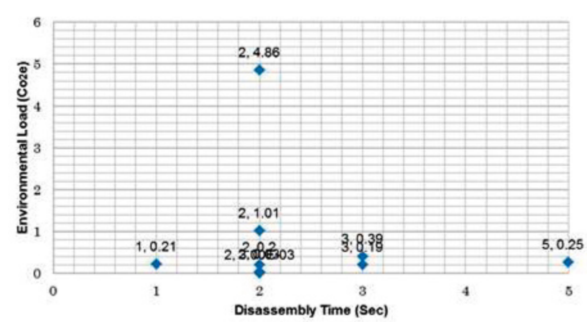

Figure 6.5.4 Analysis of material recovery values by correlation chart between disassembly times and environmental loads: Case of Cell phone

5 Design Example: Computer Versus Cell Phone

5.1 Analysis Example of Material Recovery Values with BOM

It is necessary for the disassembly line to pursue an economic design with higher recovered materials values and shorter disassembly time [7]. However, parts with higher environmental loads should be disassembled and recycled instead of the destructive disassembly. The disassembly line balancing is here designed by part recovery values such as recovered material prices, disassembly times and environmental loads at the same time.

Figures 6.5.5 and 6.5.6 show the environmental loads for each part in the case of the computer and cell phone. The line balancing designed is considered in prior to disassemble the HDD and power in the case of the computer and speaker in the case of the cell phone because of their higher environmental loads.

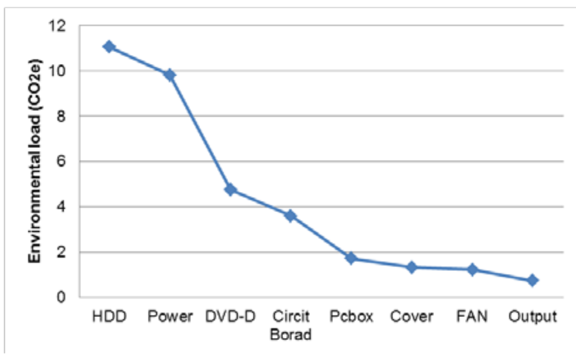

Fig. 6.5.5 Environmental loads for each part: case of computer

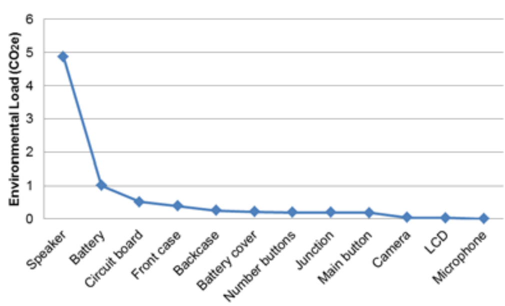

Fig. 6.5.6 Environmental loads for each part: case of cell phone

Figures 6.5.7 and 6.5.8 show a precedence relations among disassembly element task times with product recovery values in the case of computer and cell phone. Each element disassembly task show the precedence relations among tasks and product recovery values. The product recovery values are consisted of recovered material prices, disassembly task times and environmental impacts. Therefore, the disassembly line balancing is designed by considering not only the economic but also environmental aspects.

Based on the product values as shown in Figures 6.5.7 and 6.5.8, it is determined that destructive disassembly parts are selected. In the case of computer, the part of DVD-D and Output are selected because of zero material prices, longer disassembly task times and the lower environmental loads. Like the case of computers, battery, battery case, button of main and numbers and liquid crystal are selected as the destructive disassembly in the case of the cell phone.

5.2 Design Example for Disassembly System with Environmental Loads

Tables 6.5.3 and 6.5.4 show the design example of the disassembly line balancing in the case of the computer and cell phone. Each disassembly tasks are assigned to each station, and the disassembly times, material prices and environmental loads are summed for each station and the whole of the disassembly system. With the disassembly time, the disassembly time are balanced among each station. However, it seems that the material prices and the environmental loads are unbalanced among stations.

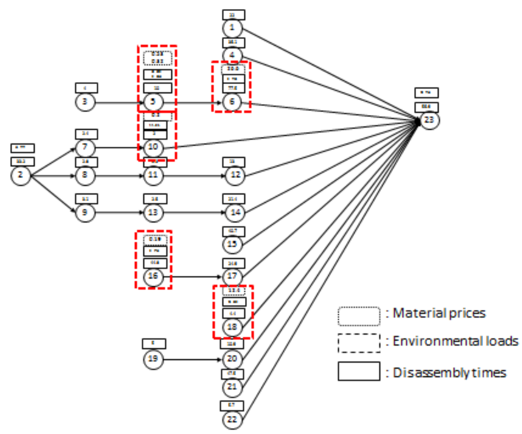

Fig. 6.5.7 A precedence relations among disassembly element task times with product recovery values: case of computer [7]

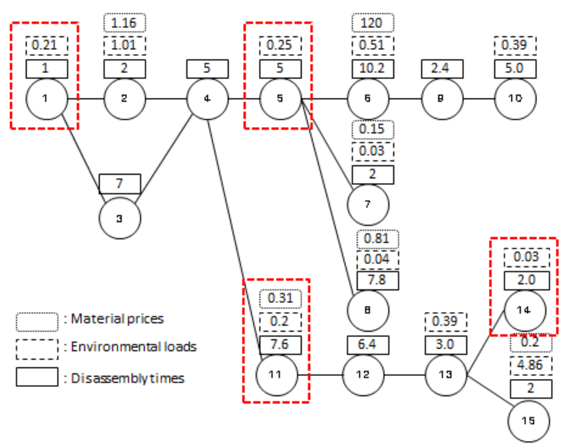

Fig. 6.5.8 A precedence relations among disassembly element task times with product recovery values: case of cell phone

Table 6.5.5 shows the design example of the disassembly line system with and without environmental loads: Computer versus Cell phone. By comparing the cases with and without the environmental loads, the total disassembly times are highly improved by 19.0% in the computer and by 24.6% in the cell phone. Therefore, it is considered that the disassembly cost is drastically reduced with higher waged countries such as Germany and Japan. Also, there is no improvement for the material prices by 0% in the computer and by—0.3% in the cell phone. In addition, the reward of the recovered materials values is almost the same as the case without the environmental loads. Therefore, the profit in the manual disassembly systems, which is the differences between the reward and cost, can be higher than one without the proposed information sharing and utilization.

However, the increase of the environmental loads is maintained within 16.1% in the computer and 8.4% in the cell phone. With the line evaluation of the balance delay and the smoothness index, the values in the both cases are basically improved except the balance delay of the computer.

Table 6.5.3 Design example of disassembly line balancing: case of computer

Number of stations	Elemental Tasks				Station			System		
	Number of elemental	Disassembly time	Material prices	Environmental loads	Disassembly time	Material prices	Environmental loads	Disassembly time	Material prices	Environmental loads
Station 1	3	4			91.5	0.85	4.95	383.1	40.24	28.78
	5	10	0.85	4.95						
	6	77.5								
Station 2	1	22			107.7	26.8	12.78			
	4	36.1	26.6	1.73						
	7	2.4								
	8	2.8								
	9	3.1								
	10	2	0.2	11.05						
	11	2.3								
	12	13								
	13	2.6								
	14	21.4								
Station 3	15	40.7			110.4	0.19	1.24			
	16	44.8	0.19	1.24						
	17	24.9								
Station 4	18	4.4	12.4	9.81	73.5	12.4	9.81			
	19	5								
	20	10.9								
	21	47.5								
	22	5.7								

Table 6.5.4 Design example of disassembly line balancing: case of cell phone

Number of stations	Elemental Tasks				Station			System		
	Number of elemental tasks	Disassembly time	Material prices	Environmental loads	Disassembly time	Material prices	Environmental loads	Disassembly time	Material prices	Environmental loads
Station 1	2	2	1.16	1.01	16	1.16	1.04	52.8	122.17	7.23
	3	7								
	4	5								
	7	2		0.03						
Station 2	6	10.2	120	0.51	20.4	120.81	0.55			
	8	7.8	0.81	0.04						
	9	2.4								
Station 3	10	5		0.39	16.4	0.2	5.64			
	12	6.4								
	13	3		0.39						
	15	2	0.2	4.86						

Table 6.5.5 Design example of disassembly line system with and without environmental loads: computer versus cell phone

Types of Products		Computer			Cell Phone		
Environmental loads		Without	With	Differences (%)	Without	With	Differences (%)
Product	Total disassembly time [sec]	473.20	383.10	-19.0	70.00	52.80	-24.6
	Material prices [yen/ product]	40.24	40.24	0.0	122.63	122.32	-0.3
	Environmental loads [CO2e]	34.29	28.78	-16.1	7.89	7.23	-8.4
System	Blance Delay	0.19	0.47	146.3	0.67	0.30	-55.8
	Smoothness Index	105.30	41.55	-60.5	47.61	5.95	-87.5

6 Summary

This study considered the environmental loads for the recovered parts/materials as well as the product recovery values and the system efficiency in the disassembly system design, and proposed the information sharing and utilization for lower environmental loads in the disassembly system design with PLM. By information sharing and utilization of the product recovery values with the environmental loads, it is considered that the economic design for the disassembly system can be done by maintaining the limited environmental impacts.

Future challenges should optimize the disassembly line balancing in terms of the material recovery values, share this disassembly factory design with a product designer, etc.

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6.6 Performance Indicators for Quantifying Sustainable Development: Focus in Reverse Logistics

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Abstract

Sustainable development is based on three basic components: environmental sustainability, economic sustainability and sociopolitical sustainability. Economic sustainability is in reality the incorporation of environmentally friendly measures in the regulated social and economic policies of each country, in an effort to integrate the principles of social equality, environmental preservation, controlled and sustainable economic growth, in which profit is not only calculated by financial terms, but also in terms of human development. Parallel to this, the concept of reverse logistics has gained increased attention in the corporate environment. The inclusion of practices in which the company is responsible for collecting and recycling its own used products is not only positive from an environmental perspective, but also an important means of generating employment and of social inclusion, which along with environmental preservation form the bases of sustainable development. In this context, this article aims to propose and present indicators, as well as their interrelations, which could help to measure the level of sustainable development in an initiative, program or process, from the perspective of reverse logistics. A study case in which these indicator were applied will also be present.

Keywords:

Performance indicators, Sustainable development, Reverse logistics

1 Introduction

Many companies have taken the lead in regards to the final destination of their waste, the reuse of intermediate materials, and of after sales and post consumer products. This concern can be attributed to number of factors, some which are: global responsibility, which has gained strength; currently laws that continually require more alternatives for the reduction of the environmental impact, and the search for competitive advantages.

Furthermore, sustainability has taken a central role in discussions about the dimensions of development and of its alternatives. The socio-environmental scenario revels that the impact of human beings on the environment has reached increasingly more complex dimensions, in both qualitative and quantitative aspects [1]. Nevertheless, the ethical and social dimensions of sustainability remain largely unexplored, particularly when applied to reverse logistics [2].

In analyzing the area of logistics, organizations that offer reverse logistics as part of their services standout. Reverse logistics represents an adequate commercial solution in the a post-consumer and after-sales processes and helps to add value to products with a clear return policy, due to commercial, legal, operational or environmental reasons [3].

According [4] and [5], the focus on logistics becomes strategic, economic, environmental and social, and is no longer simply operational, increasing its relevance as a tool to ensure market shares.

Furthermore, according to [2] Reverse Logistics is a organizational strategy and that can help decelerate or prevent environmental degradation. It can also influence a number of social issues beyond just environmental concerns, and that issues from an ethical and socially responsible viewpoint have significant room for investigation.

Considering the scenario presented, it is possible to identify a great pressure for sustainable reverse logistics initiatives that can contribute significantly to society. In this context, this article outlines the role of reverse logistics inside companies, by evaluating the role it plays in social sustainability, since this is an aspect that has received little attention [2]. This article also presents relations that were developed from existing indicators, which make it possible to measure the impact of reverse logistics activities, in order to analyze its contribution to itself and the community in which it is inserted, from the point of view of reverse logistics and of social sustainability, from the economic and environmental perspective.

2 Reverse Logistics

The Reverse Logistic Executive Council (RLEC) [6], world reference on the topic, defines Reverse Logistics as the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process product, finished products and related information from the point of consumption to the point of origin for the purpose of recapturing value or the proper disposal of the product. It also states that Reverse logistics is more than reusing and recycling containers and packaging materials, it also includes returned merchandise due to damage, remanufacturing activities, hazardous waste treatment and resource recovery, in other words, it can be considered the management of the product life cycle [4, 5, 7].

According to the Brazilian Reverse Logistic Council (CLRB) [8] reverse logistics plans, operates, and controls the physical and information flux, for returning products from after-sales and post-consumer to the commercial or

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productive cycle. This is accomplished through Reverse Distribution channels, adding different types of value to the product: economic, ecological, legal, service and of corporate image [8]. Due to its wide range of application, investments in the area of reverse logistics are driven by several factors, which must meet the organization´s strategic objectives. The level of importance of the following factors vary from organization to organization, and are more or less active depending on the sector the organization operates in [9].

Economic—the reuse of parts and components from products allows producers to economize on purchasing virgin raw materials and provides consumer products at a lower price. For market conditions to be satisfactory, the return of goods and services must be sufficient and constant in order to ensure steady economic profitability [9, 10].

Environmental—the reuse of materials as secondary raw-material reduces the need for direct extraction of natural resources. And it also reduces significantly the amount of waste sent to landfills [9].

Legislation—the responsibility of the production industry steadying increases, due to stricter legislation that pressure the productive sectors to operate within environmentally friendly parameters [9].

Social—directly connected to society´s economic, cultural and professional development, with income generation through employment opportunities and sustainable alternatives in the use of materials [9].

Logistical—characterized by the conditions of adjusting all the steps in the reverse supply chain, such as pick-up, processing and redistribution to end users [10, 11].

Technological—related to technological advances regarding recycling, integrated systems to monitor de flux of the processes, and to projects of products with the objective of facilitating the reuse capacity of the product [10, 11].

It is important to observe that each investment factor has its own indicators, so the evolution of its objectives are measured individually. Thus, there is only a myopic view of the gains, which can often have conflicting objective.

2.1 National Solid Waste Law and Social Sustainability

In Brazil, the National Solid Waste Law was signed in August 2, 2010 [12]. This law prohibits waste from being disposed of in beaches, rivers, lakes and open burnings. It also encourages recycling and prohibits the collecting of recyclable materials at garbage dumps or landfills. In addition to these guidelines the National Policy on Solid Waste sets incentives for garbage collectors cooperatives, plans for solid waste, environmental education, inventories, and the annual solid waste declaratory system and for waste sorting. It also establishes shared responsibility for product's lifecycle, which includes manufacturers, importers, distributors and retailers, consumers and the companies that are responsible for city sanitation and solid waste management.

Other initiatives directed at the management of social responsibility, associated to sustainable development and waste management are found in the Brazilian norm ABNT NBR 16001:2004, which addresses the management system and social responsibility, not with the objective of obtaining certification, but of showing concern in the matter [13]. According to ISO 26000 [14], published on November 1, 2010, deals with social responsibility from seven central topics, among which are: the environment, community involvement and development and consumer issues. Finally, the Brazilian norm ABNT NBR 14001:2004 specifies the requirements for environmental resources management systems and enables the organization to develop and implement policy and objectives which take into account legal requirements and information about important environmental aspects. The goal of this norm is the certification on the company's environmental resources management system [13].

An expansion of frontiers in services, can be observed, with a great variety of treatments for post-consumer products, and the possibility of shared responsibilities with consumers. In the process of product return consumers have become just as important as the manufacturing industry [10].

Thus reverse logistics is no longer limited to environmental principles, shaping a new scenario in which Social Sustainability becomes one of the important components of sustainable development.

Sustainable development is understood as the process in which, in one hand, the most significant restrictions are the ones relate to the exploitation of resources, technological development and the institutional framework and in the other hand, growth must emphasize qualitative aspects such as, the use of resources and the generation of solid waste. Development must focus in overcoming the social deficit, in basic needs and in changes of consumption patterns [1].

Accoording to Sarkis et al. (2010), sustainability has at least three major dimensions—economic, environmental and social. While environmental sustainability emphasizes the management of natural resources, social sustainability emphasizes the management of social resources, management including people's skills and abilities, institutions, relationships and social values [15].

Social sustainability is defined as any attitude with the purpose of social resource management, which includes professional development and characteristics that society may deem desirable in citizens, translated into social values [15]. This includes raising educational standards, nation's health, maintaining of cultural diversity and support for social justice issues [2].

Finally, according to Hutchins and Sutherland [16], it is common for business decisions to be made based on the economic dimension of sustainability, and that in the last decade, efforts have increasingly been directed to the environmental dimension, but just until recently the social dimension had not been well defined. Figure 6.6.1 illustrates this development.

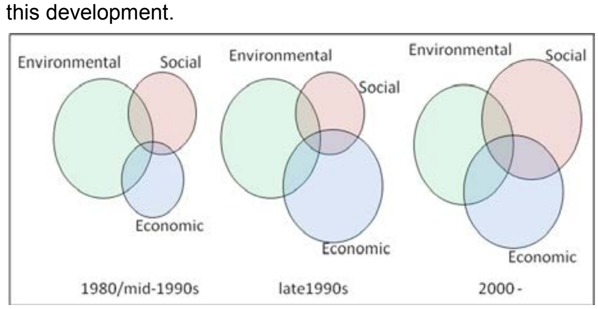

Fig. 6.6.1 Increase the proportion of interest directed to social development [17]

The authors also explain that this topic has received little attention in literature and that when it is mentioned, the emphasis is on policy issues or on health and safety rather than the ethical and cultural ramifications. The ethical and social dimensions of sustainability, particularly when applied to reverse logistics, remain largely unexplored [2].

3 Performance Indicators for Quantifying Sustainable Development

With the objective of measuring the quality of their actions, of identifying problems and assisting in finding alternative solutions, performance indicators predict consequences and optimize the use of available resources, and are a essential instrument in the construction of the evaluation process [9].

However, according to Colantonia [17] there does seem to exist a consensus on the criteria, indicators and perspectives that should be adopted to define social sustainability.

Within the presented context the main areas that make up the concept of sustainable development were defined, as shown in Fig. 6.6.2.

Fig. 6.6.2 Performance indicators that assist in quantifying sustainable development

Based on these areas, the respective indicators were selected, which can assist in measuring the degree of sustainable development within an initiative, program or process. Each of these areas and their respective indicators, are presented below.

3.1 Reverse Logistics Indicators

Indicators related to the efficiency of the return process, such as; the product return rate, reuse rate of each part in the product, partnerships with industries that use the waste generated by the reverse logistics, number of process alternatives and products benefited by the recycled parts.

3.2 Economic Indicators

It is important to note that economic indicators are not always linked to profit. An economic indicator can be used to analyze possible gains, such as reducing waste and losses, efficiency increase, cost reduction, which could generate long-term financial profit.

3.3 Environmental Indicators

These indicators are used to analyze reduction level in environmental degradation. They measure how much natural resource is saved, and how the reverse processes may be useful in sustainable development.

3.4 Legislative Indicators

The indicators of legal factors, identify the level of legality and compliance with standards and goals set by regulatory bodies, laws and decrees. It is interesting to note that Reverse Logistics, when applied to any sector, must meet several legal aspects.

3.5 Social Indicator

Are used to measure the outcome of corporate social actions, because they contribute to increased rationality in decision making, in identifying problems, an aid in the search for alternative solutions, anticipating consequences and optimizing the use of available resources [18].

3.6 Technological Indicators

Are indicators related to the technology used to monitor data, consolidate the process, disseminate information, improve effectiveness in the use of waste, and provide alternatives for recovery, with the objective of reaching as many companies as possible.

3.7 Stakeholders Perspective

The term stakeholder is utilized to define any group or individual, who affects or is affected by the achievement of business objectives [19]. According to [20] the initial idea of the term was to designate all groups without which the company would cease to exist, which include shareholders, employees, customers, suppliers, creditors and society. Each stakeholder has a different criterion of reaction because it has a different interest in the organization [21].

The return of institutional social corporate arising from stakeholders can be realized through profit and sales as images and strengthened brand loyalty and product, enhancement of business in society and the market, attracting investors and shareholders, advertising payback due to spontaneous generation of media; possibilities of tax exemptions, greater commitment and motivation of employees, and social gains by behavioral changes in society [22].

According [23] the Rio Declaration includes several specific principles addressing the role of social considerations and stakeholder participation in sustainable development. Principle 1 states that human beings are at the center of concerns for sustainable development, while the Principle 5 calls the erradication of poverty, a goal addressing both economic and social concerns. The specific issue of stakeholder involvement is adressed by Principle 10, which clearly sets out the need for participation of concerned citizens at all levels of government, including dissemination of information and effective access to judicial remedies.

Therefore, it is necessary to analyze the consumer perspective, in terms of development of social projects in various companies, as this tends to value the contribution of corporate social and even punish those who consider acting improperly.Lastly, the interrelations between the indicators of each area that make up sustainable development were defined. Each column, based on a reverse logistics process that reuses, recycles or remanufacturing materials, will consequently, have impacts on other areas, as shown in Table 6.6.1.

Table 6.6.1 Relationship between the performance indicators of the factorsimpulsionantes of reverse logistics

Reverse logistics (logistics factor)	Economical factor	Environmental factor	Legislative factor	Social factor (sustainability)	Technological factor	Stakeholder perspective
Return Rate	Percentage of direct and indirect cost reduction	Less need for landfills	Achievement of objective specified in regulatory standards	Development of society with the benefit generated by recycling	Technological advances for reverse processes	Disclosure of Information and Increasing environmental awareness
Number of collection station	Transportation cost reduction	Lower emissions and fuel consumption	Disposal alternatives and legislatives conditions for the consumer	Ease and convenience for the population	Data control	Increasing environmental awareness
Alternatives for solid waste recovery	Less material waste	The life span of the material is renovated at every cycle	Evolutions of laws and their application	Research and development on new possibilities incentive	Technological advances for reverse processes	Interest and participation by the company
Skilled labor	A more efficient process	–	Professional development	Reverse logistics as a means for generating income	Reduction of process and rework time and quality increase	Increased investment in skilled labor
Labor availability	Income increase per capita	–	Compliance to labor union's requirements	Unemployment reduction	Level of technology dissemination	Highest level of customer satisfaction
Government incentives	Investment	Increase of activities for material recovery	Increased number of enterprises in accordance with current legislation	Greater access to products with lower costs	Technology acquisition	–
Intersectoral partnerships	Sharing of responsibilities	Companies the utilize the residue generate by the reverse logistics	Supply chain integration level	Active participation in the process	Tools sharing	Increase in intersectoral partnerships
Processes audit and standardization	Decrease of the losses generated by the process	Assurance of processes with lower environmental impact	Product specification in accordance with the current legislation	Customer satisfaction	Increase in control of processes	Increase the reliability of the final product
Accountability report	Competitive advantage and trust	Incentives for environmental initiatives	Accountability to regulating agency	Dissemination, Information and greater participation	Choice of information model	Recognition by society

4 Study Case: Walmart Brazil

Based in areas identified with different degrees of impact on sustainable development, their indicators and how they relate to each other, an initiative/program was selected in order to test the applicability of the indicators.

The Walmart Institute [24] was established in 2005 and has since actively participated in the development of the local community. To this end, Walmart has made social investments, in programs for income generation, youth professional development, local development and cultural appreciation. With more than 63 social projects and approximately 15,000 people benefited, the institute also donates food that is not within standard sales, nevertheless within the consumption standards to different associations. Thus, the Walmart Group plays major role in the Brazilian context regarding responsibility related to environmental problems.

The objective of the Zero Impact program is to improve internal processes, waste recycling and reuse initiatives, with five stages of development, such as the management plan, training, implementation, monitoring and reduction. For a branch to be considered adherent to the program at least 25% of all the waste, must have a destination that is not the landfill [9]. The program has the support of nine suppliers. Since 2010 an agreement was made, with the objective of reducing the use of natural resources, improving transportation, and also reducing the amount of waste generated from manufacturing processes of products sold by the supermarket chain. This program is considered a worldwide reference, and suppliers of products that represent 40% of all who are engaged in this project are, 3M, Cargill, Coca-Cola Brazil, Colgate-Palmolive, Johnson & Johnson, Nestle, Pepsico, Procter & Gamble and Unilever. For 18 months Walmart along with the suppliers and the Center for Packaging Technology (CETEA) studied ways to reduce the impact caused to the environment at every step of the cycle.

As a direct result, in 2009, as shown in Table 6.6.2 [19relatorio walmart], Walmart Brazil reused 41% of the waste that was not sent to landfills, that is almost double the amount of the stipulated 25% [24].

In 2009, 6.7 thousand tons of plastic, paper, cardboard, glass and aluminum returned to the production cycle, thanks to the help from the cooperative of garbage collectors, thus generating income for approximately 2.800 recyclable material collectors.

4.1 Application of Indicators in the Initiatives Taken by Walmart Group

From the indicators presented in Sect. 3 and defined in Table 6.6.1, we analyzed the Walmart initiative Group in Brazil. For this analysis we collected data available in reports and also on the web. The insertion of the actions taken by the Walmart Group in Brazil, within the proposed indicators, makes it possible to analyze all the factors impacting areas for logistic, economic, environmental, legislative, social and technological, as Table 6.6.2.

Analyzing Table 6.6.2 you can see that almost all areas that characterize a sustainable development, are present in the initiative group. A deficiency can be seen in the legislative field. This is because Brazil is still developing legislation that reflects environmental awareness, income generation and promoting sustainable development.

There is also a high degree of maturity of the Walmat Group in Brazil, with regard to the factor of social sustainability, promoting the creation of worker cooperatives, which promote the generation of income.

Walmart Group in Brazil has been an example to follow. The initiative arising from this retailer has surrendered to the group numerous awards, national and international, related to the environment and sustainability that are just the beginning of what can be done to contribute to sustainable development.

Table .6.6.2 Application of indicators in the case of Walmart group

Reverse logistics (logistics factor)	Economical factor	Environmental factor	Legislative factor	Social factor (sustainability)	Technological factor	Stakeholder perspective
High (in 2009, 41% of waste was collected)	Increased income generation	Reducing waste products incorrectly	Compliance with the National Solid Waste Policy	Cooperatives have the opportunity to mediate the process of recycling and waste collection	Development of the labor of waste pickers	Disclosure of Information and Increasing environmental awareness
High (in partnership with suppliers)	Forecast to increase collection	Support for the increase in the amount of recycling materials	Division of responsibilities	Ways to increase participation of consumer	Points permanent collection of materials	Increasing environmental awareness
Possibility of reuse of organic waste	Gain on raw materials	Minor contamination by organic waste	Removal of substances harmful to nature	Health conditions high	Different ways of processing waste	Interest and participation by the company
Projects for the professionalization of youth	Higher qualification in handling, less loss in recycled materials	Reduction of losses due to lack of skilled labor	–	Opportunity to generate income in a formal way	Harnessing the ability to reuse materials	Increased investment in skilled labor
–	Possibility of professional development	–	–	Alleviation of poverty, violence, delinquency. Increased education, cultural level	–	Highest level of customer satisfaction
–	–	Informação alcança maiores públicos	–	Oportunidade de aprendizado e suporte no descarte	Ampla disposição de recursos	–
Program with the participation of nine suppliers	Competitive prices	Low probability of improperly discarded products	Integration of responsibilities of producers, consumers and government	Consumption of products within environmental standards	Improved manufacturing processes for reusable and recycled products	Increase in intersectoral partnerships
Opportunity for the development of independent producers	Income generation through reuse of material	Possibility of craft production without generating pollution	–	Participation of consumer and producer cooperatives or crafts workers	Developing new ways of processing waste products	Increase the reliability of the final product
Walmart report, available in http://www.walmartsustentabilidade.com.br/relatorios-e-cases/	Creating bonds of trust and credibility	Providing data that contribute to statistics related to the use of reverse logistics and income generation	Accountability to the community and investors	Tips and information that add knowledge of the community in creating environmental awareness	Information that reaches the consumer	Recognition by society

5 Conclusion and Future Work

The definition of the interrelation between the indicators for each of the areas that make up sustainable development, allows analysis of an action on a global basis. Thus it is possible to analyze and work on strengths and weaknesses of each institution.

When be based on a reverse logistics process, the quantification of results becomes easier, since the indicators in this area are already consolidated in the literature.

Work to quantify the sustainable development and to enable a broad view of its various areas, economic, environmental, legislative, social, technological, and stakeholder perspective, are still rare.

It is believed that from this first initiative, new research can be generated, such as the creation of different weights to relate the different indicators.

The creation of these weights allow the development of models, which help companies focus their efforts on areas that will be most interesting. Considering the different interest groups to be served.

As future work, we intend to develop a methodology based on a model that quantifies the degree of importance of each of the areas that make up sustainable development within an initiative, process or reverse logistics program presented.

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6.7 Reverse Supply Chain Framework Proposal for Malaysian Automotive Industry

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Abstract

Automotive product recovery is a process in which End of Life Vehicles (ELV) are recovered from the end user to allow reuse, remanufacture or recycling. The goal is to reduce dependency on virgin materials whilst reducing disposal of automotive waste. While being actively implemented in automotive manufacturing countries such as United States, Germany, Japan, Korea and China, Malaysia has yet to develop its recovery framework. This paper reviews the existing automotive industry framework and a reverse supply chain framework for use in Malaysia were then proposed to further facilitate automotive product recovery in Malaysia

Keywords:

Automotive recovery, Reverse supply chain strategy

1 Introduction

With the formation of the national car project in 1983, Malaysia through its first national car company, PROTON has been producing passenger cars for the mass public. This production spurt in cars saw another growth with the introduction of a second national car company, PERODUA (which has ties to Daihatsu Motors Company) in 1994.

According to the International Organization of Motor Vehicle Manufacturers (OICA), the global total production volume for cars for the year 2010 is 58.2 million cars (an increase of 22.2% from 2009), out of which Malaysia produces 522,568 (an increase by 16.9%) [1]. The report also shows that Malaysia is currently the 8th largest car producer in the Asia-Oceania block. For the past 12 years, production of cars is growing at a rate of 2.78% as shown in Fig. 6.7.1 while Malaysia's data is shown in Fig. 6.7.2.

Given that the average weight of a car is 1000 kg and the average use life for a car is around 10–15 years, a country such as Malaysia, who has yet to prepare for the recovery of ELVs, could be facing a scenario of massive pile of junk weighing 94,807.5 tons in around 2–3 years time (assuming 75% from cars produced in 1998 are to be retired, and no other ELVs from other years making up the numbers), out of which around 60% from this would be steel (56,884.5 tons, and at best recovery rate for ferrous which is at 95%, this would be 54,040 tons). In comparison, the Petronas Twin Towers which is currently the highest twin building in the world, requires 18,455 tons of steel (10,955 tons for reinforcement and 7,500 tons for structure) [2]. It is also worth pointing out that the volume mentioned here corresponds to the production volume for 1998, which is the lowest number in the last 12 years. Unless an integrated recovery plan, which involves the manufacturers are initiated soon, this scenario would be a waste to the environment and to the society.

2 Literature Review

Numerous ideas and concepts have been given to the development of ELV recovery. Guide et al. [3] described such a system as a recoverable product environment, where processes in a system were designed to extend product life and ultimately recover materials via recycling at the end of the product life. The key to the system is its recoverable manufacturing system, in which repairs and remanufacturing would be the main focus.

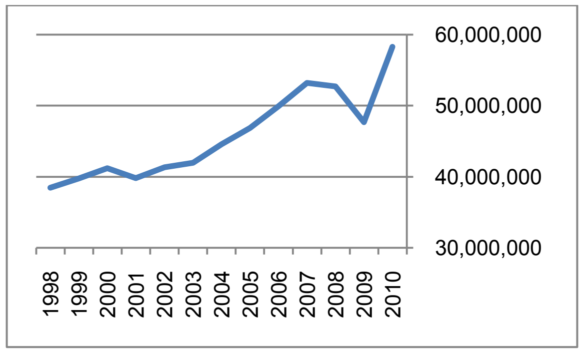

Fig. 6.7.1 Global car production performance

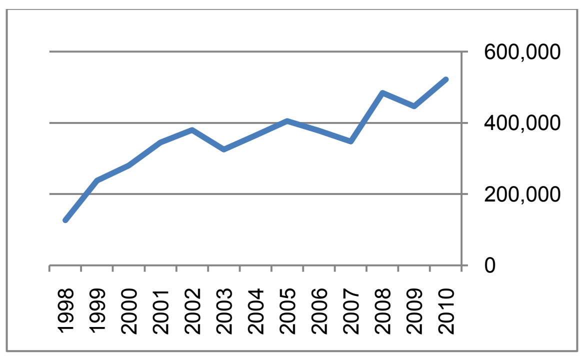

Fig. 6.7.2 Malaysia's car production performance

As the need to recover materials from End of Life Products became a reality, more ideas on such a system were developed. Blumberg [4] defines a full Closed Loop Supply Chain (CLSC) to be made up of a combination of : (1) Forward Logistics and Direct Supply Chain; (2) Reverse Logistics—which covers pickup and delivery of parts and products from the field to reprocessing and back to the field again; and (3) Depot repair, processing, diagnostics and disposal—which covers processes to diagnose, repair and/or dispose returned units/products/sub assembled

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products/materials either back to Forward Logistics or secondary market or full disposal. He further classifies the automotive market to reside in a consumer goods market (as opposed to a high technology products market) thus operates in a consumer oriented CLSC, where among the key requirements to reverse logistics would be the ability to interface with a variety of end users and parts depot(s), with the added responsibility for a rapid delivery for refurbishment or repair.

Reverse Supply Chain Management (RSCM) is another term to describe CLSC. Prahinski and Kocabasoglu [5] define RSCM as the series of activities required to retrieve a product from a customer and either dispose of it or recover value. Guide and Van Wassenhove [6] suggested that RSCM be organized sequentially in five key steps: (1) Product Acquisition; (2) Reverse Logistics; (3) Inspection and Disposition; (4) Reconditioning; and (5) Distribution and Sales.

The objective of this paper is to present the development of the reverse portion of the supply chain. It will be used to define the activities in which an ELV is to be: (1) acquired from the end user; (2) transported to a disassembly plant in which components will be disassembled and sorted; (3) transported to the next recovery process, either remanufacturing, repair, recycling or simply disposed off; and (4) transported back to the user. It will cover the processes involved in these steps plus transportation and logistics needs.

2.1 ELV Reverse Supply Chain in Practice

Ogushi et al. [7] describes that in Japan, the ELV Recycling Law mandates manufacturers to be responsible for the recycling of Automotive Shredder Residue (ASR) and airbags, plus destroying CFCs. The remaining of the system will be left to the existing mechanism and market, in which 5000 dismantlers processes around 4 million ELV per year, and the level of dismantling largely depends on market conditions, rather than reusability. In such an environment, he suggested that a closed loop system is unlikely because considerations need to be given at design and production stages.

In comparison, China which has 356 ELV dismantlers, 800 take back stations, dismantling capacity of 1.2 million per year and employs 16,000 employees in the industry, produces 200 million tons of scrap steel and 50,000 tons of non ferrous metal each year. However, issues with tools and secondary pollution plus the unpopularity of reused and remanufactured parts are limiting the full potential for the Chinese industry [8]. Nevertheless, it is considered a good yield considering that in China, there are no fixed years for compulsory dismantling of passenger cars (non business use passenger vehicle, less than 9 seats) plus there are no limit for extended use (on top of 15 fixed years of usage), except for twice yearly technical inspection for vehicles aged 16 years and above.

The Chinese Automotive Products Recycling Technology Policy (2006) was developed in response to the EU Directive 2000/53/EC. In the case of the BMW Group Germany, it has acknowledged used cars as an important source of materials, and has run a large scale trial in 2007/2008 on 501 current pre-series vehicles [9]. However, only components which has demand (such as wheels, front and rear lights) were dismantled. Another German car manufacturer, Audi believes that using recycled materials is an inferior option as opposed to lightweight construction, and this was proven using an experiment of two Audi A3 1.8Ts which ran over a distance of 200,000 km (one being 15% of lightweight construction, and the other 15% using recycled materials) and gave the result in favor of lightweight construction (by energy savings) of 48 GJ as opposed to 0.54GJ (even though it meant that there are an additional 22.8 kg of non metal to be recycled) [10]. It can be seen that by considering reverse flows during design stage, a manufacturer could benefit from direct (component reuse, material recycling) and/or indirect (energy savings by lightweight construction) means.

Managing ELV in the United States is slightly different than the EU. According to Kumar and Putnam [11], recycling in the United States is more focus on profit. Among the possible causes to this is the lack of national legislation in place to enforce OEM take back, thus prompting private enterprises to handle the recycling cycle. These private enterprises which consist of dismantlers, shredders and material recyclers, are integrated into the supply chain, and more than 95% of total ELV (roughly around 15 million cars a year) enters this recycling cycle. Concerns on recyclability of vehicles is high as it was observed that since 1978, the weight of the passenger car has decreased by 136kg, and for the same period, usage of regular steel and iron decreased by 318kg, whilst high strength steel, aluminum and plastics has increased by 91kg, 45kg and 34kg respectively; making it harder to recycle, which entails less profit [12]. On average, 75% of its materials are profitably recovered and recycle. Bandivadekar et al [13] further categorized ELVs in the US into two types—new (retiring at 8 years or less), and old (usually abandoned because accident or lack of dismantling facility) in which an old ELV may remain with the dismantler for up to 2–5 years.

In Brazil, a proposed sound ELV recovery management program (for Battery Recycling) should consider: (1) an efficient collection system at local and national level; (2) promotes materials, product and process development towards a cleaner recycling technology; (3) extends polluter pays principal to OEM; and (4) minimizes transportation waste [14]. Even though most of the proposed items were made for Brazil (and its geography), the spirit behind it is to ensure a reverse flow would be more beneficial to the environment. Such a concept in which the environmental and societal concerns were put into consideration was also discussed by Jayal et al. [15]. They further discussed that in designing a closed loop system, the challenges would be in: (1) integrating product design within the supply chain; and (2) integrating the 6R approach (reduce, reuse, recycle, recover, redesign, remanufacture) together with environmental and societal constraints, plus economic benefits.

In Malaysia, a closed loop supply chain specific for the automotive industry has yet to be established, partly due to no ELV legislation plus the lack of industrial experts in component reuse [16].

2.2 Existing ELV Reverse Supply Chain Framework

A comprehensive reverse supply chain framework for the automotive industry would be made up of several key integrated components. As shown in Table 6.7.1, common components would be: (1) Dismantlers—tasked to disassemble, removes fluids and hazmat whilst also recover components for remanufacturing, and reuse; (2) Shredder—material recovery process in which ferrous and non ferrous materials are recovered; and (3) Automotive Shredder Residue (ASR)—a byproduct of shredding in which it will have to be land filled with penalty to the manufacturers.

It is also worth pointing out that in the mentioned frameworks, all of these key components are integrated with the OEM, since it would be beneficial to the dismantlers and (to some degree) shredding companies, as information on disassembly sequence would lower the time needed to disassemble a component thus lowering its cost to disassemble (as reprocessing cost is a factor of time [21]). Even though databases such as the International Dismantling Information System, IDIS [22] is capable of providing disassembly companies with disassembly related information, these information does not show proper disassembly sequence and time required, but rather shows suggested equipment and what to remove in a given model. Recoverable components might get damaged if improper methods are used to disassemble it, thus might render it from being profitable to disassemble to a component not worth recovering.
In Malaysia, there are no disassembly companies or shredding companies which integrates its operations with the OEMs.

Table 6.7.1 List of existing automotive recovery framework

Author, Location	Key Stages / Players	Key Components
Daniels et al. [12], North America	Auto supplier	Material usage (Recycled / Virgin)
	Vehicle design, Mfg	Component Type (OEM / REM)
	Dealership, Authorized Service and Repair Centers	Under Warranty
	Independent Service and Repair Centers	Out of warranty
	Dismantlers, Salvage Yards	Parts, Tires, Fluids, Batteries, Core
	Shredders	Core, ASR, recovered materials
	Auto reuse	Reman, Reuse
Bandivadekar et al. [13], North America	Users	Auto usage, reuse market, refurbish vehicle, ELV
	Dismantler	Disassembly of ELV, recover components for Reman and used part supplier, Hulk
	Shredder	Recovered materials, ASR
	Used part supplier	Refurbish vehicles
	OEM and Supplier	Manufacturing
	Landfill Operator	ASR disposal
	Primary Material producer	Raw material, Recycled material
Schultmann et al. [17], Germany	Customer	ELV
	ELV dismantler	Dismantling and material separation
	Shredder Operator	Cannibalized ELV, ASR (Fluff), recovered materials
	Specialized reprocessing Company	material reprocessing
	Supplier	Part production
	Manufacturer	Vehicle production
Author	Key stages / players	Key components
Ferrao and Amaral [18], EU, Portugal	Recycling Industry	Recycled materials for component manufacturer and raw mat manufacturer
	Dismantler	Recovered materials for the recycling industry, Recovered parts for the REM market, Core sent to Shredder
	Shredder	Recovered materials for the recycling industry, landfill, energy valorisation
Williams et al. [19], (none specified)	Consumer, auctions	ELV
	Dismantler	Reusable parts and components, tires, fluids, hazmat, flattened hulks
	Scrap metal dealers	Flattened hulks
	Auto recycler	Recovered material, waste
Qu and Williams [20], (none specified)	Last owner	ELV, used car
	Used car dealer, auction	ELV
	Scrap metal dealers	Tire, fluids, fuel, hazmat, high value metal parts, hulk
	Auto dismantler	Tire, fluids, fuel, hazmat, reusable parts, hulk
	Auto shredder	Hulk, ASR, recovered materials
Kumar and Putnam [11], (none specified)	Recovery	Fluid removal, disassembly sequences, compression and cutting of hulk
	Shredder	Hulk
BMW Group Brochure [9], Germany	Vehicle acceptance	Vehicle assessment, determine extent of disassembly
	Neutralize pyrotechnic devices	Airbags, seatbelt tensioner

	Remove fluids	All operations fluids
	Remove hazmat	Batteries, Halogen bulbs
	Dismantling	Marketable used parts, materials
	Remove core scrap	Engine, transmission
	Shredding	ASR

2.3 Selected General Reverse Supply Chain Methods

Besides looking just into existing ELV in practice and frameworks, other relevant literature with useful and supporting information was also used in developing the Malaysian framework. One such system is the introduction of proactive acquisition alongside a passive acquisition process [23]. Adapting proactive acquisition to an environment where there is no legislation in favor of take back laws, would allow OEMs to acquire higher quality ELVs, as opposed to a passive acquisition process in which all ELVs are acquired and OEMs will have to sort the good from the bad. This additional process would incur cost thus reducing possible profit.

Nevertheless, even by implementing proactive acquisition, it is understood that for each component which is to be recovered, be it by remanufacturing means or repair, there would be N quality classes with matching remanufacturing and/or repair cost. By ignoring uncertainties of quality can lead to acquiring not enough or too many ELVs, thus increasing demand uncertainty [24]. Therefore, the focus would be in managing the product acquisition process, where an OEM needs to acquire the right quantities of the right qualities, so as to maximize profits [25].

However, it would be time consuming to evaluate the quality condition of each component in an ELV. It is therefore proposed that a thorough inspection be carried out on a selected number of components, as listed out in Table 6.7.2.

Table 6.7.2 List of automotive remanufactured components

Author	Common remanufactured automotive components
Chen and Zhang [8]	1. Engine 2. Transmission 3. Generator 4. Starter 5. Steering
Amelia et al. [16]	1. Clutch 2. Brake Shoes 3. Engine Block 4. Starter 5. Alternator 6. Water Pump 7. Carburator

3 Framework Development

Due to the size of the proposed framework, only pertinent elements will be described. It has broken down into four product life cycle stages: (1) Pre Manufacturing; (2) Manufacturing; (3) Use; (4) Post Use. This framework is developed to operate in an environment where ELVs are not recovered under legislation, thus making recovery rate low.

Pre Manufacturing Stage

The framework captures the following processes for this particular stage: (1) New Model Design and Component Improvement; and (2) Material Selection (Virgin or Recycled). Table 6.7.3 gives further details to this stage.

Manufacturing Stage

For this stage, the manufacturing term covers OEM activities as well as REM activities. In this framework, the recovery rate is low and supply of ELVs would be a challenge. It might disrupt customer demand if REM (or OEM) market depends solely on recovered (remanufactured and/or repaired) components. Therefore, decision points were set up both in the OEM production and REM warehouse utilization as to when to use recovered components as opposed to new components. To factor in possible use of recovered components in future design, another decision point is set up before component utilization (into OEM/REM production cycles), and is integrated with the Design Database. Recovered components which have potential future use would be kept in a warehouse and will only be utilized once the intended model is mass produced. Table 6.7.4 gives further details on this stage.

Table 6.7.3 Pre manufacturing stage details

Process	Input	Output
New model design and component improvement	Component feedback from damaged parts, Input from current and future users	Design database
Material Selection	Design Database (mixture rate, which component to use recycle, which to use virgin), recycled material, raw material	Required material for vendor and/or OEM production

Table 6.7.4 Manufacturing stage details

Process	Input	Output
New car production	Design database (which component to use mixture of recovered and new, which to use new only, which to use recovered), new Component (inclusive parts produced by vendors—which may or may not be of new /recovered components as well) , recovered components (for new car production)	New car
Spare part utilization (at spare parts warehouse)	New REM component by OEM and vendor, recovered components (for spare parts) by OEM and vendor	Spare part to replace damaged parts
Recovered part	Design database (which component to	Recovered components (for

utilization (into production)	utilize in current mass produced car, which to utilize in future model), recovered components (for new car production)	new car production)

Use Stage

In this stage a user is modeled to use the car until one of the following occurs: (1) periodic maintenance or service; (2) accident; or (3) break down, which might be because of warranty issue. The user is then allowed to choose either to go back to the OEM Service Centers or to choose a third party service center. These centers will then have to assess if there are any damaged components and that component requires replacement (for warranty issues, the user has to go to an OEM Service Center, in which it is a MUST to replace the damaged components). In the event a component is required to be replaced, the Service Center will have to choose either to go with REM components or to purchase from a third party supplier. Table 6.7.5 details this stage further.

Table 6.7.5 Use stage details

Process	Input	Output
Replace Damaged Components	Car with damaged components, REM components, third party spare parts	Damaged components, demand for spare parts,

Post Use Stage

This stage is the main focus of the framework. There are two main inputs into this stage: (1) ELV—by means of total loss accident or natural aging; and (2) Damaged Components. Since there are no regulations to enforce recycling, the framework provides the end user three options on how to deal with ELV: (1) Recycle with OEM—in which possible mechanisms are trade in and buy back, and in both cases proactive and passive operations are possible; (2) Recycle with Third Party—in which the ELV could reenter the supply chain as remanufactured part (by third party), recycled material or bought over by OEM to ensure steady supply of ELV; and (3) Does not Recycle.

Once an end user agrees on the price the ELV is stored at site, waiting for transportation. To optimize profit, it is proposed in this framework that OEM Dealerships and Sales Branches be upgraded as to allow take back as well. This would allow ELV Transportation and New Car Delivery be operated as a two bin system (from site to yard to plant, and vice versa). Another important aspect in realizing this is to extent OEM as the Disassembler, and the use of the same transporter. This could be possible since transporters usually are without any load coming back from New Car deliveries.

Damaged Parts on the other hand, would also have the same three options as an ELV. However, if the Service Center opted to go with the OEM, these parts will be recovered by the OEM at a free, since usually Damaged Parts are required to be handed over to the OEM for further analysis (especially for warranty cases).

With its new capacity as a Disassembler, an OEM would be able to utilize its Design Database to determine which part is best to be recovered by component value (decision point in which judgment needs to rule either a part is more profitable to be remanufactured, repaired or recycled; as opposed to being sold to a shredding company) and ease to disassemble. A third party disassembler would need experience to be able to judge this. Furthermore, battery suppliers and tire suppliers would be easier to rope into the reverse supply chain when an OEM is doing the disassembly, thus allowing for tire and battery recovery as well.

For components which are able to remanufactured, another decision point is set up to judge if it is more profitable to do the operation in house or at a third party (or send the parts back to its respective supplier for recovery at their premises). This decision point is dependent to: (1) Part Count—which requires further decision if parts are found missing, either it is possible and feasible to replace and to reassemble the component; and (2) Part Condition—which requires further decision if the wear and tear of the component is possible and feasible to repair. Components which passes both conditions would be considered as “As Is” components, and alongside reassembled and repaired components, undergoes testing. Passed components will face a final decision point to determine if it is to be utilized in a New Car or as Spare Parts. This final decision point is also integrated with the Design Database. Table 6.7.6 details this stage further.

Table 6.7.6 Post use stage details

Process	Input	Output
ELV acquisition	ELV from end user, ELV from third party recycler	ELV
* Third party recycler (ensure ELV supply to OEM)	ELV from end user	ELV to OEM, remanufactured parts (third party manufacturer), recycled materials
Disassembly	ELV, design database (which component is valuable, what to remove, what not to remove and remain as Hulk)	Valuable components, hazmat, fluids, tires, batteries, flattened hulks, possible to recycle materials, not possible to recycle materials /components (disposal)
Reman.	Valuable components with missing parts	Recovered components, valuable components which is not possible to replace missing parts and/or not feasible to reassemble but possible to recycle, not possible to recycle components (disposal)
Repair	Valuable components without missing parts but has wear and tear	Recovered components, valuable components which is not possible to repair and/or feasible to repair but

		possible to recycle, not possible to recycle components (disposal)
Recovered components destination	recovered components, design database (which component to be utilized in new car production, which to utilize as spare parts)	Recovered components for new car production, recovered components for spare parts

4 Conclusions and Further Research

This paper has presented a framework taken into consideration existing automotive reverse supply framework and selected literatures regarding reverse supply chain development. This framework can be used in an environment where OEMs are not regulated to perform take back operations, and with no integrated reverse supply chain infrastructures in place. The recommendations made in this framework, where OEMs are to be extended as a Disassembler, and perhaps as a Remanufacturer too, could be further explored. Future research into developing optimization models and decision making methods can further enhance the capability and possibility of this framework. Furthermore, in such a framework, where OEMs may need to compete for ELVs, it could be important to look into acquisition management as well.

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Chapter 7:

Adequate Environments for Entrepreneurial Initiative

7.1 Statistical Aspects of the Estimation of the Steady Development of Small Entrepreneurship

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Abstract

The article is dedicated to the principle aspects of the problem of measuring the condition and results of the activity and steady development of small business in Russia. The principle scheme of the statistical derivation traditionally used for measuring small business is examined. The range and types of possible errors and shifts of estimates of parameters is indicated. The category of 'turbulent totality' is analyzed, the 'error of vanishing totality' is revealed. The 'turbulence' of the small business totality enterprises is demonstrated and the problem is discussed whether or not it is reasonable to arrange a continuous check up of the small business subjects. The approach is formulated for measuring parameters of turbulent totalities by constructing a scheme of historical, fundamental, and strategic indicators. The model of the fundamental quantity of enterprises of small business in Novosibirsk in 2007, 2010 is created. There are presented conclusions and recommendations.

Keywords:

Error of vanishing totality, Model of fundamental quantity, Small business, Parameter, Turbulent totality

Error of Vanishing Totality Small entrepreneurship is gradually becoming a noticeable phenomenon of the Russian reality. For the economics this indicates the creation of work sites, competitory medium, special contribution in the Gross Domestic Product (GDP), tax revenues. In the political and social spheres—small business is the medium of the forming of the middle class. As a consequence of these positive expectations it is possible to examine the adoption of the following law ("Concerning the development of small and average enterprises in the Russian Federation" № 209 Federal Law dated July 24, 2007), which creates the normative basis of the activity of state Russian statistics in a study of the results of small business activity [1]. Said law, in particular, provides procedure, exemplary periods and periodicity of continuous statistical observations (once every five years, since 2010) and selective observations (monthly and (or) quarterly). Micro-enterprises (with the number of workers being below 15 people) are intended to be inspected on the basis of representative selection once per year.

With the aid of continuous inspection a picture of the general population of small enterprise subjects can be formed, which subsequently becomes the basis for the current selective observations. The specific experience of conducting such observations is already accumulated. In particular, the Federal Service of State Statistics in 2000 carried out a continuous observation of small entrepreneurship. Sample surveys are conducted, and the corresponding procedures are approved.

But there is one additional aspect of the problem. In the process of the 2000 inspection a very interesting result was found (Rosstat [State Statistics] at that time recognized it as negative)—it was possible in reality to inspect only about 80% of the subjects of small entrepreneurship from the number of those registered. Unfortunately, this result was not properly analyzed in time, and It seems that the ineffective algorithms of observation are intended to be used in future, only on a "legal" basis.

Let us examine the schematic diagram of statistical inference for the estimation of the activity of small entrepreneurship in more detail (Fig. 7.1.1).

Subjects of small entrepreneurship introduced into the combined state list form the general population (consumer, cooperatives and commercial organizations), and also natural persons, introduced into the united state list of individual owners taking into account the established limitations: volume of employment (up to 100 people); fraction in regulation capital must not exceed 25% both for the state, its subjects, municipal formations, nonresidents, funds and for enterprises of average and large business; on

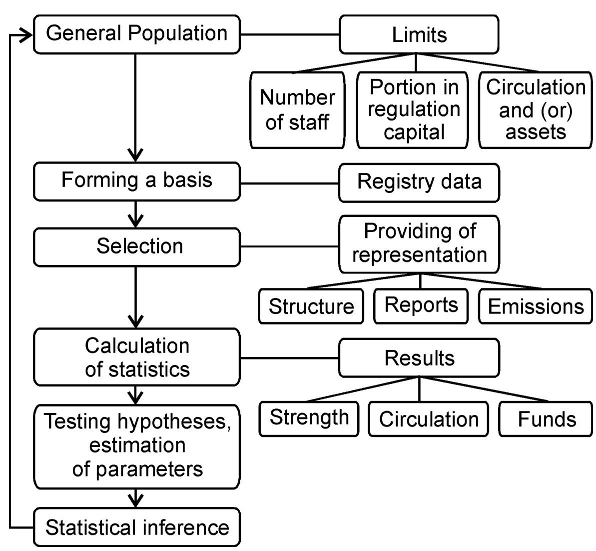

Fig. 7.1.1 Algorithm of statistical inference concerning the activity of small business

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the gain or assets (limiting values of these indices at the present moment are not assigned).

predisposition to give out information about itself. On a number of forms of economic activity the percentage of

Table 7.1.1 Risks of obtaining biased estimates for the stages of the statistical inference

Statistical inference stage	Region of risk	Form of error	Characteristics of error	Level of possible estimate displacement
1. Forming the general population	Incomplete registration	Possibility of refusal	Systematic	Not high, can be even discarded in the current situation—registered small business is observed
2. Forming a basis	Short-lived firms	Error of scope	Systematic	High
	The actual small buisness	Possibility of refusal	Systematic	High
	Affiliated structures	None	None	None
3. Selection	Retreat from the current selection scheme	Error of selection	Random	Almost none
4. Statistical inference	General population	Error of “disappearing” totality	Systematic	High

refusals reached 80. In this category there is a significant risk of refusal, and also a possible systematic error of observation [2].

The forming of the selective basis is in fact a regulated enumeration of the objects, which are contained in the general totality (register). From it is produced selection, i.e., a randomly selected part of general totality is formed. For its characteristics statistics are used—indices, calculated on selection. Then an estimation of the parameters is produced—the same characteristics for the general population. All this is conducted within the framework of statistical inference, i.e., of the propagation of the results of the general totality selection.

Thus, the algorithm of the estimation of activity and contribution of small entrepreneurship appears as follows. The general population is determined and delimited according to registry data, a basis is formed, a random selection is conducted from the basis, statistical inference is done according to the results of the selection—the parameters of the general population are evaluated (for example, volume the GDP or GRP, created by small business). Let us take a more detailed look at those stages, where exist, from our point of view, the most essential risks of future estimations displacement (Table 7.1.1).

The totality of the subjects of small entrepreneurship is not qualitatively uniform from the position of the possible conduction of statistical observation. In this sense it is possible to isolate at least three types of enterprises: short-lived firms, small business, affiliated structures.

Short-lived firms completely fall out of statistical calculation, although that does not completely indicate the absence of the results of activity in this category. In essence, a systematic error of observation is an error of scope. In the last several years we carried out sample surveys of small business organizations (requested by the City Hall of Novosibirsk). About 600 organizations were inspected, different questions were studied—attitude to taxes, administrative barriers, growth factors, lifetime of small enterprises etc. Small business in principle is not in a

Its swift renewal is a special feature of small entrepreneurship. Thus, according to the data of the World Bank from the newly organized small enterprises, in a year approximately 50% will remain active, in three years—8%, in five years—no more than three percent (mainly for reason of bankruptcy, and passage into average and large business for others). The structure of Russian small enterprise differs from the structure of the small business of developed countries, and we in our calculations obtained somewhat different, but sufficiently close results. In the first year about 60% of subjects of small business disappear (due to one-day firms). At the same time 5–7% of registered enterprises succeed in living for a five-year period (affiliated structures are subjected less to the risks of real business). Even with a constant total number of small enterprises (let us note, that in reality this is incorrect, their number in recent years increased on average by 5% per year) the coefficient of renewal exceeds 60%. The structure of the general population changes, owners pass into more profitable branches, following the tax breaks and the like. As a result statistical inference is done for the general population which already doesn’t exist. This presents a systematic error of observation, which we propose to call “the error of the disappearing totality” [2].

Totalities and Indices Totality is a fundamental category of statistics. In the contemporary theory and practice of statistics a limited number of classifications of totalities are used, let us name the most basic: according to the degree of representativeness (general, private), on representation (general, basic massif, selective), on essence, i.e., the quality coefficient of totality (population, workers, small enterprise, municipal formations and so forth). From our point of view, it is necessary to include one additional attribute to the classification of totalities—dynamics [3]. For this purpose it is proposed to introduce the concepts of stationary, stable and turbulent totalities. Stationary totality—a set of units of one quality, in which the number and structure according to the sign forming totality are invariant in time. Clockhouse totality—that, in which a change of the number occurs in accordance with known law, structure in this case does not undergo significant changes in dynamics. Turbulent (unstable) totality—this is a totality,

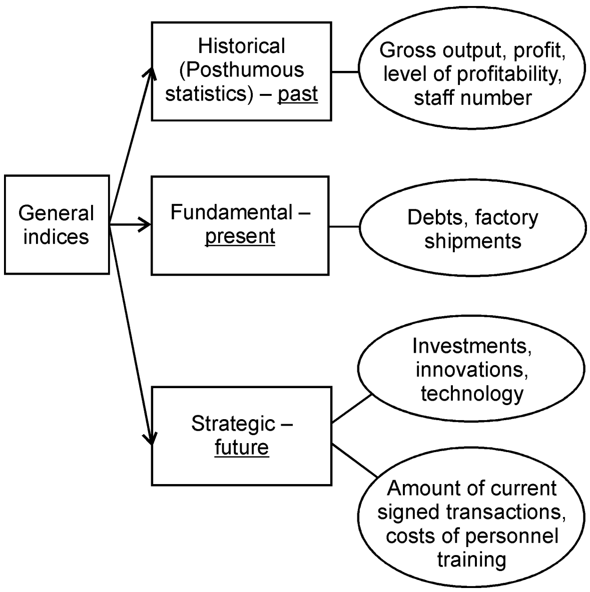

Fig. 7.1.2 Examples of activity estimation indices of enterprises in time

the number and structure of which radically change in the course of time [4].

We also recommend approaching the classification of indices from the positions of time (Fig. 7.1.2). Let us note that the given classifications of indices fairly often are used for resolving of the applied problems (for example, in management). Historical indices give a basis for the analysis of the past (sometimes this statistics is called posthumous), fundamental—for evaluating the present, strategic—for evaluating chances or risks in the future [5, 6]. Figure 7.1.2 shows an example of this approach on the level of an individual enterprise.

At the moment this classification is very rarely used in statistics. The reasons for this, in our opinion, consist in the fact that in essence the systems of the general indices are built for the stationary and stable totalities, and are historical systems of indices.

In the stationary totalities historical characteristics bear fundamental and strategic content. For the stable totalities an estimation of the future can be obtained by constructing a system of historical and fundamental parameters. With an increase in the variation of the studied totality in time the informative value of historical and fundamental indices is reduced. For the turbulent totalities the informative value of historical parameters approaches zero, the estimations of present and chances (risks) of future play the determining role [4].

A large number of subjects of small enterprise comprise a turbulent totality, and therefore the traditional diagram of statistical inference leads not only to the significant risks of displacement, but also it traditionally orients toward the obtaining of historical indices, which in sum by no means does not increase the adequacy of the solutions adopted.

Model of the Number of Enterprises of Small Business In this sense we undertook an attempt to finish building a system of traditional parameters of the estimation of small enterprise activity with fundamental and strategic characteristics. In particular, an estimation was formalized and executed which concerned the parameter model of the number of enterprises of small business in Novosibirsk in 2007, 2010 on the basis of the formula (below are given the results of 2007):

$$S(t) = S_{\text{per}} + f(x_1, x_2, x_3, y_1, y_2)\,, \quad (7.1.1)$$

Where: $S(t)$—is the fundamental parameter of the number of enterprises;

S_{per} —is the historical index of the number (it is based on the number of registered subjects of small enterprise);

x_i —significant and measured limiters of increase in the number;

y_i —significant catalysts of an increase in the number of small enterprises.

The following parameter models were extracted: x_1—level of lease pay; x_2 —the pressure of the RF tax service by means of the “system of suspicious company signs”; x_3 — the influence of circulating and fixed taxes (VAT, STII [single tax on imposed income] and so forth.), y_1 —index of the entrepreneurial activity of the population, y_2 —level of material support of small business.

As the information base of the study were used the data of RB FSSS [Regional Branch of Federal Service of State Statistics] on the Novosibirsk Region, and the results of personal selective studies of the enterprises of small business. It was necessary to assess by expert evaluation a number of characteristics.

In the terms of the indices of dynamics the following results were obtained: the basic factor—the entrepreneurial activity of the population ensures approximately 20% of the increase in the number of small enterprise businesses; the level of material support for Novosibirsk practically does not affect the fundamental parameter of number, the basic limiter of the number of enterprises of small business was in 2007 the pressure of the RF tax service—and 8% reduction in the number; the level of lease pay reduces the number of entrepreneurs by 6% (let us note that the affect of this factor goes in two directions, on the one hand, high lease rates force the number of leaseholders to displace business, on the other hand, the owners of accommodations are subjects of small business, they displace active enterprises and lease out the accommodations, as a rule, to capital firms). The joint action of limiters and catalysts so fat gives us a positive increase (at a level of 2–3% per year).

Conclusions and Recommendations The risks of parameter displacement in the statistic studies of small enterprise are so great, that the entire contemporary statistics of this segment could be defined as “mythical statistics”. It is possible to disregard the incompleteness of registration, in principle it is possible to allow an incomplete calculation of the results of the activity of small business (without the one-day firms), there is a theoretical possibility to get rid of the errors of possible refusal in the calculation of small business (for example, to use an administrative resource), however, we consider that within the framework of the common diagram of statistical inference a significant “disappearing totality” error cannot be avoided.

The specific features of small business—heterogeneity of general population, the short life cycle of enterprises, a rapid change in the branch structure, all bring into question the need of conducting continuous statistical observations of small business. An observation of the complete scope simply cannot be ensured, which was showed, including the inspection of 2000. We expect the same results from the general census of small enterprises in 2011. The results of such inspections cannot be used as a basis for conducting selective observations even for the following year, not to speak of the five-year application of this base.

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7.2 Global and Local Regulating Approach for Sustainable Development

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Abstract

The post-modernist reasoning should overcome the narrowness of industrial expansion with rational linear logic in making-decision process and generate new system of economic regulation. The world financial crisis (2008–2010) or meltdown in Fukushima (Mar 2011) demonstrate the necessity to elaborate the formal rules and procedures system, able to assure the long-term and responsible management as a basis for sustainable development; this system must rest upon the cultural background with informal patterns and requirements. This paper presents the mechanisms and the elements of the model of global regulating architecture, including fruitful societal governance of economic activity.

Keywords:

Cultural background, Producing system, Regulation, Governance

1 Environment for Sustainable Development

The concept of sustainable development appeared in the moment, when the modernist way of development showed its dip. The modernist style of management has lead to the failure in such fields as resources management (ecology, social protection, reproduction of labour and education, etc.), corporative governance in the environment with new requirements (i.e., social responsible investment, consumers' and NGO's pressure), administration of creative activity and innovation (especially, in the sectors of high technologies, intellectual property, virtual projects and enterprises, etc.).

The inability of modernist mentality to support the high level of growth in new frames of social responsibility, individual style of consumption, continuous demand for novelty, etc., squeezed out the integral theoretical and practical solutions.

The sustainable development became such a solution at the level of management as science and as practice. But we still need to extend the comprehension of this phenomenon, not only to find the tools to cope with it, but also to understand its roots and to anticipate the potential consequences.

2 Post-Modern Reasoning for Industry

The modern industrial society was obsessed with the idea of economic growth, the linear positive yield curve. Innovative economy should assure the leap of profitability, but it also put a number of problems, such as search for resources (including the resource of creativity), long-term prospective (i.e., the environmental issues, intermittent growth) or reproducing the society (i.e., family, children, culture).

The complex societal system functions in nonlinear progressing way, in compound cycle with gradual change, evolution in form of spiral with the points of bifurcation. The post-modern paradigm in entrepreneurial activity proposed the concepts of corporate governance, sustainable management, matrix organisational structure and project management, the notion of human capital, the rethinking of the sense of labour and the mechanisms of virtual and outsourced employment, game theory, catastrophe theory, chaos and fractals concepts, network, and so on.

The multitude of managerial responses to these needs represents the features of post-modernism as eclecticism and fragmentation. If the socio-cultural tradition treats the post-modernism from the point of view of refuse, in a destructive way of consumer society's abuse or irrational agnosticism, the social science elaborates the sophisticated holistic model to regulate the economic and social behaviour in the up-to-date global innovative economy.

The regulative approach integrates the essential concepts of sustainability and socioeconomic and managerial principles of successful practice.

The post-industrial orientation of economic growth towards the services sector brought some ideas on mechanisms for managing new problems in industrial world, i.e. the management of creative work, the flexibility and fractalisation of labour, outsourcing and leasing of human resources, etc. In this strange paradox, post-industrial development leaded the successful solving industrial tasks. It appeared able to give systemic vision of productive efficient value chain and new understanding of leading humans.

2.1 Time in Industrial World

The post-modern managerial reasoning brought the idea of multi-dimensional perception of time, including the timing in industry. The speed of making decision process is different from sector to sector, so is the horizon for planning. The time always was a rare resource, but in the innovative economy the timing became crucial factor for competitiveness.

Globalisation, especially, the financial world market, imposed the strict and narrow "using" of time as one of the lines in the grid of reference for calculating profit. With the informational technological revolution, the time became divided to the shortest parts—seconds, even milliseconds for the computer's automotive models for exchange trade. So, the modern time was compressed.

First of all, the horizon of planning in real sector is much larger, than milliseconds, it is stretched out to years, decades, even to a half-century: i.e., investment in a pipe-line project is calculated on the prospective 20–30 years of estimated yield.

In the high-tech sectors, where new products and new technologies appear each 6 months, the companies should organise the fundamental R&D works with advancing 10–15 years ahead.

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The long-term vision became necessary not only due to the ecological damage, obvious at the last quarter of twentieth century, but due to the logic of swift change in demand, fast evolution of technologies and aggressive competition.

Secondly, the real industrial life is cyclic, and not linear, as it was considered in the modernist approach.

2.2 Cycle as a Dimension for Management

Post-modernist reply is concentrated on the long-term idea of development, with the core concept of plurality, including the differentiation of goals, which implies, inter alia, the re-orienting managerial activity to the necessity to meet different requirements. The "sustainable" responsible manager must have in his/her mind the idea of the future generations—human beings, nature, technologies or products.

The life and the creative process are organised in round logic from birth to death through growth, crisis and recovering (or restructuring, in the case of organisations). The spiral development at individual level concerns the professional rise, the assimilation of new experience and skills, the enrichment with new competences, acquirement of new knowledge, the hierarchical promotion and getting new social status, advancement in social, economical or political position. It is also the interest of individual to improve the position for himself and to assure the future opportunities for his or her children, or spouse, or relatives, who will in their turn support the individual one day.

The spiral growth at macro-level means the creative update of technologies or products, the evolution of managerial models, of organisational forms. To change the corporative structure or core value chain, the manager should reject the old mechanisms and prior personalities, and start ab initio.

2.3 Myth

At the start, the manager has the idea, the picture of the potential future and combines the mythological conscience of desired thing or state with the rational thought of the tools to achieve them. The myth in this case includes two dimensions:

- values as the scale of priorities, the direction to move, and these values are more of less traditional and distinct;
- idea, more or less clear picture, representation of the planned future and environment.

The vision of the potential future world is mythological, due to the fact, that this vision reflects the will and the wish of the acting person, and is based on the value system, which is given to people (including managers) with education and culture.

2.4 Context

Textual prescriptions took their predominant place in the regulating working process after the Weberian formalisation. The legal legitimating and the written transfer of instructions date about a century: on the largest territory of Western Europe until the nineteenth century the decisions were made by sovereign, and the literate workers and masters were too rare. But the modernist change imposed the legal ideal-type of authority and the rational bureaucracy.

How the industries were functioning before? The processes were built on the basis of the background knowledge and of the acquired personal behavioural experience.

The context permitted to avoid instructions on dozens of pages, for example, to explain, what does it mean "quality". Now, enterprises create their policies of "philosophy of quality", implement the TQM concept, but time to time the necessity to assure the dividends for shareholders forces to decrease costs to the detriment of the quality. The textual regulation is based on complex mechanisms of sanctioning, which are also expensive. So we find the melamine in the milk, we see the BP oil leak in Meciso Gulf, etc.

Furthermore, the background makes not written things more important, then the legal prescriptions, i.e., the volunteers at the nuclear station in Fukushima were taking fatal and heroic risk due to the culture assimilated with education from the earliest childhood. Another example concerns one of the administrative tool, the dismissal (or threat of it). The dismissing for an employee has not only the direct consequence of loosing wage, it includes the loss of social position, the deprivation of pride to be a part of a company with its reputation, of identifying with this company or this place, this office, this job. It includes the new problem, what to do with a huge volume of free time. It means the rupture of friendship with colleagues. That is why in collective national cultures, incl. Russia, the strikes and protest actions of employees are not as widespread as in Western European or Northern American countries.

The behavioural economics shows many non-economical and even irrational arguments, which determine our real behaviour in economic situations. Usually, these arguments are connected to the background, the habits, the usage—all that is called "culture".

2.5 Culture

The cultural background's influence is not limited by the role of contextual grid of reference. Culture's impact can be discovered in all the facets of management: definition of objectives, choice of means, involvement of resources, etc.

Culture includes the model of education as acquiring and applying knowledge and competences, including the competence of innovative behaviour, that is why we can say, that a stable culture may produce constant innovation.

Culture forms the identifying system (i.e., national or religious belonging). The cross-cultural management, comparative researches and multi-cultural approaches were quite popular in science and even more in minds of managers in the last third of twentieth century. Since the speech of Angela Merkel, the German Chancellor, on 2010 Oct 17, the Western political world in United Kingdom and France recognised the failure of multiculturalism as a simple way of managing culture. The strong nationalist movements in Western Europe, even in Scandinavian countries, demonstrate the deepest roots and the powerful impact of this factor on the real regulation in political or industrial worlds.

3 Regulation for Sustainable Development and Specific Management

The choice between shot-term or long-term, normative or situational, textual or contextual regulation is related to the problems of sustainable development, which requires special treatment of innovative and creative human resource, the individual motivating approaches, etc. The virtual working forms also influence the labour relations, the functioning of trade unions, the correlation of forces in the relations between the employer (capital) and the employee, the real value creator (labour).

Today the regulating models of economic and organisational behaviour reflect not only the specific features of national cultures, but are determined by the stage of informational development of the world economy, when innovative labour is the crucial factor for the business success and economic growth. In particular, the problems of creativity management are considered differently by executive bodies in enterprises, by workers and their families, by trade unions, by local and national governing bodies, by non-governmental organisations and other stakeholders.

3.1 Complexity of Modern Industrial Management

The complex producing system as a nuclear power plant should be provided with the long-term regulation, bounded by formal guidelines. But the Fukushima case presents also the special necessity of the cultural background with informal patterns and requirements.

The case of spacecraft Proton-M, which was loaded with too much fuel due to the erroneous engineering calculation and was lofted into non-targeted orbit, so the three satellites crashed into the Pacific Ocean, demonstrated the necessity of the re-conceiving all the system of Human resources management in Russian high-technology sectors, including the space industry.

This is the crucial problem not only on the level of national government, but the companies also are thinking about the assuring sustainable long-term development and avoiding the costs and waste of financial, technical, human, temporal resources. The complex producing system as a nuclear power plant should be provided with the long-term regulation, bounded by formal guidelines. But the case of the Fukushima nuclear power plant shows the special necessity for the informal regulation, by the mean of the cultural background with informal patterns and requirements, because solving such problems needs the personal heroism, which can the brought up only on the basis of the deep contextual culture.

An interesting approach is implemented by the inviting the population to the control system, i.e., the USA Nuclear Regulatory Commission has a new oversight and assessment process for nuclear plants to ensure safety, it now has a better-structured process to yield publicly-accessible information on the performance of plants. Performance against each indicator is reported quarterly on the NRC web site according to whether it is normal, attracting regulatory oversight, provoking regulatory action, or unacceptable, and all stakeholders, the inhabitants or the journalists have the access to this information and can take part into the control procedures.

The high-tech innovative development rests upon the complex combination of rational tools and mythological visions, including the immediate and the long-term planning, the concrete and distant results and impacts, taking into account the local community' expectations and the global competition' pressure.

3.2 N-Dimensional Space of Regulation

The regulation today is a phenomenon which unfolds in *n-dimensional* space:

- timing, orientation to short-term or long-term results and consequences;
- linear progressing or cycle development;
- textual or contextual normative system, reflecting legal or background direction of regulation;
- mythological or rational tools and performances;
- culture as a particular space of meanings, representations and values, determining the goals and the interests;
- "glocalisation" as the global thinking and local acting, the choice of the best solution at global level and the anticipating consequences to the local community;
- dilemma and combining innovative and creative content of labour, the change with normative behaviour according the safety policy, the corporative and the technological process constraints, and the requirements for stability from the side of employees as well as shareholders.

The cultural framework and the myth or ratio' mechanisms can be understood as borders for thinking of a manager. The global and local managerial choice is made in the scale of financial and political factors. The innovative creative behaviour can be included in (and not be opposite to) the normative pattern and deep stable culture, if one may so express it, the stable regular changing.

So, the *n-dimensional* space can be represented in 3-axes (Fig. 7.2.1):

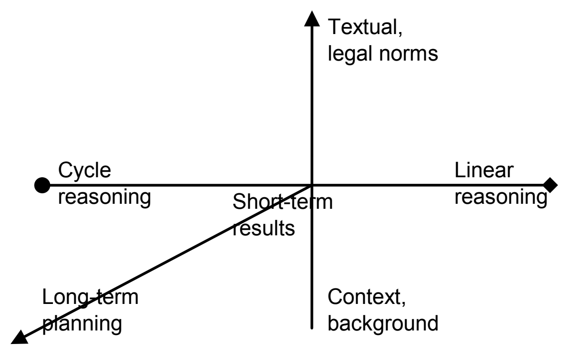

Fig. 7.2.1 Scheme of the regulation n-dimensional space

These dimensions are forming complex space of managerial action, which must take into account the following principles:

- the cyclic principle of development, to assure
  - personal motivating and interesting,
  - local impact of decisions made, i.e., environmental issues, influence to the life in inhabitants, children and adults education,
  - the requirements of stakeholders for acceptable socio-cultural and economic effects of decisions;
- the linear financial calculating to meet:
  - the requirements of shareholders for increase of dividends and of exchange value of enterprise,
  - the necessity to support and to improve the reputation of the enterprise;
- sophisticated system of written rules and instructions, including:
  - the framework for action, the normative ways to act and the essential behaviour patterns for a number of standard situation (including the potential crisis or catastrophe situation, which can be anticipated),
  - the mechanism of control of their respect,

  - the complex model of sanctioning for respect or infringement of these rules, including the bonuses and fines, the grid of requirements for promotion, etc.;
- rich socio-cultural background determining:
  - ideology of enterprise as common business for all participants, investors and employees, corporative mission and philosophy of personal identity and performance at work,
  - the individual and group behaviour in exceptional cases, which is directed to the realisation of group values and to societal commonwealth or survive,
  - the large and clear idea of positive sanctions for the correct behaviour (the community help for the family of a hero, the posthumous award, etc.);
- short-term immediate results of decision, which are made
  - to solve concrete tasks or requests of direct participants of enterprise functioning process, i.e., shareholders or trade-unions;
- long-term consequences, which should be anticipated at all levels of management or public administration, and which should:
  - help to improve the quality of life, including the humanitarian values, i.e., health care or corporative family support (children gardens, etc.),
  - avoid the drain of financial or human capital.

The postmodern reality is infinitely diverse, so this enumeration above is not exhaustive, and the real public administration or private corporate governance should be ready to new different matching with new interests or new actors, who have new tools of pressure.

But the essential legal principle is enunciated by the chairman of Russian Constitutional Court [1]—it is the principle of inalienability of future generations' rights.

3.3 The Principle of Inalienability of Future Generations' Rights

Defined in 1987 in Brundtland Report, from the UN World Commission on Environment and Development, the concept of sustainable development is based on the necessity to "meet the needs of the present without compromising the ability of future generations to meet their own needs" [2]. This idea of sustainability is expressed in economic terms of the modern legal-economic discourse: "We have not inherited the earth from our parents, but borrowed it from our children" [3].

It is an example of the use of modern legal legitimacy and financial logic to embody the postmodern value scale. The problem, which is usually mentioned in criticism of policies of responsibility or sustainability, is related to the optionality of these guidelines or strategies.

The future generations' rights should be not only described in the goodwill of intergovernmental communication, but inserted into texts of the compulsory rules for administrations in public and private sector.

Ecological issues are now represented in quite rigorous laws, but the sustainability concerns not only the nature protection, but all the resources, including the crucial resource in creative economy—human.

4 Human as a Rare Resource

Changes in industrial relations during last decades were related to the deep evolution of the content of labour: innovative creative economy needs the entrepreneurial activity and constant inventing, as well in technology (widely understood as the model of creating value chain), as in everyday perception (especially for new products).

Now, the labour contract includes not only the working hours, that the employee should pass at his or her job, but the results, the invention and even the increasing profit, instead. Kaufman [4] made interesting analysis of the evolution of labour relations in the global innovative economy.

4.1 Collective Action or Individual Negotiation

The collective way to defend the individual rights, i.e. in associative form as trade-unions, is today declined due to the process of individualisation from both sides:

- capital uses the part-time employment, outsourcing and leasing of staff to assure the flexibility at work;
- labour is changed in its deepest content, and the qualified workers or talented specialists became rare resource on the market for corporations, so each professional today takes care of his or her reputation, creates the portfolio and organises the career for himself; as a deficit crucial resource, a professional has huge possibility to achieve his or her goals in negotiating with enterprise, much more than in collective way.

The labour must became the object of a new governance, deeply different from the usual industrial relations' system. And it is not only the problem of social partnership between the State, the Trade Unions and the employers, in a form of deliberative democracy or in a form of the adversarial bargaining. Yadov [5] examined deeply the influence of transition to market economy on the labour relations in modern Russia.

4.2 Transition to Market Economy and Labour Relations

In the developed countries this change took place since 1960s, the corporations had been compelled to re-think the organisation of labour. In Russia, this pressure concerned enterprises just after the start of "perestroika" in 1985–1986, when the soviet industrial giants were forced to create their own system of sales instead of planned administrated organisation of supplies from a factory towards shops.

Specific features in Russian industrial relations are based on the very fast transition to the market economy. The rising of entrepreneurship in 1986–1996 happened almost without any regulation. The analogue period in Western Europe or in Northern America took a century or even several centuries. And the last post-industrial changes of the labour content took place in Russian economy within the last 20 years, since the beginning of 1990s.

Today we can see the cooperation between the trade unions of Russian Ford factory and their USA colleagues (i.e., for the famous strike on the 2007-Nov-20). In this case, the trade unions are still representing the important actor in the field of industrial management. But we can not imagine the same situation, i.e., in a Russian branch of Google.

4.3 Up-to-Date Role of Individuals in Self-Organisation

In intellectual, creative, innovative professional activity, especially, which is able do be performed in the virtual world, in a network enterprise, in this case the auto-organisation of employees to protect their interests does not include the trade unions as actor and does not imply the same methods.

Now in Greece, we see another example of the mass auto-organisation, the protest actions against the austerity cuts and a massive sell-out of State assets in a privatization drive designed to reduce Greece's debt. “it is a spontaneous and dynamic social mobilisation," Vassiliki Georgiadou, a political scientist at Athens’ Panteio University, wrote in June 2011. In Spain, in Portugal, in Ireland the protest moving is born of the mass self-organisation, and the trade unions play the role of the framework.

Today, the specific forms of auto-organisation of mass are concentrated around the fields of interests, and the post-industrial society represents the possibility for mass action via internet (i.e., the 2011 revolutions in Northern Africa and Middle East), and for individual or group actions by the mean of NGO. Now the trade unions are in competition with groups and individuals as emitters of action. And in the field of innovative labour, a professional represents today the rare, even exclusive resource, and he or she has the exceptional possibilities to press the employer.

The rising of these forms of group and individual self-organisation reflects the change in regulative system, which uses the modern “political” and associative ways of fight for the interests and goals, and the post-modern ways to build the new world, with specific social, cultural and economic features.

Now in Russian socio-economic space there is a lack of a real functioning of Russian trade unions, due to the soviet period of declared power of working people, when trade unions had lost their capacity and will to fight for the employees’ interests and oppose the administration. At the same time, changing sense of the relations “capital—labour” also provokes the serious evolution of the trade unions role in the industrial relations now. For Russian trade unions it is the problem of defining their position in market economy.

4.4 Modernisation Policy in Postmodern World

If in the Northern American and Western European the society implements the functional postmodernism, the new social technologies, in Russia the numerous researches find out the recurrence of fundamental values, traditional regulative tools and one-sided mythological forms of conscience in chaos of this unknown world [6, 7].

The sociologic and economic science coped with the chaos as an instrumental model for the development in the stable background, but in the transition period the complexification of the environment exceeded the possibilities of human beings to assimilate. And the destruction of ideology leaded to the lack of contextual regulation exactly at the moment, when the textual regulation was overthrown and substituted with utterly different laws.

The up-to-day peculiarity of regulation in Russia is related to this triple effect:

- the value regulation is weak due to the renunciation of the former ideological system;
- the formal normative regulation is inefficient due to the lack of law enforcement [8];
- the informal situational regulation is depending on the concrete circumstances, group and organisational environment.

Russian management was always based on the using the smart, sharp intelligence of human resource. The managerial and sociological science have carried out the enquiries of the fields of regulation, motivation, governance, and studies of behaviour at work; the administrative bodies in western countries have the colossal experience in the governing the groups, including in industrial relations. And now the Russian government attempts to implement the modern gains of experienced market economy to national case, in hope that it would be efficient and fruitful to combine the creativity of Russian practices in management with the western governing experience and institutional and political elaboration.

5 Global Lack of Regulation

The world economy is now passing the period of important social and political changes, the crisis 2008–2010 showed the importance of studying the regulating models at micro- and especially at macro-level, even the global level of decision making. The formal rules, which were regulating the pecuniary procedures, i.e. bank loans, turned out inefficient—the credit managers were motivated with their bonuses to issue credits to anyone without real control. The questions of regulating structures, economic behaviour, innovations, modernisation, etc. are discussed in the political, economical and social circles.

The new regulative architecture is to be built on the principle of diversity of cultures and values’ scales, but of the uniformity of tools. We are living on a very small planet, and such accidents as nuclear plant’ damage or oil slick in an ocean, the financial banking collapse or a reserve currency downfall, concerns all the actors in the globalised world. The global regulation should represent the safety principles for human life and for world economic stability. This safety can be understood wide and include the control over the management of dangerous technologies, the attainment of minimal acceptable living standard to avoid social protests or poverty terrorism, etc.

The alter-globalism represents some ideas of global political regulation with social accent, to counterbalance the economic globalisation fulfilling by private corporations for the purpose of increasing benefits and effectiveness. But the crisis 2008–2010 gave evidence of the necessity to regulate the corporate and individual economic behaviour. The new configuration of world economy should be founded on the new regime of all economic relations, including the new understanding of the interdependence between property and responsibility, including the societal responsibility.

The analysis of the national economic results (PIB) demonstrates the successful surviving and even the growth during the crisis period of emerging countries of BRICS (except Russia) and of some economies that can be called “religious capitalism” (Saudi Arabia, Islamic Republic of Iran, People’s Republic of China, etc.). The research of specific features of this economies and of the State policies during crisis gives evidence of the strict influence of the background and contextual regulation on the financial results [9]. Smith created his famous Inquiry into the Nature and Causes of the Wealth of Nations (1776) [10], thought the mainframe for liberal market economy, on the basis of the social limits and religious norms, that he described in his Theory of Moral sentiments (1759) [11]. These constraints reflects the social institutional pressure to assure the sustainability and growth within a stable society, the cyclic reproduction of this society understood as an absolute value.

Culture determines the limits, therewith, it grants also the competences, the behavioural patterns and the skills to solve tasks, including the making change.

So, the reconfiguration of world economic regulative model would find the new placement in the axes:

- Property—responsibility;
- Culture—competences.

Now, the complex regulation, including the sustainability concept, represents some replies to the issues of the global innovative economic growth and its influence to the industrial relations, including the understanding of the new models of regulating. The modern situation in human resource management also needs to be subject of sustainability principles, especially due to the role of creativity as the basis for leadership in innovative world economy.

Today the local communities use various ways to assure the taking into account by corporations of their local interests, but they are still in very weak position in the coordination of the policy making and implementing by the regulative bodies at national, regional or global level.

The optimal regulating system will be able to assure the sustainable development only on the assumption of the concordance of local specific requirements with global interests of business and regional or national will of public administration, combining with all the rich set of regulative tools.

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7.3 Problems of Technology and Motivation in the Use of Renewable Energy

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Abstract

Some substantial challenges in the adoption of renewable energy technologies are present even in the most developed countries. First of all it is their market incompetitiveness which is reflected in vast stimulus programmes. For their adoption governments intentionally distort market conditions, which leads to extra burden on the taxpayer and rather questionable results in the development of those technologies. This divergence in growth rates of efficiency and demand for the use of renewables cannot be eliminated by companies themselves in course of the regular market process.

Keywords:

Renewable energy sources, Power generation, Competitiveness, Stimulus, Efficiency, EROEI

1 Introduction

Today in the global energy sector discussions surrounding issues of transition to the use of renewable energy for the generation of power and heat and its applicability in transportation are more and more tense. The fact that the use of fossil fuels will sooner or later come to an end seems obvious; besides, the damage to the environment which accompanies the burning of fossils is becoming more and more significant. Such an impact can lead to the irreversible consequences of climate change, which is why many countries are implementing programmes which shift their energy mixes towards technologies of renewable generation.

However, several critical issues in the implementation of renewables can also be seen in the most successful states. The main issue is their inability to survive on the competitive market, hence the numerous incentives for adopting these technologies. Indeed, without such incentives they would not be able to have any market share in the current circumstances. The reason for their incompetitiveness is low efficiency, low capacity (which considerably restricts the potential economy of scale) and their expensiveness.

In order to implement them national authorities consequently shape market conditions, which is reflected in a growing burden on the taxpayer and to a certain extent doubtful outcomes in the development progress. We are persuaded that this is the case due to the impossibility of using market mechanisms in implementing such large-scale energy programmes: companies develop technologies (investment in R&D) only to the extent which is reasonable in the current economic situation; this conjuncture itself implies state subsidies. This is why, given the investment cycle of 20 years (which is the case in solar generation) and the existence of state pay-off guaranties, companies lack further impetus for more efficient technology use. The slow-down and stagnation in efficiency increases lead in turn to an increased burden on the taxpayers, on one hand, and to a decrease in competitiveness of a country's goods on the global market on the other hand. This especially affects energy intensive industries.

In our view this divergence in growth rates of efficiency and demand for the use of renewables cannot be eliminated by the companies themselves as part of the regular market process. Companies need state support both in scientific research, as well as in financing these arrangements.

2 Current Situation in Stimulus Programmes

Globally a lot of countries exercise market implementation programmes in renewable energy technologies in order to reduce their economies' dependence on fossil fuels and combat climate change, which tends to endanger living conditions on our planet. The main contributor to anthropogenic climate change is deemed to be CO_2, which is being produced by vehicles running on petrol and by power plants and boiler plants, using fossil energy sources such as oil, gas and coal to generate energy whether thermal or electrical. In this respect there are two directions for combating CO_2 emissions and unbundling energy production from conventional energy sources. The first is contained in the Kyoto Protocol and refers to the reduction of carbon dioxide emissions with the help of voluntary obligations to restrict them to a certain level. In order to achieve these goals governments and supranational institutions appoint energy efficiency measures to be implemented. On the other hand, there are stimulus programmes taking effect in countries to promote the use of renewable energy sources. These programmes meet both goals of emissions reduction and the unbundling of the country's economy from external dependency on fossil fuels. This is mainly the case in countries which are considered to be net importers of energy resources.

As mentioned above, many countries adopt programmes of this type, however, as in any other area, there are leaders and followers. In making both efforts successful worldwide the European Union is acknowledged to be the leader (total production of primary energy from renewables amounts to 18% of total primary energy production [1]). It therefore seems reasonable to consider how the stimulus in the countries of the EU is being applied.

At European Union level there is directive 2001/77/EG to stimulate the use of renewable energy source, which states that the share of renewable energy sources in power generation should be raised to 22.1% (21% of EU-25) by 2010 (that has not been reached) [2]. For each country there was set a threshold value. The countries should take measures to achieve this goal: create political frameworks for the maintenance of non-discriminatory access to the market, eliminate bureaucratic barriers and provide acknowledgement of the origin of the current from renewable sources. The countries should also regularly report on the implementation. How this directive is incorporated into

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national legislation can be chosen independently. For now there are four possible groups of measures that regulate the development of energy generation from renewable sources: bottom price system; quota system; competitive system; tax stimulation.

Bottom price system implies, that bottom prices, and also the general duty of acceptance of the current made using renewed energy sources are accepted by the network enterprises as well as by sales enterprises.

Quota system prescribes that all consumers (in some countries manufacturers as well) are obliged to acquire a certain quantity of green certificates from producers of electric power from renewable sources; this quantity corresponds to a certain share of their consumption (generation) of electric power.

Within the competitive system producers of current from renewable sources compete among themselves for the right to deliver a certain volume of the electric power. The winner of the competition receives a guarantee of acceptance of the current made by him for a limited period of time.

The bottom price system is recognised among the others to be the most cost-efficient, thus showing the lowest profitability of enterprises through state help [3].

This type of system is applied for instance by Germany. This country is considered to be the most successful in promoting renewable energy. The share of renewables in primary energy output lies at 21.7%, which is the highest rate in the world [1]. Germany's legislation in respect of stimulating the development of energy efficiency and renewable energy sources has been the predecessor to EU legislation on many occasions. Nowadays they set an ambitious goal for reaching the share of power output of renewables at 30% by 2020 [4].

The impetus for increasing the share of renewable energy sources in included even in the Lisbon Treaty of European Union, though precise measures are not specified there [5].

Moreover, regardless of the financial crisis, new developments in German energy policy indicate that stimulus for renewables will not be terminated.

Considering what the most efficient system of encouraging the development of renewable energy sources in the world implies, it is necessary to mention the following: as mentioned above it is legislatively regulated to grant fixed feed-in remuneration for green electricity producers. The remuneration differs from one technology to the other, wind power and solar power are prescribed to have different feed-in remunerations, but the main line is that they are granted with a fixed remuneration for a certain period of time. These tariffs are being continuously revised every 3–4 years, thus encouraging producers to develop more efficient technologies. Producers receive a clear vision of pay-off periods and are protected in that sense from unpredictable market developments and changes in global energy tendencies.

However such methods for creating new capacities present substantial challenges for the economy and society which are yet to be resolved within the existing stimulus paradigm.

These challenges will be described further.

3 Challenges Produced by the Existing Stimulus System

3.1 General Economic Challenges

First of all, such impetus implies that technology and its market maturity in a given moment are defined not by the actual supply-demand correlation, but by distorted demand properties. This can mean that technologies and business models will develop only to the extent needed to meet the market conditions which are artificially made substantially better than real ones. Thus the technology and business models are bound to be underdeveloped for a certain period of time, which can be relatively fast changed in respect of fast moving consumer goods, but not in the respect of heavy industries, where the equipment is traditionally cost-intensive. Moreover it is worth mentioning that the market for new capacities is a particularly limited one and is changing very slowly throughout time, because the main consumers of power, namely industries and population, grow or decline rather slowly, especially in developed countries. This means that installed capacities will stay on their spot for a long period of time, having the same effectiveness and not developing new competitive advantages. There is only one way to increase their efficiency: produce new ones, but then again a place to install them is needed. So considering for instance the guarantees for producers of solar energy deemed to remain the same within 20 years, it is hard to imagine how the efficiency will improve to the appropriate level of market maturity, also taking into account the very certain market limits. If you also add such a long-lasting trend of globalization as the shift of industrial production towards countries where factors of production cost are notably fewer than in developed countries of the West, and demographic trends in these countries (particularly in Europe), you will notice that nowadays the structure of value-added creation of the whole economy indicates the share of industrial production in total value-added is at about 20–30% [6]; furthermore the population of many European countries is slightly declining. This means that in future the energy market in western countries, particularly in Europe, is likely to shift insignificantly, rather than grow dramatically. Given these prerequisites, the trend of conserving ineffective production patterns seems to loom over national economies.

3.2 Efficiency Challenges

To reflect the **huge gap between the efficiency** of conventional energy generation and alternative means it is worth mentioning the following facts.

The main contributors to renewable power generation are wind turbines and solar panels. The main technologies for conventional power generation are coal, gas and oil combustion alongside nuclear energy. The so-called coefficient of efficiency defines the ratio between the input of primary energy and the output of electricity to the network. It is noteworthy that this indicator is highly representative when there is a feasible value of primary energy, something which is not the case with renewable technologies. However, the figures show that gas-fired power plants have this ration at about 40%, whereas by combined gas-steam cycle it reaches up to 58%; coal combustion provides the ratio about 50%; nuclear power plants are difficult to assess in that way, yet experts speak of some 35% efficiency; wind turbines are said to have the coefficient of efficiency at about 50%, solar panels at 15%. Whereas the aforementioned conventional technologies are able to increase this ratio up to 90% if they add thermal energy generation, which is the case on many occasions in power generation [7]. Besides, one should not disregard the fact that energy production from conventional energy sources is highly predictable and can be easily managed; on the contrary, solar and wind generation technologies do not provide any reliable possibility of foreseeing their output—it can be only done using weather forecasts or looking at the statistics of previous years. That means that sometimes they can produce excess volumes, and sometimes fail to produce required ones. The problem of saving this excess energy is yet to be resolved, because no reasonable technology for this can be used in all countries.

For the purpose of appropriately reflecting on the current efficiency of wind and solar generation technologies it seems reasonable to use another index which shows the ratio of investment costs to kW to be produced. This is called EROEI (Energy Returned on Energy Invested). People who use this index to describe the efficiency of energy production assume that the energy plant should produce more energy than it consumed during its manufacturing and installation. The 1:1 ratio and hence the 1 meaning of EROEI alone is considered to be insufficient for the technology to be adopted, because the plant should not only be capable of reproducing the energy it consumed, but it should also bring something for society. There is no generally accepted perception of how high the minimum EROEI should be, yet experts speak approximately of an 8–10:1 ratio, whereas the EROEI for US conventional power plants using gas and oil is supposed to be between 20–40:1 [8]. Moreover, it is unclear to a very high extent what should be taken as input energy. If we consider the oil combustion power plant: from what point do we start assessments of inputs? From oil extraction, or from the metal produced which is needed to construct an oil derrick? The problem of defining exactly a calculating methodology is of great importance, because this index is crucial to defining the maturity of technology. Some studies indicate the EROEI for wind turbines is at the level of 19–25:1 [9], whereas solar panels have an EROEI of between 4–10:1 [10].

As noted there is a huge calculation issue, so that by now we can consider those figures very carefully. We should underline the necessity for further research in that area. One of the potential ways could be using of proxy to EROEI for approximate calculation of its meanings for wind and solar generation. Such a proxy methodology was proposed by Jeff Vail, a Colorado business litigation attorney at The Law Office of Jeff Vail LLC. He assumes that a price-estimated EROEI can be applied for approximate assessment, because it already includes to some extent the costs of designing a solar panel, or a wind turbine. Based on his calculation, the proxy EROEI calculation for a solar panel of 2 kW is about 0.5:1 [11]. Surely it does not take into account the economy on scale, which will take effect when speaking about industrial panels, but such a methodology can be a possible further way of developing this index.

The comparison between the figures shown by wind and solar technologies on one hand and of conventional oil and gas technologies on the other provides us with a clear answer towards their comparative competitiveness. But it should be underlined once more that one should not be 100% sure of the relevance of these indicators.

As the last indicator of the relative weakness of renewable technologies it can be noted that there was a study by Ulrich Fahl from the University of Stuttgart regarding the costs of preventing 1 ton carbon dioxide emissions among different technologies. Its results were subsequently published by Spiegel [12]. They indicate that the costs of preventing 1 ton CO_2 emissions through wind and solar technologies are accordingly 611 and 91 Euros, whereas combined cycle power plants have a cost of 34 Euros and the cost of an emission certificate for 1 extra ton is 13.4 Euros.

3.3 Challenges for Society

So **who is to pay** for the stimulus that is being exercised nowadays in the most efficient way in the world? The clear answer is: taxpayers and enterprises. Since the costs of compensation for feed-in remuneration divergence lies on the state's shoulders the money needed for further impetus are acquired through taxation. These taxes are included in the price of power and, as expenses tend to rise from year to year, so does the price. The solar subsidies alone in Germany comprised 80 billion Euros during last 10 years; it helped reach their share of the total power production of 1.1%, the proposed new programme for wind turbines contains 75 billion Euros' investment until 2030, nevertheless experts warn of a possibility that much higher funds will be required for this programme, as it is hard to calculate how much for instance the permissions for new constructing would cost: the problem is that new turbines are either to be installed offshore or replace the old ones and they are higher than the old ones [12]. In the coming year German consumers will be bound to pay 70% more for energy, it goes in line with existing law (Erneuerbaren Energien Gesetz)—it was an official statement of network companies 50Hertz, Amprion, EnBW Transportnetze and Tennet. In total this year German consumers will subsidize green power to the amount of 13 billion Euros [13]. The reason is growing payments to stimulate photovoltaic and fallen prices on the Leipzig power exchange. It is no wonder that there is a huge debate regarding these matters in German society.

4 What can be Done to Promote Affordable Transition to Renewable Energy Production

First of all we need to understand that there is no other alternative in the future to 100% energy production from renewable sources, as the fossil fuels will face their end and their further development is linked with the increase in CO_2 emissions, which is not acceptable if we want to keep our living conditions more or less the same in coming decades. Nuclear energy is also not an option as latest developments at Fukushima show. The arguments written above are solely aimed at underlining that the way things are happening nowadays in the sphere of renewables cannot lead to an economically accountable and safe transition to their use.

A possible way for their development is a close and fruitful cooperation between science and governments. There is an urgent need to finally define the key index that should be applied for the assessment of energy output efficiency. With a high rate of probability this role can be given to EROEI. But it is highly important to define following:

- What meaning of this index should be perceived as the threshold which cannot be crossed in order to provide efficient energy production.
- How should this index be calculated in order to be relevant to any technology of energy production.

Implementation of this task shall be conducted in coordinated work between economists and physicists.

Furthermore it is required to establish a foundation for research in applied sciences that will subsequently finance the activities of developing technologies for renewable energy generation to the level that will make the transition towards safe and ecological energy production possible. We are convinced that such a transition is possible only with direct state financing, not putting private capital in the process too early, because current market conditions do not allow renewables to emerge on the market without significant distortions, which seem to be unbearable under the conditions of sustainable development. The current situation is leading to stagnation if not recession.

Finally it is required to further develop the construction of a renewable energy network in the country through co-state owned enterprises with the subsequent privatization of state capital share.

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7.4 Management of Services Quality as a Tool to Increase Water Supply Companies' Efficiency

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Abstract

The proof of necessity to control and manage service quality as a main factor for water supply enterprise efficiency increase is given in the article. Drinking water quality is reasoned to be a utility resource together with and inseparably linked to the quality of water supply to citizens. Hierarchic model for water supply quality estimation and management is introduced.

Keywords:

Efficiency, Company, Management, Service, Quality, Water supply

1 Introduction

Business success and functioning conditions of a company are ensured by the sum of economic, technical and intellectual resources. Economic resources are comprised of owned capital and outside funds, technical resources are provided by fixed-capital assets, intellectual resources are represented by the aggregate of professional competencies of company's personnel, intangible assets such as patents, company's brand, etc., and are increased by the synergic effect of organizational culture. The influence of organizational culture on company's business activities' efficiency is thoroughly analyzed in earlier works of Krakashova [1].

The purpose of this article is to formulate the concept of compromise efficiency of water supply companies and methodical approach to its quantitative assessment, as well as the development of assessment methods and the conceptual model of service quality management of water supply companies.

Theoretical and methodological basis of research were works by domestic and foreign scholars of theory of the effectiveness, economics and governance municipal utility service, quality control, technique and technology of the water supply, the compromise-equilibrium analysis.

2 Main Ideas

The main idea is based on the theories of effectiveness and quality, and on the concept of compromise efficiency of subjects of economic relations of Krakashova [2].

Water supply company, on the one hand, being a commercial organization, seeks to maximize the economic efficiency of its operation (that is, to maximize profits and market share), on the other hand it refers to the public utility company and is a part of the complex socio-economic life-support system, where such definitions and concepts as living standards, the stock of resources, waste problems, environmental pollution, population and health of citizens are brought into the foreground, and has a significant impact on the macroeconomic aspects of the state of the country [3].

Obviously, the water supply company in the course of its activity is in constant interaction (economic relations) with the consumers of its services and federal government and local authorities with functions of rate regulation, service provision supervision and quality control for utilities, housing and communal complex objects financing, social protection of population, tax regulation of economy, etc.

Consumers wait for quality services and products from a company. The quality as a complex value includes reliability and safety factors, as well as functional parameters, economic effectiveness, etc. Herewith, every subjects of economic relations has its own goals and aims at maximum efficiency in its own functioning.

Therefore, it is necessary to take into account that on the achievement of the water supply company's criteria efficiency the strongly influence the federal government and local authorities, which by means of state regulation should provide optimal and achievable efficiency criteria for every subject, i.e. to provide achieving of compromise efficiency of some kind for functioning of enterprise-supplier and consumers of his services.

In most parts of Russia the major consumers of water services is the population. In particular, in relation to the services for water and sewerage it is assumed that the residential sector typically consume 65–70% of tap water supplied to consumers, except in cities where there are industries with high water consumption (iron and steel industry, petroleum refining, pulp and paper industry etc.) as well as areas of intensive irrigation, where the proportion of the population may be only 25–30% of the total water consumption [4]. Therefore, for balancing the interests of suppliers and consumers in the water supply, the state authorities and local self-government strive to achieve a compromise efficiency of water utilities and the public (households, individuals).

Understanding water supply companies' efficiency using terms of profitability and stable functioning providing high-quality services compromise efficient functioning can be described as compliance with service quality requirements and service delivery regularity (uninterruptedness),

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introduction of resource-saving technologies and environmental protection measures for normative profit acquisition at given rates and proving availability of services to majority of possible customers, readiness to expand the range of goods/services and to improve quality and/or quantity of services provided when there is possibility to expand the business and receive extra profit.

Thus, the water supply company as the subject of a local natural monopoly [5] is pursuing quite conflicting goals: "… the need to improve economic efficiency, on the one hand, and social justice—on the other hand. Thus, the distribution of powers and the system of incentives created under a particular institutional alternatives are to help reduce production costs and dependence on subsidies, investment in maintenance of existing networks and building the new ones, as well as implement up-to-date technologies, and at the same time ensure constant supply for the consumers with the due quality service, the proper resources being equally accessible not only in physical but and economic terms … " [6].

In this connection, with respect to the public utility company in general and water utilities in particular, the efficiency is inextricably linked to the quality of their services. Indeed, effectively working public utility company provides services to its customers continuously, to the necessary extent, fully satisfying the requirements of quality which were stated.

On the assumption of absolute rationality of human behaviour concept given in the work by Professor Sukharev [7], household efficient behaviour is considered to be the endeavor to maximize duration of the household's members' lives and improve their quality and level of life. Obviously, the quality and quantity of water supply services consumed influence considerably on each above-mentioned element. Thus, efficient behaviour of household—services consumer—can be defined as providing maximum comfort living conditions for minimum payment, that is why its compromise efficient behaviour can be assumed as consumption of minimum necessary services (resource-saving) at economically affordable prices relevant to the quality of the services provided and its readiness to increase expenses when consuming more utilities and/or consumed water supply services quality increases.

The main conflict of water supply services providers and consumers lies in the estimation of service rates (tariffs), quantity and quality ratio.

High quality drinking water supply to households is number one problem not only in Russia but all over the world. Results of drinking water samples analysis carried out in more than 75 cities of Russia by experts of Human Ecology Scientific Research Institute has shown that only 1% of tap water in Russia complies with international standards, the rest can be used for drinking only after boiling or advanced fine purification [8].

Necessity to increase the quality of drinking water consumed by households is doubtless. However the solution to this problem is impossible to find without complex assessment technique development, water supply quality management and monitoring that will consider drinking water quality as a utility resource together with and inseparably from the quality of water supply services provision. The abovementioned proves urgency for household water supply quality complex assessment technique development.

Consumers' views on water supply quality are comprised of technical level of water treatment, bulk water transport and water delivery, attendant services level and company's image.

Water supply quality requirements are strictly prescribed by current Russian legislation such as GOST (Federal Government Standard), SNiP (Construction Norms and Regulations) and SanPiN (Sanitary Regulations and Standards). According to them, particular parameters of pressure and temperature have to be provided and required microbiological, toxicological and organoleptical characteristics of water have to be ensured. Otherwise, water supply service becomes unfit for consumption. Moreover, one of the basic requirements that characterize all utility services provision including water supply is consumer's regular uninterrupted access to utility resources [9].

When we examine water supply quality we need to take into account two major elements: quality of water as a utility resource and water supply service quality. (See Fig. 7.4.1)

In fact, all the abovementioned factors are closely connected. No matter how high the quality of water treatment at purification facilities is, if 40–60% of water distribution system is worn out and is in accident conditions, it is next to impossible to avoid repeated pollution of drinking water including epidemically dangerous germ contamination and microbiosis.

For the purposes of mathematical modeling of the influence on the quality of water supply and the water supply companies' efficiency of the factors presented in Fig. 7.4.1, is required a quantitative assessment of potable water quality and water supply services.

In accordance with GOST 2874-82 "…Potable water should be safe in epidemiological regard, harmless chemical composition and have favorable organoleptic properties …." [10]. Microbiological, toxicological and organoleptic characteristics of potable water, which determine its safety in the epidemiological regard, safety of its chemical composition and favorable organoleptic properties must meet the standard set of indicators, the list and specific values of which are given in the GOST which was stated.

Due to that the standards are generally defined as the maximum value of various impurities in potable water, and in the case of pH in the form of the acceptable range of values, the particular indicators potable water quality can vary quite significantly.

To quantify the quality of potable water, we introduce the set of partial coefficients of quality (K_i), which consistently aggregated in microbiological (K_{MWQ}), toxicological (K_{TWQ}) and organoleptic (K_{OWQ}) coefficients of water quality, and then into a single indicator of water quality (K_{WQ}).

Particular coefficients potable water quality will be introduced under the principle:

$$K_i = \frac{X_i^{max} - X_i}{X_i^{max} - X_i^{min}}, \quad (7.4.1)$$

where X_i, X_i^{min}, X_i^{max} are the actual, minimum (lower limit of normal, according to GOST 287-82) and maximum (upper limit of normal, according to GOST 287-82) content in potable water of i- normalized impurity i^{th} $(i = \overline{1,n})$, respectively, unless otherwise is given by GOST 287-82, then we assume $X_i^{min} = 0$.

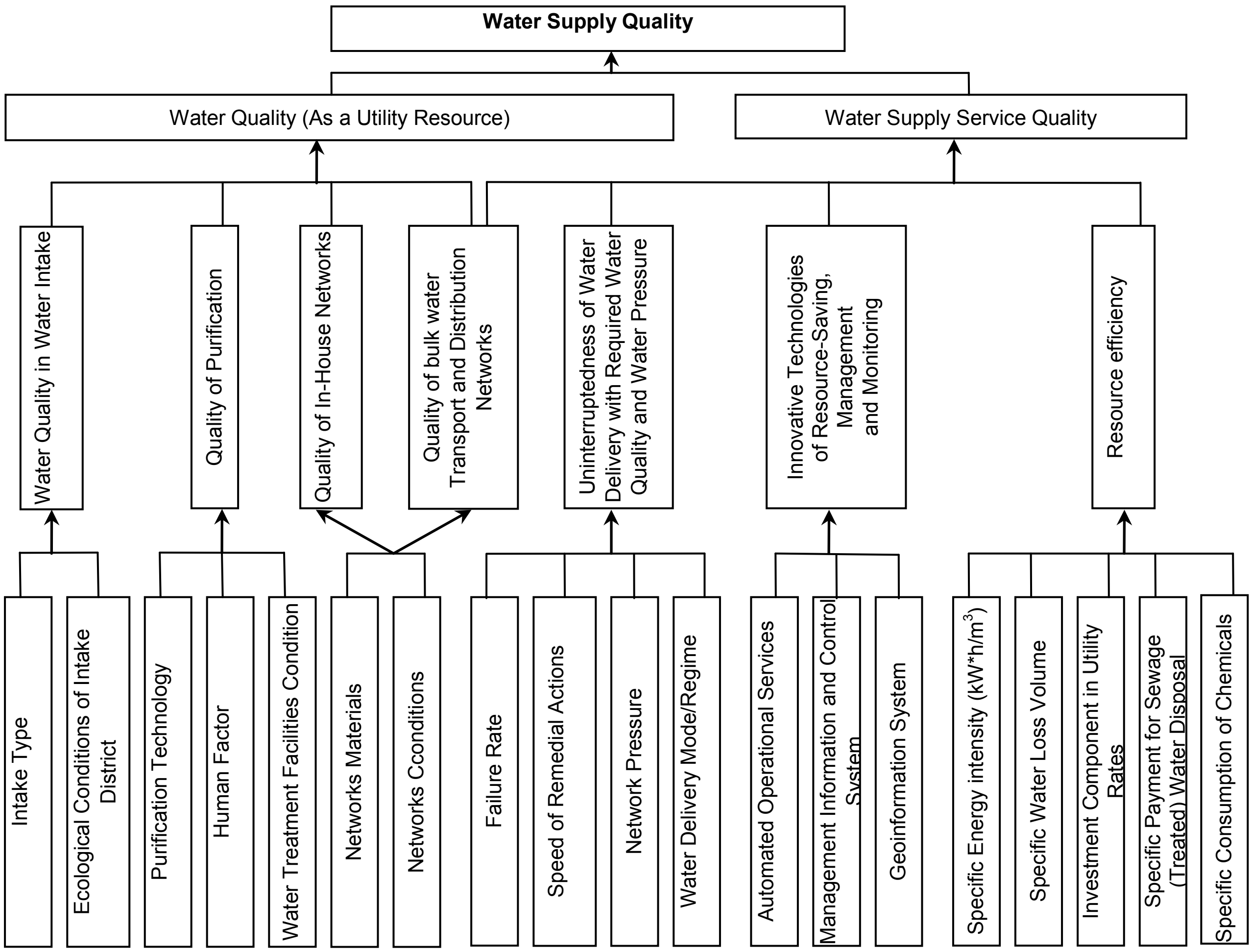

Fig. 7.4.1 Hierarchic model for household water supply quality assessment and management

Allowing different effects of various impurities on potable water quality, we use the formula of the arithmetic weighted average to aggregate factors of quality. We believe that potable water contains *n* impurities of normalized, *m* of them are microbiological (according to GOST 287-82 *m*=2—groups of microorganisms and bacteria Escherichia coli), *l* are chemicals that determine the harmlessness of its chemical composition and *k* are chemicals affecting the organoleptic properties of water. Then the coefficients of the microbiological (K_{MWQ}), toxicological (K_{TWQ}) and organoleptic (K_{OWQ}) water quality will take the form (7.4.2–7.4.4):

$$K_{MWQ} = \frac{\sum_{i=1}^{m} \xi_i \cdot K_i^{MWQ}}{\sum_{i=1}^{m} \xi_i}, \quad (7.4.2)$$

$$K_{TWQ} = \frac{\sum_{i=1}^{l} \xi_i \cdot K_i^{TWQ}}{\sum_{i=1}^{l} \xi_i}, \quad (7.4.3)$$

$$K_{OWQ} = \frac{\sum_{i=1}^{k} \xi_i \cdot K_i^{OWQ} + \xi_{k+1} \cdot K_S + \xi_{k+2} \cdot K_{Ta} + \xi_{k+3} \cdot K_C + \xi_{k+4} \cdot K_{Tu}}{\sum_{i=1}^{k+4} \xi_i}, \quad (7.4.4)$$

where ξ_i are the weighting values of the *ith* quality indicators for particular aggregated value according to the respective quality characteristics, K_S, K_{Ta}, K_C, K_{Tu} are the quality factors, which are in compliance with standards of smell, taste, flavor, color and turbidity of potable water.

In addition to the above, requirement of radiation safety for potable water is placed by SanPiN 2.1.4.1074-01. Coefficient of water quality in the aspect of radiation (K_{RWQ}) is introduced as in the previous (7.4.5):

$$K_{RWQ} = \frac{\xi_1 \cdot K_\alpha + \xi_2 \cdot K_\beta}{\sum_{i=1}^{2} \xi_i}, \quad (7.4.5)$$

where K_α, K_β are coefficients of water quality in compliance with radiation safety standards and defined by its compliance with standards in terms of overall alpha and beta activity.

Assuming varying degrees of negative impact of various pollutants on the human body, and, consequently, the nonequivalence of coefficients (7.4.2)–(7.4.5) for the general characteristics of potable water, we get aggregated coefficient of water quality (7.4.6):

$$K_{WQ} = \frac{\zeta_1 \cdot K_{MWQ} + \zeta_2 \cdot K_{TWQ} + \zeta_3 \cdot K_{OWQ} + \zeta_4 \cdot K_{RWQ}}{\sum_{j=1}^{4} \zeta_j}, \quad (7.4.6)$$

where ζ_j are is weighting value of the j^{th} characteristic in the overall assessment of the quality of potable water.

Similarly, particular and aggregate coefficients quality of water supply services can be introduced. Standard values of indicators describing the quality of water provision, such as accident elimination on the outer pipes, free head in the system, tightness and pressure in the interior and exterior water pipes, etc., are determined by the requirements of GOST R 51617-2000, SNiP 04.02.01 85 *, SNiP 2.04.02-84 *, Set of Rules 40-102-2000, Methodical Documentation in Construction 40-1.2000 and other regulations in force in the Russian Federation.

When designing the system of water supply quality assessment indicators and factors we take into account that lower level factors affect higher level factors of the hierarchy. (See Fig. 7.4.1)

The influence of lower level factors on each other should be also taken into consideration. For example, the volume of water fed to water treatment facilities depends on the type of water intake and as a result is conditioned by the water intake mode/regime; utility network condition influences failure rate and uninterruptedness of household water delivery.

To combine several indicators that characterize some factor we suggest using methodology of functional analysis.

Alongside with that the most interesting fact would be not the value of the factor itself but the deviation of real indicator from required one, which could characterize level of meeting the needs or degree of function realization.

It is necessary to mention that in the process of service consumption consumers indirectly assess technical level and quality of the company's operation. Thus, image of the company in the eye of the consumer and consumer's expectations about water quality are influenced by their current needs, former experience in communication with the company, service quality and price changes dynamics as well as official and unofficial information on company's activity.

Water supply quality in its turn influences costs and price of the services directly and, consequently, is inseparably bound to company's efficient functioning.

That's why to get an integrated assessment of the efficiency it's necessary to solve quite serious problems connected with the substantiation of the choice of indices and criteria determination of different efficiency components. Not least important task is negative phenomena risk assessment for the enterprise as well as external impacts for the whole municipal units (for their social and economic development, ecology, political background).

If we assume that is efficiency is always defined by the level of its functioning goals achievement, it is possible to allocate 4 groups of efficiency indicators:

1. Absolute indicators of goals achievement;
2. Relative indicators reflecting the ratio of acquired results and expenses aroused due to their acquisition;
3. Relative indicators depicting increase of above-mentioned markers in dynamics;
4. Relative (comparable) indicators describing the ratio of the above-mentioned indicators to the average ones in the group of similar or quasi-similar businesses or, in case of absence of such information, to the average indicators of the industry.

The indicators comprising the 4^{th} group are non-dimensional and allow coefficient compression, combining the ones that estimate different efficiency components in one integral indicator.

Methods of 4^{th} group efficiency indicators determination at the example of enterprise's organization culture efficiency is thoroughly described by the Krakashova [1]. There are three stages to it:

1. **Selection of efficiency indicators for the business and their value definition.**

2. **Calculation of society-acceptable (normal or typical) values for corresponding parameters.**

2.1. *Information on general universal set of enterprises in the given industry is available.* Using the method of cluster analysis allowing enterprise differentiation within the industry depending on the size, type of production, form of property and other factors, groups of similar enterprises are formed according to similar examined factors and average group parameters are calculated for each factor selected at stage 1. Acquired set of group efficiency parameters can be assumed as characteristic features of an average enterprise in the given industry.

2.2. *Industry indicators necessary for calculations are available.* Average parameters for the industry are calculated for the parameters selected at stage 1. Acquired set of group efficiency parameters can be assumed as characteristic features of an average enterprise in the given industry.

When the average enterprise and the examined enterprise comply with the requirements of similarity it is possible to use "scale coefficients" such as elasticity coefficients for parameters' changes depending on changes of the parameters selected for grouping at stage 2.1. Elasticity coefficients are determined when solving multiple regression equations (see stages 2.3 or 2.4).

2.3. *Information on necessary indicators dynamics for the industry is available.* In the equation acquired when solving multiple regression problem on the basis of the data on industry indicators dynamics instead of factors-signs we use company's parameters respectively. As a result we receive society-acceptable (normal, typical) values for the parameters selected at stage 1.

2.4. *Information on industry dynamics is unavailable.* In this case it is possible to comply with the similarity requirement by "correcting" parameter values for enterprise's economic efficiency selected at stage 1. To correct them you need to use average industry parameters instead of factor-signs when solving the multiple regression problem on the basis of the given enterprise parameters' dynamics.

Thus, we compare "two enterprises": the examined enterprise and the average enterprise for the group or the industry.

3. **Determination of relative parameters for business efficiency estimation.** To define them we need to divide parameters by appropriate socially-accepted normal values for maximized parameters and vice versa for minimized parameter.

There are three possible options for the relative parameters of efficiency ratio: <1, =1 and >1.

At that, the described method of efficiency parameters estimation allows to receive quantitative assessment of efficiency for such intangible factor as enterprise's organization culture [1], which reflect human factor influence on the quality water supply (Fig. 7.4.1) and the enterprise efficiency, when needed. In fact, taking into consideration heterogeneity of a business it is possible to conclude that relative parameters' values variations are conditioned by enterprise's organization culture influence. In the first case enterprise's organization culture is an obstacle to efficient functioning and enterprise development, in the second case it is neutral, neither an obstacle, nor a facilitator; in the third case it is a facilitator.

3 Conclusions

In result of study was formulated the concept of compromise efficiency, which consists in achieving of the highest possible values of the criteria of economic, environmental and social effectiveness of the enterprise, i.e. to provide a compromise between economic efficiency of water services supplier's functioning and social justice and maximum aggregate effect (economic, ecological, social, political) for municipality as a whole.

Impossibility of simultaneously achieving the optimum values all components of a comprehensive evaluation of the effectiveness of water supply companies requires finding a compromise in the ratio criteria for management purposes, the costs of their achieving and risks that may appear negative phenomena.

The proposed methods of obtaining the relative efficiency coefficients ensures the comparability of organizations on the scale of business. When needed, objective factors that influence the parameters of their operation can be taken into consideration. For example, when we compare water supply companies working in different regions it is important to consider climatic regimes and ecological situation of the regions that sufficiently influence the expenditure level for the company; and business culture of the region formed under the influence of different factors including national culture of the region can influence utility payments collectability in the region.

Suggested hierarchic model assessment and management quality of the water supply and methods of quantitative assessment of quality of water supply and the water supply companies' efficiency allows proceeding to the construction of analysis models and predict the effects of selected factors on the results and after that to development of a mechanism for monitoring and management of water supply quality as a major factor that determines efficiency and influences image of a water supply services provider in the eyes of the consumers.

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7.5 Current State and Future Expectations of Sustainable Development and Sustainable Production in the Finnish Manufacturing Industry

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Abstract
Realization of sustainable development and sustainable production and meeting the related requirements cause massive challenges for the manufacturing industry. The motivation for this study was the assumption that better understanding of the different aspects of sustainable development helps the companies to adapt more sustainable practices. The paper presents a literature review on sustainable development and production with practices related to the respective topics and then summarizes a study conducted within Finnish manufacturing industry. The results in this study are presented in a framework consisting of six categories. For each category the challenges, means and motivation for realization and objectives are presented. The obtained results provide further and in depth information of sustainable development and sustainable production within the Finnish manufacturing industry for both the industry and academia.

Keywords:
Manufacturing industry, Sustainable development, Sustainable production

1 Introduction

Sustainability is often expressed as meeting the needs of present without compromising the ability of future generations to meet their own needs [1]. Companies in the manufacturing industry struggle to meet this objective alongside the several challenges such as dependency on non-renewable resources [2]. Furthermore, the companies face increasing pressure to revise their actions in regard of sustainability as the supply of natural resources such as gas and oil is reaching its peak while demand continues to increase [3]. Hence, further work and effort is needed from both the industry and academia. The importance of understanding the challenges related to sustainable development and production in the Finnish manufacturing industry serve as the motivation for this study and paper. The assumption is that clarifying the current state and future expectations of Finnish manufacturing industry supports the progress towards sustainability in manufacturing practices.

This paper aims to clarify the current challenges and future expectations related to sustainable development and sustainable production in the Finnish manufacturing industry. Data is collected from Finnish manufacturing industry by carrying out workshops and the aim is to answer the following questions:

- What are the challenges of sustainable development and production?
- What are the means and motivation to realize sustainable development and production?
- What are the goals manufacturing companies aim to in sustainable development and sustainable production?

The answers to these questions and the results of this study are expected to be beneficial for both the academia and the industry sector. The first question identifies the current challenges and obstacles for sustainable development and production. This also gives better understanding for both the industry sector and academia where to focus research and development in the progress towards sustainability. Then the second question identifies means for realizing sustainability in every day practices. The second question also gives a better understanding why these challenges are important and why a company should invest resources to find a solution for the problem. Lastly, the final question answers what are the objectives of sustainable development and production from the Finnish manufacturing industry's point of view. The study and the results obtained from the workshops contribute to the available literature and theory on sustainable development and sustainable practices. The results provide practical information on the current state, means and motivation for realization and objectives which the Finnish industry regards as relevant and useful in pursuing sustainable development and objectives. The results of this study will also be utilized in an ongoing research project that aims at developing tools for designing and developing sustainable production systems and processes [4].

The paper is structured as follows. The next section provides an introduction to sustainable development and sustainable production. It covers the definitions and descriptions of these as we as advantages of means and realizing sustainability. Sect. 3 presents research methods and data used in this study. Then, Sect. 4 reports views of Finnish companies on sustainable development and sustainable production and answers the research questions presented. Finally, Sect. 5 summarizes the paper.

2 Sustainable Development and Sustainable Manufacturing

2.1 Definitions and Aspects

The most widely accepted definition for sustainable development is to meet the needs of the present consumption without compromising the ability for the future generation to meet their needs was formed by the Brundtland commission [1]. In addition to this, The Lowell Centre for Sustainable Production [5] defines sustainability in manufacturing and production practices as 'the creation of goods and services using processes and systems that are non-polluting, conserving of energy and natural resources, economically

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viable, safe and healthful for employees, communities, consumers and socially and creatively rewarding for all working people.'. Furthermore, as the ability to achieve sustainable development is dependent on both the customer and the producer, both aspects have to be taken into consideration. Hence, sustainable consumption can be defined as 'the use of goods and services that respond to basic needs and bring a better quality of life, while minimizing the use of natural resources, toxic materials and emissions of waste and pollutants over the life cycle, so as not jeopardize the needs of future generations.' [6].

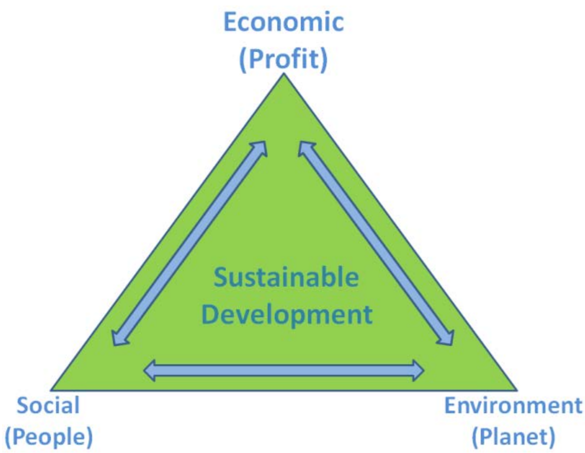

Fig. 7.5.1 Triple bottom line

Sustainable development is commonly linked to cover three aspects: environmental, social and economic sustainability. These aspects presented in Fig. 7.5.1 are generally referred as the 'triple bottom line' or 'the three P's', planet, people and profit [6, 7]. Environmental sustainability 'seeks to improve human welfare by conserving the sources of raw material used for human needs and ensuring that the sinks for human wastes are not exceeded, in order to prevent harm to humans' [8]. Manufacturing companies typically seek to reduce the use of materials and energy, and waste and pollution generated. Furthermore, social sustainability can be achieved by assuring people a reasonable enough share of wealth, influence and safety [9]. From the perspective of the manufacturing companies, this aspect covers issues such as personnel welfare, development and education, occupational health and safety, and compensation. The focus on economic sustainability is to secure both short and long term profitability and economic viability of the company. On the national level the issues related to the economic aspect of sustainable development are for example related to gross domestic product and its development as well as inflation which also affect companies and their operations. The vital point in realizing sustainable development is to balance and develop these three aspects, environmental, societal and economic in unison.

2.2 Required Changes and Potential Advantages

The Ad-hoc Industrial Advisory group concludes that pursuing and achieving sustainable development requires changes in various areas such as technology, processes, organizational culture and management [10]. With new technologies companies can reduce the environmental impacts, such as the energy consumption and emissions generated, of their products and processes. In regard to processes, the current trend of utilizing end-of-pipe technologies for decreasing the environmental impact of the company needs to be changed and the sustainability and environmental related issues must be addressed and improved in every phase of the production process [11]. These improvements could focus for example on process efficiency or on increasing recycling and reuse of waste materials. The perspective in the organizational culture and management should regard sustainability as a mean of increasing the company's competitiveness rather than a source of additional costs. Sustainability should have a central role in company's strategy, vision and decision making [12, 13].

In addition to the required changes, sustainable development offers several increased advantages and benefits such as competitiveness, financial savings, improved employee motivation, new markets and improved brand image to companies. Adapting new technologies or improved processes can lead to financial savings within the company through the reduction of energy and material consumption [10]. Additionally, focusing on personnel welfare and employees' occupational health and safety can have an impact in improved motivation towards work within the employees. Furthermore, addressing the sustainability in the company's operations can improve the brands image and value in increased sales or create totally new market segments to realize [11, 12]. Finally, the importance of sustainability as a business driver is expected to increase due to change in customer requirements such as the growth of environmental awareness (e.g. [11, 14]).

3 Research Approach and Methods

This study aims to identify and describe Finnish manufacturing industry's challenges, means and motivations as well as objectives of sustainable development and sustainable manufacturing. Hence, the study can be classified as nomothetical research and as theory developing empirical study [15, 16].

Literature review, a questionnaire survey and workshops were carried out to collect the required data for the project. However, this paper does not include the results from the questionnaire survey. The workshops conducted in the companies yielded detailed and in depth information of the companies' views on sustainability as the questionnaire survey worked as a framework to describe the overall situation of each company and the manufacturing industry. The results presented in this paper are based on the data obtained from the workshops. The workshop conducted consisted of three phases. In the first phase the participants were asked to list challenges and possibilities regarding sustainable development and sustainable production. In the second phase the participants were asked to place the challenges and possibilities from the first phase to a matrix consisting of four fields. The vertical axis represented the importance and the horizontal axis represented time when the challenge or possibility is expected to be current. Furthermore, each axis was divided in two sections, the vertical importance axis was divided into important and very important and the horizontal time axis was divided into time intervals of 1–3 years and 4–10 years. The participants gave further explanation on the topics they had written on the first phase to give a better understanding of the issue. In the last phase an open discussion took place to comment and ask about the presented challenges and possibilities.

The workshops were held in 21 companies which had presented interest in the research project with a total of 23 workshops carried out. In the workshops 399 issues were mentioned. The presented issues were narrowed down to 91 issues by eliminating similar issues. The 91 issues were presented to a group of researchers for a workshop. In this workshop the participants were placed in three groups which all categorized the presented issues into different subgroups. An additional joint categorization was formed by all participants of the workshop which was a combination of the initial classification. This categorization is the basis of the framework used to present the results in this study.

4 Finnish Companies Views on Sustainable Development and Sustainable Production

The discussion is based on the data and results obtained from the workshops. The results are divided to six categories and the amount of issues in each category is presented in brackets. Some of the presented issues can be considered in two or more categories, the categories are as follows:

- Product and Product Design (15)
- Supply Chain (9)
- Production (19)
- Personnel (17)
- Business (23)
- Society (19)

The challenges, means and motivations for realization and objectives of sustainable development and sustainable production in the Finnish manufacturing industry are presented for each of the categories.

4.1 Product and Product Design

Viewing sustainable development from the product and product design aspect, several challenges relate to products end of life management and life cycle assessment. Currently product design is not focused on the sustainability aspect of the product as much as the cost aspect. Products are often viewed as disposable and the current product recovery options are viewed as limited. Furthermore, designing sustainable products is regarded as more time consuming and often the qualities of ‘green materials’ are not comparable with the traditionally used materials. Also, issues such as reduction of noise and small particle emissions are hard to eliminate from the product without compromising the cost-effectiveness.

Solutions for overcoming these challenges are seen as developing a systematic product service and recovery strategy. Virtual design tools are seen as an important tool to realize sustainability in the products, in virtual environment many options can be measured, but further development of the design tools needs to take place before it will become a feasible solution for product design. Many companies are also evaluating alternative fuels to power their products and their effects on the emission and sustainability of their product. Companies in the Finnish manufacturing industry view product design as an important phase to have an effect on the products sustainability. Especially in products with long life cycles, the issues in the life cycle should be addressed in an early phase of the product design.

The objectives in sustainable product design in the Finnish manufacturing industry are seen as making products modular and updatable. Sustainability in product design is viewed as better life cycle management of the product. Longer term objective for product design is to have an ‘eco-product’ for which a secondary life cycle can already be planned before the initial life cycle has begun.

4.2 Supply Chain

In many ways several challenges reside in the planning and operating a successful and sustainable supply chain in the Finnish manufacturing industry sector. Partners are often chosen based solely on the cost while other aspects such as environmental impact in the decision play a minor role. Often when a supplier is chosen the goods are delivered in relatively small batches over a long distance. Furthermore, modal transportation is not taking place effectively in the Finnish manufacturing industry. Another issue with the suppliers is that, especially when a supplier is chosen from another country, for example China, the origins of the part are not always made clear for the Finnish company. This raises several ethical questions by the Finnish manufacturing industry, such as worker safety and rights for collective bargaining, work conditions and child labour. The small and medium enterprises consider assessing sustainability in their supply chain operations to be expensive and the time for return of investment for the sustainable practices is considered to be too long to be profitable. Additionally, many of the companies are not sure how they need to address sustainability in their practices. Thus, another issue the companies see is the metrics regarding sustainability in the supply chain, often it is hard for companies to measure their supply chain from a sustainable aspect

The motivation for enhancing sustainability in the supply chain was expressed by the Finnish manufacturing company as a threat that some work might be outsourced to another country than Finland. The means to enhance sustainability in the supply chain are viewed as further collaboration between the companies. For the small and medium enterprises collaboration is considered as extremely important to address the sustainability regulations and issues in the future. Several companies also see committing to sustainability not only in own actions but in the whole supply chain. The companies selling the goods to the end customers see themselves as the operator to address sustainability and ensure that sustainable practices are being used. However, the pressure to be cost-effective is significantly hindering decisions in the corporate strategy to choose the sustainable choice. Several companies expressed willingness to be able to buy the sustainable services from a third party.

In the supply chain both long and short term objectives were presented by the Finnish manufacturing industry. A sustainable supply chain is viewed as short distance transports between the operators. Companies see that it is important for the operators in the supply chain to be located close to each other. Long term objective for supply chain is viewed as an eco-friendly industrial area where several operators of the supply chain are located and a third party would provide them with services regarding sustainability. Tampere University of Technology’s department of production engineering has an ongoing project regarding this called ‘CSM-Hotel’ [17]. The CSM-Hotel offers operators equipment and facilities on a pay-per-use basis.

4.3 Production

In the production operations the biggest challenges lies in the finances and measurements. The Finnish manufacturing companies experience the costs of a sustainable investment to be far too expensive compared to the benefit gained. Sustainability related investments are seen to be expensive bulk investments, therefore several companies are reluctant to carry out such large scale projects. Furthermore, the lack of knowledge and understanding in what to do and when to do it increases the reluctance to realize sustainable investments in the production and manufacturing processes and operations. In addition the lack of easily adaptable measurements for small and medium enterprises decreases the support for investing in sustainability. The companies in the Finnish manufacturing industry do not feel a standardized enough set of metrics and indices has been established to support smaller enterprises in realizing sustainability.

However, Finnish companies in the manufacturing industry see several benefits in investing to sustainability despite the lack of financial support. With these investments the companies can continue the production in the original location and achieve savings in the production costs. Hence, including sustainability within the bigger future projects is a more feasible way to realize sustainable development in the manufacturing and production processes and operation rather than initiating multiple smaller projects. The paradigm for sustainability in the production and manufacturing field by the Finnish manufacturing industry is to enhance the existing operations to be more efficient and adapting energy conserving equipment and processes in the factory. Several companies see energy recovery from the processes and the overall reduction in the energy use as a way to address sustainability. Increasing the reusability of the used materials and increasing the recyclability of the waste materials generated from the production and manufacturing processes is also seen as a mean to increase sustainability. In addition, the use of packaging materials was mentioned by a number of companies. Reducing the materials used for packaging directly reduces the capital spent on both the packages and transportation, smaller packages can be loaded more efficiently in the transportation and generate less waste. With digital manufacturing several advantages can be achieved in the production and manufacturing processes. With a virtual testing environment the sustainability factor of the planned changes in the production system can be thoroughly tested. The companies in the Finnish manufacturing industry supports automation as a solution to address sustainability, investing in virtual testing of the processes and operations increases the benefit gained from automation. However, realizing the presented things requires commitment from the companies. Currently the companies in the Finnish manufacturing industry aim for short term profits while the focus on the long term plans in the company's strategy and vision does not support realizing the investments. Hence, the companies have to commit themselves in the field of sustainability to realize sustainable production.

Finnish manufacturing industry sees that a sustainable production system can be described as effective use of available resources. As a short term goal the Finnish manufacturing industry aims to develop new production systems and enhance the existing ones to be more sustainable. Over a longer period of time several Finnish companies aim for an eco-factory concept. However, eco factory in Finland is considered to be out of reach especially for the small and medium sized enterprise industry.

4.4 Personnel

Commitment to sustainable development of the personnel is seen as one of the key challenges in the Finnish manufacturing industry. The interviewed companies expressed the lack of understanding the greater effect of everyone's actions to be a part reason for the lack of commitment. The reluctance for change is regarded to partially originate from the relatively high average age of the workforce in the Finnish manufacturing industry. Currently changing the mindset of the factory floor workers is seen as a hard task because of the unwillingness.

Companies in the Finnish manufacturing industry see countering the mindset issues is considered to be extremely important. The motivation for social sustainability in the company is to keep the skilled individuals within the company. Thus, companies consider the role of sustainable development to be important especially in recruitment. A number of companies expressed that younger generations consider the company's image as a big part of choosing their employer. For companies to get the best individuals they need to focus on how the company is seen in the public. To address the commitment issues the management plays an important role. The management has to effectively emphasize the importance of sustainable development to the employees. In the workshops several participants issued that the sustainable development related practices in everyday work are tedious and adds additional work for everyone but in good time and proper education of the staff the desired change is said to occur. In the coming years much of the workforce is retiring and the knowhow accumulated over their career is not kept within the company. Thus, the aging of the workforce is considered to be an important issue in the coming years and the actions taken to countering the issue are taking place. Companies have suggested on initiating a mentor-system to ensure that the knowhow is kept within the company and the important knowledge can be transferred from worker to worker. Furthermore, companies are increasingly addressing the ergonomics and wellbeing of the employees to lengthen their careers. Companies also struggle with how the assumed concept of career is experienced as continuous and promotion oriented. A suggestion from a workshop was to shift the paradigm of career to more cycle and trend oriented. The careers of the employees would become related to how well the business is going for the company. Guiding the employees to an alternative career within the company is a way to counter the big layoffs when the business is not doing well. However, the worker safety and health related issues are considered to be in good shape in Finland. Companies focus on preventing work related injuries and accidents by keeping track of occurred accidents and near misses. Additionally, the Finnish manufacturing industry sees the worker safety and health related metrics and indices to be easily adaptable and informative.

The Finnish manufacturing industry sees keeping the talented individuals within the company as the most important objective. Furthermore, the objectives related to personnel can be viewed as focusing on ensuring the health and safety of the employees. Objectives in the personnel related issues serve multiple purposes for the company. Hence, by focusing on these issues such as workplace ergonomics the work related injuries decreases. Decreasing the amount of injuries also keeps the workers at workplace and thus keeps the productivity of the company at high level.

4.5 Business

The challenges related to the business activity for the companies in sustainable development and sustainable production is the lack of information and demand from both the customers and the management. The company's strategy and vision is formed to meet the customer's requirements and demands. For most companies the external or internal customer does not demand sustainability related practices or information to the extent it would become business driver. The customers typically choose the product or equipment they buy based on other attributes rather than sustainability. Companies currently are also reluctant to make decision supporting sustainability as there is no demand for it, focusing the resources on the currently important demands from the customer are regarded as more feasible option. Furthermore, the lack of pioneer companies engraving sustainability deeper in the strategy and vision does not encourage the companies in the Finnish manufacturing industry to promote sustainability. Small and medium enterprises are reluctant to become pioneers for sustainable development and sustainable production as the effects of promoting sustainability without concrete demand for it from the customers can lead to loss of sales.

Motivation for realizing sustainable development and sustainable production should originate from the company's strategy and vision. However, the current metrics does not give the companies support to lead the change towards sustainable production and sustainability in the company's operations. Further development of standardized and easily adaptable metrics is required. Shifting the company's management model to support sustainability the metrics and indices should be standardized to allow evaluation of progress and benchmarking with other companies as well as setting goals. Majority of the customers do not value the sustainability attributes of the products as highly as the Finnish manufacturing companies wants them to. A number of companies experiences the Finnish brand to give an advantage in selling products which are supporting sustainable development. Furthermore, being the pioneer for sustainability in each industry sector can work as a marketing advantage. Focusing resources on tackling the upcoming challenges is experienced to become an advantage when planning for a longer period of time.

The Finnish manufacturing aims to realize business supporting sustainable development and sustainable production. The companies' objectives are to differentiate from the competitors by offering the customers a sustainable choice for the product. Engraving sustainable development and sustainable operations deep in the company's strategy and vision, the companies in the Finnish manufacturing industry expects to give the public a positive image of the company and its values.

4.6 Society

Society places a lot of pressure for the companies by instituting new and tighter regulations. Companies experience politics as both a driver for sustainable development as well as a barrier for business. The pressure to stay competitive with the increasing regulations is considered as one of the bigger challenges for realizing voluntary sustainability in the companies' actions. In addition, the costs of manufacturing a product in Finland compared to manufacturing in cheap labour countries are becoming more expensive. Furthermore, realizing similar practices in Finland compared to a country with less strict regulations for emissions and waste management is not considered to be possible. The companies which have production in a cheap labour countries stated that there is no support in realizing similar regulations.

Overcoming these challenges is considered to be hard from the companies' perspective alone, hence companies state that support from both the European Union and the Finnish government is required. The current projects to support sustainable development are considered to be taking too much time before they are realized thus the pace for the change in the industry sector should be faster for them to be feasible for the companies. Furthermore, several projects, especially the projects in Finland, do not have a production oriented perspective and the focus is on the general level issues. Environment is currently experienced in too great extent, thus financial and social sustainability does not have the desired emphasis in the projects. The companies in the Finnish manufacturing industry see realizing sustainability as a joint operation with the governing bodies. The pace for the changes should be set in co-operation with the companies to ensure that it does not jeopardise the business by applying stricter regulations too fast. Certificates are currently experienced as a good way for a company to promote their actions for sustainable development. However, in the manufacturing industry the benefit of the certificate is not seen as important as in some other industry sectors.

Finnish manufacturing industry experiences the objects for the social aspect of sustainability as being able to generate jobs throughout the supply chain and supporting local production and manufacturing. However, co-operation with the governments and the industry is required in realizing this. A longer term objective for the Finnish manufacturing industry is to have a worldwide consensus of the regulations. In future it should not matter where the goods are produced and jobs are generated in places where the workers wish to live.

5 Summary

This paper discussed the current state and future expectations of the Finnish manufacturing industry for sustainable development and sustainable production. Based literature, definitions and aspects as well as means for and advantages of sustainable development were presented. Finally, results from the workshops among Finnish manufacturing companies were reported and the research questions answered. The aim was to clarify the challenges, needs and objectives for realizing sustainability within the industry.

The results from the workshops are presented in six categories, product and product design, supply chain, production, personnel, business and society. In product design the biggest challenges focus in the products life cycle assessment, thus further effort is required in this field. Virtual product design environment is suggested as a mean to realize sustainability in the product. The objective to address sustainability in product and product design is experienced as better life cycle management in the near future. Challenges in the supply chain to address sustainability can be considered as mostly financial. Currently being cost-efficient is more important than being sustainable. Therefore, the companies suggest further collaboration between the operators in the supply chain to achieve sustainability. The Finnish manufacturing industry aims to have short distance transportation in the future and working within close distance between the operators in the supply chain. Finances play a big part in the production operations and processes as well. The companies feel that the big bulk investments to address sustainability are often too expensive to realize, hence grouping the sustainability related issues in the future projects is considered as a more feasible solution rather than carrying out smaller projects. In the production operations and processes the industry aims for both energy and resource efficient production. In Finland the personnel aspect has been in high focus in the recent years with the challenge of aging workforce. The focus within the industry is to address the employee health and wellbeing to further lengthen their careers. However, the importance of other personnel related issues such as retaining the knowhow of the older workers within the company and changing the mindset of the employees to adapt sustainable practices. The companies in the Finnish manufacturing industry wishes to keep the talented individuals within the company and view personal talent as valuable asset for the company. Sustainability is not a big issue in the business oriented practices such as marketing for the company. The customers demand for sustainability is regarded to be a minor factor when making new sales. However, in future the demand for sustainability is seen to become an important part of the business. Companies in the Finnish manufacturing industry aim to strengthen their brand image by working in the forefront of sustainability. The societal aspect of sustainable development has been in focus along the personnel aspect. Currently the strict legislation place too much pressure especially for the small and medium enterprises to follow. Companies suggest that collaboration with the European Union and the Finnish government is required to set the right pace for realizing the sustainable practices. The industry’s objective is to be able to provide jobs for people wishing to live outside the bigger cities.

The results and discussion presented clearly imply that great efforts are required to realize sustainability in the Finnish manufacturing industry. The discovered challenges, means and motivations as well as objectives indicate the desired direction by the Finnish manufacturing industry as well as academia. For the authors, this study presented practical and in depth information for further research. The results are planned to be used in a research project, which aims to develop new tools and models for realizing sustainable development and sustainable production.

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7.6 Sustainable Key-Figure Benchmarking for Small and Medium Sized Enterprises

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Abstract

Sustainability as a concept of long-term economical, ecological and social orientation has an increasing impact on decision making processes within today's industry. In order to catch up with this development, modern Benchmarking approaches need to cover more than economical aspects. Therefore, the Fraunhofer IPK has extended the scope of the BenchmarkIndex, which is the leading key-figure-based Benchmarking analysis for SMEs. The core element of this approach is the integration of an additional "sustainability perspective" to the underlying four perspectives of the Balanced Scorecard (BSC), so that Benchmarking results will not only enhance companies' economical performances, but also take environmental requirements such as energy-efficiency and social responsibility into consideration. Due to the wide dissemination of the BenchmarkIndex, comprehensive sustainable indicators will be accessible to more than 100,000 SMEs worldwide, especially sensitising those that barely have paid attention to sustainability yet, in order to realise a targeted impact for the sustainable production worldwide.

Keywords:

CIRP international conference, BenchmarkIndex, SME, Sustainable benchmarking, Sustainable manufacturing

1 Introduction

Sustainability, as one of the most addressed issues regarding the development across all organizational structures, has a symbolic character, which may only become a practical concept, if the requirements for sustainability are implemented in all activities capable of shaping future development.

The contemporary definition of sustainable development refers to the long-term correlation between the distinct dimensions of economic, ecologic and social sustainability (Fig. 7.6.1). Therein it is not possible to pursue strategic goals of only one dimension without the neglect of one or both of the other aspects. This neglect ultimately leads to negative effects, which may influence the underlying objective of sustainable development [1].

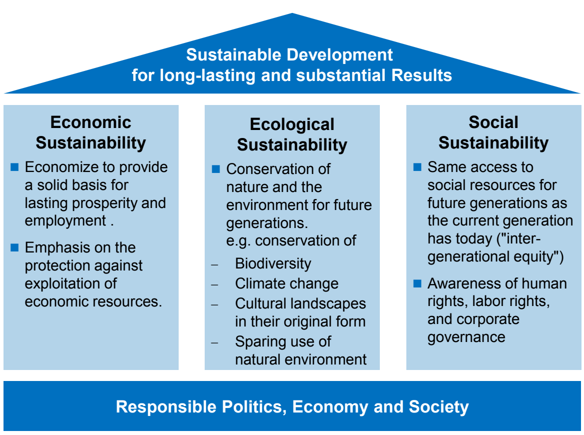

Fig. 7.6.1 The three pillars of sustainability

The social dimension comprises the establishment of a society capable of sustaining economic and societal welfare by including and enabling all those participating in economic and societal processes. Ecologic sustainability focuses on the preservation of nature and the environment in its original state. Since economic prosperity has been generated by a consumption of natural resources exceeding a sustainable rate, it is apparent that the preservation of the environment can only be a limited aspect of ecological sustainability. The ecologic dimension of sustainability is strongly oriented at the principles of environmental management. Considering the limited occurrence of natural resources, the sustainable consumption has to be countenanced by the development of innovative and efficient means to provide these resources [1].

This aspect is also a main driver of the economic dimension of sustainability, where economies and their entities should focus on developing and maintaining an overall stable and regulated economic environment, which enables them to perform at high levels without exploiting economical resources neither in the present nor in the future [2]. This performance can only be achieved by efficient corporate processes and the integration of the outlined aspects of sustainable development into the underlying corporate objectives.

While sustainable commitment can be determined as a common prevailing course today, the actual path to achieve a sustainable development is subject to company specific estimations and practices. In order to identify those practices leading towards a sustainable development, Best Practices have to be identified to point out individual potential for improvement [3].

2 Sustainabile BenchmarkIndex-Analysis

2.1 Benchmarking

Benchmarking signifies a continuous process, in which products and services and in particular processes and methods of operational functions are compared with those of several other companies or organizations [3]. Within this process the differences of the own products, services, processes, methods etc. to those of other entities are disclosed. On the other hand the causes for those

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differences and several possibilities to enhance the own position can be identified by means of Benchmarking. The comparison is accordingly performed with respective organizations that control some of the examined methods or processes well above average. Such companies are, with respect to the identified processes and methods, termed as "best in class" [4].

Benchmarking allows the acquisition of ideas from outside the own organizational structures and derivation of measures, which can be adapted and implemented as a company-specific solution. With a view of the bigger picture a company is able to achieve a top position among all potential competitors by setting new standards in the world of the world's best.

According to the increasing pressure in a global competition, enterprises face market situations, which are becoming more complex and are changing faster and more extensive. While large, established companies are able to provide the required financial, personal and knowledge resources to apply for such extensive Benchmarking projects, in particular small and medium-sized enterprises, as the backbone of most economies, need alternative solutions due to their limited resources [5]. In this context the key-figure Benchmarking analysis by the Information Centre Benchmarking at the Fraunhofer Institute for Production Systems and Design Technology (IPK) has shown a great story of success within the last decade.

2.2 BenchmarkIndex

The KPI-based Benchmarking method for SME, the BenchmarkIndex, provides a characteristic indicator comparison with industry-specific competitors and facilitates the implementation of Best Practices within an enterprise. A BenchmarkIndex-Analysis may be performed by enterprises employing a maximum of 500 employees from any industries and annual revenue of max. 100 million euros. The basis of the KPI-comparison is a database, which was developed and created in 1996 in the United Kingdom, containing more than 100,000 enterprises today [6, 7]. Since the BenchmarkIndex-Analysis is used in more than 20 countries today and the database is classifying the containing companies according to the “Standard Industrial Classification Code (SIC)”, national as well as international comparisons in 961 detailed structured branches of SMEs are possible.

The groundwork of an analysis of enterprises are standardized BenchmarkIndex-Questionnaires for manufacturing companies as well as for service providers, which provide the necessary input for the following KPI generation of the BenchmarkIndex-Report. The BenchmarkIndex-Questionnaires as well as the BenchmarkIndex-Report are structured based on the Balanced Scorecard (BSC) model, which enables a comprehensive view at a company encompassing four perspectives: “Finances”, “Customers”, “Process” as well as “Learning and Growth” [8, 9]. Although a methodology based on the Balanced Scorecard provides an encompassing insight of a company’s performance, the most part of the BenchmarkIndex results focuses only on short and medium-term economic improvement. Even if this is associated with certain aspects of the social dimension of sustainability, however, the ecological dimension has been neglected so far. Thus, a systematic approach had to be developed, which complements each of the four perspectives of the Balanced Scorecard with a sustainable point of view. This includes the adaption of each individual perspective separately as well as the coordination of the perspectives among each other.

Incorporate Economic Sustainability

To achieve and sustain economic success in most cases a certain competitive advantage or at least a competitive ability is required. Therefore, the management of a company is construed to provide a permanent basis for current and future competitiveness leading to prosperity. In this context, the foundation for this prosperity should not be based on the exploitation of natural, social or economic resources since this leads at best only to short-term success. In fact, long-lasting competitive advantages are highly dependent on advanced and innovative technologies and processes. Therefore, Benchmarking methods need to point out performance gaps and potential for improvement according to these aspects of long-term orientation [9].

Incorporate Social Sustainability

Benchmarking based on key figures as the BenchmarkIndex is oftentimes limited to internal social aspects like personnel correlating figures related to security or motivation. To serve a comprehensive social sustainability, the external stakeholder-oriented perspective needs to get further attention. In this context significant impacts of corporate activities on direct external stakeholders, like end customers or residents, and on overall societal structures need to be considered and evaluated [2].

Incorporate Ecological Sustainability

The third dimension of sustainability inherits the highest potential regarding new developments in Benchmarking. The first and foremost obvious benefit of ecological sustainable Benchmarking and a remarkable potential for synergy effects can be derived from the evaluation of different resource management approaches. The comparison of resource utilizing habits of organizations allows the identification of significant potentials in terms of energy and resources savings. Regarding the overall savings, which could be possible for a certain industry, this indicates how sustainable Benchmarking not only contributes to the success of companies, but also to the welfare of whole economies, too [10]. Due to the limited choice of directly comparable key performance indicators (KPI) within the resource management, companies’ awareness to collect these indicators needs to be raised.

This also portrays the major problem of sustainable Benchmarking. The most important requirement for a working key-figure Benchmarking method is a solid KPI-system. If the chosen KPIs are too specific the comparability among sectors gets lost. Therefore, the KPIs, which are shown below, have been selected in regard to an appropriate comparability, rather than an extensive coverage.

2.3 Procedure of the Sustainable BenchmarkIndex

The process model of a BenchmarkIndex-Analysis consists of the steps [5] shown in Fig. 7.6.2.

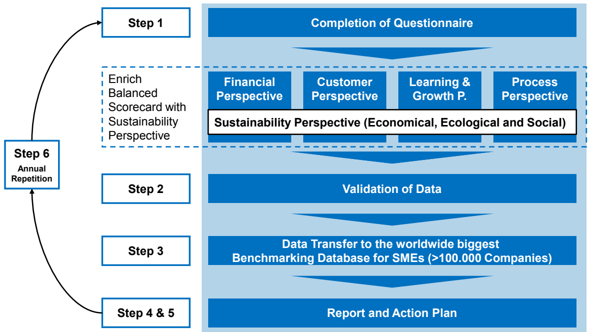

Fig. 7.6.2 Procedure of the BenchmarkIndex advanced

The BenchmarkIndex is a supporting method. A BenchmarkIndex-Advisor trained and certified by the respective national Benchmarking Centre provides a company with the fundamentals of data collection and evaluation respectively discusses the comparison criteria. The effort of completing the questionnaire (Step 1) differs depending on data availability and data-relevant know how on the part of the company. In general, the comparative data can be taken primarily from the balance sheet and the income statement as well as from quality management and is available even in SMEs without extensive controlling systems. This ensures a resource saving data collection. Data, which is not included in these sources, has to be collected manually by divisional experts. After the data collection is finished the data will be validated (Step 2) and entered anonymously into the data base (Step 3). Thereby, the selection of the Benchmarking criteria (revenue/year, number of employees, industry, and location) to identify a suitable peer group of enterprises from the database is of critical importance. To ensure reasonable statistical results, a minimum sample size of 11 companies needs to be considered in the comparison. Within a short time period the comparison is preformed and the results are generated and codified in the BenchmarkIndex-Report (Step 4). The execution of the steps 2, 3 and 4 usually takes about two hours. Step 5 the generation of the action plan, is usually done in a half-day workshop, led by the BenchmarkIndex-Advisor, together with a Benchmarking-Team including members of the consulted company. According to the average duration of the data collection, the execution of a BenchmarkIndex-Analysis does not take more than 3 days in the end. To monitor the effectiveness of the implemented measures and to get the maximum benefit out of the Benchmarking process, it is reasonable to repeat the procedure, described above, annually. So basically, the BenchmarkIndex is designed for continuous use [9].

3 Key-Figures Adaption

In general, the performance of an organization is determined on the basis of economic indicators. Therefore, companies that achieve consistently good results are successful in the traditional sense and therefore called sustainable. Here, the definition of “successful“ is often only linked to economic conditions, which generally have a short-term horizon instead of providing information about the long-term prospects of an organization. Also most economic indicators refer to a performance of the past and give little information about the likely future development. If an organization wants to deal with sustainability development, it is however necessary to record not only economic indicators, but also those describing the environmental and social impact. On the other hand the selection of indicators has to focus on its ability to measure sustainable matters. Many sustainable ecological and social indicators are, however, leading indicators. Furthermore, these indicators are linked with the future economic developments of an organization. In this sense, for example, customer and employee satisfaction are considered as leading indicators of sales performance. The following Tables 7.6.1, 7.6.2 and 7.6.3 provide an overview on the enhanced BenchmarkIndex for measuring the “sustainability performance” of SMEs by using the BenchmarkIndex [1, 9].

Table 7.6.1 Previous versus innovative key figures of the BenchmarkIndex (economic sustainability)

Economic sustainability of the BenchmarkIndex advanced		
Perspectives	Previous key figures (extract)	Innovative key figures (extract)
Financial	• ROCE • Working capital turnover • Gross gearing • Net profit growth • Equity ratio	• Long-term development of the share price • Taxes paid (or the percentage paid in taxes on revenues) • Value added for key stakeholders • Share management staff with sustainability goal agreement
Customer	• Complaints per customer / order • Percentage of orders rejected during warranty period (%)	• Satisfaction of key stakeholders / interest groups
Learning & Growth	• Average staff cost per employee • Training expenditure to turnover	• Agreements for executives with long-term goals • Personal and social skills of business management
Process	• Delivery schedule deviation (%)	

Table 7.6.2 Previous versus innovative key figures of the BenchmarkIndex (ecologic sustainability)

Ecological sustainability of the BenchmarkIndex advanced		
Perspectives	Previous key figures (extract)	Innovative key figures (extract)
Financial		• Number of new products with sustainability features per year • Locations with eco-balances • Number of product-cycle assessments (IPP) in relation to the total number of products • Environmental management systems: Duration of certification (ISO, EMAS)
Learning & Growth		• Expenditure on R&D to improve the sustainability of products (e.g. to extend the product life time)
Process	• Sales generated per square meter	• Pollution (air, soil, water) • Waste • Recycling rate • Consumption of resources (water, energy, etc.) • Proportion of environmentally friendly materials and products of the total material consumption

Table 7.6.3 Previous versus innovative key figures of the BenchmarkIndex (social sustainability)

Social sustainability of the BenchmarkIndex advanced		
Perspectives	Previous key figures (extract)	Innovative key figures (extract)
Financial	• Staff costs as a percentage of sales	• Label share of sales • Percentage of employees engaged in pro bono and community activities • Number of corporate volunteering projects • Number of corruption cases • Proportion of revenue for expenditure in support of research and development for sustainability
Learning & Growth	• Training expenditure to turnover • Employees with formal work-related qualifications per FTE employee • New employees per FTE employee • Absenteeism per FTE employee • Number of reportable accidents per year • Actual weekly working hours per year • Absenteeism per employee per year	• Training days per employee per year • Expenditure on staff training in relation to sales • Proportion of women executives • Earnings ratio men / women • Percentage of employees over 50 years • Parents share in parental leave • Share of managers with leadership training • Percentage of employees in training programs • Share trainee • Number of jobs created • Expenses for health care and safety precaution

4 Evaluation and Report

The participating enterprise receives the results of the BenchmarkIndex-Analysis presented in the BenchmarkIndex-Report, which shows the relative position of the analysed enterprise performance within the respective peer group for each KPI. In addition, the BenchmarkIndex-Report contains a table, which shows the allocation of all performances (KPIs) within the peer group according to the following five categories (Table 7.6.4):

Table 7.6.4 Classification of company performances compared with the peer group

Weakest	Performance of the company with the relatively weakest result of the peer group
Weak	Performance of the company with a result worse than 25% of the peer group
Median	Performance of the company with a result worse than 50% of the peer group

Strong	Performance of the company with a result worse than 75% of the peer group
Strongest	Performance of the company with the relatively best result of the peer group

To increase the level of statistical confidence, the best and worse 5%-performances of the peer group is excluded from the comparison. Furthermore, a peer group size of at least 11 comparable companies is required in order to have a sufficient sample size to generate an adequate BenchmarkIndex-Report. This is attributed to the reliability and validity of the grid points (quartiles) evaluated in the BenchmarkIndex-Report.

In general, the results of the BenchmarkIndex-Report are statistically as well as graphically illustrated and can be used to discuss and analyse the relevant strengths and open potentials of the enterprise (Fig. 7.6.3) [5].

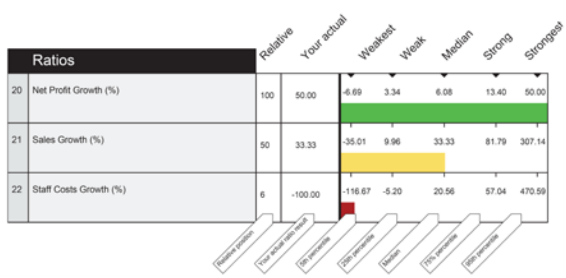

Fig. 7.6.3 Extract of the BenchmarkIndex-Report

Within the framework of a BenchmarkIndex-Analysis, the strengths and weaknesses of SMEs are identified very easily. Furthermore the SMEs receive KPIs of Best Practice companies, which can be used specifically for the derivation of improvement measures. As a result of the discussion with the management, a verified action plan will be created to implement the desired changes. Usually this derivation process is applied with the advisor. Depending on the selection of the relevant indicators, the causes of company issues can be illustrated, analysed and quantified by using fishbone diagrams (Fig. 7.6.4).

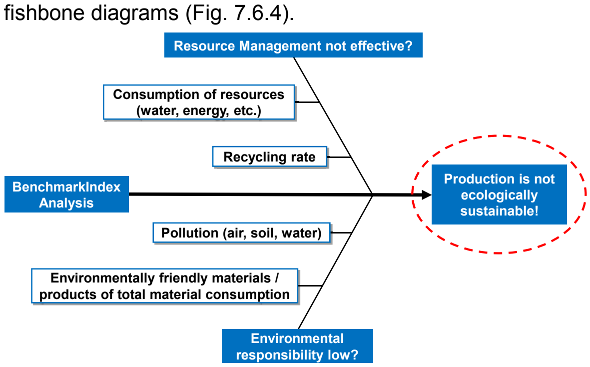

Fig. 7.6.4 Example Fishbone Diagram: Results analysis and evaluation (Process perspective)

Even regardless of an action plan, the BenchmarkIndex-Report still provides a comprehensive image of the situation the analysed enterprise is in compared to the peer group.

5 Summary

The by sustainability indicators enhanced BenchmarkIndex explicitly takes the framework conditions of SMEs into account and also includes the external comparison of key performance indicators to identify performance gaps not only in terms of the overall competitiveness but also in the sustainability performance. However, an inclusion of Best Practice processes is not intended. The vast dissemination of the BenchmarkIndex also allows a fast and efficient transfer of sustainability indicators and practices of best performing enterprises to thousands of enterprises worldwide. Hence the impact of sustainability Best Practice sharing is vast.

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7.7 Enterprise Innovativeness is a Necessary Condition for Sustainable Development

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Abstract
Innovativeness is the decisive factor in establishing economic self-sufficiency and competitive market position of the regions and enterprises. The study and measurement of innovativeness is a means to analyze company's ability to innovative solutions. Information on the innovativeness condition and dynamics is needed to choose appropriate development strategies, it is also important for the bodies of regional governance to define innovation policy-making, implement measures to support innovation activity, to form the roster of innovative organizations. The paper deals with the factors characterizing innovation activity in the region; criteria, metrics and methodology to determine enterprise innovativeness.

Keywords:
Innovation, Innovativeness, Innovation activity, Innovation potential

1 Introduction

To compete with the economies of industrialized countries, Belarus would require an annual gross domestic product (GDP) growth in as much as 7–8%. However, if GDP grows only at the expense of physical production, you get an alarming increase of the resource component of social production. Scientific, technical and innovation potential should become the most important factor in economic efficiency improving and the basis of improving the population quality of life.

It is impossible to form knowledge-based society without economically strong regions, effective regional innovation policies and innovation systems development. The main components of any innovation system are:

- knowledge generation (science and education);
- knowledge implementation (production of goods and services);
- regulation (public administration bodies).

Communication between the innovation system components is achieved by the means of innovative environment, formed by the innovation infrastructure activity, culture, society, state policy, legal and regulatory framework.

The necessity and urgency of modernizing the industry is due to the increasing technology gap between the growing industry of the country and the enterprises in industrialized foreign countries. For sustainable and efficient development of industrial enterprises in their transition to innovation economy it is necessary not only to increase modernization in the advanced sectors and industries, but also to intensify technological modernization of traditional industries as a basis of their development. However, the issue of innovative development path in the strict sense, that is, qualitatively and quantitatively measured degree of innovation is not developed enough. Enterprise efficiency is determined by innovation, which is regarded as one of the most important resources that involves systems controlling the processes of knowledge production, development and transformation into a commercial product to provide competitive advantages [1].

The main concern of the article is to ground the necessity of enterprise innovativeness monitoring and measurement as an economic entity.

Innovative activity of an enterprise is defined as a business advantage over other business entities. This comparison can be based both on qualitative characteristics of products and services, and on quantitative (individual, group, integral) characteristics. Short-term advantage of an economic entity can be achieved by minimizing the costs and skilled management. Long-term benefits can only be achieved by constant products (services) updating, replacing the outdated forms by new ones, designed to meet ever-changing market needs. The most difficult task is to assess the degree of innovativeness.

The **object** of the research is enterprise innovative activity.

The **subject** is enterprise innovativeness measurement.

2 Measuring Innovativeness

According to the State Statistics Committee of Grodno region innovative activity of the industrial enterprises has been extremely low during the latest decade. Unsatisfactory situation with investment activity, negative dynamics of the products sold, work and services performed in manufacturing field are due to a number of unfavourable factors the main of which are:

- worn out and outdated equipment;
- low quantity and quality of innovation projects, patents, know-hows;
- low investment attractiveness, which entails substantial underinvestment in the modernization process (in practice most of the industry enterprises come to upgrading using internal resources);
- outdated funds distribution policy management: main part of the investments is involved in technical and economic

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product characteristics improvement without taking into account changes in economic policies and programs, the degree of imbalance in markets and management;

- innovations are prevented by low-level of cooperation when developing technological innovations.

Analysis of industrial enterprises activity showed that the main factors hindering or limiting innovation activity are:

- Low level of scientific and technological potential;
- Lack of internal funds;
- Insufficient financial state support;
- Lack of qualified personnel;
- High cost of innovation.

Innovativeness is a crucial factor in strengthening economic independence and competitive market position of an enterprise. Information on the innovation condition and dynamics is important to the managers and staff of an enterprise to choose development strategies and adopt appropriate management decisions, as well as to the regional bodies when managing innovation policies, implementing measures to support innovation, forming the roster of innovative organizations.

3 Innovative Companies Financing

When studying specific features and opportunities of innovation activity funding it is necessary to distinguish between the concepts of innovative and traditional businesses, as well as measure the degree of innovativeness. The draft law defines the subject of innovation activity (including innovation company) as a physical or corporate person carrying out innovative activities and (or) facilitating their performing. And innovative activity is that providing creation, implementation, and commercialization of innovation. In Europe another concept is used—“New technology-based companies” [2]. Another new category of companies represented in contemporary literature—“Knowledge intensive organizations”. According to the authors Swart, Kinnie those organizations can be referred to as “Knowledge intensive organizations” that base their major activity on the use of scientific results, and that mostly have highly qualified employees with higher education [2]. Stabuck emphasizes that for knowledge-based organizations, the factor of knowledge is more important than other factors of production process (capital, labor) [3]. Various definitions of an innovative enterprise demonstrate the importance of the concept and great diversity of such companies. In today's economy, such enterprises are particularly important to establish economic well-being.

The main feature of the innovation activity capital market is its riskiness. Market uncertainty often makes it difficult for innovative enterprises to successfully seek for capital using traditional methods. In this regard a number of issues specific to innovation activity financing arise:

1. The payback period of innovation often can not be determined accurately. Companies create products or services for the market, which is not stable, so investors can not be sure when estimating risk;
2. Entrepreneurs may have more information about new products and processes, and this may cause information gap and prevent signing financial contracts;
3. Innovative activity has unbounded character, so it is usually difficult to estimate financially until it succeeds.

Thus, the problem of innovation activity financing is based on its specificity and uncertainty that make it more complicated to search for and conclude financing offers.

Innovative enterprises are characterized by growing fairly rapidly and by being a source of technological, economic and social changes. At the same time, they also have some negative qualities that prevent their successful use of financial resources (Table 7.7.1).

When financing innovative enterprises or projects, an investor must evaluate all the risks and dangers (Table 7.7.2) [4].

Hence, despite the advantages of a fast-growing innovative company, there are many threats and risk elements that hinder financial flows movement in innovation activities. I.e. traditional model of funding such enterprises (including credits and loans) is not very successful and risk capital financing is an alternative in such a case.

Table 7.7.1 Positive and negative characteristics of innovative enterprises [4]

Advantages	Disadvantages
Rapid growth	Suffer from lack of funds
Focused on export / international business	Depend on their own capital
Create high added value	Unsteady flows of funds
Skilled staff	Limited research expenses
Innovative, easily adjusted to the situation	It is hard to manage rapid company growth
Spreads technological advances	Long investment cycles
If successful, provides rapid return on investment	Characterized by “the success of one product”
Ensure large corporations success	Unstable public policy
Create the future of corporations	Only a small portion of companies are successful in the long run

Table 7.7.2 Risk reasons of innovative enterprises financing

Risk	Risk profile
Management risk	An antrepreneur and his team do not have experience enough to ensure effective growth and development of an enterprise
Market risk	Company product / service is not attractive to the market and income ensuring, the target market is rather small or competitors start their response actions
Technology risk	New technology created is not successful, functioning poorly or does not bring a consumer needed benefit
Pricing risk	Investor overestimated the company value
Financing risk	A company does not generate the necessary income and the investor does not receive the expected return on investment
Liquidation / exit risk	Investor can't find a company purchaser in order to a return on capital

4 Innovative Susceptibility

The main characteristic of new economy is innovative processes intensification, regarding them as a factor of economic growth. That is exactly innovations embodied in new scientific knowledge, products, technologies, services, equipment, skills, production organization, that are the main factors of competitiveness. Market gives motivation for innovations and they are always put into practice in certain organizations—an industry, enterprise or institution.

Degree of susceptibility, namely, social demand in general, and particular users' demand in particular for the products and results obtained in the field of innovation is considered to be an important factor in the efficiency of science, technology and innovation. And the innovative capacity of any organization as a complex of innovative elements is a major characteristic of innovation susceptibility, which determines the actual intensity level of innovations assimilation, i.e. innovative activeness. Innovation susceptibility stimulating is a necessary prerequisite for the economic potential development in the Republic of Belarus.

Innovation susceptibility of an organization can be measured by:

- a period of time necessary for mastering any specific innovation;
- the total number of innovations that have been mastered (or that have to be mastered) in the organization by a certain moment.

Sustainable enterprise development is ensured by a complex of innovations: product, process, organizational, administrative, and others. To obtain sufficient information to evaluate enterprises and organizations in order to determine the innovation susceptibility level it is necessary to get and process a special data collection that fully reflects not only manufacturing and technological, but also social and economic changes that are fairly easy to classify, systematize and analyze quantitavely.

When monitoring innovation susceptibility (innovation development) of an enterprise or organization we should consider the following factors:

- technical and economic data;
- innovative element;
- staff;
- information support;
- investment activities;
- innovation needs and innovation susceptibility self-esteem of the staff (their psychological and professional aptitude to perform definite actions to implement innovations).

Research results in the field of enterprise innovative susceptibility are first of all to help managers to get guidance in their innovation activity, to approach personnel skills and organization structure to the appropriate form and thus, to facilitate innovation mastering process greatly.

In determining methods and ways to stimulate innovation susceptibility innovation process is analyzed as the resultant of many economic factors, both objective and subjective, external and internal, which are coordinated with each other and form a motivation system to generate innovative strategies [5].

The objective factors include those factors from the external environment that are caused by long-term trends and not by somebody's personal decisions. For example, economic laws that influence innovation activity greatly: the value, profit earning and appropriation, demand and supply, etc.

Factors of subjective nature are direct results of conscious decisions, among which we should mention the following:

- state innovation policy as the major constituent of government economic policy;
- monetary policy of organizations functioning as investors;
- consumer behavior, which largely define the demand for emerging innovations as a result of innovation activity development. For an innovative company, taking this fact into account means additional efforts to shape the future consumer demand for a new product, service, technology, etc. [6].

The factors of innovation susceptibility can be classified as global—defined by macro-economy and society in general and local, defined by the micro level of enterprises [7].

Innovative potential of an enterprise is represented by a set of material, financial, labor, infrastructure, intellectual, information and communication resources [8]. Innovative activeness is determined by two groups of factors: internal, aimed at establishing and managing innovation activity of an enterprise and external, contributing to altering the boundaries of innovation activity.

The external factors are those causing company interaction with economic and social environments [9]:

- using external sources to support all stages of the innovation process, starting from discovery and development to commercialization;
- communication with customers, business partners, investors, competitors, research organizations and universities;
- interaction with local authorities.

Internal factors are significant company peculiarities that distinguish it from its competitors and determine its innovative viability:

- motivated administration;
- integration of technological, organizational and managerial innovations;
- efficient production;
- effective relationships with staff, their active involvement in the innovation process;
- continuous organizational learning;
- efficient marketing system, carrying out communication with ultimate customers;
- control of the technological and organizational development, quality, and infrastructure.

Let us consider some measures to stimulate enterprise innovative susceptibility through state active intervention into the process of innovation development through the economic incentive system.

1. Tax support.
   - tax breaks not as advance payment, but as a reward for a definite innovation;
   - tax breaks not only for research organizations, but for businesses and investors who appear to be active participants of the innovation process.

Then benefits and competition are going to ensure high demand for research and innovations.

2. Stimulation of non-budgetary investment in research.

For private, banking, industrial and other types of investment in research when calculating the sum of investor tax expenditure on R & D (research and development activities) and technology transfer at the rate increasing the performed one (in half, for instance) should be deducted from taxable income.

3. The quality of the personnel is an important factor in innovative activity development. Increasing education level, skills development is one of the most important factors for innovation susceptibility development. It results in more efficient use of productive resources. Science performs here a special role. It should therefore be closely integrated into production, become a member of the innovation cycle development, innovation advancement and mastering.

4. Training for innovation sector, including technicians, able to use modern tools to work successfully and promote innovation in manufacturing.

Company competitive opportunities can be measured by evaluating factors of controlled relative market share, speed of reaction to changing market conditions, etc. Technical capabilities are due to the equipment parameters, production technological scheme, etc. We should also mention the organizational culture possibilities in innovation promoting and the role of strong management in creating such a culture.

5. Innovation culture.

To make innovation susceptibility for a business or organization a consistent process, it is necessary to create an innovative atmosphere and to introduce a new corporate cultural value—innovativeness.

5 The Role of Higher Education in the Innovative Economy Development

An important role in implementing the State program of innovation development in the Republic of Belarus is given to high school. To address the key program issues and basing on the needs of the forming innovative economy innovation potential upgrading in education is called for. Education system is crucial for intellectual capacity development on which knowledge production and implementation depends, as well as to introduce lifelong learning practices required to update human knowledge and skills.

The University today has not only to be dynamic and "flexible", but more open as well. It means it has to actively position its contribution to the innovation process and social development, i.e. it needs to become both an educational institution and an organization of innovative type.

Innovative University is adaptive to environmental demands, it is an academic complex of collective enterpreneurship functioning and actively developing, operating in a competitive environment of domestic and foreign major markets, such as:

- intellectual work specialists training;
- high technology products and scientific services;
- educational and consulting services;

The main activity fields of an innovative university are: education, research and innovation based on advanced technologies and management principles.

Scientific activity of the University is aimed at generating new knowledge, educational activity—at knowledge implementation during professional training process, and the aim of innovative activity is knowledge commercialization.

Social status and role of modern university as knowledge generator for the benefit of economy and society must meet the following criteria:

- show initiative and not wait for organizational and financial support from the companies. It has its share of responsibility in this process;
- improve the "governing capacity": to develop business plans, identify definite mechanisms and choose the way of introducing its activity results to the real economy;
- to make appropriate steps in creating infrastructure for fruitful cooperation of higher education and the real economy;
- increase the managerial competence level of the faculty to ensure cooperation in the system "high school—business entity";
- to create internal innovation and entrepreneurial culture and infrastructure.

Innovative orientation of the university requires an adequate system of scientific personnel, whose potential allows university development strategy implementation.

INNOVATIVENESS involves effective introduction of new sound ideas, projects, developments, achievements, etc. into a multi-faceted educational, scientific and technical activities of the University by enhancing the principle of uniting education, science and industry in order to prepare highly qualified specialists of various profiles on the basis of innovation activity.

6 Conclusions

Thus, it is necessary to develop and promote innovative susceptibility and activeness of enterprises and organizations, i.e. the following capacities: appropriate and rational use of the most available resources and the results of innovation activity to meet market needs; timely and effectively create organizational and economic mechanisms aimed at reducing the life cycle of innovation development and its commercialization; to create flexible organizational structures; to form a competitive strategy, based on innovations; to create a special atmosphere in the organization, using and developing company personnel creativity, as well as acquiring the best experience and revealing specialists potential; coordinate management and organizational structures of enterprises in compliance with the strategy for competitiveness.

Innovativeness is a key feature increasing efficiency and sustainable businesses and organizations development, it’s involved in management solutions in order to increase efficiency of operation. According to the analysis of innovativeness development and implementation of management decisions aimed at improving the efficiency of enterprise innovation sustainability prove to be fruitful. The level of innovativeness can be identified by each company and organization in the future, and then they may compare their innovative index with the index of innovation in the whole industry. This will give the head of the enterprise the following opportunities: first, to define company place among the industry in the context of innovation development, and hence to assess their competitive advantages, and secondly, to develop an appropriate strategy for further market penetration. Besides, the company manager, analyzing the results of calculating the innovative development index, can study its structure in detail and identify what factors cause its decrease and increase.

Having calculated the innovative development index for certain periods of time it is possible to observe its changes, and the changes in its structural elements over time, and adjust the strategy of the company according to the data obtained.

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Chapter 8:

Engineering Education for Sustainability

8.1 Life Cycle Model of Professional Higher Education in Russia as a Management Tool of the Stable Development of the Sector

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Abstract

In the article the history and the actual state of the system of professional higher education (PHE) in Russia is examined. The analysis of recent tendencies of the sector is presented, and its life cycle is investigated. The necessity as well as the possibility of the approximation of key parameters of the higher education system are proved using the logistic function. A specific situation emerged in 1991–2009, characterized by a saturating avalanche-like process. It included mass demand of the Russian population for higher education, low cost of educational service, lowering of the market entrance barriers for new educational institutions. The education law of 1992 played the role of catalyst in these processes. The model of quantity of students is constructed; the conditions, which define the level and dynamics of the key indicators of PHE are examined. Authors formulated and substantiated their position in relation to the planned trends of PHE restructure.

Keywords:

Catalyst of demand, Life cycle, Logistic function, Professional higher education

1 Introduction

In the beginning of October Medvedev instructed the Ministry of education and science of the Russian Federation to conduct public discussions concerning the new bill "about education", the Head of the state gave the ministry this commission during a meeting with the laureates of the "teacher of the year 2010" competition. The current state and prospects of the development of higher professional education affects the interests of the entire population of the country. There aren't and cannot be uninvolved or indifferent people when we are discussing this subject. It is possible that the direct motive of this commission was also a result of the circumstance that on one side, the number of negative appraisals of the future law both from interested parties (for example, the Russian council of rectors), and the general public, passed a certain critical level, and secondly, that the leaders of departments, in particular, minister A.Fursenko, frequently and consecutively voiced the radical component of the planned conversions in public appearances. The Higher education system is an inertial system, the errors of the solutions adopted today will determine the fate and position of the country in the distant future, and in this connection even an attempt to take into account the entire spectrum of opinions is completely justified.

2 Brief Information about the Sector

At the beginning of the 2008–2009 school year the main parameters of Russia's higher education system were as follows: number of higher education institutions—1034, out of those municipal and state—660; number of workers—around 900,000, the number of professors teaching in universities and colleges—404.5 thousand, in state and municipal—341.1 thousand; number of students—7513 thousand people, out of those in state institutions—6215 thousand [1].

In the work [2, pp. 4–20] the authors in sufficient detail systematized the international statistics of the level of educational development in 2005, it is in particular noted that on the basis of a comparable system of indices is given a list of "… the group of the leading countries in the sphere of education: Australia, Great Britain, Germany, India, Spain, Canada, Korea, China, the Netherlands, Poland, Russia, the USA, Finland, France, Sweden, Japan. The highest indices of the general level of education from this group of countries have: by the index of education—Australia, Spain, Canada, Finland (index of education 0.99); by the portion of the adult population with higher education ([ISCE] 5[A]/6)—the USA (30%), the Netherlands (28%), Canada, Australia, Korea (23%); by quantity of students in Institutes of Higher Education ([ISCE] 5[A]/6)—the USA (13.2 million), India (11.8 million), China (10.8 million), Russia (6.9 million); by the portion of students in Institutes of Higher Education ([ISCE] 5[A]/6) relative to the population of the country: taking into account the factor of the scale of the population—Poland (5.4% with a quantity of students of 2 million), Russia (4.8% with a quantity of students of 6.9 million), the USA (4 ,4% with a quantity of students of 13.2 million); without taking into account the factor of scale—Finland (5.6% with a quantity of students of 0.3 million); by the portion of the adult population with tertiary education—Russia (54.6%), Canada (44.6%), the USA (39.1%). In recent years, the leaders in the international ratings of higher education are as follows: USA, Great Britain, Germany, France, Australia—on the export of educational services (Russia has 7th place); USA, Great Britain—in the international ratings of the universities of the world; Finland, Korea, Japan—in the PISA international study of the functional literacy of the students; China, India, the USA—by the scale of long-distance education development; India, China, Russia—by the dynamics of an increase in the number of students in higher education".

In 2009 Russia as a whole preserved these positions, on the number and fraction of students, the portion of the adult population with tertiary education (high school (secondary professional) + higher education) grew considerably according to the levels of indices. As relatively weak points

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of Russian education, international statistic studies established in recent years two positions: the insufficient functional literacy of schoolchildren (at the level of USA) and the low academic rating of Russian universities. For comparison, let us note: Russia puts less than 1% GDP into higher professional education, the USA, Great Britain, and the majority of other countries of the "leaders in education" invest—3–4%.

3 Aim of the Work

We would like, using statistical methods, to attempt to check and (or) discuss several "postulates" of the ideologists behind the planned reforms of higher education, for example:

1. "An increase in the number of students is a factor of the reduced quality of the services provided by higher education, "we" do not require this quantity of universities—500, 100 would be sufficient, and so forth" [3];
2. "The country has an overproduction of humanitarians, economists, lawyers, "we" need engineers, mathematicians, physicists and so forth" [4].

4 A Study of the Dynamics of the Number of Students in Higher Educational Institutions in Modern Russia

It is indisputable; the number of students in institutes of higher education in Russia as well as the number of Institutes of Higher Education is a phenomenon, which requires detailed study. In 15 years these indices grew three times as many, moreover the accelerated positive dynamics are observed against the background of depopulation. The GDP was planned in 10 years to increase two times, however statistics show that this is not the case—we will consider that the crisis hindered this, we obtained a threefold increase according to an index, which the state did not actually govern, but which unconditionally acts on the basic macro-indices of the country, including the GDP. It was decided that this is not good, and that we take urgent measures to reform the system of higher professional education. There is in these results and the phenomenon itself a certain mystical component. Let us attempt to find out what actually occurs.

Table 8.1.1 presents official data of Rosstat [Russian Federal Statistics Agency] concerning the number of students in higher professional education in Russia from 1990–2009. (by the start of the school year) [1, 5]. Let us level off the initial data according to the logistic function. One of the frequently used versions of the logistic trend is in general form reflected in the formula:

$$y_t = \frac{y_{\max} - y_{\min}}{e^{a+bt} + 1} + y_{\min}\,, \qquad (8.1.1)$$

where y_t —theoretical (equalized along the trend) values of the number of students of higher professional education in the time interval (1990–2009) in question;

$y_{\max}$ —the maximum level of the number of the dynamics being investigated ($y_{\max}$ = 7513, Table. 8.1.1);

$y_{\min}$ —minimum level of the dynamic number ($y_{\min}$ = 2613, Table 8.1.1);

a, *b*—parameters of the logistic trend;

t—time.

Calculations are carried out using the program Statistica 8.0. Estimation of the parameters by method of the smallest parameters gave the following results:

$$\text{var}_6 = \frac{4900}{e^{6,34231 - 0,54972\,\text{var}_5} + 1} + 2613\,, \qquad (8.1.2)$$

where var_6 —the theoretical values of the number of students in the IHE of Russia, obtained on the logistic trend, in the formula (1) y_t ;

var_5 —time, in the formula (1) *t*;

a = 6,34231;

b = –0,54972—parameter values.

The equalized (theoretical) values of the number of students and deviation of the equalized values from the actual data with respect to the quantity are represented in Table 8.1.1 (Predicted and Residuals respectively).

The obtained equation of the trend very closely describes initial data, this conclusion clearly confirms the graphic representation of the obtained results (Fig. 8.1.1). For affirming the results the reliability of the obtained equation should be verified with the aid of the Fischer F-statistics and determine the computed value according to the formula:

$$F_{\text{расч}} = \frac{\sigma^2_{\text{регр}}(n-k)}{\sigma^2_{\text{ост}}(n-1)}\,, \qquad (8.1.3)$$

where $F_{\text{расч}}$ —computed value of the Fischer *F*—statistic;

$\sigma^2_{\text{регр}}$ —factor dispersion;

$\sigma^2_{\text{ост}}$ —residual dispersion;

N—number of levels in the timeline;

K—number of parameters.

The following values of the parameters are obtained as a result of the calculations:

$$\sigma^2_{\text{регр}} = 3768596{,}5;\ \ \sigma^2_{\text{ост}} = 5150{,}5.$$

Accordingly

$$F_{\text{расч}} = \frac{3768596{,}5 \cdot 18}{5150{,}5 \cdot 1} = 13170{,}42\,.$$

Let us compare the computed value of the Fischer statistic with the tabular values with a level of 0.05 value, and the corresponding degrees of freedom of numerator and denominator:

$$F_{\text{табл}}\begin{pmatrix}\alpha = 0{,}05\\ \upsilon_1 = 19\\ \upsilon_2 = 1\end{pmatrix} = 247{,}69.$$

where α—level value;

υ_1 —amount of freedom levels of the numerator;

υ_2 —amount of freedom levels of the denominator.

We have:

$F_{расч} = \frac{3768596{,}5 \cdot 18}{5150{,}5 \cdot 1} = 13170{,}42$, which is bigger than

$$F_{табл}\begin{pmatrix} \alpha = 0{,}05 \\ \upsilon_1 = 19 \\ \upsilon_2 = 1 \end{pmatrix} = 247{,}69.$$

Thus, the equation is reliable.

The history of the application of the logistic function in simulating the most different processes is almost three centuries long. The idea of the prognostication of demographic determinants (population) on the logistic curve belongs to nineteen century Belgian scientist Ferkhyust [6, 7]; it underwent further development in the works of the early twenty century American scientists Pearl and Reed. According to the Pearl—Reed theory, in the logistic curve is laid the connection between the growth rates in the population and its quantity. Since the territory of the country is constant, this dependence is converted into the dependence between the growth rates in the population and its density. At first the density of the population rapidly grows, then, meeting the increased resistance of the environment, it decreases, reaching zero. After giving the logistic curve a biological base, the biologist Pearl and the mathematician Reed began to use it to level off of the empirical data concerning the population. With the application of a logistic function the forecasts were carried out in sufficient frequency. The relation to the results was always ambiguous. The most radical and consecutively negative relation to this type to calculation was voiced in its time by Urlanis [8]: "The complete disruption of forecasts on the basis of the logistic curve indicates an abolishment of theories concerning the general law of reproduction, supposedly characteristic of all living beings".

Nevertheless, the logistic curve is frequently used to evaluate the life cycle of a product or branch—creation, introduction, increase, maturity, and decrease. Altschuller [9], while studying (evolution of) technical systems in time formulated the laws of technical systems development, among which is the law of S-shaped development: the evolution of many systems can be depicted as a logistic curve, which shows, as the rates of its development change in time, three characteristic stages are shown: "childhood", "prosperity", "old age".

Taking into account the above stated, let us note the following, the statistically adequate model of the number of students, the result is certainly important, however the task is not contained by this exclusively, it is necessary by theoretical qualitative analysis to explain the need of applying the logistic model. As is known, real totality (process) can be approximated by a logistic model, if the following conditions are satisfied: firstly, the rate of the development of the totality is, other conditions being equal, proportional to its current number; secondly, the rate of development is, other conditions being equal, proportional to a quantity of accessible resources, the second member of equation reflects the competition for resources, which limits an increase in the totality. It is possible to formulate these conditions somewhat otherwise: totality is developed avalanche-type with saturation: development, with which the increase in essence depends on the level reached, moreover the influence of the limiting factor is strengthened with an increase in the level reached.

Table 8.1.1 Number of students in higher professional education in modern Russia

VAR5 (Years)	Observed (number of students; thousands)	Predicted	Residuals
1-1990	2825,000	2627,900	197,100
2-1991	2762,000	2638,760	123,240
3-1992	2638,000	2657,465	–19,465
4-1993	2613,000	2689,539	–76,539
5-1994	2644,000	2744,123	–100,123
6-1995	2791,000	2835,836	–44,836
7-1996	2965,000	2986,670	–21,670
8-1997	3248,000	3226,216	21,784
9-1998	3598,000	3586,303	11,697
10-1999	4073,000	4085,220	–12,220
11-2000	4741,000	4703,715	37,285
12-2001	5427,000	5372,841	54,159
13-2002	5948,000	5998,075	–50,075
14-2003	6458,000	6507,218	–49,218
15-2004	6884,000	6877,377	6,623
16-2005	7065,000	7124,883	–59,883
17-2006	7310,000	7281,250	28,750
18-2007	7461,000	7376,524	84,476
19-2008	7513,000	7433,299	79,701
20-2009	7419,000	7466,685	–47,685

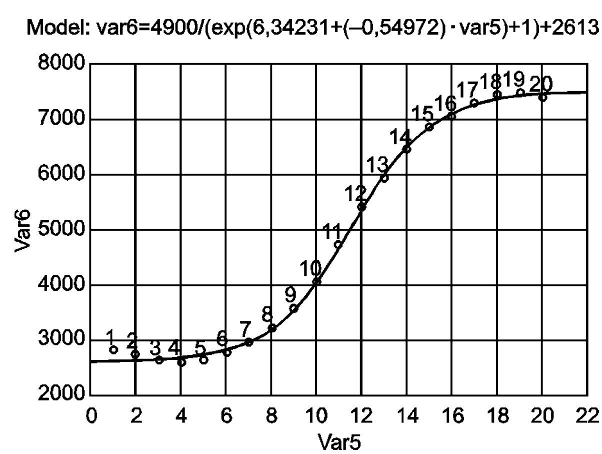

Fig. 8.1.1 Actual and equalized values of the number of students in higher professional education in Russia

Model is: var6 = 4,900/((exp(a + b·var5) +1)) + 2,613 (education.sta) Dep. Var.: Var6 Level of confidence: 95.0% (alpha=0,050)

Let us examine the basic factors, which formed the number of students in HE in Russia, in the time interval in question (1990–2009).

Demand It is traditionally considered that if society makes one of the steps of education a requirement, then demand for the following level sharply grows. Which was shown—the Soviet regime in the recent decades of its existence ensured compulsory secondary education to the Russian people. The presence of general secondary education in the country stimulated the general demand of the Russian population for higher education. The catalyst of demand—the RF law "Concerning Education" from 10.07.1992 N 3266-1 (rejection of state and departmental monopoly on educational services, the possibility of creating non-governmental educational institutions, including Institutes of Higher Education, forms of education—full-time, postal tuition, externship, removal of age limits).

Resources Constant population with average and above education. Number of institutes of higher education. Their functional territory. Amount of university faculty.

Environment (PEST). Politics and ideology. The CPSU (Communist Party of the Soviet Union) and Soviet State using truths and untruths, somewhere artificially supported the prestige of working professions, farmers, and so forth. Cinema, television and literature formed demand for professions, projects and the like (working class, teacher, physicist, BAM [Baikal Amur Mainline], the Novosibirsk Akademgorodok…) Now in parliament there is not one worker or peasant—doctors of sciences, deserved athletes, artists.

Economy Low cost of educational services. A subsidiary network of Institutes of Higher Education. Areas. Higher professional education was traditionally a salesman market, after several years it changed its paradigm—now it is a sufficiently developed market for the buyer, practically in all its manifestations and consequences.

Sociology Demographic transition. Independent woman, oriented towards career, money, and higher education as means of realization of these priorities. University, post-doctorate are taken by Russian population as means to avoid military service (for males).

Technology Internet. Distance education.

Branch factors of the medium Input barriers are maximally reduced (the USE [Unified State Exam] is a temporary problem, more artificial than not, the Russian people are accustomed to deciding tasks more serious). The commodity—substitution. Practically it does not exist. Colleges—these are rather another way (somewhere more economic-related) to obtain higher education, than an alternative in the selection of a future occupation. Schools, colleges are incorporated in the system of higher professional education. At the present moment they are aimed at the training of high school seniors. Negotiations are on the side of educational service consumers.

Thus, at the beginning of the 90's, the entire totality of conditions and factors, which determine the development of higher professional education in the country was formed in such a way that the possibility of further dynamics in the form of an avalanche-type process became a reality.

"We today have proof of the fact that humanitarian specialties—economists, jurists, teachers—are specialties, which do not ensure work sites. This is road into nowhere…", from Fursenko's appearance in the Council of Russian Rectors in July 2009. [4].

In the time interval in question, quantitative and qualitative changes actually occurred in the release of higher education specialists (Table 8.1.2). For example, in 2006 in comparison with 1990 the release of specialists increased, composing 853925 people, economists, jurists and pedagogues together comprised 81.9% of this increase (699599 people). In 1990 the release of specialists comprised 401,100 people, of them jurists, economists, pedagogues—145,600 people (36.3%).

In 2006 the fraction of humanitarians in the total number of graduates composed 67.3%, the remaining groups of specialties—32.7%. Structure was qualitatively changed. Judging by the 2010 admission, the release of specialists

Table 8.1.2 Dynamics of specialist graduation via the higher professional education system in 1990; 1997–2006 (people) [1, 10]

Year	Specialist Graduation			Specialist graduation (government-financed)
	General	Including		
		Economics and management, the humanities, education and pedagogy	*Specialist graduation without graph 2*	
A	1	2	3	4
1990	401,100	145,600	255,500	401,100
1997	457,702	217,500	240,202	384,200
1998	500,789	261,095	239,694	408,600
1999	554,814	304,426	250,388	426,100
2000	635,069	365,224	269,845	451,800
2001	720,205	430,664	289,541	473,800
2002	840,405	523,346	317,059	509,600
2003	976,930	633,575	343,355	520,600
2004	1076,577	720,097	356,480	522,500
2005	1151,645	773,554	378,091	517,200
2006	1255,025	845,199	409,826	541,300

approximately of this structure will be preserved at least until 2015. The total graduation growth rate in the interval is 3.13; in three categories at the same time—5.8; the rest (excluding jurists, economists and pedagogues)—1.6, for comparison, the government-funded release of specialists at the same time increased by 1.35. Let us also note that the total release of non-humanitarians at the turn of 1999–2000 restored its pre-reformist quantity, but in 2006 this index exceeded the absolute value of the entire 1990 graduation release in Russia by more than 8.0 thousand people. (409826–401100—see Table 8.1.2). This paragraph can be seen as a general explanation concerning the "overproduction" of some professional categories and the "need" for us!? of others. Let us pause in more detail at the economists, jurists and pedagogues. "… These are specialties, which do not ensure normal work sites. This is road to nowhere". It is difficult to understand what "…normal work sites" means. We can understand it, for example, thus: the President of the country—a normal work site? Supposedly not bad. For a decade it is occupied by jurists. Minister of Education—normal work site? From our outside view, the answer is yes, what we have—jurists have ensured this job for a doctor of physical and mathematical sciences. We can go on: Kudrin, the best minister of finance on the planet in 2010—an economist (has a normal work site and ensures state work sites) and so on and so forth.

Further, concerning work sites, let us take for comparison a graduate from the group of specialties "economics and management" and one from the group of specialties "aviation and rocket-space technology", a normal working site for the latter—an existing factory of civil or military aviation—was there much such sites in the 90's of the past century? Are there now? Economists and jurists differ from other specialists in the sense that, firstly, the creation of work sites for them does not require significant expenditures, secondly, they themselves are a worksite. Obtaining higher education in the direction of a humanitarian profile the population of Russia created and creates for itself a material pillow of safety beneath the turbulent conditions of Russian reality. On an everyday general basis, a nuclear physicist with his specific knowledge and qualification will hardly be in demand; a jurist, economist or pedagogue is a potential source of additional family income or expenditure savings. [11].

We agree with the position of the director of the Institute for the Development of Education SU-HSE (State University—Higher School of Economics) Abankina [12]: "Economic and juridical knowledge—these are rather, no longer forms of higher education, but an absolutely necessary basis for the contemporary person. A graduate of an economic department will not necessary work according to his profession, he can use the obtained knowledge, for example, to organize his private business". Now in Russia there are approximately 1 million small business enterprises, several million individual entrepreneurs, the contribution of this sector to the Russian GDP is 20%, 14–15% of the total volume of those employed in the economy of the country. A substantial part of this sector is created by humanitarians. In reality, the state actively forms an increased demand for economic and juridical specialties: the financial sector of the economy (banks, insurance companies, funds) increased numerously, many fiscal and control structures (tax inspection, treasury, the service of judicial police officers .....) are created, and so forth. Further, there is something, about which we do not speak: the system of pedagogical universities even from the Soviet times was used as a method of urbanization of young people in rural areas (by the way, the release of agrarian universities also considerably increased in the considered time interval). The state stimulates this process by government-financing at all levels.

Summing up this chapter, let us note that the "humanization" of higher education is not a Russian achievement. The increased demand for these educational trajectories is characteristic for all or almost all countries of the "gold billion". In the USA for a long time now Russian pedagogues teach mathematics and physics to immigrants from the CPR, India, Singapore; young Britons have a taste for free professions—designers, artists, journalists; in France approximately the same picture, finally Germany, which was traditionally characterized by having a cult relation to the engineering specialties now with difficulty recruits freshmen into technical universities [13]. The heroes of the time are changed, the mentality changes, now everyone wants a piece of the pie, and it matters little what the stuffing is—finance, petroleum, gas or "capital (both in the literal and figurative sense)".

The contemporary value of education, the demand for one or the other group of specialties depends, unfortunately, not only and not so much on "our" desire, but on, for example, how ready the economy of our! country is to ensure work sites for future specialists. The real actions of the state in the proclaimed direction are unconvincing in this sense, rather, they speak about the reverse. Innovations, nano-technology, Skolkovo … Chubais … with all respect for such personas it is unclear, will any skills be in demand in this direction, besides the skill to master budgets. Here we have professionals sufficient for the entire terrestrial globe.

Direct participation of the state in this process was minimal: the law about education of 1992, which played an essential role in the catalyzation of the accelerated dynamics, government-financing at a level of 40% of the general expenditures of Institutes of Higher Education, the soft regulations of licensing and accreditation of higher education establishments.

5 Conclusions

The analysis and the executed calculations make it possible to make several conclusions:

1. The time interval of 1991–2009 in the history of the development of higher professional education it is possible to examine the minimum in two measurements: as a complete life cycle of the branch: introduction (1991–1992), increase (1993–1998), maturity (1999–2008), the beginning of the decrease (2009…), and also as a transition stage from the Soviet educational system to the Russian, which must still be constructed.
2. Basic qualitative changes as the sum of the branch life cycle: the educational market as a consumer market; a cardinal change of structure in the cross-section of the generalized groups of specialities (in 1990 the fraction of "humanitarians" in the total release of specialists composed 36.3%, in recent years it holds a level of 67–68% (see Table 8.1.2)—"lyrics" numerically conquer "physicists".
3. Direct participation of the state in this process was minimal: the law concerning education in 1992, which played an essential role in the catalyzation of the

accelerated dynamics, government-financing at a 40% level of the general expenditures of Institutes of Higher Education, the soft regulations on licensing and the accreditation of higher education establishments.

4. The "overproduction" of economists, jurists and pedagogues is a myth; the need of engineers, technologists, mathematicians and physicists for the needs of our economy in the contemporary state of our country is fallacy.
5. Nevertheless, the executed study shows that the task of saturating the domestic market with the necessary professional categories of the highest qualification is solvable. There is a counterpart. There is a viable system of realization—Higher Professional Education. It is necessary to form a mechanism of creating demand. The sums of the enrollment period of 2010 showed that the redistribution of limited government funds will not solve the problem. In order to change the paradigm of demand means of another level and other priorities of investments are necessary. Let us return to the weaknesses of Russian education, revealed according to the results of international studies: the low academic rating of Russian universities and the insufficient functional literacy of schoolchildren (at the level of the USA), concerning the university ratings—they are creative and relative—mostly, the low ratings of our leading universities (especially in the Shanghai or Academic rating) can be explained by the organizational isolation of RAN (Russian Academy of Science), is possible to construct an alternative rating along a comparable system of parameters and to attain its acknowledgement by the international community, as far as the insufficient functional literacy of schoolchildren is concerned, this problem is serious, requires thorough investigation and correct solutions, it is possible that rescuing the school system must become not just a part of the national project, but a national idea, if we want to, of course, remain a great country.

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8.2 Internationalizing the Engineering Qualifications

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Abstract

Internationalization is a main strategy for companies to increase their profit and growth, to achieve this strategy a highly qualified work force is required to live and work in an international community. Engineers should not be shaped to have hard and soft qualifications only, but also having the capacity, knowledge, and skill that make them eligible for working International. Preparations of engineer who has the ability to work and participate in multicultural communities, provides a great opportunity for companies to achieve their targets. To produce a well-prepared engineering workforce in the future, the EU has been precipitated by the Bologna Declaration, while the USA has been encouraged by the transition to the Accreditation Board for Engineering and Technology EC2000 accreditation criteria. To help in the on-going process, in this article, a new approach for internationalizing the engineering qualifications will be presented. This approach will model the international qualifications based on the major elements of the target country, which are environment, government, people, and market. End up with case study based on the authors' background in Saudi Arabia for the qualifications related to each element.

Keywords:

Internationalization; Qualifications; Education; Engineering

1 INTRODUCTION

The world is rapidly transitioning from one of nationally differentiated organizations and cultural identities to one increasingly characterized by transnational institutions and multicultural communities. This transformation is having a profound effect on national and international systems of commerce, education, and governance [1]. This new world will require an even more sophisticated workforce to address a growing list of customer demands, such as quality, cost, and flexibility. These challenges are increasing as the job market becoming more internationally competitive.

In order to survive in the current business world, companies are competing for highly qualified manpower. Engineers should have the qualifications to work with colleagues, suppliers, and clients from different cultural backgrounds and operate as part of International team. They need to have broad engineering skills and know-how, and to be flexible and mobile, and able to work collaboratively in international networks.

The US Accreditation Board for Engineering Education (ABET) now requires programmes to graduate engineers with the ability to function in multidisciplinary teams and for broad education necessary to understand the impact of engineering solutions in a International and social context [2].

The Bologna Process involves more than 45 countries in Europe. The aim of this process is to set up throughout Europe a system of easily readable and comparable degrees. The Bologna Process introducing modular structures and clearly defined learning outcomes for the various degree awarded [3].

To help in the ongoing process, in this article, a new approach for internationalizing the engineering qualifications will be presented. This approach will model the international qualifications based on the major elements of the target country, which are environment, government, people, and market. End up with case study based on the authors' background in Saudi Arabia for the qualifications related to each factor.

2 INTERNATIONALIZATION SCENARIO

Profit and growth are the driving force for the companies to enter a new market. Governmental and competitors barriers restrict the entrance of these new foreign/international markets. To break down these barriers companies have to shift some of their value creation elements (products, processes, qualifications) to the international markets. This normally ends up with some risks, which could threat the existence of the company especially small and medium enterprises (SMEs). To avoid most of these risks companies must have strategies and models as tools for internationalization to assure goals achievement and risks avoidance at the same time. This scenario is what called internationalization scenario as shown in figure 1.

Figure 1: Internationalization scenario.

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3 INTERNATIONAL MARKETS

International markets are not only expanding business opportunities, they are also intensifying competitive pressure and causing the center of economic gravity to shift to new locations. In the years ahead, the economies of the so called BRIC countries – Brazil, Russia, India and China – are expected to grow twice as fast as those of their industrialized counterparts [4].

To ensure the long term existence of each and every company, the current market economy and the competitive situation also require that a company is growing with respect to its volume and its profitability [5, 6]. To achieve this goal companies intended to enter a new market must realize the barriers, risks, and should have a structured plan for entering the new market. A well-prepared engineering workforce for facing these challenges is a major player for the success of these efforts.

3.1 Barriers

The realization of company's profitable growth by serving the worldwide markets through export business is limited because of the market entry barriers. The biggest part of these barriers cannot be influenced by a single company, because generally they are constructed by competitors and the regulatory authorities [7-9]. With reference to [7, 9-13] some of the most common market entry barriers are as shown below:

- Import and export duties
- Local-Content-Regulations
- Currency effects
- Pricing rules
- Price wars between competitors
- Demand behavior
- Nationalism
- Special standards

Worldwide active companies cannot change anything on the creation or the existence of market entry barriers. So the target is to break down the barriers for having unrestricted access to new foreign markets and hence to allow more profitable growth. This often means that parts of the value creation to be distributed on the foreign markets [6, 7]. Especially the local production in foreign markets can break down many barriers like local-content-regulations, import and export duties and currency effects [7, 14].

Shifting some of the company's value creation to the foreign markets is associated with risks. For small and medium enterprises (SMEs), these risks may mean the end of their existence, because of the very high efforts they have to invest in internationalizing parts of their value creation compared with their available resources [15].

3.2 Risks

The successes and failures of internationalization may have very different reasons. One main reason are the existing risks of international activities e.g. production in international markets. According to a survey by the Fraunhofer Institute for Systems and Innovation Research (Fraunhofer ISI) and the Federal Ministry of Education and Research the following risks of international activities and production were the mainly result [11, 16]:

- Quality risks (Product, Process)
- Know-how- loss /-flow (staff turnover)
- Productivity of foreign locations
- Costs of production factors
- Staff qualifications
- Supplier quality
- Flexibility and ability to deliver
- Overestimation of the local market potential
- Cultural barriers

The above mentioned risks restrict the companies in participation in international market, hence losing a great opportunity for increasing their competitive advantage.

3.3 Competitive advantage

Since several years, the competitive situation and the competitive conditions are changing for many companies. The product, labor and information markets are increasingly internationalized and new information and communication technologies provide international access to markets that were previously difficult to reach [5, 7].

The intensification of competition through entry of new competitors from Asia and Eastern Europe, who brings a significant price advantage as a result of lower production costs and who are also winning market acceptance because of continually improving quality, leads to a strong change in buyers' market [17]. The buyers have become more demanding and their expectations for the performance of manufacturing companies have risen dramatically. It is now assumed that the following criteria are fulfilled at the same time:

- High quality
- Lower cost
- High flexibility
- Shorter development and delivery times [5].

To succeed as a company in such competitive situation and to secure competitiveness it is necessary to consider different success factors in the company's strategic decisions:

- Innovation (Product & Process)
- Technology leadership
- Cost leader ship
- Differentiation

Qualifications are the major driver for the companies to achieve the above mentioned success factors, hence successful internationalization.

4 ROLE OF QUALIFICATION

Highly qualified staff is the major driver for the companies to achieve the necessary level of innovative products and processes. Also for being technology or cost leader in the market or for differentiating from competitors, it is necessary to have highly qualified staff. The staff should not only have hard and soft qualifications, but also International context is necessary. They need to understand market demand of several international markets and to work with people from several countries with different cultures, behaviors and understandings.

The necessary qualifications for being successful in the internationalization process of a company to be discussed in the following sections. Mainly the companies looking for internationalization should be able to answer two basic questions:

- What qualifications needed in home countries to work successfully with international colleagues?
- How to qualify people in home country and to prepare them to work with their international colleagues?

In the following sections the answer of these questions will be discussed and an approach will be presented, which can be used as a guideline for the companies to qualify their staff for successfully entering and competing in international markets.

5 ENGINEERS FOR SUSTAINABILITY

The United Nations (UN) has defined sustainable development as "meets the needs of the present without compromising the ability of future generations to meet their own needs" [18]. At the 2005 World Summit it was noted that this requires the reconciliation of environmental, social and economic demands-the "three pillars" of sustainability. The relationship between the three pillars of sustainability suggesting that both economy and society are constrained by environmental limits as shown in figure 2 [19].

Engineering qualifications captures the essence of the UN definition of sustainable development by the preparation of creative engineers who are able to design and develop sustainable products and processes. Therefore higher education institution should define the curriculum which create engineers who consider the environmental, social, and economical issues in their designs.

Engineers for sustainability, therefore, can be thought of as the creation of engineering graduates who are able to design and develop sustainable products and processes. This concept can help higher education institution to analyze and design their curriculum by integrating issues such as global climate change, dwindling natural resources, and deteriorating public health.

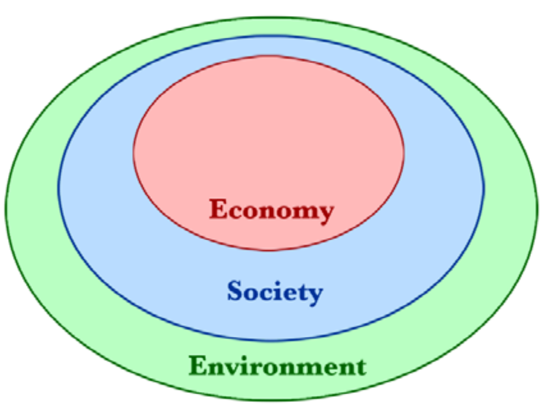

Figure 2: The relationship between the three pillars of sustainability.

6 ENGINEERING QUALIFICATIONS

Engineers, whether working abroad or at home, play a critical role in addressing the above mentioned internationalization challenges. They need to have broad engineering qualifications and practical know-how, theoretical know-why, and strategic know what [20]. The knowledge, skill, or ability that makes someone eligible for a duty refers to as qualifications. The strength of the person in possessing these qualifications, determine his success in performing the tasks assigned to him.

Engineering qualifications divided into three general categories: hard, soft and International qualifications [21]. The hard qualifications divided into technical and managerial qualifications. The soft qualifications divided into personal and interpersonal qualifications, and the International qualifications divided based on the environment, government, people and market of the foreign country as shown in figure 3.

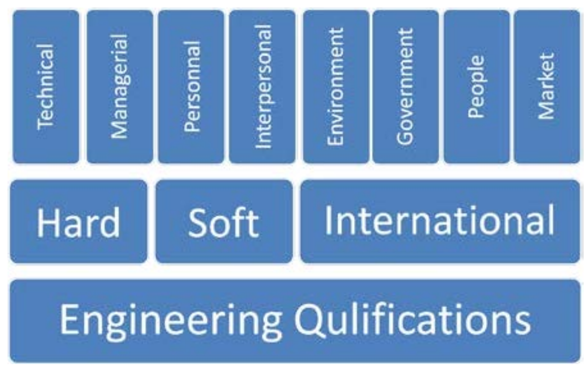

Figure 3: Categories of engineering qualifications

6.1 Hard qualifications

Hard qualifications are the technical and managerial requirements of a job. They are specific abilities that can be defined, taught and measured. For example quality management, milling, solid-works. Hard qualifications enable the engineer to be technically flexible in designing and constructing a product/process that meet the foreign market demand. Engineer who has a broad knowledge of the hard qualifications can propose a better alternative design considering the constraints in the foreign market.

6.2 Soft qualifications

Soft qualifications refer to the personal qualities and interpersonal skills, such as self-management and ability to participate as a member of a team. Contrast to the hard qualifications, soft qualifications are less tangible and harder to quantify. Engineers who possess these qualifications can be successfully build relations and communicate with the colleagues, customers and suppliers.

6.3 International qualifications

Additional to the hard and soft qualifications, staffs working in a foreign country should possess International qualifications. International qualifications refer to the capacity, knowledge, or skill that makes someone eligible for working in another country. These qualifications related to the foreign country's environment, government, people, and market as shown in figure 4.

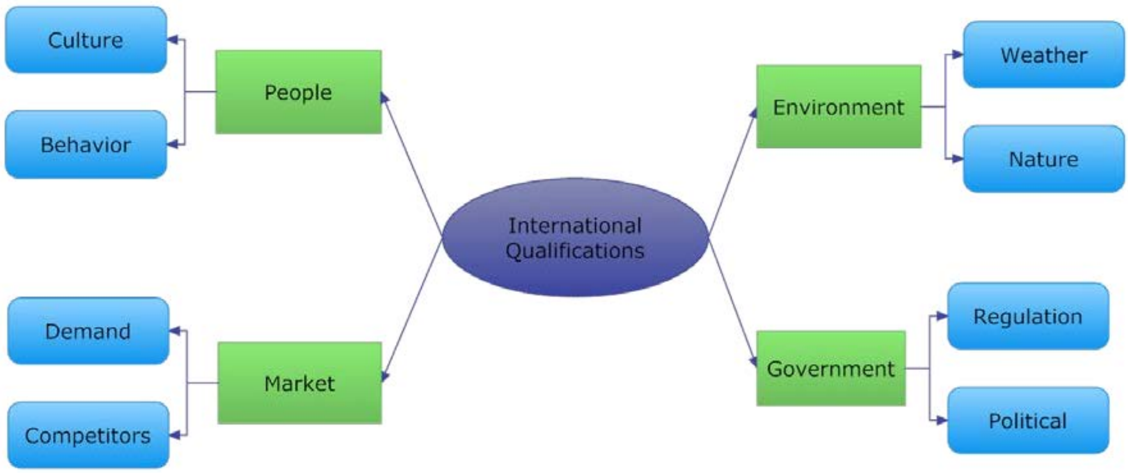

Figure 4: Elements of International qualifications

Each of these elements has its own effects in shaping the related qualifications for specific county, if the engineer possess these qualifications he will be able to perform the tasks assigned satisfactory and hence success of the internationalization efforts. These related qualifications vary from country to another, which make this approach flexible to be shaped based on each country. Table 1, shows the elements of the International qualifications and the factors associated with each elements which influence the qualifications as well as examples for each factor. Discussion of each element as below:

Table 1: Elements of International qualifications

Elements of international qualifications	Factors of each element	Examples of international qualifications
Environment	Weather	physical ability
		physical adaptability
	Nature	physical flexibility
		ability to self-organization
Government	Regulations	knowledge of government regulations
		knowledge of government incentives
People	Culture	acceptance of different culture
		assimilation, willingness to adaptation
	Ethics	integrity
		honesty
	Behavior	openness
		behavioral flexibility
	Language	knowledge of foriegn language
		communication skills
Market	Competition	comprehensive knowledge
		analyse and solve problems
	Demand	future-oriented thinking
		target oriented

- The environment is the weather and nature of the target country. The environment influences the company decision in selecting an individual who could work abroad. Qualifications such as the physical ability and adaptability related to the weather are essential to be considered in selecting an individual for living in a foreign country with different atmosphere especially if this difference is huge.
- Government is the legislators, administrators, and arbitrators in the administrative bureaucracy who control a state at a given time, and to the system of government by which they are organized [22]. Knowledge of the foreign government system and regulation is major determinant of the success of the internationalization effort. Hence individual who attend to work in a foreign country must have the enough knowledge of the government system, regulation, incentives etc.
- People of the foreign country have their own culture, ethics, behavior and language. For the individual to success in working with these people he should possess specific qualifications. These qualifications will make it easy for the individual to understand the behavior of these people, and on the other hand it will make these people interesting in working with this individual. Examples of the qualification are open minded, acceptance of different culture, knowledge of the foreign language etc.
- Market of the foreign country is the main motivator for the companies to open new business. Success of this business is highly influenced by the market situation. Knowledge of the market specific demand and competition in these markets grant the competitive advantage for the companies. Individual who intend to work in a foreign market should possess the qualifications such as ability to collect and analyze the information, knowledge of the country specific standards etc.

The mentioned elements of International qualifications give a guideline for companies to prepare or train their staff, for working in foreign countries, although the facts differ from country to another. The qualifications related to each element show what type of qualifications are necessary for being able to work successfully in international markets. The qualifications needed for working successfully in foreign countries to be highlighted based on the target country.

After defining, the necessary qualifications needed for working successfully with international colleagues based on the targeted country the techniques for training the people can be determined for example:

- Participation in trainings about the specific elements in the targeted foreign countries (in ideal case, the trainer comes from the targeted country or at least has enough experience in that country)

- Working with International teams on joint projects while stay in home country, before being send to work in foreign country

7 CASE STUDY

The above-mentioned approach will be tested based on the authors' background and experience of different cultures. Saudi-Arabian market will be considered as an example for the discussion of different elements of the stated approach as follow:

7.1 Environment

The weather and the nature are two very important factors effecting the selection of the individual to work in a foreign country, especially in a country like Saudi-Arabia, with very special environmental conditions.

The weather is mainly very hot and dry. The temperature can reach more than 50 degrees during the daytime. By night, the temperature can be less than 0 degree with strong wind and sandstorms. Also challenging are the elevation extremes with high temperature differences, from the lowest point in the eastern region (golf region) with 0m to the highest point in the western region (red see and Yemen border) with 3133m [22].

What do these environmental conditions mean for the qualification of the staff to work in Saudi-Arabia:

- somebody with blood pressure problems or breathing problems will be highly effected by the environmental conditions, means also the ability to work or the performance efficiency will not be that high.
- knowing about the nature and especially the sandstorms and the dessert is very important to avoid any risks, e.g. going outside by car and stuck in the desert sand or going somewhere for a weekend adventure and caught in a sandstorm which can be dangerous for the life.

7.2 Government

The governmental type in Saudi-Arabia is the monarchy and the legal system is the Islamic legal system with some elements of Egyptian, French, and customary law; several secular codes have been introduced; commercial disputes handled by special committees.

The economy of Saudi-Arabia is mainly based on the oil-industry, as the country is the largest petroleum exporter in the world. 80% of the country's economy is related to the petroleum industry.

The governmental regulations and incentives are very friendly made for foreign investors and workers. There are nearly no taxes to be paid in the Kingdom. The fact that there are 6 million foreign employees in a country of 27 million citizens shows how friendly the working conditions are for foreign staff and investors [22, 23]. Nevertheless it is necessary to know the local regulations and incentives to know how to enable yourself doing business in the country.

In case a company wants to make business with any governmental customers e.g. in energy sector, it is necessary to have a local representative or a local partner to be able to participate in tenders and to get orders. A local representative means mainly a sales office, there are no local-content-regulations. The regulations allow to any company to import its goods from all over the world after getting approval about the delivering quality of the goods.

7.3 People

Culture: The culture in Saudi-Arabia is highly influenced by the religion, because of the existence of the two holy cities Mekka and Medina and the long Islamic history of the country. Cultural events like theater, music or cinemas existing in Europe are not allowed in the kingdom. Also alcohol is something missing in the country and the smuggling of it will be punished severely.

The existing culture differences mean for the qualification of staff coming from Europe, they have to:

- accept, tolerate and respect the existing cultural rules, e.g. that people stop everything to go for praying during the working time.
- live without your familiar cultural behaviours as long as you are in the kingdom, e.g. drinking alcohol, visiting cinemas or meeting girl/boy friends.
- willing to adapt to the countries cultural specifics, at least for the time somebody spent there.
- able to maintain good relation to the Saudi people by respecting their cultural specifics, means not only to work with them as colleagues, but also to spend some free time with the domestic population for building the trust.

Ethics: The ethical behavior in the kingdom is also influenced by the religion, as well as by long traditional behavior learned from father and grandfathers. The respect towards older people and towards colleagues and superior colleagues is one the traditional behaviors you face in the country. To be successful in the kingdom under the existing conditions and the known ethical behavior it is necessary to:

- face especially older people and women with high degree of respect and integrity
- deal with the people with courage and honesty to gain their trust, because for doing business successfully in Saudi-Arabia trust is one of the most important factors
- work with great dedication to ensure that you are willing to support the country in developing itself

Behavior: The people in Saudi-Arabia behave differently than the European people. While Europeans are very true to details and want to have everything in written form, the Saudis are very target oriented without much attention to details and highly refer to and rely on the said words. Therefore it is necessary for somebody working in the kingdom to have a high behavioral flexibility in dealing with the people there. The differences in the behavior between Saudis and European require that foreigners working there and also the natives:

- are open in dealing with each other to avoid any loss of trust between them
- have a high ability to self-organization to ensure the achievement of common targets
- have problem solving abilities and conflict management skills to avoid the escalation of any misunderstandings

Communication: The official language in Saudi-Arabia is Arabic, but nearly everyone in the country speaks English as second language, which is the main business language. Communication is very important for getting to know the culture, the ethics and the behavior of the people what enables you to work successfully and to live more comfortable in the country. For being communicative it is necessary to have more than the language skills, you need also:

- to be cooperative in dealing with others to break the ice between two different cultures
- to have presentation skills to explain your intensions and plans
- to be a team work oriented, which is an important prerequisite for successful communication

7.4 Market

In Saudi-Arabia there is a huge market for different kinds of goods and businesses. The market size for the different sectors is growing continuously, especially in the following sectors [22, 23]:

- energy
- oil
- petrochemical
- steel
- civil constructions (trains, bridges, streets, hospitals, universities, houses)

The fact that the market size is growing continuously and fast, cause a very high competition in the country. Such a great market which means a great opportunity for all companies call competitors from Europe, USA and Asia to compete each other in the kingdom. This makes business not easy and forces all companies to find suitable ways how to gain big shares of the market.

For being successful in such a competitive market, a company needs to have qualified people with focus on company's strategies and targets. Especially managerial and interpersonal skills are important to assure the success in the market. Following some of the most important skills needed:

- Organizational skills
- Target orientation
- A clear own view about the targets and visions
- A good picture about the competition and the competitors strength and weak points
- A clear idea about the customer wishes and the market demand in all sectors

8 SUMMARY

In this article, a new approach for Internationalizing the engineering qualifications has been presented. This approach is based on the major elements of the target country, which are environment, government, people, and market. These elements have been divided into factors; each factor has been clarified by some examples of qualifications needed for the mentioned elements. The approach can be adapted to other factors and additional qualifications. The adaptation depends on the targeted country and also on the product and processes which is to be internationalized. Therefore the introduced approach can be consider as a basis for companies to prepare themselves and their staff for any international activity. For this paper Saudi Arabia has been taken as a case study for the implementation of this approach based on the authors background and experience of several cultures.

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8.3 Knowledge Sharing as the Key Driver for Sustainable Innovation of Large Organisations

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Abstract
Knowledge management is considered to be the most critical step for developing innovation processes and reaching sustainable competitive advantage in the marketplace. However, the systematic handling of knowledge in many organisations is far from being complete. In particular, for large organisations the competitive capability becomes more dependent on the efficient intra-organisational sharing of resources—especially knowledge. The aim of the article is to study knowledge sharing in large organisations as linked with the transaction cost theory. Therefore, we start with defining the term "knowledge" and classifying the process of "knowledge sharing". Having transferred the transaction cost theory into intra-organisational knowledge sharing, we will build up a comprehensive theoretical construct of knowledge sharing in large organisations from the transaction cost theory perspective.

Keywords:
Innovation, Knowledge sharing, Large organisations, Transaction cost theory

1 Introduction

The term "innovation" is one of the most widespread words in management literature and public discussions. Organisations can create competitive advantage if they have a distinctive competence that allows them to perform better than their competitors. Moreover, a competitive advantage becomes sustainable if other organisations can not duplicate the distinctive competence held in the organisation [1]. Therefore, sustainable innovation matters in organisations. Creating own innovative ideas is the way for an organisation to sustain competitive advantage. A starting point for managing innovation is managing the sources of innovation. The sources of innovation are connected with people as the carriers of knowledge. Accordingly, organisations can be seen as knowledge or competence reactors [2] and the organisational competitive advantage arises especially from knowledge creation and sharing and further knowledge combined with other resources can lead to innovations. Only few organisations have great thinkers and inventors, however, the organisation can provide a framework and environment for intra-organisational knowledge sharing. Up to now there exist only few studies on intra-organisational knowledge sharing in large organisations [3, 4]. This research focuses on knowledge sharing as a key driver for creation of innovations in large organisations from the transaction cost theory perspective.

2 Definition of the Term "Knowledge"

The term "knowledge" is one of those management words which has multilayered meanings depending on the perspective and school of thoughts [5]. However, the discussion on the term "knowledge" goes back to the ancient world and lives through the history of philosophy until present. Philosophers like Plato and Antisthenes thought out the first widespread definition of knowledge as a true belief [6]. However, it is extraordinarily difficult to define what a true belief is and this deficit makes the definition of truth incomplete; consequently, we are unable to exactly define knowledge.[1] It remains a definitional conundrum. According to this the "absolute truth" is not possible to reach, thus it cannot be the aim of knowledge. Therefore the ultimate goal can only be *profound knowledge* which cannot be equated with acquiring more knowledge. Knowledge can be understood as penetrating thinking process that never stops to obtain certainty. Moreover, knowledge in the core is an interpretation of experience and perception arising from the environment. Furthermore, knowledge is always connected to people, unlike to data and information [8]. Thus we assume that human being gives meaning to things and he is the carrier of knowledge.

The literature review shows several ways of classifying knowledge according to its characteristics. Many definitions of knowledge in Knowledge Management theory distinguish between two types of knowledge: explicit and tacit knowledge [9, 10]. Explicit knowledge can be codified; it is more formal and systematic, e.g. found in documents, databases and a number of other transfer deliverables. However, there remains knowledge in the minds of individuals that will not find its way to online knowledge storehouses or printouts. The critical or tacit knowledge in the minds of many people derives through experiences over time. While tacit knowledge is highly individual, specific to context and very hard to evaluate, it is vital for our ability to act. Another well-known concept of knowledge is the enterprise or organisational knowledge [9–11]. Organisational knowledge is said to be a dynamic sum of individual, group and organisational knowledge originated in the individual minds and emerged via interaction with other colleagues and environment. Therefore,

[1] Still in the 20th century philosopher Ludwig Wittgenstein indicated the difficulty defining the term "knowledge" and suggested: "There is no exact usage of the word *knowledge*; but we can make up several such usages, which will more or less agree with the ways the word is actually used" [7].

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the quantity and quality of organisational knowledge depends basically on how efficiently different knowledge and knowledge carriers are combined [8].

It is organisational knowledge, including explicit and tacit knowledge, which is on principle available for the organisation and makes a contribution into solving working tasks and ideas presently or in the future, that comes into consideration in this study. Furthermore, we assume that the organisation is obliged to provide their employees with maximal knowledge. Otherwise, if the employees hold only minimal knowledge, meaning only the amount of information to function in their work, they can generate neither more profound knowledge nor new ideas for innovation.

3 The Concept of Knowledge Sharing

3.1 Classification of Knowledge Sharing

The concept of knowledge sharing is closely related to the creation of new knowledge in order to be innovative. Researchers and practitioners report that knowledge sharing increases organisational performance, encourages competitive advantage and organisational learning [12, 13].

The literature review reveals that knowledge sharing[2] can be classified in different ways, commonly including knowledge creation processes, knowledge sharing practices. The literature on international management distinguishes further between inter-organisational and intra-organisational knowledge sharing.[3] In our study we focus on intra-organisational knowledge sharing, i.e. sharing of knowledge between the individuals, departments or rather units within the organisation.

3.2 Intra-Organisational Knowledge Sharing

Intra-organisational knowledge sharing has become the focus of Knowledge Management programs in many large organisations whose competitive advantage lies in the ability to utilize and share resources, especially knowledge, more efficiently internally than it would be possible through external market mechanisms [2]. The sharing of knowledge helps to combine and utilize isolated local knowledge in the whole organisation. Allocating and transferring existing organisational knowledge to the right place where it is actually needed is the most challenging for a successful Knowledge Management program [8].

Despite the challenge of managing knowledge sharing, the general mode of operation is in every similar Knowledge Management program and can, as in Fig. 8.3.1, be described as a "knowledge flow", consisting of three phases:

Fig. 8.3.1 Three phases of the knowledge flow

For a successful knowledge sharing process all three phases of the "knowledge flow" are equally important. Difficulties in one of those three phases lead to hindering or rather breaking the knowledge flow; even so the other two parts of the knowledge flow are operating optimally. The human—as the carrier of knowledge—occupies the central role in the phases "Sending knowledge" and "Receiving knowledge" of the knowledge sharing process. The "Social interaction" phase reflects the networks of social interactions within the organisation.

In the recent research the focus lays on the influencing factors and barriers of intra-organisational knowledge sharing, including: the knowledge itself, the conditions of the sender and receiver, trust, social interaction and costs. Some scholars stress the different characteristics of the *knowledge itself* such as knowledge tacitness [9], knowledge completeness and knowledge uncertainty [15]. The *conditions of the sender and receiver* regard to motivation, ability to absorb knowledge, value of knowledge stock as well as the existence and functional knowledge sharing mechanism between the individuals, departments [16]. The issue of *trust* is a close associate of each research in knowledge sharing. A literature review shows that trust can be classified into two main perspectives: personal (work-related) trust and trust in a system. Personal trust is a generalised expectation that the other will act according to how he represents himself and it is identified as an important factor in regard to personal motivation to share knowledge. According to this trust in a system relates to trusting the functioning of a system and not to personal relationships. In their well-known work concerning organisational knowledge creation Nonaka and Takeuchi highlight the importance of the socialisation phase, i.e. sharing of tacit knowledge in the *social interaction* at the individual and group level [9]. Their theory of organisational knowledge creation embraces four knowledge conversion phases: socialisation, externalisation, combination and internalisation reflecting the process of knowledge sharing, which is necessary for new knowledge and innovation to be created. Lee who studied knowledge sharing measurement from Nonaka´s and Takeuchi´s perspective of the theory of knowledge creation argues that tacit knowledge sharing (socialisation phase) covers up to 90% of total knowledge sharing which emphasizes the importance of tacit knowledge sharing and social interactions as prerequisites [9,17]. Knowledge sharing is related to the creation of value; however, there are immanent knowledge sharing *costs*, such as money, time and energy which are limited resources as well [3].

In this study knowledge sharing is not meant to be a logistic coordination of knowledge packages, but rather as sharing (tacit) knowledge between people [9]. Therefore, knowledge sharing cannot be managed only by the leaders; it is a wider organisational task including the support of general framework, development of organisational culture, improvement of network structure and so forth.

4 The Concept of Transaction Cost

4.1 Transaction Cost Theory

The transaction cost theory is an approach to organisations, which is the origin of the institutional theory. In the 1930s the idea of transaction cost was developed by Coase and rediscovered and modelled into the transaction cost approach

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2 In the literature review both terms "knowledge transfer" and "knowledge sharing" are used as synonyms to express the exchange of knowledge in organisational context.

3 Inter-organisational knowledge sharing means acquisition of knowledge from external sources. For example, in the context of joint venture and strategic alliances, acquisitions and supplier-customer market relationship.

in the 1970s by Williamson. Since that time the transaction cost approach has been applied to various fields of research.

Williamson´s transaction cost approach is based on Coase´s finding that an optimal coordination form is determined by the requirements and actions of the transaction [18a]. He further argues that the transaction itself is not only a basic unit to be looked at, but a core unit of the analysis [18b]. Basically, the transaction cost approach analyzes the development of institutions in regard to the cost of the resources utilization.

In our study we transfer the transaction cost theory into intra-organisational knowledge sharing. We aim at building up a comprehensive theoretical construct for intra-organisational knowledge sharing based on the transaction cost theory.

4.2 Knowledge Sharing as a Form of a Transaction

Understanding the term "transaction" is an essential precondition to be transferred into intra-organisational knowledge sharing in large organisations.

A *transaction* is defined as an "exchange of any object" as, for example, knowledge from one subject to another [19]. Furthermore, a transaction is two-sided: it is a joint action. Williamson makes a contribution to explicate the specific attributes of a transaction with the vest of an individual and collective variable set [18a]: human factor and specific environmental factors. The analysis of a transaction or rather interaction between two actors is carried out according to the presumption of human factor in combination with specific environmental factors.

The human factor is characterized by bounded rationality and opportunism [18a]. Bounded rationality turns away from the ideal of the Neoclassic so-called "homo oeconomicus" who acts rationally in any situation. It considers the circumstance that a human is bounded by limited information access. Opportunism is the second presumption of the human factor. It involves the possibility of "self-interest seeking with guile" behaviour. However, this perspective does not fulfil a realistic view of a human, because the concept of bounded rationality neglects the motivational side of human behaviour and opportunism in the sense that "self-interest seeking with guile" [18a] encompasses only a part of the whole spectrum of possible behaviour forms. The property rights theory provides an alternative to opportunism which is in our opinion a very narrow human variable. This alternative is the concept of individual utility maximization. The main instrument of the property rights theory is the contract, which enables the handling of transaction-decisions and, therefore, reflects more personal values and moral concepts [20].

According to Williamson the specific environmental factors of a transaction are [18b] those of uncertainty, frequency and specificity of a transaction. *Uncertainty* relates to the fact that nearly all transactions in an economic system are uncertain in the sense that the happening of an aspired result can only be forecast up to a certain probability. Besides the system-related uncertainty, the focus is adverted to the transaction object itself in regard to economic risks and to the reactions of the contract partners, i.e. opportunistic behaviour and/or shirking. With greater *frequency* of transactions, the results of earlier transactions can be collected, and they provide interpretable experience. The third environmental factor is the transaction-specific investment in human and / or physical capital needed for a transaction. In the end the main criterion for a decision in favour or against a transaction is the sum of the transaction costs. In other words, the transaction producing least costs and having proportionally high value for the organisation is chosen.

The attributes of a transaction according to the transaction cost approach discussed above and their interconnections are represented in Fig. 8.3.2.

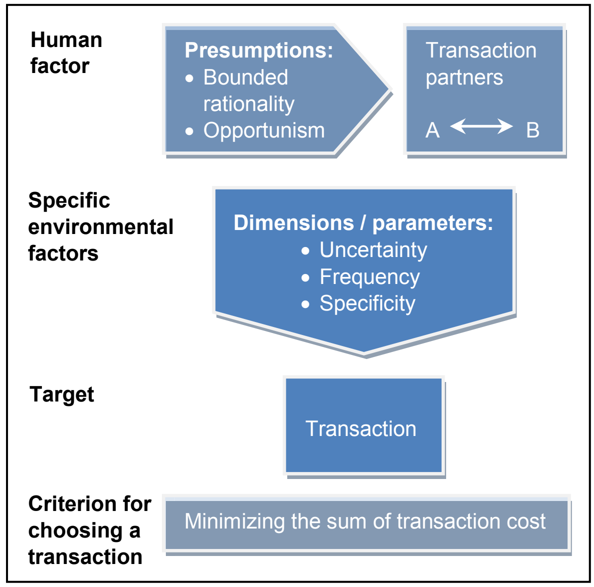

Fig. 8.3.2 The connection between the attributes of a transaction

Further we transfer the examined term "transaction" into the context of *intra-organisational knowledge sharing*. Knowledge sharing within an organisation can be generally understood as a flow of transactions between people, despite the existence of knowledge data bases. Knowledge sharing as a transaction embraces, beyond the exchange of knowledge, such side effects as symbols, communication style, and strategic thoughts. However, the central part of any knowledge sharing transaction is the exchange of the object "knowledge".

As already discussed in the Chap. 1.2 knowledge in the core is an interpretation of experience and perception arising from the environment. Therefore, the exchange of knowledge between individuals gets very complex. "Because knowledge resides in our bodies and is closely tied to our senses and previous experience, we will come to create the world in the ways, that are unique to ourselves" [21]. Accordingly, knowledge sharing reflects only the mutual exchange of property rights on valuable resources between at least two actors [22]. The principle of the smallest exchange of two resources between two actors is shown in Fig. 8.3.3.

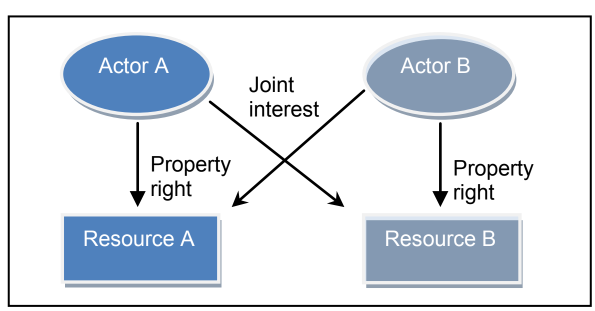

Fig. 8.3.3 The elementary system of an exchange

In principle, the exchanged resources can be of different kind. For example a task-related advice can be exchanged against the feeling of appreciation. However, it is important that the exchange is a joint action so that both sides get a sum in return equally.

Moreover, the institutional theory researches into voluntary and inherent dynamic emerging relationships of exchange and aims to conceive them from the rational cost-value-perspective. Considering the presumption of a bounded rational acting human aiming individual utility maximization, knowledge exchange refers to voluntary actions that are motivated by the returns they are expected to bring, and is not based on the wish just to share with somebody [22].

Another meaningful contribution is given by Heinen who defines transaction with the vest of three components [23]:

1. **Exchange component:** Transactions adhere mutual exchange of material or nonmaterial goods.
2. **Social component:** Transactions take place in social environment and therefore they are accompanied by communication processes between the transaction partners.
3. **Normative component:** Transaction partners must consider legal and cultural specifics summarized in so called collective norms.

According to Heinen, transactions are social interactions between individuals or groups under the normative umbrella with the target to secure individual rights through exchange of rights on material or nonmaterial goods [23].

In this study we define a transaction as a joint action and take up Williamson's general differentiation of individual and collective variable to carry out the analysis of a transaction, however, we diversify the presumptions. As for the human component we assume that individuals act at work bounded rational and self-interest seeking, but we do not agree that in general individuals manipulate on purpose to boost his/her own transaction benefit at the expense of that of the transaction partner. Therefore, we presume that individual utility maximization behaviour is an alternative to the variable opportunism, because it takes into consideration the fact that the actors want to maximize personal benefits within the environmental framework based on expectations of how the transaction partner is acting. Furthermore, we understand mutual exchange of property rights on resources as the basic principle of organisational knowledge exchange. In our research we assume that the transaction of knowledge sharing involves exchanging work-related organisational knowledge by both actors. Such substitutes as receiving or giving back a feeling of appreciation during transaction are considered as a side effect. Beside the well-known environmental components by Williamson, there are other influencing factors discussed in the literature. We add collective norms advised by Heinen as normative umbrella and emphasize the importance of trust into relationships and system. Moreover, we agree with Heinen that transactions are social interactions between individuals and groups. The main criterion for choosing a transaction is based on evaluating the sum of the transaction costs and transaction value and also on analyzing all the components summarized in Fig. 8.3.4.

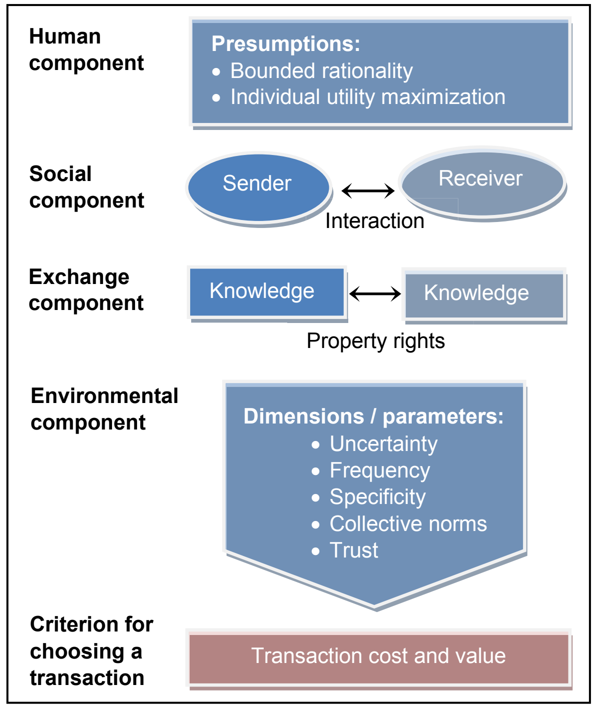

Fig. 8.3.4 Components of the transaction: intra-organisational knowledge sharing

4.3 Knowledge Sharing Costs and Value

Transaction is considered to be a basic element in economic life and it is only natural that its handling causes costs. The arising costs of a transaction are differentiated into *transaction costs* and immediate costs. In term of knowledge sharing the immediate costs equal to the subjective value of the resource the knowledge sender is sharing with the exchange partner. If the subjective expectations of both knowledge sender and knowledge receiver are fulfilled so that both maximise their individual utility out of the knowledge sharing process, the situation is called a joint win-win-situation.

On the contrary, transaction costs are organisational costs arising during the process of transaction. Examples of transaction costs in the context of knowledge sharing are costs of finding an appropriate exchange partner, gathering information about the credibility of the exchange partner, time spent etc.

The existence of transaction costs is proved, but coming to the practical operationalisation of transaction costs the following problems arise [20]:

- Problem of classification. It is difficult to select what transaction costs actually are and which costs are not transaction costs.
- Problem of quantification. Transaction also involves factors difficult to quantify and until now there are only few empirical studies.

Consequently, a generalised way of determining the exact cardinal sum of the transaction costs is not possible. Therefore, transaction costs can only be captured and appraised in particular cases depending on the structure and composition of the specific attributes of a transaction. According to the transaction cost theory the specific attributes of the specific environmental factor dimensions (see Fig. 8.3.2) have impact on arising different kinds of transaction costs and this, on the other hand, influences the total amount of transaction costs. Williamson classifies costs appropriate to the point in time of happening, whereas Picot differentiates costs arising during certain phases of transaction. The explication of the transaction costs in intra-organisational knowledge sharing promotes defining the costs according to the transaction phases, represented in Fig. 8.3.1

1. **Phase of sending knowledge:** Costs for search, acquisition and preparation.
2. **Phase of social interaction:** Costs for communication and connecting carriers of knowledge asked for.
3. **Phase of receiving knowledge:** Costs for conduction, adaptation and controlling.

This phase-specific types of costs explain the nature of transaction costs for knowledge sharing. Furthermore, transaction costs are differentiated into ex ante and ex post costs. Further the phases will be connected to the components of intra-organisational knowledge sharing.

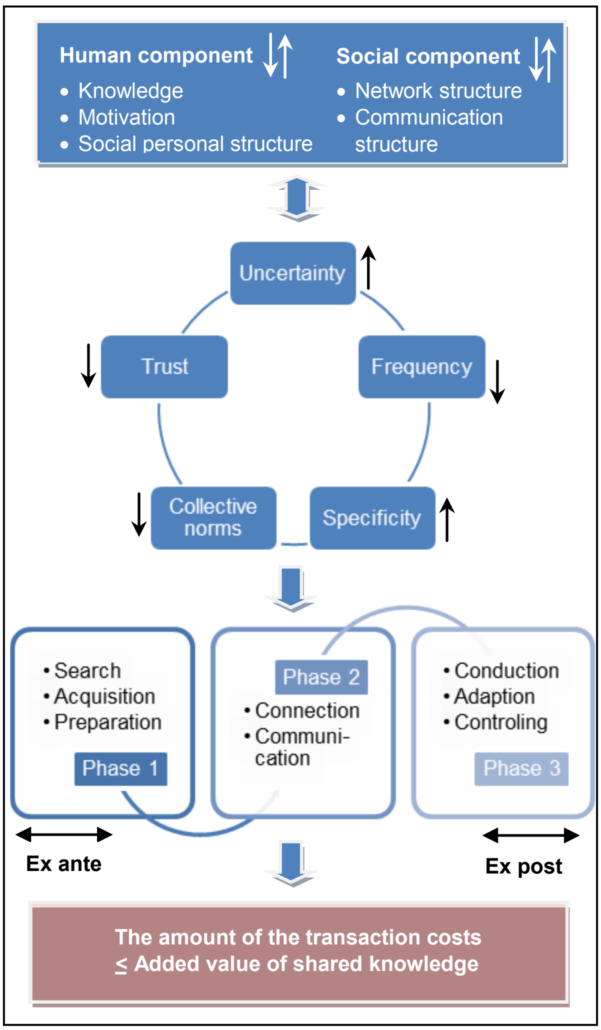

Fig. 8.3.5 Intra-organisational knowledge sharing transaction

As we have already discussed, in a successful knowledge sharing process all three phases of the transaction are equally important. The *human component* is a significant influencing factor for knowledge sharing transactions. The phases of acquisition and knowledge exchange take place in the social environment and are, therefore, influenced by motivational personal traits and social personal structure. Thus, these are influencing factors in the process of search for relevant knowledge carriers [20]. They display probable variable costs due to changing sharing partners especially grounded on (missing) trustworthy relationships.

The network and communication structure are important prerequisites for establishing social connections needed for successful knowledge sharing process. The more transparently they are designed, the lower the transaction costs for that *social component* will be. The existence of *trust* is considered to be a crucial component of social relationship [3, 12, 24]. In organisations social relationships are based on structures of mutual dependence, which makes the actors vulnerable to each other's actions. For example, knowledge sharing is inherently risky. In the context of knowledge sharing risk means giving potential benefit to another without receiving something equally valued in return. The uncertainty of a risky exchange depends on the amount and quality of knowledge that an actor has for estimating the probability of the outcome. For example, not returning or giving back knowledge, which is only partly true, can be the partner's intention. On the other hand, if risk is absent, trust is irrelevant because there is no vulnerability. However, organisations and their personnel can not possess all and true information; therefore, the notion of uncertainty and risk is always present. Technical innovations and the pace of development might lead to the conclusion that risks and complexity can be reduced and controlled with the vest of technology, so that the social mechanism of trust would be replaced and thus not needed anymore. On the contrary, trust can be rather expected to be more and more used in order to handle the technically produced complexity in a globalised dynamic environment. Consequently, trust would play an important role in the management of knowledge in organisations.

In organisational context the management style, norms and values of the company (and of the society) play an important role for the individual's behaviour. The human being is only marginally motivated by instincts telling him what has to be done. On the other hand, human being has available rationality, self-awareness and imagination. Therefore, he needs a scope of orientation and an object of dedication [25]. In this connection it is important that the "*collective norms* and vision" e.g. from an organisation, motivate the employee's behaviour, because what internally concerns the individual, motivates his behaviour.

The more frequently transactions of knowledge sharing are repeated, the more interpretable experience organisation has. Therefore, the *frequency* of a specific attribute, for example, the cooperative behaviour of the knowledge sharing partners, leads to reducing uncertainty and simultaneously to saving transaction costs.

According to Williamson, the *specificity* parameter of a transaction is one of the most important. Specificity is the degree of centralization of unique knowledge or task [18a]. The higher the degree of transaction specificity is, the more transaction costs will be. Such costs arise in form of high investment at the beginning, e.g. when a specified team is formed and during the work when, for example, a highly specialised employee leaves the organisation. On the other hand, the specific knowledge held by an actor increases the (tacit) knowledge sharing success.

Uncertainty relates to the fact that we are only aware of partial information about the characteristics of a transaction object. Besides the system-related uncertainty, the focus is adverted to the transaction object itself and to the reactions of the transaction actors [18a]. The greater the extent of the complexity of the transaction and transaction period is, the greater the extent of incomplete information on the transaction characteristics will be. Thus, more information will be needed in the phases of sending and receiving knowledge and the transaction costs will increase.

In addition we also propose giving emphasis to the created value of the transaction and explicate the term "transaction value" as the basic unit of the analysis besides the variable transaction cost. The difficulty of knowledge sharing in the decision-making process is in defining the optimal point, which theoretically exists, when the additional cost for knowledge acquisition and conduction is equal to the added value brought by the additional knowledge.

5 Conclusion

The aim of this article is to build up a theoretical framework of intra-organisational knowledge sharing in large organisations from the transaction cost theory perspective.

This study makes important contributions to understanding knowledge sharing and the way costs and value are accumulated in organisational transactions. Moreover, this study explicates additional influencing factors beyond the dimensions offered by the transaction cost theory. In particular, the role of social connections, trust and collective norms in knowledge sharing transaction are discussed.

An interesting way for the future research would be to discover how to classify transaction costs further and estimate the amount of transaction costs as well as the added value of knowledge sharing processes.

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8.4 Training on the Job in Remanufacturing Supported by Information Technology Systems

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Abstract
The economical and ecological potentials of remanufacturing are inadequately exploited. Due to unforeseen products types, conditions and quantities remanufacturing processes are often manually or mechanically supported. Performed by highly qualified workers they are strongly based on implicit knowledge. Because of the growing remanufacturing market it is important to enable efficient processes andadapt training courses on remanufacturing processes for humans with different qualification levels. Manufacturing- and information technology based components for both process execution and qualification have been integrated. The resultinginformation technology system can support the worker with a work description and lists of means of production necessary for a work order. With access to approved work descriptions the worker will be able to analyse his working process and to access his own qualification. Improved descriptions can be used for process engineering also.

Keywords:
Humans and technology, Qualification, Image based recognition, Remanufacturing

1 Introduction

In today's global economy end of life products are found in all regions of the world. Exploiting the potential of end-of-life products as a source of spare parts for all kinds of products and product modules gives us chances (a) to cope with the challenges of shortages of resources, (b) to produce more cheaply due to saved production capacity and resources and c) to integrate people in less developed areas in global value creation processes and let them participate in wealth increase of their local community.

Remanufacturing is a process of refurbishing old products to a good as new functional state, often backed by a full warranty. By reconditioning an old product, a substantial proportion of material, energy, transport and disposal from its former production can be saved [1]. Moreover upgrades in material and design can be integrated into the remanufacturing process, and higher performance standards can be provided [2].

Remanufacturing is often hindered by a lack of knowledge and research about the process. This has led to few remanufacturing tools and techniques being developed to improve its efficiency and effectiveness so far [3]. Furthermore unforeseen product types, conditions and quantities have led to primarily manual or mechanically supported remanufacturing processes, which are often strongly based on implicit knowledge [4, 5].

The remanufacturing of a starter motor, for instance, requires only a ninth of the material and an eleventh of energy compared to the first production [6]. In 2009 the automotive supplier Bosch has saved 23.000 tons of CO_2 by the remanufacturing of 2,5 millions of parts instead of their production and is expecting a growth of the remanufacturing market up to 30 millions of products per year till 2015 [7].

According to the Global Industry Analysts the world's automotive remanufacturing market is projected to reach 104.8 billion USD by 2015 [8].

Due to the fact that remanufacturing processes are usually characterized by a high percentage of manual work, less developed regions have good chances to achieve a high market share in remanufacturing processes. The reasons for this are (a) the often lower salaries to earlier industrialized countries and (b) the local availability of end-of-life products as resources.

A particular challenge lies in the need for qualified workers in the remanufacturing process, which often does not exist. This seems to the authors the most critical factor for implementing a globally successful remanufacturing industry in emerging regions.

2 Increasing Demand for Fast Qualification for Efficient Remanufacturing Processes

Many sources have signalled a growth in the remanufacturing market. Considering the case of Bosch, the increase of up to 30 million parts per year would lead to 4.500 new workplaces and 4.100 new employees to train on the shop floor level by 2015 (Table 8.4.1).

Table 8.4.1 Calculation of workplaces created with market growth expected in [4], tenfold increase from less than 400 to more than 4000 workplaces

Description	Assumption
Working days per year	$d_y = 220$
Shift operations	$s = 1$
Working time per sift	$t_S = 420\ min$
Disturbance	$a = 10\%$
Effective working time	$t_E = 378\ min$
Working time per alternator including disassembly, cleaning, replacement of parts (if necessary), reassembly and testing performed on a manual workplace (data based on methods of time measurement)	$t_A = 12{,}5\ min$

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Products in 2009	$n_{09} = 2{,}5 \text{ million}$
Products per year by 2015	$n_{15} = 30 \text{ million}$
Market growth in BRIC-countries	$A_{15USD} = 104{,}8 \text{ billion USD}$
Calculation	
Working time per year	$t_y = d_y \cdot t_E \cdot s = 220 \cdot 387 \text{ min} \cdot 1 = 83.160 \text{ min}$
Alternators per year for one workplace/ employee	$n_y = \frac{t_y}{t_A} = \frac{83.160 \text{ min}}{12{,}5 \text{ min}} = 6.652{,}8$
Total workplace/ employee needed for expected amount of products	$WP_T = \frac{n_{15}}{n_y} = \frac{30 \text{ million}}{6652{,}8} = 4.509$
New employees till 2015 at BOSCH	$WP_N = WP_T - \frac{n_{09}}{n_y} = 4509 - \frac{2{,}5 \text{ million}}{6652{,}8} = \mathbf{4.133}$
Price per alternator	$P_A = 93 \text{ USD}$
Market share BOSCH in [USD]	$B_{15USD} = n_{15} \cdot P_A = 30 \text{ million} \cdot 93 \text{ USD} = 2{,}5 \text{ billion USD}$
Market share BOSCH in [%]	$B_{15\%} = \frac{B_{15USD}}{A_{15USD}} \cdot 100 = \frac{104{,}8 \text{ billion USD}}{2{,}5 \text{ billion USD}} \cdot 100\% = 2{,}7\%$
New employees till 2015 in BRIC-countries	$WP_{BRIC} = \frac{WP_N}{B_{15\%}} \cdot 100\% = \frac{4133}{2{,}7\%} \cdot 100\% = \mathbf{153.074}$

The growth of the remanufacturing market in developing and emerging countries is even higher. One reason is the low prices of refurbished products and the other is the fitting with resoled machinery. In China, for instance, the resale market for used construction machinery equipment rises every year by 20 percent [9]. Assuming a remanufacturing market of 104.8 billion USD by 2015, the number of new jobs can be roughly estimated at more than 150.000. Due to the drastic increase of the automobile market in Brazil, Russia, India and China (BRIC), an increase of remanufacturing jobs in less developed areas of these countries is predicted.

3 Qualification Concept

The focus of the qualification concepts introduced in this paper lies in adapted training courses on remanufacturing processes for humans. They shall be enabled to create value for income generation on a local level. Integrating manufacturing- and information technology based components for both process execution and qualification "training on the job" shall be provided.

An information technological network, the so-called sustainable manufacturing community is planned to be developed. It is supposed to support the communication, the share of best practice and the provision of teaching material between the workplaces worldwide. Diverse qualification levels of local workers are a challenging aspect for such a training system, especially in regions with low education, and where end of life products are recycled in a human and environmental harmful ways [10].

Thus structured training on the job plays an important role. Employees should be trained according to their personal training profile.

3.1 Structured Training on the Job

Through learning-by-doing the worker attains knowledge about the purpose of an activity by performing and increased competence by repeating it [11]. In a structured learning environment, like in a university, learning concepts, such as the learning-factory, enable learning-by-doing [12]. In these concepts working and learning environments can be merged. Students as well as employees can be trained in a realistic mock-up [13, 14].

Unstructured learning-by-imitation is risky in an industrial environment. Approximately 90 percent of an employee's work skills as well as shortcuts, mistakes, confusion and inconsistency are taught by other employees.

Structured training on the job as an alternative to this is a one-on-one training at or near the actual workplace which is delivered by a designated trainer. Written guidelines provide observable and measurable performance of the pupil to be later tested. It is developed and delivered in a systematic manner. [15]

3.2 Learnstrument Approach

Learnstruments are objects of problem-solving-oriented projects which automatically teach the student its functioning. This includes technical systems, with self-explanatory functionality like remanufacturing tools as well as methodological procedures that provide meaningful solutions, like context specific simulations or best practice videos of remanufacturing processes.

Learnstruments combine innovative teaching methods and e-learning tools. The learning process occurs at the multimodal and interactive level and, when possible, in language independent transfers of knowledge and skills. The object supports the student with context dependent hints and information and guides him on his interest based learning process.

The integration of an information technology system into a remanufacturing workplace is by this definition an exemplarily learnstrument. Many aspects and features of learnstruments can be developed and tested within the prototypical implementation of an interactive teaching workplace for remanufacturing.

3.3 Training Profiles

The key research question within the learnstrument workplace for remanufacturing is what kind of guidance and training the particular worker needs. Out of that the following questions result: (a) Which process steps of the individual worker within the remanufacturing process should be improved? (b) What is the qualification gap of the worker and which specific qualifications should be gained by him to improve his work results? (c) Which training modules match the needed qualifications and how should they be presented to the worker.

Answering these questions requires information about qualification requirements, individual qualification profiles, training profiles and learning outcome statements of learning modules. That information is based on a multitude of data about remanufacturing processes and qualification statements within a dynamic and complex learning environment. ICT using artificial intelligence can help to support this task by identifying relevant data and supporting humans by processing this data and providing context specific information.

For such tasks the so-called Plotin software framework has been developed. The software consists of a semantic web knowledge base, an inference engine and a metadata annotation tool. Here, the processing of qualification data is based on an outcome oriented qualification model for engineering education [16]. The Plotin framework was developed and tested within the campus-management system of the international Master's programme Global Production Engineering (GPE) [17] for the analysis, coordination and evaluation of courses and of individual qualification planning of teaching activities and learning paths [18].

Other taxonomies based algorithms to compare qualification profiles have been developed and employed, for example in the project 'ePeople' at the Daimler AG factory in Würth and at the Siemens AG factory in Erlangen [19, 20].

3.4 Training System a Learning Process

The goal here is to systematically translate the technical requirements of the remanufacturing process from the observation of an experienced worker to a self-explanatory work description.

The examination of this description should be as simple as possible so that workers with all kinds of technical background can be reached. The product to be handled, equipment to be used and process to be performed should be specified.

The qualification system shall train the employee and act both as an instructor as well as an unobtrusive supporter and promote a continuous improvement process. Improvement shall be enabled within the remanufacturing process as well as in the design of the workplace.

Qualification statements should be described in a way that human and computer can understand and process them. So-called Learning Outcomes (LO) describe the capability of a learner to demonstrate a particular task at the end of a defined learning sequence. LO have proven their particular strengths in practice and are recognized as the "building blocks of the Bologna Process". LO strength lies especially in their semi-standardization, natural language and high capacity to describe the value creation in a learning process.

4 Qualification Systems for Workplace Application

An information technology system for image based recognition of manual work steps has been partially implemented [21]. This system allows the creation of performance based profiles of employees as well as profiles for several work tasks performed at a workplace to be accomplished.

4.1 Information Technology System and Work Principles

An information technology system for image based recognition of manual work steps has been developed. It consists of a 3D-camera and an image processing algorithm for the workers' hand tracking as well as a knowledge-based expert system with a user interface for the recognition of work steps.

Through marker-less hand tracking with a 3D Time-of-Flight (TOF) camera, exemplary selected work steps as part of the remanufacturing process of an alternator have been recorded. Image registration is done with the Iterative-Closest-Point (ICP) algorithm so that the trajectory of the hand movement can be stored in a text file. Over time corresponding images of the workplace have been stored as well.

Through a user interface, environmental information has been stored in a knowledge-base. The trajectory has been screened by the expert system for work steps like pick, place or use of objects. Based on the content of the workers hand and its position, automatically recognised work steps have been validated or completed with used means of production and work pieces by the user.

Work steps that were analysed included separation and joining of parts as well as unsoldering, unscrewing and screwing. Output is a work description accessible by other interconnected workers for qualification (Fig. 8.4.1) [21].

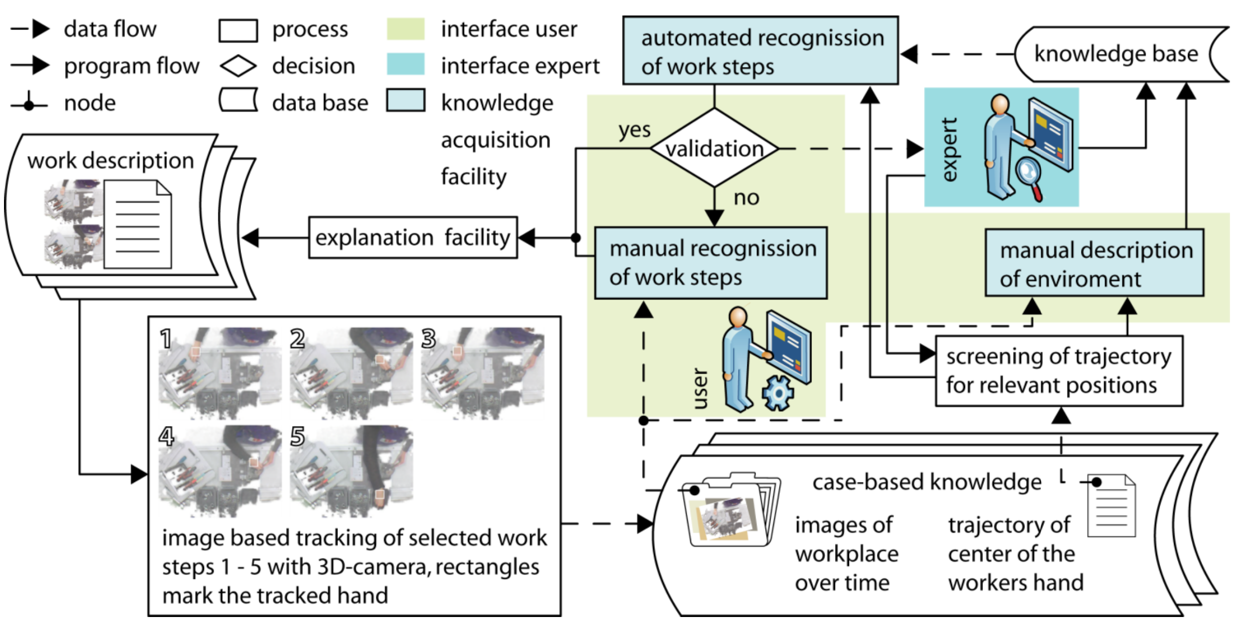

Fig. 8.4.1 Cognitive process dimension and learning process (after [21])

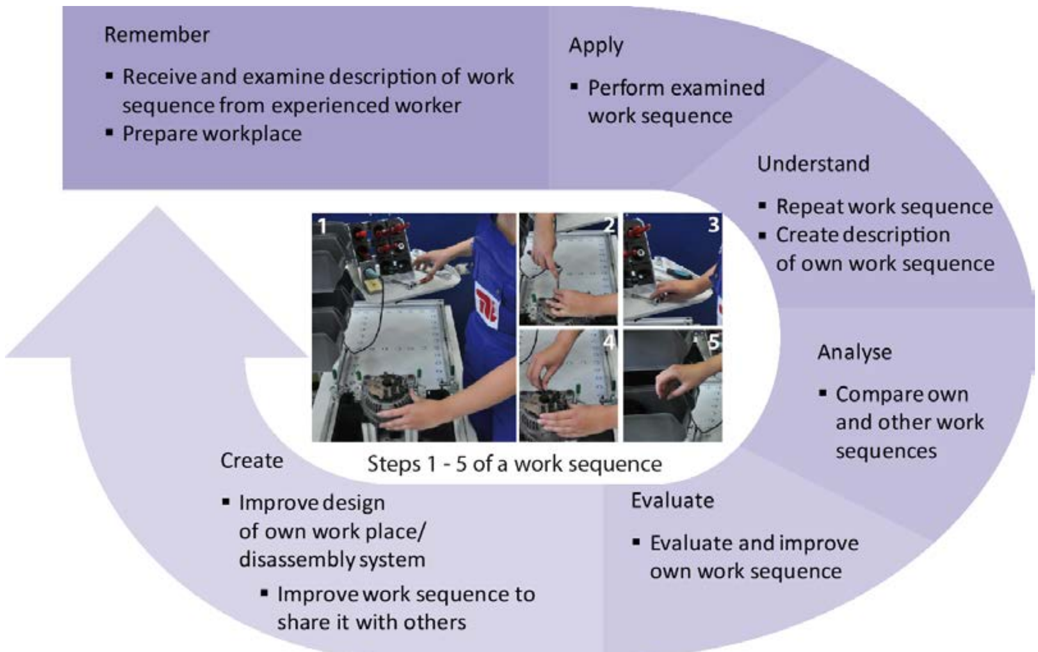

Fig. 8.4.2 Cognitive process dimension and learning process

4.2 Supported Learning Process

So called learning outcome statements can be analyzed regarding their cognitive challenge using learning taxonomies. One of the most widely used ones is Blooms taxonomy [22] revised by [18, 23]. The qualification system presented here uses the cognitive process dimension based on [18] which classifies: (a) remember, (b) apply, (c) understand, (d) analyse, (e) evaluate and (f) create [18]. An example of learning outcome statements for different cognitive dimensions for a resulting learning process is shown in Fig. 8.4.2.

Remember

The user receives the sequence of work steps to be performed and can examine it over the user interface (Fig. 8.4.3). He or she gets information about used tools and handled parts of the product. The work place can be prepared. The depth of assembly is indicated (Fig. 8.4.4).

Apply

The user applies the received knowledge through performing the examined work sequence.

Understand

The user repeats the work sequence to understand and internalise it.

To create an own work description he or she has to describe the environment of the workplace first. This helps to understand the information technological system and the own workplace better. Description of the environment can be done before or simultaneously with the creation of a work description (Fig. 8.4.5).

Analyse

The information technology system can be used to display two work descriptions next to each other so that they can be compared directly by the user. The system matches the descriptions and highlights differences in time, number and content of work steps (Figs. 8.4.6 and 8.4.7).

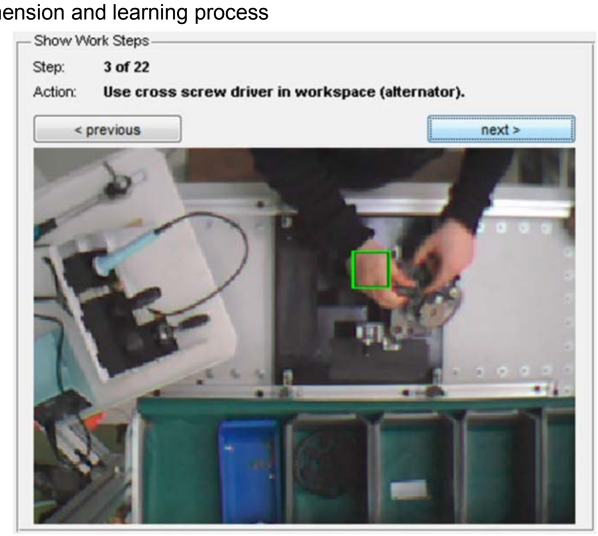

Fig. 8.4.3 User interface to show work steps, hand is tracked with *rectangle*

WD1 File: alternator_right_2.txt

	i	T(s)	PLACE	AC...	TOOL	PART	...
1	10	0					0
2	40	1.3333	tool holder (cross screw driver)	pick	cros...		
3	90	3	workspace (alternator)	use	cros...		
4	...	27.66...	tool holder (cross screw driver)	place	cros...		
5	...	29.66...	workspace (alternator)	pick		screw M3	3
6	...	36.66...	bunker (standard parts)	place		screw M3	3
7	...	38.66...	tool holder (ratchet)	pick	ratchet		
8	...	40	workspace (alternator)	use	ratchet		
9	...	73.66...	tool holder (ratchet)	place	ratchet		
10	...	76.33...	workspace (alternator)	pick		nut M3	3
11	...	82	bunker (standard parts)	place		nut M3	3
12	...	85.33...	workspace (alternator)	pick		carbon b...	1
13	...	87.66...	bunker (parts)	place		carbon b...	1

...

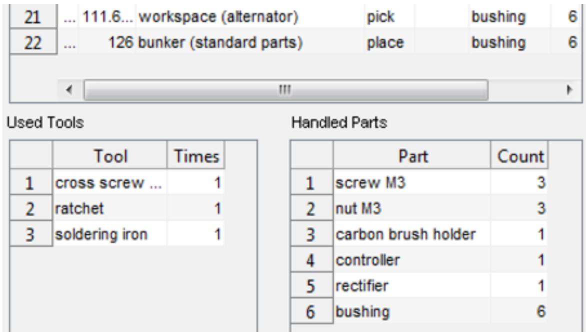

Fig. 8.4.4 List of work steps, used tools and handled parts

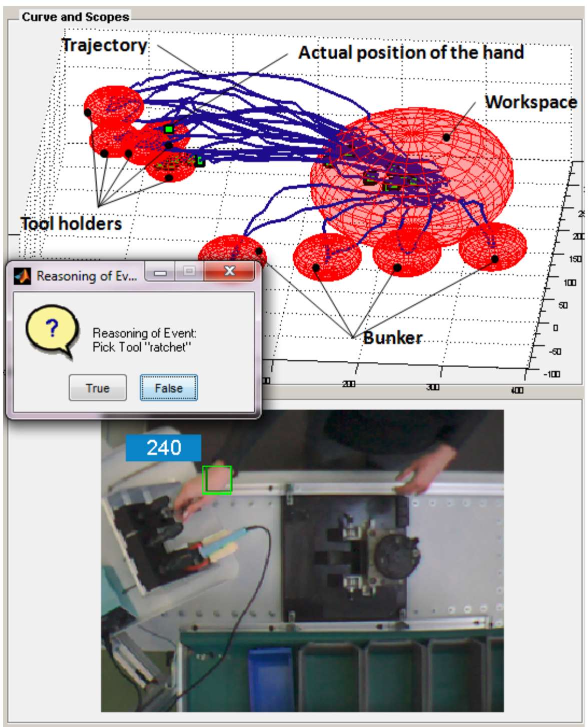

Fig. 8.4.5 System is reasoning events based on the content of the workers hand and its position, visualisation of knowledgebase/environmental knowledge

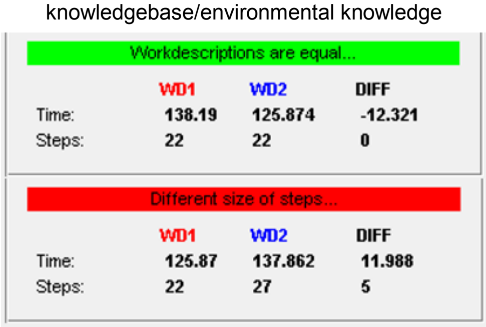

Fig.8.4.6 Matching of work descriptions

Evaluate

By evaluating different tools being used in the process, such as manual or pneumatic tools, number of work steps coming from different assembling or disassembling methods, the worker can improve his work routine.

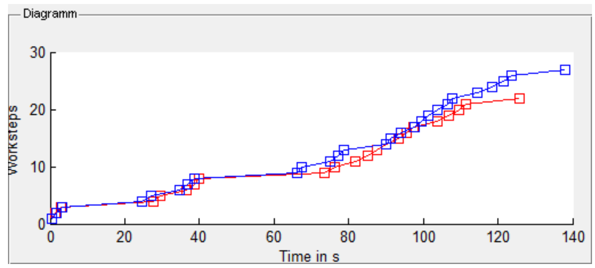

Fig. 8.4.7 Work steps over time (*red* experienced worker, *blue* worker to be taught)

Create

After improving the design of own workplace/ (dis-)assembly system or work sequence, a new work description can be created and shared with the manufacturing community that the worker is connected to.

4.3 Further Development

The aim of further development is the combination of the described system with the Plotin information technology system, which is responsible for the planning of the qualification. In addition a tool will be integrated, which helps deriving qualification requirements out of faulty or inefficient remanufacturing processes executed by the worker. Through the comparison of work profiles it can be tested whether process requirements were met and learning objectives reached.

In case there is a qualification deficiency of the worker, the individual qualification demand has to be identified and stated in form of Learning Outcomes. A Failure Mode and Effect Analyses (FMEA) Ontology will be developed to derive qualification requirements. The Plotin framework creates from the qualification requirements a training plan and suggests various training modules to the worker. The person picks the modules with the teaching and learning style he likes based on his individual preferences.

These learning modules will be shared in a global community. Based on the open knowledge principle a so called sustainable manufacturing community will be established that allows access to learning modules and teaching materials. In order to support automized sharing of such learning resources by all participants, metadata is used to annotate learning objectives, prerequisites, desired learning outcomes and the appropriate learning context to the online data.

5 Summary

Remanufacturing should be better utilized in order to promote economical and ecological benefits. By establishing remanufacturing industries, the BRIC countries have excellent chances for wealth creation and technological development, especially in less developed regions,. Due to unforeseen products types, conditions and quantity, remanufacturing processes are often manual or mechanically supported. Performed by highly qualified workers they are strongly based on implicit knowledge. With a growing remanufacturing market and to enable efficient processes even in regions without a qualified workforce, adapted training courses on remanufacturing processes for people with various qualification levels are needed. To integrate manufacturing- and information technology based components for both process execution and qualification, an information technology system has been created. This system can support the worker with a work description and lists of means of production necessary for a work order. With access to approved work descriptions the worker will be able to analyse his working process and qualify himself. Improved descriptions can be used for process engineering also.

An information technology system for image based recognition of manual work steps has been developed. Through marker-less hand tracking with a 3D TOF camera examples of work steps as part of the remanufacturing process of an alternator have been recorded. Image registration is done with the ICP algorithm so that the trajectory of the hand movement can be extracted and screened by an expert system.

Over a user interface, environmental information has been stored in a knowledge base. Based on the content of the workers' hand and its position, automatically recognised work steps like pick, place or use of objects have been validated or completed with used means of production and work pieces by the user.

Output is a work description accessible by other interconnected workers for qualification.

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8.5 Human Dimension of Agency and Sustainable Corporative Growth

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Abstract

The economic theoretical knowledge ranks the agent's activity with opportunist individualistic behaviour, reflecting the behavioural pattern opposite to the sustainable developement's logic. This paper intends to set forth arguments substantiating the deep embeddedness of successful agency in social, cultural, legal and managerial custom. The entrepreneurial initiative is restricted by the law, while the agency is confined within the entrepreneurial usage, the consumer traditions, the limits imposed by the contractual requirements of the principal (organisation or institution), and the social and economic environment. Long-term concerns, human dimension and vital simpathy in future generations are necessary to build the individual agent's business.

Keywords:

Agency, Human, Initiative, Governance, Economic agent

1 Human Capitalist

The capital—labour relations are deeply influenced by the personalising of producing abitiliies. Today, the personal features of the individual carrying out an activity play the much more important role, than the corporative hierarchy endows his or her position.

The development of these abilities is similar to a successful investment in financial assets, that is why the human capital strategy is a widespread term in up-to-date corporate management.

1.1 Human Capital Concept

The human capital concept was introduced in the middle of XX century [1], but it reflects the situation described by the classic economist Adam Smith, who defined it as "the acquired and useful abilities of all the inhabitants or members of the society. The acquisition of such talents, by the maintenance of the acquirer during his education, study, or apprenticeship, always costs a real expense, which is a capital fixed and realized, as it were, in his person. Those talents, as they make a part of his fortune, so do they likewise that of the society to which he belongs. The improved dexterity of a workman may be considered in the same light as a machine or instrument of trade which facilitates and abridges labor, and which, though it costs a certain expense, repays that expense with a profit" [2]. This is the core asset for the successful carrying out of business.

Due to the key role of the human factor in producing profit, the expenditure in training, development, health and support of individual and group attitudes, skills and abilities should be took as investment and not as expense. The innovative skills and creativity at work should be supported by the complex arrangements in ergonomics and personal development of the bearer of talent, of competences and professional skills, of original vision or ability to invent.

In a society which places a strong emphasis on competition, financial return and viability, the people issues can sometimes be neglected. In the context of fierce competition and fast change, any competitive edge gained by the introduction of new processes or technology can be short-lived if competitors adopt the same technology. But to implement change, their people must have the same or better skills and abilities.

So, the human capital is the whole of the aptitudes, talents, qualifications, experiments accumulated by an individual, which determine the personal capacity to produce. And the volume of the acquired competences in a moment passes the certain critical mass, when the person becomes able to function well in the frame of his or her own culture and persue the personal interests.

1.2 Agent as Autonomous Actor

Human capitalists became today an important actor in business, they a able to dictate their demands to an administration and to impose their decision.

Corporative management prefers (and is obliged) to allocate the resources according a strict adopted policy, therefore an exceptional talented or experienced person considers, that an autonomous activity and self-investment would be more beneficial for him or her.

In this way an independent economic agent gets the following advantages:

- he or she is free in the professional decision making;
- an independent agent uses the income according to his or her will, so he or she saves on the executive bodies or big office maintenance expenditure;
- in the human investment all consumption is treated as investment, this relates to the individualised choice of expenses and also to the responsibility of resources use, including the use of time;
- the challenge of the entrepreneurial responsibility and taking risks makes the person to improve his or her skills, to increase the qualification, to further training;
- the autonomous activity puts interesting and peculiar tasks and avoid the monotonous of functioning in a company.

The responsibilities and risks are attractive only for persons who estimate themselves as able to such a challenge, according to their working experience.

1.3 Individual Economic Agent in the Market

The individuals who hold the exceptional professional skills and competences, understand their efficiency and advantage of independent occupation. Their competitive advantages include:

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- the high professional level, taking into account that the quality of work in a corporation is evaluated at the level of the less qualified person involved in process, i.e. working with an independent agent the client usually has no chance to meet the boorishness of a secretary;
- the minimal cost, due to the mobilisation of one person and not a whole organisation;
- the principle of one contracting party, when the client needs to coordinate the details with only one person, and avoid to explain many times the same situation to different employees;
- the flexibility towards customer' requests, including the time (i.e., to meet with client after the working office hours), the characteristics of the order, etc.;
- the psychological emotional comfort for the client, due to the fact, that the agent is really interesting in good image and impression.

To be competitve in the market, the autonomous agent carries out his own strategy of investment and "technological" development and innovation.

1.4 Individual Economic Agent as Self-Investor

The neccessity to assure the competitiveness, the agents are compelled to make many efforts to maintain and improve the professional level, the skills and the up-to-date knowledge. The economic agents invest in themselves in following ways:

- regular update of legal information in field of regulation of the professional activity;
- taking part in conferences, round-tables etc., to make acquaintance with the best practices or the actual problems in the professional field;
- dynamic communication with different competitors, especially the leaders in the branch;
- mobilising the personal relations to keep up about the prospectives and anticipations in the professional field;
- creating the portfolio;
- investing in reputation , i.e. the maintenance of good souvenirs of the cooperation with former clients;
- investing in image, i.e., in the health care, the look, the dress code, the style, including the behavioural patterns, rules of etiquette;
- investing in education in allied fields and in the spheres of general erudition.

It is specific for the independent agents, that all the consumption of an agent should be of higher quality, the recreations, the food, etc.

In the competition environment, the independent agent is poorly protected against the risks and uncertainty of the market. In this case, the stability is opposite to the self-realisation, and the agent which activity is directed to the best self-actualisation of his or her personality, is a very representative of what is called "funky business" [3].

2 Agency and Opportunism

The principal—agent relations usually are presented as an opposition of interests, where the agent seeks to get the one-sided advantage. But, the agent has not only the interest to use the asymmetric information to the detriment of principal, but there are many limits to the opportunist behaviour of an independent agent, which are not efficient for organisation, i.e. the traditions, the socio-cultural norms, the religious requirements or prohibitions.

2.1 Asymmetry

The dynamic game approach demonstrates, that in a perfect economic model the agent uses his or her access to the full volume of information about the process and the results of value chain, even to get advantage on account of principal, the client or the employer.

Introducing the socio-cultural and innovative dimension in this model, changes the results due to the fact of long-term logic of agent, who is interested in sustainable cooperation. The knowledge capital evolution factor influences the real behaviour of dynamic agents, who seek to create the long-run relations of friendship with principals, especially, if the professional activity implies the restricted number of principals [4].

In the situation of an aggressive competition in the market, the agent uses the transparency as a competitive advantage, and in this case the asymmetric access represents the base for the competitiveness—if the agent is able to open all the data to the principal, in can be recompensed with the increasing demand.

2.2 Opportunistic Behaviour

The opportunity of asymmetric access to a resource, especially, to information represents a temptation for agent, in the economic-mathematical model. In reality, his situational behavioural pattern is expressed in the deviation from the normative regulation towards the choice of momentary gain [5].

In the transaction costs economics the opportunist behaviour is described with negative emotion: "By opportunism I mean self-interest seeking with guile. This includes ... lying, stealing, and cheating... Opportunism refers to the incomplete or distorted disclosure of information, especially to calculated efforts to mislead, distort, disguise, obfuscate, or otherwise confuse" [6]. Opportunistic behaviour is assumed to be ultimately caused by the nexus of a given human nature of self-interest with certain situational or structural conditions [7], the opportunities provoke the action.

This model is correct in the conditions of pure individualistic world with one-step planning and forecast. In the real world people organises their behaviour in strategic "multi-moves" planning [8–10] with long-term prospective anticipation.

The opportunistic behaviour of an agent is confined within the entrepreneurial usage and customs, the non written rules of business conducting. The agent is limited with local pressure of the consumer traditions, specific characteristics and requirements with deep roots in local or national culture.

The social and economic environment put out the specific constraints, i.e., a transition economy imposes the instable regulative system and constant change of rules without any setting of normative expectations. In this example, the agent may choose the normative behaviour as a competitive advantage comparing to the rivals.

3 Sustainability as Competitive Advantage

An agent as a professional, especially when he or she is freelance, should implement the long-run strategic thinking and take care of the customer's reaction and satisfaction. All these criteria meet the principles of sustainability, which represent the requirements for the successful development of an agent network, for the expansion and stable growth.

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8.6 Pioneering Life Cycle Assessment in Russia: Application of the EcoScarcity Method for Russia

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Abstract

Russian industry grows rapidly every year, but the environmental assessment of the products and processes are not yet developed enough. It is obvious that the growth of manufacturing causes the growth of environmental loads as well. Today it is important to use appropriate methods for evaluating the environmental impacts of the production. The application of Ecological Scarcity method is proposed as a first step towards sustainable production in Russia. This method is transparent and easy for use. It also takes into account legislation and political environmental targets. The method was developed according international standards International Organization for Standardization (ISO) 14044. The application of the method will advance Russian manufacturing's products to international market. EcoScarcity can support product development, comparisons, optimization and overall life cycle assessment.

Keywords:

Ecological scarcity method, LCA, Manufacturing in Russia, Political targets

1 Introduction

According to International Organization for Standardization (ISO) 14040 Life Cycle Assessment (LCA) is compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle [1]. Thus, it is a tool for the analysis of the environmental effects of products at all stages of their life cycle—from the resource extraction to the final disposal. The main fields of application of LCA are product design, comparison and development, analysing the origins of problem for particular product, environmental product declaration, support for regulatory measures and policy instruments, etc. [2, 3].

In Russia LCA is not widely applied, though ISO standards 14040 and 14044 exist even in Russian translation. There are some joint projects with EU regarding the harmonization of environmental standards. But today Environmental Impact Assessment (EIA) remains the main tool for evaluation. EIA is designed to identify the nature, intensity and level of risk of the impact on the environment and human health for every kind of planned activity. It is obvious, that it is not suitable for environmental analysis of manufacturing processes.

LCA has as an ultimate aim to contribute to sustainable development [4]. Ecological Scarcity Method is one of LCA methods. It originally was developed in Switzerland. Initially, Ruedi Müller-Wenk has been working on a method for Ecological Accounting. He established the main principle of the method, creation of single-score index, an ecological currency, which shall express priorities for action.

First version of the EcoScarsity method was published in 1990.The method was used for Life Cycle Assessment of products and processes first, then it was integrated into the so called ÖBU-Method developed by the Swiss Association and Environmental Management [5]. The EcoScarsity method was updated in 2006 because political and statutory settings had changed. Today updated version of the method is used.

Application of adopted EcoScarcity method will allow Russian manufacturing companies to bring the products to a new level and ensure their competitiveness in the changing world. It can be extremely attractive from commercial point of view as well as from the international image and competition point of view [6].

2 Method Concept

The Swiss Ecological Scarcity method is based on the distance to target principle. A critical flow is deduced for every substance where legislative guidelines or political goals exist. The current flow corresponds to the actual situation. The calculation of the eco-factor is determined by setting the current flow into relation with the critical flow [7]. Simplicity and transparency of the eco-factor calculation on one hand, and direct derivation from political targets on the other hand are this method's strengths. As a consequence, eco-factors can only be determined for substances with an applicable political target [5, 8].

Another advantage of the ecological scarcity method is that the concept can be used to establish an ecological scarcity method valid for other nations or political entities. Several nations, for example Japan (JEPIX- Environmental Policy Priorities Index for Japan), have adopted the methodology in the past and are calculating its own ecofactors based on their national environmental situation and legislation.

Ecofactors are defined as eco-points per unit of pollutant emission or resource extraction. The method could be applied for evaluation of emission to air, surface waters, groundwater, soil, resource extraction, waste and even

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noise. That means that it is needed to collect and process big quantity of data.

The formula is used in the former the Swiss ecological scarcity method [7]:

$$Eco-factor = K \cdot \frac{1 \cdot EP}{F_n} \cdot \left(\frac{F}{F_k}\right)^2 \cdot c \qquad (8.6.1)$$

with:

K = Characterization factor of a pollutant or of a resource;

Flow = Load of a pollutant, quantity of a resource consumed, or level of an environmental pressure characterized;

Fn = Normalization flow: current annual flow, with Switzerland as system boundary;

F = Current flow: current annual flow in the reference area;

Fk = Critical flow: critical annual flow in the reference area;

c = Constant (10^{12}/a);

EP = Eco-point: the unit of the assessed result.

Unfortunately, sometimes it is not possible to get the information about current flow of emissions or political targets for some pollution categories are not clear enough. Another important aspect of the method application is setting of the time scope of the actual and target flow data. Data of actual flows taken from the older statistic should be adjusted due to current situation, for example, population change [5]. Target flows are even more complex because of deriving from not only national legislation but from international agreements and approaches to sustainable level of environment as well.

It is special for EcoScarcity method that ecofactors are calculated based on regional explicit substance flow targets or by deriving substance flow targets based on the actual environmental data. Therefore, so-called virtual flow based on the data from monitoring stations should be modelled. This is critical part of the work that requires time and accurate calculations.

3 Example of the Method Application for Evaluation the Green House Gases Emission

The Greenhouse gases (GHG) contribute to global warming. Its consist of a great variety of substances. Among them the most important substances are CO_2, CH_4, NO_2, SF_6 and various chlorinated and fluorinated hydrocarbons (CFCs, HCFCs, HFCs, PFCs) [8].

Target flow for GHG in Russia derives from the Kyoto Protocol. According this document Russian Federation must keep the average annual emissions on the level of base year 1990. The actual flow was taken from the inventory data of year 2008.

The paper presents preliminary results for some GHG (Table 8.6.1).
The very core of the original idea could be presented in the following form [9]:
Envoronmental impact * Ecofactor = Environmental Impact

In Physical Units (EP/kg, in EP (kg, m^3, etc) EP/m^3, etc)

The Ecofactors (Ecological Impact Factors), which are the key elements of this formula, are expressed as EP (Ecopoint)/kg or EP/m^3, and work as weighting factors to indicate the degree of damage to the environment, which normally consists of various kinds of environmental impact, e.g. emissions to the air, the sea, consumption of rare natural resources and energy, pollution of soil [9].

Table 8.6.1 Ecofactors for some GHG

Sub-stance	F* target, Gg CO2 equivalent	F* actual, Gg CO2 equivalent	GWP** (Global warming potential)	Ecofactor, EP/ kg
CO2	2499718.59	1615116.82	1	0.26
CH4	575546.54	486151.85	23	33.76
NO2	226781.23	111051.93	296	639.15
SF6	217.65	577.09	22200	270445139

*All flows are taken from UNFCCC statistic data

**GWP is taken according IPCC (2001)

4 Method Perspectives in Russia

In 2010, Russia ranked the third in the speed of industrial production growth among the G8 countries. Leading production companies play a key role for innovative changes that lead to an entirely new level of development of the whole country.

For many Russian manufacturing companies it is clear that sustainable development of the company combines economic, social and environmental factors. Sustainability leads to lower business risks, improves competitiveness, increases the efficiency of staff and customer loyalty, enhances the reputation of company, creates a positive contribution to the business community in economic and social development of areas where it operates. Thereby, creating favourable conditions for implementing long-term business development strategies is the basis of balancing stakeholder interests.

It is important that among Russian businessmen there is a trend to understand that environmental responsibility is important element of the corporate system non-financial risk management. Environmental responsibility improves efficiency and enhances competitiveness [10].

Companies have to solve many problems associated with the environmental consequences of their activities. Investment programs of technical modernization, as well as environmental programs are in the plans of all major companies. Information contained in the companies reports is amenable for comparison, primarily on a qualitative level. The description of the major programs can generate ideas about the priorities and content of the activities that companies consider significant and relevant to environmental responsibility. Regarding quantitative indicators, comparison opportunities are quite limited. The problem of the comparability of data can be solved by applying the universal set of baseline indicators in practice [10].

EcoScarcity has high potential for application as flexible tools for environmental control of business companies. It is important to notice, that EcoScarcity method is not only tool for technical improvement of the environment, but also a mean for overall management control [9].

EcoScarcity is a policy-oriented method. As a result, the priorities which are set by government will automatically be the priorities of each company with adopts the method for its environmental management because if a national target figure of environmental impact of government becomes stricter, the corresponding eco-factor will calculated lager. In turn, it will bring greater amount of eco points (EP) for the environmental impact. In such a case, a reasonable decision of management would be to focus on this particular environmental impact [11].

5 Conclusion

Application of ecological scarcity method in Russia could help to set priorities for environmental improvements. For Russian companies it can be new, useful tool in order to realize environmental management.

Wide spread of the method will help to:

- Evaluate the modern ecological situation according to the international standards;
- Promote the exchange of information on common environmental concerns;
- Set the priorities and targets;
- Strengthen co-operation on environmental matters;
- Collaborate in analysis of common concerns, to share information, to raise public awareness;
- Avoid some environmental problems caused by economical growth in the future.

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8.7 Enhancing Traditional Integrated Product Development Processes with PSS Practices for Sustainability

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Abstract

Product service systems can be presented as a viable alternative for the development of products and services by creating value added solutions to the consumer and providing lowest environmental impact for manufacturers. Despite the existence of PSS practices related to product servitization, the addition of services within product development doesn't necessarily lead to the mitigation of environmental impacts. Therefore, there isn't evidence of works regarding the systematization and integration of these practices into the product development process. The present paper presents a proposal for the integration of PSS practices into an existing New Product Development (NPD) reference model aiming at better environmental performance.

Keywords:

New product development, Product service system, Sustainability

1 Introduction

Increasing pressure, attention and effort allocated to sustainable development has recently driven companies to focus on a more harmonic balance among environmental protection, as well as economical and social development. In particular, producers are expected to exercise corporate social responsibility to promote sustainable development and achieve the planned revenues. In addition, legislation is also an important driver to motivate companies to consider the environment aspects throughout its life cycle.

McAloone and Andreasen [1] suggest that it is necessary to move the focus from design and development of a simple artifact, to the development of an entire system, where the traditional producer-consumer relationship is rearranged in order to deliver environmental and economical benefits to the stakeholders, involving changes in products property rights. According to Yang et al. [2], as well as Webster and Mitra [3], companies must be responsible for managing the product lifecycle, regardless of the business model deployment, whether it is based on product-service systems or not. Thus, in this case it is advantageous to ensure the use of the functions within the product and introduce incentive systems to expand the product's durability, adaptation, reuse and renewal. Williams [4] and Baines et al. [5] state that the main benefits of PSS are:

1. The possibility to provide strategic market opportunities for traditional producers, improving the total value offered to consumers by increasing services elements.
2. The environmental consciousness towards sustainability. Companies become more responsible for their products, and in this sense, develop services activities regarding product return, recycling and renewal (reducing waste through the life of the product). Another activity carried out by manufacturing companies is to design products that are easier and cheaper to dismantle, recycle and renew. Design strategies such as modularity and product upgrades can become important issues during the process of product development.
3. Delivery of the same or an improved product with increased value in use through less energy and/or material consumption, providing reduction in costs and in environmental impacts. The replacement of raw materials by recovered components, without affecting product performance, can promote positive environmental responsibility image and facilitate product monitoring and discontinuance.

Despite the citation of a considerable number of PSS practices (methods and tools) in the literature, there is no systematization and integration of these practices into an New Product Development (NPD) model. This fact can contribute to increase barriers associated to PSS development, described by Mont [6] such as: (1) lack of knowledge about PSS concept; (2) unclear presentation of opportunities for reducing environmental impacts and obtaining economic gains; and (3) required organizational changes to leverage the deployment of a PSS model.

In addition, to successfully implement PSS, it is necessary to deploy tools and techniques that potentially use all available information related to the product development process for the purpose of implementation or improvement of existing practices. Therefore, this work aims to collect PSS practices and integrate them into a reference model for product development processes, ultimately envisioning product-service systems that are significantly more competitive and sustainable.

Regarding the structure of the present work, the 'Introduction' section described the context of this paper. Section 'Product Service System (PSS) Concept' presents the most relevant PSS concepts available in the recent literature and their classification. This is followed by section Methodological Approach, which explains methodology aspects used to develop this work. Section 'Reference Model' presents the NPD reference model to be considered in the PSS practices

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integration. The next section lists the methods and tools related to PSS and NPD, which have been collected during the systematic literature review.

2 Product Service System Concepts

Product service systems achieve differentiation through the integration of products and services, providing use value to the customer. In other words: what can PSS deliver that simply product development cannot? From a consumer's perspective, it can deliver new usage patterns, lifestyle, selling process and flexibility. From a company's standpoint, it can close contact with end users, accomplish new markets, higher market shares and redefine key activities. And from the society's perspective, it can raise the possibility of sustainable growth. PSS is based on the assumption that product optimization can significantly reduce the environmental impact by means of effective appropriation of a product during its consumption stage. That is because products are certainly more efficient if better maintained, repaired and controlled.

Despite of that, Tukker [7] mentions that the simple application of any PSS category may not present either significant or automatic results towards sustainability, because it is not clear whether there will be mitigation of environmental impacts or not. It should be implemented after extensive analysis, case by case, because PSS is often applied viewing improvement of the business itself, without having the objective of environmental improvement. Tukker [7] also suggests that PSS has a great potential for the sustainable integration of requirements, which may be included in all phases of the project. The most popular classification of PSS found in the literature presents three different PSS categories, as described in the following sub-sections.

2.1 PSS1: Product-Oriented Service

In this category, there is no change in the process of product selling. Basically the difference is related to the addition of some after-sales services in order to ensure functionality and durability.

According to Webster and Mitra [3], maintenance contracts, extended warranties and provision of spare parts may change the product concept, and can potentially extend the life of the product. Baines et al. [5] state that companies which encompass the responsibility for after-sales services and product end-of-life are motivated to introduce PSS upon their NPD in order to minimize use extended costs and consider smooth operation in regards to the end of product life cycle.

According to [2], if a producer considers PSS during NPD, the producer might win twice, because will design a lower manufacturing energy consumption product aiming ease of maintenance, reuse or recycling, thus it will spend less time and resources with after-sales activities.

2.2 PSS2: Use-Oriented Service

This PSS category is characterized by the use of a product that is not owned by the customer. According to Baines et al. [5], the element of negotiation is the product use or product accessibility. Since the producer or a third party company is the product owner, it is motivated to create a PSS. Tukker [7] states that PSS2 targets at maximizing the product use to meet demand. In this case, NPD must bring either product's life and service provision considerations.

In this model, a company is responsible not only to provide the product itself for customer use, but also to develop product features for achieving the desired results. The customer obtains utility (use of functions) but does not own the product itself; he pays only for the time the product is used. Depending on the contract, this time can vary from one use or a period when the product can be used several times (in parallel or sequentially).

Morelli [8] states that PSS1 and PSS2 often contribute to mitigate environmental burdens by means of more careful use of the product as well as increasing productivity of resources. Zhao [9] mentions that the economic use of vehicles is a good example of use-oriented service with ecological benefits, since there are reduced emissions and lower fuel consumption. With respect to product-oriented services, preventive maintenance and adjustments are strong collaborators for the closed chain manufacturing. Services are therefore great enablers of sustainability.

2.3 PSS3: Result-Oriented Service

This is the most sophisticated of the three models. In this category, a physical product is replaced by a so-called "solution". Examples include the provision of thermal comfort, refrigeration, cleaning, among others. The producer or service provider offers a personalized service or a mix of products, where the final customer owns no items. According to Baines et al. [5] the consumer pays only for results, with no further involvement with any physical product. The producer or service provider presents the customer some instructions and suggestions for a more efficient use of the product. Since the customer pays for the results, he has no responsibility for eventual problems and costs related to the product acquisition, use, maintenance and end-of-life (EOL).

The advantages of this type of PSS include minimization of energy, materials consumption and optimized product use. Service payment is based on service quality, but not on the resources consumption. Surely, companies that utilize such approach aim at more economical and efficient product use.

All categories and subcategories of product-service systems can meet the needs of consumers through a mix of products and services. Any loss of product features may require consumers overcome cultural change for acceptance of new paradigms; On the other hand, PSS3 has proven to be well accepted and therefore represents the most popular interpretation of the characteristics of PSS.

3 Methodological Approach

A systematic literature review was made to collect and interpret available data on PSS. This review was guided by a main question: what are the existing methods and tools for the development of new product-service systems? The key words or expressions were PSS, NPD and Sustainability. The database for data collection was Emerald, Elsevier, Science Direct, Google academic and CSA Illumina.

About 240 articles have being pre-selected by their title. Initially all *Abstracts* were read to be able to select the article as per a established criteria, taking as premise the three PSS categories—PSS1, PSS2 and PSS3. Even though there were abstracts that presented some relevance about PSS, some of the corresponding articles did not present acknowledged results. In such cases these sources were removed from the previous selection.

The second question of the analysis was: how is it possible to systemize the PSS practices and apply to a PDP reference model for a sustainable PSS development? An analysis was made of the possibility of applying PSS practices in a NPD reference model, and a proposal was drawn up to integrate the two concepts, PSS and NPD, in order to achieve environmental sustainability.

4 NPD Reference Model

According to Rozenfeld [10], an NPD reference model contains a collection of best practices related to product development and process management. A general view of their proposed reference model is divided into macro-phases and phases.

Phase Product Strategic Planning includes product portfolio management in accordance to the business strategic plan, taking market and technological innovations into consideration. In phase Project Planning, the project scope, resources, duration and costs are defined.

In phase Informational Design, product requirements are quantified in measurable variables with target values. The requirements defined during product strategic planning are further detailed in the informational design for a specific product. Product functions (physical, quality, interface, etc.), technological solutions and product architecture are established in phase Conceptual Design in order to meet product requirements.

Calculations, simulations, product modeling, drafting, bill of materials, process plans, failure analysis, prototypes, evaluations and tests are carried out in phase Detailed Design, as well as the specification of all manufacturing resources. In phase Production Preparation, new production machinery, defined in the previous phase, is installed, tested and a pilot production is run to certify the production facilities and products being manufactured with the definitive resources. Phase Product Launching takes place in parallel to Production Preparation. In traditional NPD reference models, other business processes are mapped in this phase, such as technical assistance and customer service.

Even though the project team is disbanded, product life cycle management continues, since efforts must now focus on monitoring the product and manufacturing processes. Continuous customer support and engineering change management (ECM) must be provided to eliminate failures or improve product performance. At the end of the life cycle of a product, the product is discontinued and could be reused, remanufactured, recycled, disposed according to the EOL plan, which is normally developed during macro-phase Development.

This brief description of the process provides only an overall functional vision of NPD, since only the main activities have been mentioned. Other complementary visions have not been addressed here.

5 Integration of PSS Practices into an NDP Reference Model

Even though PSS can be defined as one of most relevant ideas for placing the environmental discourse in evidence, practical implementation of PSS still needs to overcome several barriers. The proposal of innovative scenarios, such as serviced-based product development, is still treated with caution by companies, society and professionals in product development. Thus, the integration of PSS (as one of the tools of design for sustainability) to the NPD reference model provides a greater coordination among the production processes and sustainability in its various ramifications.

According to Baines et al. [5] and Morelli [8], for a PSS approach to succeed, early involvement with consumers is imperative. Besides, some changes in the organizational structures of producers as well as suppliers may be required. On the other hand, it is recommended to run some tools to assess differences between what the market needs, what the service provider can offer and what competitors are offering. It is suggested to use techniques and formal methods for ideas generation.

For example, the application of a practice named Requirement Information Cell (RIC) as proposed by Feng et al. [11], requires that the concept of a new product be developed through customers/suppliers/third partners' involvement. It is characterized by the intensive use of internet-based tools, such as Twitter and Facebook. This is an example of open innovation, which uses purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively. It assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as they look forward to develop new technologies.

Melo, Neto and Turrioni [12] state that, regardless of whether market requirements are tangible or not, all non-technical statements that express the needs or client expectations must be translated into design patterns. Quality Function Deployment (QFD), also know as House of Quality, enables all market requisites to be mapped into product/service functions.

Regarding a strategy that focuses on designing and selling an interconnected system of products and services, creating new product-service offerings, some authors (e.g. Baines et al. [5], Kang [13], Yang et al. [14]) present MEPSS (Methodology for Product Service Systems), which is as a method that can facilitate the product design process by means of visualization, analysis and stakeholder management. In addition, Silva et al. [15] conducted a comparative study between MEPSS and product development NPD reference model.

The PSS practices can be combined and applied in different phases of an NPD model. Table 8.7.1 presents a brief view on the most important practices identified, the ones that could be easily combined into existent activities within a NPD reference model. Some practices identified as PSS precursors were identified as practices already integrated into the NPD reference model.

For brevity reasons, in the present article two groups of PSS practices were omitted: those already combined within NPD practices and activities, and those that would demand deeper adjustments in an NDP reference model. Nevertheless, only a comprehensive validation of the enhanced reference model (integrated with PSS practices) would prove it right.

6 Discussion

A collection of PSS practices, to be integrated into an NPD reference model, aims at more competitiveness and sustainable product development, as well as related services. Several PSS related methods and tools that might influence changes regarding product portfolio, product functional modeling, development of product alternative solutions, product concept selection, definition of suppliers and co-development partnerships, system and subsystem design, risks analysis and phase approval mechanisms.

Macro-phases Pre-Development and Development are clearly the most affected ones. Therefore, most PSS practices should be integrated in phases Product Strategic Planning, Informational Design, Conceptual Design and Detailed Design, either by being applied during existing NPD process activities or, in some cases, by being integrated to activities yet to be proposed. Phase Conceptual Design is clearly the most affected one by PSS practices.

The integration of PSS practices related to risk analysis into phase Project Planning would only be supported by adding new activities into an NPD reference.

Some PSS practices related to document management (Product Data and Knowledge Management), decision-making activities (Decision Support System) and approval/definition discussion (Life Cycle Oriented PSS Design Model) might be integrated in most phases.

The Design Orienting Sustainability Toolkit (SDO) is an application of sustainability indexes within the processes of product ideation, creation and design detailing. In this sense, it is suggested to integrate SDO in phases Product Strategic Planning, Conceptual Design and Detailed Design.

The main limitation of this research is related to the fact that the full implementation of any PSS practice and corresponding results was not identified in the existing literature. Therefore, it was not possible to identify the best sustainable practices that might have improved environmental performance. In order to control PSS sustainable performance, the development of a monitoring tool should be considered in future research works.

Another suggestion is the classification of PSS practices according to PSS categories (or modes). If implemented, depending on the service strategy (product-oriented, use-oriented or result-oriented service) to be adopted, it would be possible to focus on mode-specific methods and tools throughout an NPD reference model.

Table 8.7.1 Practices to be integrated into existing activities within an NPD reference model as proposed by Rozenfeld et al. [10]

Method or tool	Description, purpose and justification	NPD phase	Suggested NPD activity to benefit from method or tool use
Life cycle oriented PSS design model [14]	This practice implies the use of software to run scenarios and use cases, aiming at lower environment impact throughout a product life cycle. This practice should be applied for change evaluation and phase approval. As a result, decision-making activities may take sustainability into consideration.	1. Product strategic planning	1.6 Propose product portfolio changes
			1.7 Verify product portfolio feasibility
		2. Project planning	2.8 Evaluate risks
		3. Informational design	3.9 Approve phase
		4. Conceptual design	4.8 Define suppliers and co-development partnerships
			4.14 Approve phase
		5. Detailed design	5.16 Approve phase
		6. Production preparation	6.13 Approve phase—release production
		7. Product launch	7.12 Approve phase
Kano Model [16], [17]	The Kano model is proposed to classify customer demand attributes. This information may be used to justify product portfolio changes.	1. Product strategic planning	1.6 Propose product portfolio changes
CLD—Causal Loop Diagram [18], SFD—Stock and Flow Diagram [18]	Causal loop diagram is a diagram shows how interrelated variables affect each other. This practice can be used in activities that provide function modeling and SSC definition. It may be used to identify possible "rebound effects".	4. Conceptual design	4.2 Model product functions
			4.4 Develop product alternative solution
			4.5 Define product architecture
			4.6 Analyze Systems, Subsystems and Components (SSC)
PDKM—Product Data and Knowledge Management [19]	PDKM is a data repository used to systematically integrate, manage and consolidate detailed data from all life cycle phases, creating knowledge out of information. The use of this practice may support the documentation of decisions and lessons learned. In the long term, the use of this repository enables the development of improved products. For example, all data related to product life cycle can support the development of a more sustainable system.	1. Product strategic planning	1.5 Analyze enterprise product portfolio
		3. Informational design	3.4 Identify customer/consumer requirements
		4. Conceptual design	4.15 Document decisions taken and register key learnings
		5. Detailed design	5.17 Document decisions taken and register key learnings
		6. Production preparation	6.14 Document decisions taken and register key learnings
		7. Product launch	7.13 Document decisions taken and register key learnings

DSS—Decision Support System software [19]	This practice uses simulation techniques for improving decision-making. For example, if sustainability indexes are to be used as product requirements, simulations can be run to help decide for concepts related to lower environment impact.	1. Product strategic planning	1.6 Propose changes in product portfolio
		4. Conceptual design	4.8 Define suppliers and co-development partnership
		5. Detailed design	5.3 Define make or buy SSC
		5. Detailed design	5.15 Evaluate phase
		6. Production prep.	6.12 Evaluate phase
		7. Product launch	7.11 Evaluate phase
GUI—Graphic User Interface [20]	GUI facilitates collaborative design procedures, considering customer involvement in the co-creation of value (open innovation).	4. Conceptual design	4.2 Model product functions
Storyboarding [12]	Storyboards are graphic organizers such as a series of illustrations/images displayed in sequence for the purpose of pre-visualizing a motion picture/graphic, animation or interactive media sequence.	4. Conceptual design	4.2 Model product functions
			4.4 Develop product alternative solution
			4.9 Select product concept
IDEF0—Integration Definition for Function Modeling [12]	Refers to a family of modeling languages in the field of systems and software engineering. They cover a wide range of uses, from functional modeling to data, simulation, object-oriented analysis/design and knowledge acquisition.	4. Conceptual Design	4.2 Model product functions
Sustainability Design-Orienting (SDO) Toolkit [21]	SDO is used to orient the design process towards sustainable PSS solutions, setting sustainability priorities, using sustainable design orienting guidelines and checking and visualizing the improvements in relation to existing reference systems and their sustainability priorities.	1. Product Strategic Planning	1.5 Analyze enterprise product portfolio
			1.6 Propose changes in product portfolio
		4. Conceptual Design	4.2 Model product functionally
		5. Detailed Design	5.2 Create and detail SSCs, documentation and configuration
Regression analysis [22]	Techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables.	4. Conceptual Design	4.2 Model product functionally
			4.4 Develop product alternative solution
			4.5 Define product architecture
			4.6 Analyze SSC
		5. Detailed Design	5.2 Create and detail SSCs, documentation and configuration

7 Final Remarks

PSS can create new market opportunities and is therefore characterized as a potential competitive advantage. However, it is a fact that there are still many barriers for fully implementing PSS. As a result of the literature review, it was possible to verify the reasons for the lack of enthusiasm in the world of business with respect to PSS.

On the other hand, once PSS is deployed, the benefits are evident when compared to the traditional manufacturing, as a result of transferred daily investment, smaller stocks (being able to even vanish in a fully functional market). Long-term customer loyalty planning can be developed, as well as optimized resources allocation.

The present research has identified that it is possible to integrate PSS practices into Pre-Development and Development macro phases of an NPD process model. In this sense it might be possible to develop new products that already consider a rearranged producer-consumer relationship in order to deliver environmental and economical benefits to shareholders and stakeholders. The integration of most PSS practices can be carried out considering existing NPD activities.

Concerning the integration of sustainability within PSS, a new business model that combines product and services development may guide companies to be profitable, yet reducing materials consumption without affecting consumer demand and desires, by delivering an efficient and effective combination of existing products with services and knowledge. In addition, the increasing use of non-material elements supported by PSS may lead this approach to be more sustainable than the conventional product selling paradigm.

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Chapter 9:

Economics for Sustainable Development

9.1 Evaluation of the Institutional Environment's Influence on Innovative Output of Enterprises in the National Economy

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Abstract

The aim of this article is to study how institutional environment encourages or impedes innovative activity of enterprises and other subjects of the National Innovation System (NSI). NSI is defined as a system of interconnected elements such as state policy, knowledge infrastructure and institutional environment. Institutional environment is divided into eight domains (institutions managing markets and competition, legal institutions, institutions of higher education and research system, etc); expert evaluations of the institutions' quality for 37 OECD member countries and candidates (including Russia) are correlated with the innovation output of these countries; with the help of factor analysis the weight of every institutional domain is defined. Strengths and weaknesses of institutional environment of Russia's NSI are discussed; recommendations aimed at the improvement of its quality and therefore increasing the innovation output of enterprises are developed for every domain of institutions.

Keywords:

Innovation output, Institutional environment, National innovation system

1 Introduction

In public discussions of politicians and economists, in the official documents issued in Russia in recent years it is emphasized that all state and private institutes have to make an effort and "transfer the country in the direction of modernization" [1]. In general among the politicians, in business sector and in the academic environment there is a clear understanding in society that it is modernization and innovative development leading to the improvement of the country competitiveness. In order to generate and successfully commercialize innovations it is important to have an efficient National System of Innovation (NSI) consisting of such elements as state policy, knowledge infrastructure and also institutional environment [2, 3]. At the moment in Russian Federation many legislative acts are being developed, new elements of NSI are being created, financial mechanisms are being modified. However, there is no systemic approach which would help to connect the separated elements of the NSI and help them to perform their functions. Therefore it is very important to research into the institutional environment (IE) of Russia's NSI, reveal the most important institutional domains that influence the IE effectiveness, develop recommendations which would increase the output of NSI as a whole. In our research we are drawing on the theory of NSI and institutional theory.

2 Institutional Environment of the Innovation System

2.1 Overview of the Theories Researching into Institutions and Innovative activity

Institutional environment (IE) of NSI is defined as a stable system of economic, legal, social and organizational conditions which provide efficient functioning of NSI. Let us consider three scientific schools investigating interrelations between institutional model and innovative activities in the country.

Political science research on industrial policy and competitiveness began approximately in the 1970s when competitiveness of the national economy was first linked with governmental policy, especially industrial policy. One of the most important statements was that institutional framework in the country determines the type of political instruments to be used by the government for managing the economy.

In 1970–1980s success could still be determined by state policies, for example, in heavy industries, but starting from the late 1980s innovation systems became more complex, especially in high-tech industries; interdependencies between larger and smaller companies grew up, importance of interactions between business and science increased [4]. The economy became more decentralized. Therefore many countries started to develop complex technological infrastructures aiming at subsidizing innovative activities and direct the flow of the new technologies into the market without trying to control it.

Sociological institutionalism focuses on studying the influence of the institutional frameworks on companies while the role of the state is considered to be pro-active, more as developing institutional frameworks and legal acts. A remarkable research was conducted by Streeck [5] where it is discussed how institutional frameworks affect organizations. For example, it was revealed that limitations put on employers in Germany (such as strict hiring and firing procedures) encourage them to consider personnel as the main asset of the organization and therefore motivates them to invest into human resources; this follows in the development of "para-public" institutions such as qualification improvement system.

The varieties of capitalism tradition unites sociological and neo-institutional approaches, develops deeper understanding of interconnections between strategies of enterprises and institutional environment of the country [6, 7]. Hall and Soskice propose that different innovative strategies require different forms of coordination. Liberal market economies (LME) such as the USA and the Great Britain have institutions

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which encourage radical innovations while institutions in the coordinated market economies (CME—Germany, Japan) encourage incremental innovations. For example, in LME companies are managed by the Boards of Directors consisting of owners, shareholders, their representatives; venture capital market is developed, financing is mostly short-term; successful companies are able to attract further investment by issuing additional shares. Labor markets are flexible, short-term contracts (projects) with high remuneration prevail. High-qualified personnel is very dynamic; there are pools of researchers and engineers to be hired very quickly into the project if needed. Amable in his research proved that all these features lead LME countries to producing more radical innovations.

In CME countries, the other way around, companies are monitored by banks and insurance companies via supervisory boards; loans are mostly long-term and are aimed at investing into assets. Capital for risky projects is limited; therefore companies have to use retained earnings for them which does not allow them to provide quick investment into new technologies. As a result companies in CME mainly avoid radical innovative strategies, which is proven by empirical data [8].

No matter how different the research approaches discussed above are, in all of them the distinctive groups of institutions are usually in the focus of attention: labor contracts, corporate governance in companies, financial system.

2.2 Composing the Integral Factor Characterizing the Quality of Institutional Environment

We suggest increasing the number of institutional domains and looking at the institutional environment as a composition of eight groups of institutions: (a) institutions regulating markets and competition; (b) financial institutions; (c) labor market institutions; (d) legal institutions; (e) institutions in education and research; (f) informal institutions; (g) taxation institutions; (h) institutions of knowledge transfer.

Table 9.1.1 represents 8 groups of indicators describing every institutional domain (6 indicators per domain). The scale is 0–7 (if not, other scales are given in brackets). In the first column there are the names of the indicators. In the second column there are the weights of every indicator defined with vest of factor analysis. In the last 2 columns there are indicator values for the IE of Germany and Russia. Altogether the sample was composed of 37 countries (OECD countries and OECD candidates).

Table 9.1.1 Indicators showing the quality of institutional environment

Name of an indicator	*f*	Indicators' values q^*_{ij}		Name of an indicator	*f*	Indicators' values q^*_{ij}	
		Rus	Ger			Rus	Ger
1. Institutions regulating markets and competition, W1 = 0.148				**5. Institutions of education and research, W5 = 0.074**			
1.1. Control of prices	0.13	1	4.75	5.1. Quality of research institutions	0.20	3.9	5.9
1.2. State control of business	0.12	1.81	3.77	5.2. Quality of engineering education	0.19	4.4	4.7
1.3. Barriers for investment and trade	0.13	3.5	1.27	5.3. Quality of management schools	0.18	3.8	4.9
1.4. Efficiency of anti-monopoly policies	0.21	3.4	5.5	5.4.Index of Human Potential Development (0–1)	0.21	0.7	0.9
1.5. Barriers for private business	0.20	3	5.75	5.5. Availability of scientists	0.02	4.3	4.8
1.6. Index of doing business	0.21	0.21	0.33	5.6. Quality of education system	0.24	5	3.6
2.Financial institutions W2 = 0.076				**6.Informal institutions, W6 = 0.170**			
2.1. Investor protection (0–10)	0.11	5	5	6.1. Irregular payments and bribes (7–no bribes)	0.18	3.2	5.9
2.2. Availability of venture capital	0.31	2.3	2.8	6.2. Trust to politicians	0.15	2.9	4
2.3. Availability of loans	0.26	2.3	2.8	6.3. Corruption perception (10-neg.)	0.18	2.1	7.9
2.4. Soundness of banks	0.08	3.8	4.4	6.4. Innovation culture	0.15	4.2	5.7
2.5.Availability of financial services	0.24	3.8	6.1	6.5. Business ethics	0.17	3.3	6.0
2.6.Financing though local equity market	0.15	2.7	3.9	6.6. Favoritism in decisions of government officials	0.16	2.6	46
3. Labor market institutions, W3 = 0.087				**7. Taxation institutions, W7 = 0.102**			
3.1. «Brain drain» (7–no drain)	0.34	3.1	4.5	7.1. Total tax rate (%)	0.19	48.3	44.9
3.2. Flexibility of wage determination	0.06	5.0	2.9	7.2. Extent and effect of taxation	0.16	3.2	3.3
3.3. Hiring and firing practices	0.18	3.9	2.7	7.3. Custom tariffs (%)	0.18	11.6	0.9
3.4. Redundancy costs (paid weeks)	0.19	17	69	7.4. Auditing and reporting standards	0.17	3.8	5.6
3.5. Trust to management	0.39	3.9	5.7	7.5. Licenses and permits (6–good)	-0.06	4	2
3.6. Cooperation and labor-employer relations	0.34	3.8	53	7.6. Tariffs (6–low)	0.27	3	5
4. Legal institutions, W4 = 0.175				**8. Institutions of knowledge distribution, W8 = 0.167**			
4.1. Independence of courts	0.17	2.3	6.4	8.1. University-industry collaboration in R&D	0.21	3.7	5.2
4.2.Legal and political environment (0–10)	0.18	3.3	8.3	8.2. State of cluster development	0.14	3.9	4.5
4.3. Private property protection (0–10)	0.16	5.0	7.1	8.3. FDI and knowledge transfer	0.02	3.2	5.0
4.4. Intellectual property protection (0–10)	0.18	4.6	8.2	8.4. Absorptive capacity of enterprises	0.21	4	6
4.5. Index of Patent Rights (0–5)	0.16	3.52	4.5	8.5.Teaching personnel in firms	0.22	3.7	5.2
4.6. Risk of expropriation (5—no risk)	0.16	1.48	3.9	8.6. Availability of new technologies	0.20	4.2	6.3

Let us define the following characteristics for every institutional domain: *wi*—the weight of every domain in the overall NSI's institutional environment quality; for every indicator in a domain *qij* there is a weight coefficient *fij* (1≤i≤8; 1≤j≤6). All indicators q^*_{ij} are normalized before calculations.

Then the factor of institutional development (*IFIEi*) for every domain is calculated as follows:

$$IFIE_i = \sum_{j=1}^{6} q^*_{ij} f_{ij}.$$

Integral factor of the IE quality (*IFIE*) looks as follows:

$$IFIE = \sum_{i=1}^{8} w_i \sum_{j=1}^{6} q^*_{ij} f_{ij}.$$

Table 9.1.2 represents the selected results of *IFIE* calculations and also the indicators of Innovation Output [10] including such components as the number of patents, the export volume of high-tech products etc. for every country.

Table 9.1.2 Integral factor of the institutional environment quality and innovation output

Country	IFIE	Innovation Output	Average IFIE for a cluster
Cluster 1	Developed countries (IFIE >0.72)		
Germany Canada Finland	0.768 0.799 0.817	0.509 0.504 0.557	Average IFIE = 0.769
Cluster 2	Catching up countries (0.54<IFIE<0.72)		
Slovenia China Estonia	0.631 0.546 0.686	0.438 0.329 0.401	Average IFIE=0.610
Cluster 3	Countries lagging behind (IFIE <0.53)		
Russia Poland Mexico	0.481 0.575 0.507	0.371 0.367 0.344	Average IFIE=0.544

IFIE is regressed against the Innovative Output (IO). The regression model appeared: *IO=0.679·IFIE–0.028.* Correlation coefficient is: *R* = 0.802, strong correlation. Quality of the model and significance of correlation coefficient are proven. Average values of *IFIE* for the three clusters of the countries under consideration can be used to work out the criteria of defining the quality of a certain institution in the NSI's institutional environment.

The analysis showed that there is a strong positive correlation between IFIE and the IO; when the quality of the IE grows, the IO of the NSI increases (Fig. 9.1.1).

The most influential institutions which define the innovative activity are: informal, legal institutions and institutions of knowledge transfer.

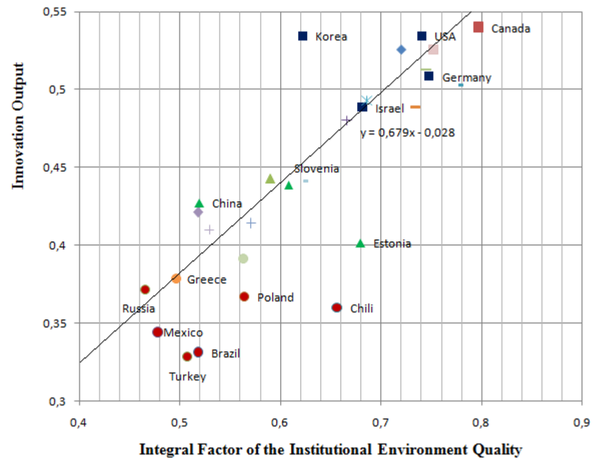

Fig. 9.1.1 Innovation output and integral factor of the IE quality: clusters of the countries and regression line

An interesting observation is that there is almost no correlation between IO and such indicators as flexibility of wage determination and the size of redundancy payment. However, trust to professional management and cooperation between employers and employees has a significant effect on innovative activity (correlation coefficients are correspondingly 0.82 and 0.71). The number of scientists and engineers do not correlate with the IO while quality of engineering education and scientific institutions are strongly correlated with the IO.

Table 9.1.3 shows the hierarchy of institutional domains and institutions according to their correlation to the IO.

Russia holds the last place in IE quality. Certain indicators will be analyzed in p.2.3.

Further the correlations between *IFIE* and such indicators as *GDP* per capita, royalties received by the considered countries, etc are calculated. A strong correlation is revealed between *IFIE* and *GDP* (*R=0.753*). Linear regression line is confirmed between these indicators: *GDP=89330 IFIE–38749.6.* Correlation coefficient between Royalty and *IFIE*: *R*=0.697, regression line: *Royalty=821.93·IFIE–433.07.* Quality of regression lines and significance of correlation coefficients are confirmed.

2.3 Factors Indicating the Quality of the Institutional Environment of Russia's NSI

IFIE for Russia is 0.481 which is the lowest among the 37 countries considered in the analysis. Speaking about institutional domains, institutions regulating competition and markets turned out to be the lowest in quality (0.38 out of 1), then come legal and informal institutions (0.415 each domain). The highest grade was given to institutions of higher education and science (0.591), but anyway it is lower than the average one for the cluster of catching up countries (for example, for China it equals to 0.62).

Table 9.1.3 Hierarchy of institutions according to the influence on the innovation output

Most powerful institutions	Institutional domain	Correlation of institutions with IO	Correlation of the domain with IO
Legal and political environment, intellectual property protection	4. Legal institutions	0.75–0.84	0.864
Corruption perception	6. Informal institutions	0.69–0.83	0.840
Teaching personnel, adsorptive capacity	8. Institutions of knowledge transfer	0.53–0.81	0.825
Anti-monopoly policy, conditions of doing business	1. Institutions of market and competition	0.41–0.70	0.733
Reporting standards, tariffs	7. Taxation institutions	0.38–0.56	0.510
Trust to management, cooperation in working relations	3. Labour market institutions	0.37–0.81	0.431
Availability of venture capital	2. Financial institutions	0.20–0.56	0.370
Quality of education system, human resources development	5. Institutions of education and science	0.64–0.85	0.367

Let us take a closer look at the institutions of intellectual property protection in Russia (the indicator is 0.38, one of the weakest marks). According to the Intellectual Property Rights Index (IPRI) in 2009 Russia took 88th place out of 125 countries having lost 25 positions comparing to 2006 (63th place).

According to the World Intellectual Property Organization (WIPO), in 2006 Russia produced 160 patent claims per 1 mln. people while in Japan this indicator was 2884 claims,

in the USA–645, in Germany–587 claims. By the end of 2004 in Russia 108721 patents were active while in the USA–1 633 355, in Japan–1 104 640, in Germany–411 671 [9]

The volume of the world intellectual property market increases by 12% per year; Russia has 0.3–0.5% of this market. During the last 10 years the number of intellectual property (IP) units in Russia has decreased 20 times. From all the patents issued in 1996 only one third is now active.

Scientific research organizations are of good quality but their efficiency is not comparable to those in the leading countries. In Russia these organizations have no real right for the results of the R&D financed from the state budget. Then, the IP market (which means production and consumption of IP) is not well developed. For example, in the USA IP is bought as the result of certain scientific activity. In Russia the situation is different: the State pays not for IP, but for the work of the specialists according to the preliminary estimate. As a result it turns out that the research is conducted, the results are published, but the efficiency of the investment is low because nothing is introduced into industry. According to Russian Real Estate Bureau (Rosimushchestvo) the value of IP in Russia (including private investments) equals to 5 bln.rub. (€125 mln); this amount includes the IP accumulated in Russia in Soviet times (3.5bln.rub–€89 mln). But annual expenditure on R&D in Russia is approximately 250 bln.rub. (€6.25 bln) [10].

According to Rospatent [11], from 100% of results of R&D financed by the State of Russia only 10% are patented, only 1–2% are participating in the IP market; by the end of 2008 the State of Russia had had the rights only for 386 IP objects. Therefore it can be stated that there is almost no legal turnover in the innovation market and most of the R&D results cannot be the object of market relations according to the article 129 of RF Civil Code.

3 Innovative Activity of Russian Industry

3.1 R&D in Production and Service Organizations

Statistical data on innovative enterprises in Russia varies depending on the source of information. In [12] the proportion of innovative enterprises in industry was estimated as 9.4% in 2007 (Fig. 9.1.2). According to the methodology officially accepted in Russia innovative enterprises are those which have produced and commercialized (or introduced into their own daily operations) innovations (i.e. new or significantly modified products, services or production technologies) in the last 3 years. Innovative products (those having undergone technological change during the recent years) compose now 10–12% of the production volume of innovative enterprises and around 5% of all production volume of industrial enterprises (innovative or not).

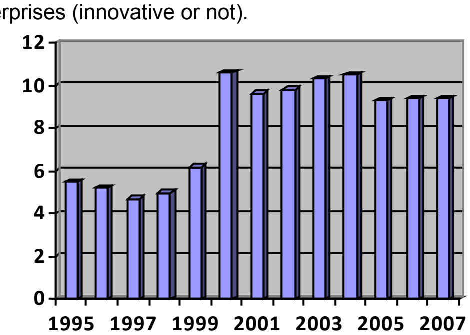

Fig. 9.1.2 The proportion of innovative enterprises in industry, 1995–2007

The proportion of innovative products in the volume of dispatched products was 4.2%, which is twice as low as it was in 2006 (8.4%). No matter which source is used, the general conclusion is that at present innovative activity in Russia remains quite low (just to compare: in Germany the proportion of innovative enterprises is 60–75% depending on the branch of industry).

Let us look carefully at the expenditures on innovation in industries (2007): 57% of money is spent on purchasing equipment to produce new products and on production planning. Expenditures on knowledge-intensive activities are more modest: expenditures on R&D of new products and technologies are approximately 17.3% of total expenditures on innovation. Only in such industries as oil and gas extraction, production of planes and spaceships, electronics expenditures on knowledge-intensive activities reach 40–50%. 2.2% is spent on acquiring new technologies, IT, training personnel, market research.

The leaders of Russian business such as Gazprom and Lukoil are very comparable in the economic potential with similar foreign companies. Within their structure there are scientific institutes performing large-scale modernization and technological upgrade projects. However, their input into scientific and innovative potential of the country cannot be compared with the ones of the world technological leaders: Microsoft, Ford Motor and Pfizer spent on R&D $7.7, $7.5 and $7.1 bln., correspondingly, Daimler and Siemens–$6.6 and $6.0 bln.). Gazprom and Lukoil in the same period of time spent on R&D about $100 and $25 mln., correspondingly. The core of high-tech companies determining scientific potential of the country had not yet been created in Russia and scientific research conducted in R&D laboratories of industrial enterprises does not have such high status as it does in other countries.

3.2 Reasons for Low Innovative Activity in Russia Production Enterprises

The reasons for low innovative activity are as follows:

1. Many Russian enterprises do not compete globally. For example in [3, 13] it is discussed that more than half of the industrial processing enterprises (metallurgic, chemical, light, forest, food) do not compete with foreign producers, which does not stimulate innovative activity. 20% of Russian enterprises do not compete with any enterprises as the degree of the market monopolization is quite high. Today 23 biggest enterprises produce 36% of sales in the country and employ 38% of personnel [14]. This criticism goes altogether with the market institutions quality and those of competition and taxation institutions (see Table 9.1.1, p.2.2): low efficiency of anti-monopoly law, high barriers for competition and trade as well as high custom tariffs make it difficult for foreign companies to enter the Russian market and compete there.
2. Among the reasons of low innovative activity businessmen list first of all weak innovation policy of the State as well as lack of support from the State, which goes in line with low estimates of financial institutions development (Table 9.1.1, institutional domain №2). 80% of enterprises do innovative activities at their own expense. In the structure of expenditures money from federal budget amounts to about 4%; it is mostly forwarded to the production of medical, and other high-tech products. Foreign investments constitute about 2% in the total amount of expenditures on innovation and go first of all into food and construction material production [15].
3. Lack of own financial resources; high interest rates in banks which make loans for small and medium-sized companies unreachable (inefficient financial institutions).
4. Low demand for innovative products caused by low standard of living hindering the process of innovation diffusion to the ultimate consumers–households.
5. Lack of qualified personnel (institutions of education and science as well as labor market have to be improved).
6. Underdeveloped venture capital market and the market of intellectual property (institutions of financing and legal institutions).
7. Lack of theoretical managerial knowledge among managers-owners, especially knowledge about project, time, risk, value-chain management, etc. Manager-owners often perform both enterprise management and planning functions.
8. Low level of innovation culture in the society (informal institutions).

4 Discussion

4.1 Recommendations on the Improvement of Russia's Institutional Environment

Selected recommendations on the improvement of Russia's institutional environment, which should encourage generation and commercialization of innovations by enterprises in the NSI, are grouped according to the institutional domains discussed earlier in p. 2.2.

Improving institutions regulating markets and competition

- Stimulating larger companies to do R&D, to purchase new technologies;
- Simplifying paperwork at customs, introducing easier rules for importing/exporting product samples in order to ease the work of innovative companies;
- Improving technical and environmental control in order to increase companies' motivation to develop and introduce innovations into their business processes; the system of standards and norms in production should be upgraded to the standards existing in developed countries;
- Creating legal incentives for using domestic energy-saving technologies; prohibiting the use of inefficient and harmful technologies; introducing benefits for enterprises which use modern and ecologically friendly technologies;
- Monitoring world achievements in science and technology; working out recommendations on how to apply them in Russian industry;
- Encouraging technology borrowing by means of regulating import of new equipment and buying licenses; encouraging direct foreign investment; stimulating outsourcing; interacting with foreign specialists, joint research, internships abroad;

Financial institutions

Developing venture capital market—creating a new legal entity for venture funds similar to limited partnerships existing abroad. At the moment there is no such organizational form and big world venture market players prefer to develop in off shores attracting there Russian companies [15].

Labor market institutions

- Increasing transparency of the country, making it easier for foreign specialists to come here, simplifying visa requirements;
- Working out the efficient program encouraging Russian researchers and scientists working abroad to come back to their home country;
- Increasing mobility of university professors by encouraging them to participate in business;
- Modifying the system of salary formation in universities by introducing additional benefits for professors doing research and building up connections with businesses;

Legal institutions

- Improving the Federal Law №217 allowing universities to create small enterprises by introducing more benefits to new-formed firms (taxation benefits, ability to use university facilities, etc); improving the mechanism of adding the rights to IP into the company's assets;
- Strengthening the IP protection and patent laws;

Institutions of education and science

- Working out programs on innovation management and entrepreneurship to be introduced into bachelor and master curricula, also for technical universities; providing seminars and trainings for mixed audience to help representatives of isolated groups (science, business, city administration) be in contact;
- Creating business incubators at universities; encouraging initiative from researchers, young specialists, students;

Informal institutions

- Disseminating success stories about innovative and entrepreneurial activities (examples from business life);
- Improving political institutions;
- Working on improving trust in the society including personal trust and trust to the governmental decisions;
- Struggling against corruption;

Taxation institutions

- Provide tax benefits for companies producing and exporting high-tech and science intensive products;
- Decreasing taxes on imported technologies and equipment;
- Introducing progressive taxation scale for physical persons; increasing taxes on luxury products;

Institutions of knowledge transfer.

- Creating a unified database on R&D performed in state research organizations in order to create unified information space;
- Creating a database of knowledge acquired in the past decades in order not to waste the knowledge accumulated but not yet commercialized;
- Perfecting the IP commercialization mechanisms: (a) formation of commercialization centers at universities, uniting them into a network; making them act as intermediaries between science and business; (b) creation of innovative solutions centers in the regions of the country; (c) development of consulting milieu for state and private companies similar to project management institutions in Germany; expertise and consulting should be independent and involve foreign specialists.

4.2 Conclusion

The aim of this article was to represent the results of the research on the composition of the institutional environment and reveal the most influential institutions which encourage innovative activities of enterprises in the National System of Innovation. For achieving this aim the following tasks were performed: various institutional theories were studied; main institutional domains important for doing innovation were elaborated with the help of empirical research of OECD countries. The integral factor characterizing the quality of institutional environment was formed. Drawing on the theoretical and empirical findings the list of recommendations on how to improve the institutional environment for innovations was composed. Further research may involve analyzing more statistical data and studying foreign experience of designing and putting into practice institutional mechanisms to serve as connectors between different actors of the National Innovation System—i.e. enterprises, research institutes, universities and governmental policies.

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9.2 National Innovation System in the Economic Cycle: Principles and Perspectives

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Abstract
The economic cycle considerably changes the strategy of innovative development companies. From the statistics we have considered the conclusion about significant reduction in innovative activity of enterprises in a recession and the uneven growth in terms of the rise: growth only occurs in industries that are in the process of technological expansion. To solve this problem the impact on businesses within the national innovation system is necessary. We have formulated the principles of the functioning of the NIS in the economic cycle and priorities of the innovation at various levels of the national economy, grounded innovativeness of education as a factor in ensuring the competitiveness of the Russian Federation. In goal setting it is necessary to appreciate trends in world technological development. We have made a forecast of the duration of long-term cycles, which shows that it is expected to increase the duration of these cycles and the transition from empirical to fundamental technologies in the future. On this basis we propose a system of NIS's priorities.

Keywords:
Economics for sustainability and development, Long-term technological cycle, National innovation system (NIS), Regional innovation system (RIS), Technological development

1 Innovative Strategies in the Goals and Objectives of the Formation and Development of National Innovation Systems

In a globalizing world economy the principal factor in creating and maintaining a high level of competitive advantage is the innovative activity of all economic actors. In general we can say about the complex of innovative growth factors: the creation of new products, new services, new technologies, organizational, informational and other innovations.

Globalization creates conditions of interdependence of the world economic community. The cyclical economic development brings about substantial changes in the strategy of innovative development of this community. Moreover, these changes in each country are different. They depend on the level of economic and technological development, availability of strategic resources, the regulatory system of the national economy as a separate country and as a member of various unions and associations. Finally, these changes are largely dependent on the level of human capacity, especially in science.

The national innovative system (NIS) of the country consists of three main components: the research and development sector (basic and applied sciences), the education sector (the system of high and postgraduate education), the business sector (corporations, integrated business groups, small, medium and large businesses). The linkage between these components that determines the national model of the NIS to Russia, is a very knotty problem at the federal and regional levels in consequence of the revolutionary transformation of the economic system in the 1990s. Now the national economy consists of many elements with conflicting interests and this conflict is particularly acute in the different phases of the economic cycle.

In a recession the main interest of the majority of economic actors is a survival only. So they operate on the principle of compensation costs, begin to produce goods with simplified functions and sell it at a discount. This behaviour can revive demand for their products.

Analysis of indicators of innovation activity of Russian enterprises showed the reduction of the share of organizations implementing technological innovations and the proportion of expenditure on technological innovation in the total value of output during a recession and the crisis of 1998 [5]. In the phase of recovery we can see some increase in these indices.

In the phase of recovery firms are trying to maximize profit, their investment activity primarily aimed at solving the problems of speculation in the stock markets. Innovations are not beneficial in this phase of the economic cycle.

In the period 2001–2004, at the phase of recovery of the Russian economy, few sectors showed a significant increase in the level of innovative activity [5]: mining, leather, wood products, non-metallic mineral products, electric, electronic and optical equipment. In other sectors the innovation activity decreased or changed slightly. The main type of innovation activities of industrial enterprises was the purchasing of machinery and equipment (63%). In 2004 the production design was carried out 35.5% of the firms, research and development—33%. It is below the 2001 level (39.7 and 35.6% accordingly) [5].

This statistics shows a significant reduction in innovative activity of enterprises in conditions of recession and the uneven growth in its recovery. Growth occurs mainly in the sectors are in the process of technological expansion. In other sectors, especially in preserving relict technological structures, the growth of innovative activity does not take place. It is necessary the impact on businesses within the national innovation system to solve this problem.

In our view, the strategic goal of the NIS is to create and maintain a constant high level of competitive advantage by continuously developing the knowledge, access to specific resources, taking into account the geopolitical, economic and geographic factors and features of the institutional environment, the strategic controlling in the creation and the dissemination of knowledge and technology. So, the strategy of innovative development is, on the one hand, an integral part of an overall strategy of national economy, and on the other hand, the backbone of the national and regional innovation systems.

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According to the theory of large systems we can decompose the strategic goal of the NIS. We can use such principles of decomposition:

- An area—strategies of development areas and regions are formulated as a part of a national strategy;
- A sector—the overall strategic goal is decomposed to the strategic goals of industrial, educational, infrastructural and market subsystems;
- A field of science.

Theoretical works on the problems of formation and functioning of NIS don't pay attention to the factor of cyclic recurrence. National studies don't contain the analysis of the impact of economic cycles on the functioning and development of the NIS [1, 3, 7–12]. In most national surveys NIS are considered at the tactical level, and the concept and the strategy are not investigated and not under debate. Though NIS in many OECD countries already have NIS with long history, but this approach still seems not quite substantiated.

The basic principles of functioning and development usually are [2, p. 28]:

- Creation of conditions for innovation activities of firms and research organizations;
- Creation of framework conditions for the diffusion of modern technologies;
- Development of cooperation and strategic partnership between government research and development agencies and industry;
- Formation of innovative clusters and networks;
- Development of procedures for financing the early stages of an innovation process;
- Development of learning and retraining;
- Monitoring the current status of the NIS by government agencies.

And there is no any principle that takes into account the impact of cyclical factors. So it is necessary to include the principle of cyclic recurrence in a group of basic principles. According to this principle a system of priorities of innovation and industrial policies is based on forecast long-term economic cycles and a support of innovation activity of enterprises is based on the analysis and forecast of medium- and short-term economic cycles.

2 Priorities for Innovation at Various Levels of the National Economy

The national innovation system includes the complex of scientific institutions in the country—basic, applied, industrial research organizations, university and corporate laboratories—and such essential elements as state, regional and inter-company institutions that organize and ensure the creation and the dissemination of innovations. Functions of the elements of the innovation system and the existing relations between them determine the national characteristics of the organization of the innovation process.

At the same time, it should be noted that the national innovation system is exposed to globalization as well as other members of the world economy. This influence becomes apparent in:

- The increasing the degree of integration of individual elements of national innovation systems in a single world system;
- The strengthening the bonds of 'science–production' at the global level;
- The intensification of collaboration between the public and the private sectors in the innovation system;
- The integration of national educational systems.

Obviously, the globalization of innovation leads to more profound disparities in development countries. Countries with effective systems of innovation increase amounts of scientific and technological cooperation, implement large-scale projects that are important both scientifically and commercially, ensuring the expansion of production, creating new jobs. The rate of economic growth may not be high, but this approach provides growth for the medium- and long-term perspectives. Countries with weak or undeveloped innovation systems are not able to use innovative resources, and therefore they follow extensive way, basing economic growth on the use of natural resources. In such a case the economic growth is linked to world market conditions. An example of this is the dynamics of the Russia's GDP.

In these circumstances it becomes necessary to form and develop an innovative system of Russia and to increase its effectiveness. In recent years the Russian innovation system has experienced a strong influence of destructive processes of different nature, especially the socio-political and socio-economic. So now in Russia we can see some elements of the innovation system with the destruction of the functional relations between them. Consequently, the priority of economic growth is the formation of the innovation system, which means the consolidation of disparate elements together and the determination of the strategic goal of the NIS.

Russia has the most important component to form effective innovation system, the fundamental science. With all the losses and the problems of the last time this sphere has the potential for future development. The accumulated potential of the Russian fundamental science can serve as a basis for economic growth in the country if the government has a systematic and complex innovation policy. Based on a careful analysis of the leaders of research and development and their comparison with the world level of innovation the government defines:

1. In the aspect of the formation of industrial structure:

- Priority sectors in which the leadership should be given maximum support;
- Troubled sectors which have a lag behind the world level, but whose development is essential to the national economy;

2. At the sectoral level:

- The most efficient scientific organizations;
- Inefficient scientific organizations which need of reform;
- The needs of scientific organizations in the human, material, financial and other resources.

The next stage is the formation of the complex program of development of the NIS. Goals and objectives of this program are subject to adjustment depending on the outcomes and the transition from one phase of one economic cycle to another.

With limited financial resources it is necessary to pay special attention to the use of organizational resources. The NIS of Russia is ineffective, because the existing functional relations between its elements are random and unordered. For example, the foundation of innovation city 'Skolkovo' is in accordance with a specific purpose, objectives and the mechanism of implementation, but it is separated from the existing innovation NIS infrastructure. This approach—'from scratch'—is appropriate in the absence or the inefficiency of existing innovation centers, but the Russian NIS is need of organizational restructuring, rather than radical change, and it is necessary to pay greater attention to information, resource and product flows between NIS agents.

The identifying strategic priorities and objectives and priorities of innovation policy would help to give the innovation system institutional integrity.

3 The Structure of the National Innovation System in a Cyclical Economy

National innovation system includes regional innovation systems, which, unfortunately, are characterized by the same problems as for the entire national system. The problem of development of a regional innovation system and its effective 'embedding' in the national system is more important for major scientific and industrial centers with high intellectual and innovative, scientific, industrial, cultural potential.

It should be noted that the development of the NIS should involve not only the basic sciences. The industrial science is very important too. In addition, there are weak links in the system 'science–engineering–manufacturing' in Russia. The development of links between research organizations and industry will move the core funding from the public to the private sector. If the industrial economy is characterized by the perception of science in terms of short-term commercial viability of, large firms in the post-industrial society are well aware of the need to fund basic scientific research, participation in large cooperative projects to ensure their long-term competitiveness and sustainability.

Of course, this process should be gradual, in line with the rate of economic development. It is necessary to take into account the business cycle of economic development when different government programs and projects of innovative development are created. We must analyze not only long-term cycles, which are associated with the change of technological structures, but also medium- and short-term. In our opinion, mid-cycles need special attention, because now they pose the greatest threat to world and national economies.

A special role in the NIS is played by the development of the innovative small businesses as a market entity, ensuring adaptability of the system. Small firms, which are the source of numerous scientific, technological and organizational innovations, are experimenting widely in the formation and the development of various elements of market mechanisms, as well as in establishing links between them. The exceptional flexibility and mobility of a small business enables it to maximize the opportunities offered by the market that cannot be implemented medium and large businesses.

Small businesses activities are located in close relation with other actors of the economy—large and medium-sized enterprises, public authorities, financial institutions, educational institutions. In larger cities, which are scientific, industrial, financial, cultural centers, the variety and the complexity of links between different economic actors are highest.

The extent and the form of integration of large and small firms largely depend on the industries in which firms operate. In the manufacture of high technology products small firms often are highly specialized, giving rise to close cooperation links with the big business.

4 Regionalization of Innovation as a Principle of the NIS

Usually regional innovation systems (RIS) are regarded as terms of the NIS. As a rule, the standard concept of innovation systems at regional level is placed the same set of postulates that is formulated for the NIS:

- Development and adoption of measures aimed at strong growth in the number of regional universities and research institutes, university technology parks (the spin-out companies) and contributed to the close linking of local firms to external sources of knowledge;
- Involvement in the region of highly skilled labor force and actively promoting the growth of professional qualifications already existing staff;
- Networking of business incubators to support small business innovation at the initial stage of activity;
- Establish and long-term financing of a research organization that monitors on a regular basis the key to major regional industry clusters and technology markets;
- The establishment of effective mechanisms of functioning of the system of interaction and long-term cooperation between regional companies, research organizations and government agencies;
- Development of formal and informal networks that form a single culture of the business environment;
- Ensuring the flow of venture capital into the region.

With this approach, the regional innovation system is regarded as actually a small version of the national innovation system, including, of course, certain resource limitations, in connection with which the RIS pay more attention to selection of priority sectors on which a well-functioning cluster may appear.

This view of the place of regional innovation systems in the NIS is fundamentally flawed. The national innovation system is not simply the sum of smaller regional components. It is a great system, consisting of a sub regional innovation system. In turn, the regional innovation system itself is an open large system, which is fully characterized by features common to all large systems.

Regional innovation systems combine elements in different ways: industry science dominates in one system, high school—in another; some regions need to upgrade skills and retain highly skilled professionals and others must involve staff from other regions in any scenario. Some regions develop relatively apart, others are actively involved in cross-border cooperation. Therefore, management at the national level should take this into account as accurately as possible the structural and content diversity, so it is need a transition from management on the pattern to the management of the subsystems of a larger system.

5 Innovativeness of Education as a Factor in the Competitiveness of the Russian Federation

One of the most important areas of national innovation system is the development of the university science. The strengthening the innovation orientation of the high education is a factor for international competitiveness in the long-term perspective. It is necessary to develop an innovative component of the intellectual potential of a person—an innovative way of thinking. It is based on common cultural, economic, technical, technological, political, historical training and the interdisciplinary communication between economic, technical and technological knowledge. The perception of knowledge as an integrated information system allows a person to effectively generate new knowledge and to use opportunities of lateral thinking.

For the formation of innovative thinking in the education of economic cadres it is necessary radically change the approach to define functions, roles and teaching methods of technology as one of the disciplines that form the professionalism of a specialist.

1. Technology determines not a method of production, but also determines the formation and the development of spiritual ideas, the sharing of spiritual values, the establishment of diverse social contacts. In this context technology plays not only creative but also destructive role in the sphere of material production and in the field of culture.
2. High-tech technologies play a leading role in changing patterns of production and circulation of commodities. The proportion of raw material flows is sharply reduced, the share of high-tech products increases. At the same time humanity is becoming increasingly dependent on high-tech goods.
3. It must be carefully analyze the relations in the system 'Science–Technology–Manufacturing–Market' because the production becomes a technological application of science.

All these aspects should be taken into account in the preparation of plans and programs of technological learning of economic training. First of all, state standards on economic sciences should include disciplines about technology base of industries.
On the other hand, the learning new technologies and trends in the field of innovation is not enough for the formation of innovative thinking. There is another, equally important aspect—the use of new technology learning process. The traditional form of knowledge transfer is not conducive to innovative thinking (in other words, it does not prevent a person having such a thought, use it, but it does not develop it). So, we must use new educational methods and forms to develop creative thinking, so we need to pay serious attention to the study of humanities.

6 The Long-Term Technological Cycle as a Reflection of the Level of Scientific and Technical Progress

The analysis of major theories of long-term technological cycles gives us a possibility to produce a new enlarged and more complete classification of technological cycles that best reflect the technological development of the world.
Technological development involves the evolution of technology, which in turn implies a certain chronology of the transition from one technological system to others. The main feature of this classification is that it carries an attempt to review the technological development since the beginning of mankind. Another feature of this classification is that the duration of a technological system means a period of time from the first developments of their technology to the mass application of human activity and, consequently, the obsolescence of the technologies that make up the core of every technological cycle.
The historical sources give different data on the appearance of inventions and discoveries, characterizing fundamental technological shifts, and therefore the duration of the periodization of technological cycles will always be a very rough [4, 13, 14]. The technological cycles have very fuzzy boundaries; they overlay each other and even cross each other. That is why the duration of the technological cycles is also a very approximate.
Our calculation of the duration of the technological cycles [6] shows that their dynamics tends to decrease. However a reducing of the duration of the technological structures observed up to 1980–1990s, and then we see an increase in duration (the 16th technological cycle during 1990 and 2100). Forecast duration of further technological cycles (Table 9.2.1) is realized by means of the application package of statistical programs SPSS.

Table 9.2.1 Forecasts estimated duration of the technological cycles

Number of the technological cycles	17	18	19	20	21
Forecasts estimated duration of the technological cycles	132	156	179	202	226

It should be noted that the first fifteen of the sixteen cycles are based on empirical technologies. The fundamental technology is built on already established scientific and technological base. They are associated with the identification of fundamental laws of nature that lead to lengthening product life cycle, as well as creating the possibility of constructing diverse classes and systems and their possible use in various industries. A striking example and proof of this statement is one of the latest trends in the development of advanced science–nanotechnology.

Results obtained in the course of the study allow us to formulate the basic concept of the effective development of national and regional innovation systems.
The way to the fundamental technological cycle requires special attention to the formation of the directions and priorities for basic scientific research.
In the transition to a fundamental technological cycle to increase and in a systematic way to build links between basic science and high education by providing a single target vector of studies (taking into account the emergence of objective functions and differences in sources of funding). It is necessary to build on a systematic basis and to strengthen links between basic science and high education by providing a single target vector studies (taking into account the difference of objective functions and differences in sources of funding).
In addition, the presence of the priorities of the national innovation system must be combined with the consistent development other areas, which not have an obvious theoretical and practical significance at present. Perhaps they will form the basis of the new technological order in future.
The increase of the duration of the technological cycles is dual, therefore. On the one hand, a sufficient time period for the formation and development of a scientific school is formed, and a long-term sustainable development of the national economy is provided. On the other hand, the economic return from the currently ongoing prospective basic research becomes a matter of the distant future.
The effective development of the national innovation system requires minimizing the proportion of relict technological structures in the economy. At present, institutions of the NIS ignore the existence of such structures, because they focus on finding and developing innovations, while old technologies are still being used in a number of industries. Therefore, one of the actual tasks of the NIS and its subsystems (regional and sectoral) is a discovery of relict technologies and industries to transfer them to a new, advanced level. The identifying the elements of primitive cycles forms a group of priority areas for scientific research inside the national innovation system and its subsystems.

7 Interference of Innovation Strategy and Competitive Advantages of the National Economy in Recession and Recovery Phases

In the cyclical economic actors of the national innovation system to regularly review the challenges they face strategic and tactical goals and objectives. Accordingly, the aims and objectives of the NIS should also be considered at two levels.
The overall strategic objective of the NIS has already been determined by us at the beginning of this article as the creation and ongoing maintenance of a high level of competitive advantages by continuously developing the knowledge, access to specific resources. However, the cyclical nature of economic development requires linking the strategic objectives with the tactical purpose of the NIS, which is a sustainability of the functioning of NIS actors at different stages of the economic cycle. It is clear that, being left to themselves, these actors will solve the problem of survival in recession, and their objective at the stage of rise is the expansion of activities in the short term. The strategic development is possible only in the segment of big business.
As a result, we can offer some directions of state innovation policy in maintaining the functioning and development of the NIS (Table 9.2.2).
It is not a complete system of advices but only an example to show the direction of the state innovation policy in different stages of the economic cycle.

Table 9.2.2 Recommended directions of state policy on the functioning and development of NIS in various stages of the economic cycle

Subjects NIS	Phase of the cycle	
	Recession	Rise
Science		
Fundamental	Investment of financial resources to priority research areas; Formulation of priorities for the medium and long term; Maintenance of the other branches of science at the level of preservation of the existing potential	Active development of priority research areas; Funding for breakthrough projects
Industrial	Increased state involvement in venture capital financing; Formation of state order for innovative goods and services at the level of preservation of the existing potential; Insurance against risks of innovation; Co-financing of training programs for industry research	Search and usage of reserves of organizational resources in the 'Science–Technology–Production'; Increase the state order for innovative products and services; Insurance against risks of innovation
Education		
High	Promotion of research through grants and competitions	Funding for training in specialties relevant to the medium and long term; Stimulation of research through grants and competitions; Inclusion of students' innovation work into the state educational standards
Postgraduate	Promotion of training in the field of the real sector	Strengthening control over the quality of educational services
Business		
Large	Insurance against risks of innovation	Involvement of the big business in the development priorities of the economy
Small	Maintaining clusters of small innovative companies around the major subjects of the NIS and RIS; Increase of the state involvement in venture financing and creation of opportunities for small business to access to these resources Formation of state order for innovative goods and services at the level of preservation of the existing potential	Creation of clusters of small innovative companies around the major subjects of the NIS and RIS; Increase the state order for innovative goods and services

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9.3 Mathematical Modeling, Estimation and Choice of Investment Projects in the Conditions of Risk

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Abstract
One of the main problems of the modern theory and investment practice is the problem of acceptance of effective decisions in the conditions of equivocation. The problem of a choice of investment projects in the conditions of risk is actual in the conditions of development of investment economy. The estimation of the investment project is resolve into construction and research of economic-mathematical model of process of realization of the project. In the course of formalization of an estimation of efficiency of the investment project are introduce concept of an investment corridor and an expected trajectory of realization of the project . In the project problems of a choice of investment projects in the conditions of equivocation of statistically distributed results was mathematically concretized at aspiration of the person making the decision to the maximum residual cost or the provided income taking into account dynamics of capitalization. And also defined mechanisms of a choice of projects on the basis of preferences of the investor, namely mechanisms of creation bidimensional functions of utility and methods of an estimation of investment projects. Has been developed the method of an estimation of dynamics of capitalization. Offered is the method of the decision with application of simulation modeling.

Keywords:
Utility function, Dynamics of capitalization, Estimation of investment projects, Simulation modeling, Pessimistic scenario, Optimistic scenario

One of the ways creations of the positive environment for business development is the effective investment.

The main problems of modern theory and practice of investment is the problem of effective decision-making in conditions of uncertainty. This period of development of the Russian economy is characterized by the increase in the number of factors of uncertainty, in which investment activity is carried out, however, these factors for the most part is not taken into account in the framework of the assumptions of traditional approaches.

In addition, in solving problems of selection of projects, as a rule, simplified approaches are used, not taking into account the particular preferences of the investor.

These circumstances determine the urgency of the task of development of mathematical models of estimation and selection of investment projects.

1 Theoretical Bases of Estimation of Investment Projects and a Formulation of the Tasks of Selection of Investment Projects

1.1 *The Form of Presentation of the Investment Project*

Define a core list of information required for the formulation and solution of the considered further tasks.

Under the investment project I financial plan will be implied, which, as a minimum, contains the following information [2]:

- planned cash flow $d(t)$;
- temporal structure $f(t)$ of the supposed financial exemptions;
- the pessimistic scenario $\underline{C}(t)$ of project development;
- optimistic scenario $\overline{C}(t)$ of project development.

1.2 *Choice of Investment Projects from the Point of View of the Residual Value*

It is assumed that the investor is able to indicate that it is more priority—consumption or capitalization, when the fixation of one of the criteria for the desired level of investor is carried out. Thus, we will consider two types of tasks: maximization of the rest value under fixed level of seizures and the maximization of consumption under the condition of achieving the desired residual value.

Let us consider the problem of the choice of the investment project with the commitment of the investor to have at the end of the planned period as much as possible residual value of the project, taking into account the required level Y^w of financial exemptions. Suppose that the investment horizon T is the same for all projects.

Status of the project at the moment of time t is characterized by capitalization $C_t^I\left(Y^w\right)$, which depends on the capitalization in the previous point, from the data of the financial plan for the current time and a given by investor levels of exemptions.

In terms of stochastic uncertainty, dynamics of capitalization in the period $[1,T]$ is a random process $C(t)$ (or C_t), the

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realization $\widetilde{C}_t$ of which characterizes the outcome of the investment project. The dependence of the residual value $\widetilde{C}_T \in R^1$ of the project from the whole trajectory $\widetilde{C}_t$ presented in the form of functions $C_T\left(\widetilde{C}_t\right)$.

The location path of the project on the investment of the corridor is estimated by the value $\widetilde{q} \in R^1$.

The dependence of the value $\widetilde{q} \in R^1$ of the whole trajectory $\widetilde{C}_t$ symbolically presented in the form of functions $q(\widetilde{C}_t)$.

Let u the utility function defined on the indicators of the residual value and dynamics of capitalization of the investment project. In this case the task is specified in the following form [4]:

$$I^{opt} = Arg\max_{I \in \mathrm{I}} \left\{ \int_{C_t^I(Y^w)} u\left(C_T\left(C_t^I\left(Y^w\right)\right), q\left(C_t^I\left(Y^w\right)\right)\right) dC_t^I\left(Y^w\right) \right\} \quad (9.3.1)$$

Thus, the challenge lies in the choice of such investment project, the expected utility of residual value and assessment of the dynamics of capitalization of which is maximal at a given level of financial exemptions.

1.3 *Selection of Investment Projects on the Basis of the Provided Income*

To assess the investment project in the desire to consume, the investor specifies the desired level C^w of residual value of the investment project, as well as the permissible deviation Δ_C from the specified level.

Each project is evaluated from the position of such a level exemptions Y^*, for which the condition is satisfied $\left|C_T\left(\widetilde{C}_t\left(Y^*\right)\right) - C^w\right| \le \Delta_C$, where Δ_C are specified the investor of the permissible deviation from C^w.

Let a function ν is a utility function defined in the terms provided by the income and assessment of the dynamics of capitalization of the investment project. In this case, we have [4]:

$$I^{opt} = Arg\max_{I \in \mathrm{I}} \left\{ \int_{Y_I^*} \nu\left(Y_I^*, q\left(C_t^I\left(Y_I^*\right)\right)\right) dY_I^* \right\} \quad (9.3.2)$$

Thus, the problem (9.3.2) is in the choice of such investment project, the expected utility provided by income and assessment of the dynamics of capitalization of which is maximal.

1.4 *Selection of Investment Projects Taking into Account the Credit Limit of the Investor*

It is necessary to carry out registration of the investor's possibilities on attraction of the borrowed capital, with a view to eliminating the possibility of choosing a potentially which is lacking of the project. Credit limits of investor we denote by function $L(t)$.

The need for borrowing occurs in the following situation $\exists t \in [1, T] : \widetilde{C}(t) < 0$.

We introduce for consideration the event of the receipt of nonfinance project: $A = \{\exists t \in [1, T] : -C(t) > L(t)\}$, as well as the indicator of the given event

$$J_A(C_t) = \begin{cases} 0, C_t \in A, \\ 1, C_t \notin A. \end{cases}$$

Then the usefulness of outcome in the event A is determined and is equal to zero. In this case, (9.3.1) has the form [4]:

$$I^{opt} = Arg\max \left\{ \int_{C_t^I(Y^w)} u_L\left(C_T\left(C_t^I\left(Y^w\right)\right), q\left(C_t^I\left(Y^w\right)\right)\right) dC_t^I\left(Y^w\right) \right\} \quad (9.3.3),$$

similar to the modified (9.3.2):

$$I^{opt} = Arg\max \left\{ \int_{Y_I^*} \nu_L\left(Y_I^*, q\left(C_t^I\left(Y_I^*\right)\right)\right) dY_I^* \right\}, \quad (9.3.4)$$

where

$$\nu_L\left(Y^*, q\left(Y^*\right)\right) = J_A\left(C_t\left(Y^*\right)\right) \nu\left(Y^*, q\left(C_t\left(Y^*\right)\right)\right).$$

Thus, the problem of the form (9.3.3) and (9.3.4) allows to make a choice of investment project in the conditions of the limited capital market.

2 Mathematical Modeling, Methods of Assessment and Selection of Investment Projects in Conditions of Risk

2.1 *The Mechanisms For the Selection of Projects Based on the Preferences of the Investor*

Construction of utility function is carried out with the use of interval estimates for the preferences of the investor.

The approach is based on the information from the person of the decision-making on the basis of the proposed choice between the lottery $\Lambda(x, h)$ and some of the guaranteed result $x' \in [x - h, x + h]$. In the end, by enumeration of values is formed area $D \in [x - h, x + h]$ that contains the deterministic equivalent $\hat{x}$ of a lottery $\Lambda(x, h)$. You need to limit the area where expose preferences under the least possible dimensions $[x_{\min}, x_{\max}]$.

Dividing the range of possible outcomes at m equal intervals, get m lotteries $\Lambda(x_1, h), \ldots, \Lambda(x_m, h)$ with the same panache $h = \dfrac{x_{\max} - x_{\min}}{2m}$.

On the basis of the received lotteries using the criteria developed by the Mikhno V.N. and Katulaev A.N [3] is determined the type of relationship of investor to risk. Each type of attitude to risk corresponds the utility function.

To calculate the parameters of the utility function a, b and c solves the optimization problem $u(x) = \arg\min_{u(x)\in U} \sum_{i=1}^{m} \left(\overline{u}(\tilde{x}_i) - u(\hat{x}_i)\right)^2$, where $\overline{u}(\tilde{x}_i) = \frac{1}{2}u(x_i - h) + \frac{1}{2}u(x_i + h)$ in the performance conditions $u(x_{\min}) = 0, u(x_{\max}) = 1$.

Two-criterial utility function $u(x, y)$ is appeared in an additive form [1]:

$u(x, y) = \lambda_1 u_x(x) + \lambda_2 u_y(y)$. Here $\lambda_1, \lambda_2 > 0, \lambda_1 + \lambda_2 = 1$ are scale coefficients, $u_x(x), u_y(y)$—contingent one-criterial utility function.

2.2 *Methods of Estimation of Investment Projects*

Assessment of residual value of multiperiod project.

For the assessment of projects proposed the use of a modified model of the NPV, with the account of the credit constraints of the investor:

$$C_t = \begin{cases} d_t - f_t Y + (1 + h_t)C_{t-1}, C_{t-1} > 0, \\ d_t - f_t Y + (1 + s_t)C_{t-1}, C_{t-1} < 0 \\ A_t - C_{t-1} > L_t \end{cases} \quad (9.3.5),$$

where f_t—is an element of the vector $\mathrm{f} = (f_1, ..., f_T)$ structure of the exemptions in the moment of time t; h_t—the percent rate for additional investment in time from up $t-1$ to t; s_t—the rate for supplementing of borrowing in the moments of time from $t-1$ to t.

Speaking about the dynamics state of the investment environment, we note that the special statistical research showed that the distribution of a number of economic indicators, such as inflation, are not normal.

Dynamics state of the investment environment is considered as the vector process $x(t) = (x_1(t), ..., x_n(t))$ with independent components in the assumption that each process $x_i(t)$ is stationary and is described by model $G_{a,\sigma,\varepsilon}$ with a density [4]:

$$p_i(x_i) = (1 - \varepsilon_i)N(a_i, \sigma_i^2) + \varepsilon_i \phi(x_i) \quad (9.3.6).$$

Assessment of the dynamics of capitalization of the investment project.

We assume that the outcome of the project in time t is negative for the investor, if the path of the project is below pessimistic scenario $C(t) < \underline{C}(t)$, lost capital in the moment of time t is determined by the formula $\underline{\Delta}C(t) = C(t) - \underline{C}(t)$, and a continuous set of such points $M^- = \{t \mid \underline{\Delta}C(t) < 0\}$ is called a negative period of the project implementation. Similarly, the outcome of the project at the moment t is positive, if $C(t) > \overline{C}(t)$ the additional capital: $\overline{\Delta}C(t) = C(t) - \overline{C}(t)$, and the continuous lot of such moments $M^+ = \{t \mid \overline{\Delta}C(t) > 0\}$ is a positive project implementation period.

The author of the work has been developed algorithm Q for evaluation of the implementation $C(t)$:

analyze the trajectory $C(t)$ and are formed M^+ and M^-;

next is made a calculation by model:

$$q = \begin{cases} \left(C(t) - \underline{C}(t)\right)r^{-1}, C(t) \in M^-; \\ \left(C(t) - \overline{C}(t)\right)r^{-1}, C(t) \in M^+; \\ C(t) - \left(\overline{C}(t) - \underline{C}(t)\right)r^{-1}, C(t) \in \left(\underline{C}(t); \overline{C}(t)\right) \end{cases}$$

In view of the earlier assumptions, the discount rate is a random process $r(t)$. As a method of calculating the discount factor suggests the use of Fisher equation: $r(t) = s(t) + i(t) + s(t)i(t)$, where $s(t)$—is the interest rate on borrowing; $i(t)$— the inflation level [5].

Search algorithm given the level of seizures.

For the calculation provided by the levels of seizures we use the F. Aizenfurs algorithms [6].

At the initial stage the search of value $Y^{\min} : C_T(Y^{\min}) > C^w + \Delta_C$ and value $Y^{\max} : C_T(Y^{\max}) < C^w - \Delta_C$.

Then carried out the procedure of calculation:

$$Y_t = Y_t^{\max} + \left(C^w - C_T(Y_t^{\min})\right)\frac{Y_t^{\max} - Y_t^{\min}}{C_T(Y_t^{\max}) - C_T(Y_t^{\min})}$$

The use of simulation modeling in the assessment of projects.

For certification of the proposed methods proposed the use of a simulation.

Element of cash flow is treated as a random variable with the distribution of (9.3.6) with parameters $a_t^i = \hat{d}_t^i$, $\varepsilon_t^i = 0{,}5$ and to determine the procedures σ_t^i is applied:

1. ranked elements of reference flows $\hat{d}_t^1 \le \hat{d}_t^2 \le \ldots \le \hat{d}_t^N$;
2. for each $\hat{d}_t^i$ calculates the value of $\Delta\hat{d}_t^i$:

$$\Delta\hat{d}_t^i = \begin{cases} 0{,}5\left(\hat{d}_t^{i+1} - \hat{d}_t^i\right), i = 1, \\ 0{,}5\min\left(\hat{d}_t^i - \hat{d}_t^{i-1}, \hat{d}_t^{i+1} - \hat{d}_t^i\right), 1 < i < N, \\ 0{,}5\left(\hat{d}_t^i - \hat{d}_t^{i-1}\right), i = N; \end{cases}$$

3. using the rule of three sigma is calculated $\sigma_t^i = \Delta\hat{d}_t^i / 3$.

At the end model cash flow will be characterized by a set of $\left\{G_{a_t,\sigma_t,\varepsilon_t}\right\}_{t=1}^T$ distributions of its elements.

In the general form of the structure of a simulation model of decision-making can be represented as follows:

$$< S, F > \xrightarrow{K} < \Psi > \xrightarrow{IIM} < X, D > \longrightarrow < Q, Y, C > \xrightarrow{\bar{u},\bar{v}} I^{opt}$$

where S—a set of statistical data; F—collection of data of financial plans; K procedure of parametric identification distribution of family $G_{a,\sigma,\varepsilon}$; $\Psi = \left\{\rho_i\left(x_i\right)_{i=1}^n\right\}$—a set of probabilistic models of the investment environment; $X = \left\{\tilde{x}^i(t) \mid \forall t \in [1, T]\right\}_{t=1}^m$—many implementations of the state of the investment environment, obtained with the use of simulation modeling; D—a set of cash flows, obtained with the help of simulation modeling; Q—the algorithm of estimation of the trajectory of the project; Y the search algorithm provided by levels of seizures; C—method of capitalization calculation using in the model of taking decisions.

3 The Use of the Mentioned Methods and Algorithms with the Help of Computational Experiment

The initial conditions of the experiment:

investor has a volume of liquid funds in the amount of 550 000 USD and the planning period T = 6 years;

operates in the conditions of imperfect and limited capital;

examines the projects A, B and C.

3.1 *Construction of Utility Functions*

Construction of utility functions for project choice from the point of view of residual value.

On the first phase one-demensional utility function of criteria x is constructed.

Was formed a range $[x_{\min}, x_{\max}]$ of possible values for the criteria x. The minimum value of the criterion of the residual value is determined from the relation $x_{\min} = -\min_{i=\overline{1,N}} L_i(T) = -630$. The upper limit was determined from the ratio $x_{\max} = \max_{i=\overline{1,N}} C_i^{\max}(T) = 2338{,}92$, where $C_i^{\max}$ is net book value of the project i obtained under the most favorable conditions of the investment environment.

A range of possible outcomes was divided into 10 lotteries with reference accurate. According to the criteria, attitudes towards risk, individual decision maker is characterized by a decreasing disinclination to risk. Hence, a parametric family of utility function has the form: $u_x(x) = ax - be^{-cx}$.

As a result of made parametric identification were obtained the values for the parameters $\hat{a} = 0{,}000428$, $\hat{b} = 0{,}03777$ and $\hat{c} = 0{,}003139$. In this manner $u_x(x) = 0{,}000428x - 0{,}03777e^{-0{,}003139x}$.

The second phase will build a one-dimensional utility function of the criteria y.

The minimum possible value of $y_{\min}$ the criterion of the dynamics of investment projects was determined from the relation $y_{\min} = \min_{i=\overline{1,N}} q_i^{\min} = -607{,}18$, where $q_i^{\min}$ — assessment the dynamics of the project i, obtained under the most negative conditions of the investment environment. The maximum value $y_{\max}$ determined $y_{\max} = \max_{i=\overline{1,N}} q_i^{\max} = 525{,}85$, where $q_i^{\max}$ — assessment of the dynamics of the project i, obtained under conditions most favorable investment environment.

In this manner $u_y(y) = 0{,}00166y - 0{,}32906e^{-0{,}001861y}$.

Two-criterial utility function has a view:

$$u(x, y) = 0{,}000209x - 0{,}01858e^{-0{,}002144x} + 0{,}000846y - 0{,}16782e^{-0{,}00059y}.$$

Building a utility function for the selection of projects from the point of view of the income provided by.

We denote the level of seizures Y^* by symbol x, and evaluation of the dynamics of the symbol y.

Construction of the function is the same:

$$v(x, y) = 0{,}0000435x - 0{,}36315e^{0{,}00185x} + 0{,}0000286y - 0{,}00691e^{-0{,}000311y}$$

3.2 ***Creating a Simulation Model***

Model generation of the cash flow of the project A has the form:

$$\left\{\begin{matrix} G^1_{380,7;12,42;0,5}, G^2_{354,1;16,85;0,5}, G^3_{308,8;24,40;0,5}, G^4_{280,2;29,17;0,5}, \\ G^5_{259,4;32,63;0,5}, G^6_{245,8;34,90;0,5} \end{matrix}\right\}$$

the project B:

$$\left\{\begin{matrix} G^1_{209,2;28,58;0,5}, G^2_{546,9;15,28;0,5}, G^3_{546,9;15,28;0,5}, G^4_{546,9;15,28;0,5}, \\ G^5_{546,9;15,28;0,5}, G^6_{546,9;15,28;0,5} \end{matrix}\right\}$$

the project C:

$$\left\{\begin{matrix} G^1_{455,2;12,42;0,5}, G^2_{455,2;15,28;0,5}, G^3_{455,2;15,28;0,5}, G^4_{455,2;15,28;0,5}, \\ G^5_{455,2;15,28;0,5}, G^6_{455,2;15,28;0,5} \end{matrix}\right\}$$

With the help of the simulation model were also calculated parameters of the investment environment and on their basis the discount factor.

3.3 ***Appraisal and Selection of Investment Project with the Positions of the Residual Value***

On the basis of the results of simulations have been calculated the expected utility of each of the projects according to the utility function with given indicator of the event of failure of the project. The results of the task 9.3.3. are presented in Table 9.3.1.

Table 9.3.1. Solution of the task 9.3.3

	$\frac{1}{125}\sum_{i=1}^{125}\widetilde{C}_T^i$	$\overline{u}_L(C_T, q) = \frac{1}{125}\sum_{i=1}^{125} u\left(\widetilde{C}_T^i, \widetilde{q}^i\right) J_A\left(\widetilde{C}_t^i\right)$
Project A	4371,92	2,815
Project B	8888,89	6,314
Project C	10640,51	9,091

Thus, according to the data of the projects are ranked as follows: $C \succ B \succ A$.

Further investigated the correctness of the developed methods by comparing the obtained results with the results obtained in case of refusal of criteria of assessment of the trajectory and use of the normal distribution for the investment environment, the results are shown in Table 9.3.2.

Table 9.3.2. The decision of one-criterial task

	$\overline{u}_L(C_T) = \frac{1}{125}\sum_{i=1}^{125} u\left(\widetilde{C}_T^i\right) J_A\left(\widetilde{C}_t^i\right)$
Project A	1,857
Project B	3,677
Project C	4,335

As can be seen from the data obtained, the solution of the classical problem coincides with the solution of problem (9.3.3).

3.4 *Assessment and Selection of Investment Project with the Positions Provided by the Income*

Similarly was conducted certification of methods of solution of problem (9.3.4). In its decision were established the following parameters:

- the desired level of income of 500;
- permissible deviation of 30;
- the total number of simulation implementations 125.

Table 9.3.3. Solution of the task 9.3.4

	$\frac{1}{125}\sum_{i=1}^{125}\widetilde{Y}_T^i$	$\overline{\nu}_L\left(Y^*,q\right)=\frac{1}{125}\sum_{i=1}^{125}\nu\left(\widetilde{Y}_i^*,\widetilde{q}^i\right)$ $J_A\left(\widetilde{Y}_i^*\right)$
Project A	5589,973	13,98
Project B	10085,218	61,26
Project C	5419,539	13,09

Table 9.3.4. The decision of one-criterial task

	$\overline{\nu}_L\left(C_T\right)=\frac{1}{125}\sum_{i=1}^{125}\nu\left(\widetilde{Y}_i^*\right)J_A\left(\widetilde{Y}_i^*\right)$
Project A	37,76
Project B	311,31
Project C	35,51

So, in both cases, the projects are ranjed as follows: $B \succ A \succ C$.

Thus, the listed results determine the complex of mathematical models, methods and algorithms describing a uniform approach to the assessment and selection of various on structure and characteristics of investment projects.

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The results of the task 9.3.4 and one-criterial task are presented in Tables 9.3.3, and 9.3.4.

9.4 Sustainable Development of the Economy of a Region

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Abstract
Science developments of the recent years let researchers to tackle problems that has remained unsolvable till the present day.One of such problems is the substantiation of sustainable development of a civilization and of economy as one of its components. In its turn, substantiation of sustainable development of economy is subject to financial policies on global, regional, national levels and also within individual businesses and households.The problem of sustainable development counts for all aspects of industrial and information-type societies, and it can not be solved outside of the general trend of our civilization. This trend does not depend upon a society's political and religious values, structures and mentalities. All developing countries including young economies have to go through the same chain of development stages because the civilization is an integral global super-system. Its progress can described by the general principles of the Self-Organization Theory or Synergetics.
Recent scientific achievements were the basis upon which the paper's author has developed and substantiated a model of sustainable development of a regional economy.

Keywords:
Model of sustainable development, Sustainable development of economy, Region, Synergetics

1 Introduction

The English term "sustainable development" first emerged in a discussion of the health of the planet and its inhabitability for future generations, at a session of the UN World Commission on Environment and Development. Mr. Harlem Brutland, 'father' of the phrase, chairman of the Commission, explains its meaning in the following way: "Humankind is surely capable of making its development sustainable, i.e. ensuring that this development can fulfill the needs of the present and never puts at risk the capability of future generations to fulfill their future needs" [1]. Thinking about this dilemma, a Russian Doctor of Geography Mr. A. V. Pozdnyakov from the Institute for Optical Monitoring of the Siberian Branch of Russian Academy of Sciences (city of Tomsk), has proved that basically a sustainable social economic development is feasible. The problem with building sustainably developing (in the sense of a gradually growing trend) social and economic systems is that the vast majority of politicians and economists still are unfamiliar with the methods of the theory of self-organization—the Synergy theory [2]. However, the situation has changed recently. New trends have been initiated by V. B. Zang's works about a Synergetic Economy [3], by "the second-order cybernetics" of S. Bier [4], by V. V. Vassilkova's ideas about the ratio between order and chaos in social systems, etc.

2 Samuelson, Hicks Model of Sustainable Development

Application of the method of analysis of system development depends on the goals we set. If our interests lie only in the prognosis of a development trend, then analysis of simple cognitive patterns and methods of mathematical modelling based on boundary problems and their numerical solution, will certainly do. Minor fluctuations around the trend may be studied by the method of perturbations. More complicated fluctuations require application of the methods of non-linear dynamic, neural networks, fuzzy logic, etc. A region's economy is a complex dynamic non-linear system, i.e. substantiation of a model of sustainable development is possible only if synergy methods are applied. Synergetic parameters of economy in [3] are viewed in the following way: "… in the synergetic economy more stress is placed upon non-linear aspects of economic development instead of linear ones, on unstable processes instead of stability, on gaps not continuity, on structural change not constancy; all this is opposed to the traditional approach based on linearity, stability, continuity and constancy." In connection with this, in the present paper we are using the Samuelson–Hicks model for substantiation of a sustainable development of the economy of a geographical region, and studying the conditions of its stability. It has also been proved that at certain parameter values this model becomes synergetic. A continuity equivalent of the Samuelson–Hicks model is the following linear second order non-homogeneous equation:

$$\frac{1}{1-c}\cdot\frac{d^2y}{dt^2}+\frac{1-r}{1-c}\cdot\frac{dy}{dt}+y=\frac{\underline{C}+I}{1-c}. \qquad (9.4.1)$$

where y(t)—gross regional product (GRP), $\underline{C}$—minimal consumption fund, *I*—investments, (1–c)—propensity to save.

According to the theory of linear differential equations, a more general solution of a non-homogeneous equation is the sum of a general solution of a homogeneous equation and a specific solution of a non-homogeneous equation.

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The general solution of a homogeneous equation is a linear combination of fundamental solutions $e^{\lambda_1 t}$, $e^{\lambda_2 t}$

$$A_1 e^{\lambda_1 t} + A_2 e^{\lambda_2 t}, \quad (9.4.2)$$

where λ_1, λ_2 are the roots of a performance equation

$$\frac{1}{1-c}\lambda^2 + \frac{(1-r)}{1-c}\lambda + 1 = 0, \quad (9.4.3)$$

that has been determined by solving a homogeneous equation.

Since the invariable in the right-hand part of the non-homogeneous equation is in fact its specific solution (9.4.1), then its general solution is:

$$y(t) = A_1 e^{\lambda_1 t} A_2 e^{\lambda_2 t} + \frac{\bar{C} + I}{1-c}$$

Then we can determine a specific solution under given initial conditions.

The chosen specific solution of a non-homogeneous equation is, at the same time, its steady solution

$$y^E = \frac{\bar{C} + I}{1-c},$$

while the point (y^E, 0) on the plane (y, u) of the y variable and its derivative and u = y' is the equilibrium point.

Now we'll study the behavior of the solution of the equation (9.4.1) in the vicinity of the equilibrium point (y^E, 0). It would seem that after a minor deviation from this point due to some external impulse action $\delta(t)\begin{pmatrix}\eta_0 \\ u_0\end{pmatrix}$, a system that has hit the point $(y^E + \eta_0, u_0)$, must after the end of a transition process return to the equilibrium (y^E, 0).

Here η (t) is the variable part of the transition y(t).

However, as shall be demonstrated below, this is not always so. Hereinafter, for the sake of certainty, we'll consider the case where $\eta_0 < 0$, $u_0 < 0$, i.e. where the value of GRP has gone down while the rate of its growth from zero point in a steady state has been changed by a negative value.

The solution of equation (9.4.1) under the given initial conditions $y(0) = y^E + \eta_0$, $y'(0) = u_0$

is as follows:

$$y = y^E + \eta,$$

then the increment of the GRP compared with the stationary solution y^E will satisfy a homogeneous equation

$$\frac{1}{1-c}\cdot\frac{d^2\eta}{dt^2} + (1-r)\frac{d\eta}{dt} + 1 = 0,\ \eta(0) = \eta_0,\ \eta'(0) = u_0. \quad (9.4.4)$$

Below, in addition to the GRP behaviour, the evolution of investment and consumption will also be studied. According to the model, annual investment consists of a constant *I* and a variable i = r(y(t) – y(t – 1)). During time period Δt the variable part will be Δi = r(y(t) – y(t – 1)).

Proceeding to the Δt → 0 limit we have the following:

$$\frac{di}{dt} = r\frac{dy}{dt} = r\frac{d\eta}{dt}.$$

Since i(0) = 0, η(0) = 0, then i = rη.

This makes the current investment value to be

I(t) = I + i = I + rη(t), (9.4.5)

Accordingly, the current consumption taken as a difference between GRP and investment is

C(t) = y^E – I + (1 – r)η(t). (9.4.6)

The solution of a homogeneous equation (9.4.4), under given initial conditions, looks then like (9.4.2) where A_1, A_2 are defined proceeding from the initial conditions. The type of solution depends on the type of the roots of a performance equation (9.4.2), while the type of the latter, in their turn, results from the value of parameters r, c.

Let's consider all possible values of the r under condition that:

$$1 - 2\sqrt{1-c} > 0,\ c > \frac{3}{4} \quad (9.4.7)$$

In the present paper, a detailed study is carried out in order to reveal cases when the system behaves synergistically.

Case One: $0 < r < 1 - 2\sqrt{1-c}$.

Here the discriminant of the performance equation is positive, while its roots λ_1, λ_2 ($\lambda_1 > \lambda_2$)

$$\lambda_{1,2} = -\frac{1-r}{2} \pm \sqrt{\frac{(1-r)^2}{4} - (1-c)}, \quad (9.4.8)$$

are real and negative, because the larger root λ_1 is negative when $1 - r > 2\sqrt{1-c}$.

Using the initial conditions (9.4.4) we determine that:

$$A_1 = \frac{u_0 - \lambda_2\eta_0}{\lambda_1 - \lambda_2}, \qquad A_2 = \frac{u_0 - \lambda_1\eta_0}{\lambda_1 - \lambda_2}.$$

Therefore

$$\eta(t) = \frac{1}{\lambda_1 - \lambda_2}\left[(u_0 - \lambda_2\eta_0)e^{\lambda_1 t} - (u_0 - \lambda_1\eta_0)e^{\lambda_2 t}\right]$$

As

$\lambda_1 < 0$, $\lambda_2 < 0$, then $\lim_{t\to\infty}\eta(t) = 0$

Hence

$$\lim_{t\to\infty} y(t) = y^E, \qquad \lim_{t\to\infty} y'(t) = \lim_{t\to\infty}\eta'(t) =$$

$$= \lim_{t\to\infty}\frac{1}{\lambda_1 - \lambda_2}\left[(u_0 - \lambda_2\eta_0)\lambda_1 e^{\lambda_1 t} - (u_0 - \lambda_1\eta_0)\lambda_2 e^{\lambda_2 t}\right] = 0.$$

Thus, the system after the completion of aperiodic transition returns to its initial rest conditions (y^E, 0) and is therefore stable.

At the beginning of the transition process when $\eta_0 < 0$, $u_0 < 0$, GRP and, accordingly, consumption and investment continue to decrease for some time, then their monotone growth begins until their static values are reached: y^E, y^E – I, I, respectively.

Case Two: $r = 1 - 2\sqrt{1-c}$.

In this case the discriminant is zero, and the performance equation has a single multiplicity root $\lambda_1 = -\frac{1-r}{2}$ with the order 2. Therefore fundamental solutions for the homogeneous equation (9.4.1) are $e^{\lambda_1 t}$ and $te^{\lambda_1 t}$.

Hence, a general solution would be:

$$\eta(t) = e^{\lambda_1 t}(A_1 + A_2 t).$$

Using the initial conditions (9.4.4), we determine that $A_1 = \eta_0$, $A_2 = u_0 - \lambda_1\eta_0$.

Therefore $\eta(t)=e^{\lambda_1 t}\left[\eta_0+(u_0-\lambda_1\eta_0)\,t\right].$

Since $\lambda_1<0$, then $\lim\limits_{t\to\infty}\eta(t)=0,\ \lim\limits_{t\to\infty}\eta'(t)=0.$

Hence

$$\lim_{t\to\infty}y(t)=y^E,\qquad \lim_{t\to\infty}y'(t)=0.$$

i.e. the system returns to its initial rest condition and, therefore, is stable.

The GRP, consumption and investment during the transition process behave similarly to their behaviour in Case One.

Case Three: $1-2\sqrt{1-c}<r<1$

Here the discriminant of the performance equation is negative, therefore its roots are complex and mutually conjugate:

$$\lambda_1=\alpha+i\omega,\quad \lambda_2=\alpha-i\omega,$$

where

$$\alpha=-\frac{1-r}{2}<0,\quad \omega=\sqrt{1-c-\frac{(1-r)^2}{4}}>0.$$

Using the initial conditions (9.4.4) we determine that:

$$A_1=\frac{u_0-(\alpha-i\omega)\eta_0}{2i\omega},\qquad A_2=\frac{u_0-(\alpha+i\omega)\eta_0}{2i\omega},$$

hence

$$\eta(t)=e^{\alpha t}\left(\eta_0\cos\omega t+\frac{u_0-\alpha\eta_0}{\omega}\sin\omega t\right),$$

Because $\alpha<0$, then $\lim\limits_{t\to\infty}\eta(t)=0,\ \lim\limits_{t\to\infty}\eta'(t)=0.$

Hence

$$\lim_{t\to\infty}y(t)=y^E,\qquad \lim_{t\to\infty}y'(t)=\lim_{t\to\infty}\eta'(t)=0.$$

Thus, the system after damped harmonic oscillations returns to its initial rest conditions, i.e. it is stable. If $\eta_0<0$, $u_0<0$, then the GRP, consumption and investment continue to decrease and then begin to grow and reach the established values; after which this self-sustained oscillation process continues with exponentially damping amplitude till these parameters reach their static values over an endless continued period of time.

Case Four: r = 1.

Substantially, this means that an annual incremental GRP growth is fully spent on investment. If r = 1 then the roots of a performance equation are mutually conjugate:

$$\lambda_1=i\omega,\quad \lambda_2=-i\omega,\ \omega=\sqrt{1-c}.$$

Using the initial conditions we determine that:

$$A_1=\frac{u_0+i\omega\eta_0}{2i\omega},\qquad A_2=-\frac{u_0-i\omega\eta_0}{2i\omega},$$

therefore (9.4.9)

$$\eta(t)=\left(\eta_0\cos\omega t+\frac{u_0}{\omega}\sin\omega t=\rho\sin(\omega t+\varphi)\right),$$

$$u(t)=\eta'(t)=-\omega\eta_0\sin\omega t+\frac{u_0}{\omega}\cos\omega t=\omega\rho\cos(\omega t+\varphi),\qquad (9.4.10)$$

where:

$$\sin\varphi=\frac{\eta_0}{\sqrt{\eta_0^2+\left(\frac{u_0}{\omega}\right)^2}},\quad \rho=\sqrt{\eta_0^2+\left(\frac{u_0}{\omega}\right)^2}.$$

Thus, with r = 1 the system will be in the state of persistent harmonic oscillations, i.e. unstable, because it does not return to its initial stable conditions, and therefore it is synergetic. On the phase variable plane the system's trajectory defined by equations (9.4.9), (9.4.10) will look like a normal ellipse (see Fig. 9.4.1):

$$\frac{\eta^2}{a^2}+\frac{u^2}{b^2}=1,$$

where ρ is the share of gross investment, a = ρ, b = ωρ.

The GRP shall vary over the range of $y^E\pm\rho$, consumption shall remain stable and equal to its static value y^E-I, while investment shall remain in the state of persistent self-oscillations according to equation $I(t)=I+\eta(t)$.

Case Five: $1<r<1-2\sqrt{1-c}$

This is an extreme case because additional investment (greater than the static value I) will require more than the incremental growth of the GRP, and this surplus can be compensated only through appropriate reduction of consumption. Here the discriminant of the performance equation is negative, therefore its roots are complex and mutually conjugate

$$\lambda_1=\alpha+i\omega,\quad \lambda_2=\alpha-i\omega,$$

$$\alpha=\frac{1-2}{2}>0,\quad \omega=\sqrt{1-c-\frac{(1-r)^2}{4}}>0.$$

Therefore:

$$\eta(t)=\rho e^{\alpha t}\sin(\omega t+\varphi),\ \rho=\sqrt{\eta_0^2+\left(\frac{u_0-\alpha\eta_0}{\omega}\right)^2},$$

$$\sin\varphi=\frac{\eta_0}{\rho}$$

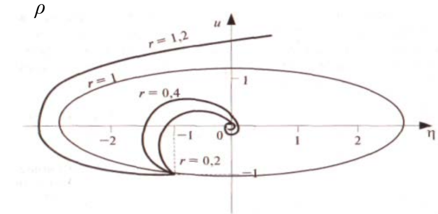

Fig. 9.4.1 Phase trajectories of the system at different acceleration factors $r(c=0{,}84,\eta_0=-1,u_0=-1)$

i.e. the system will be in the state of harmonic self-oscillation with exponentially rising amplitude, in other words the system is unstable and synergetic. Consumption and investment will also be in harmonic self-oscillation with exponentially rising amplitude around its static values:

$$C(t)=y^E-I-(r-1)e^{\alpha t}\rho\sin(\omega t+\varphi),\quad I(t)=I+re^{\alpha t}\rho\sin(\omega t+\varphi),$$

Figure 9.4.1 shows system's trajectories on the phase variable plane $(\eta,\ u)$, $u=\eta$ for all the above cases.

Thus, the economy described by the Samuelson-Hicks model is stable at 0 < r < 1 and has synergetic properties (unstable) at r ≥ 1.

As a result, we have determined that the model of sustainably developing regional economy possesses synergetic properties.

3 A Model of Sustainable Development of Regional Economy

By introducing the inflation factor (E) into the Samuelson–Hicks model, we make the mathematical model of a sustainable development of a regional economy look like (ideally) a one-sheet hyperboloid:

$$\frac{\eta^2}{a^2}+\frac{u^2}{b^2}-\frac{E^2}{c^2}=1$$

Economic interpretation of the model: the lower part of the hyperboloid is the area of sustainable development of a regional economy (inside a truncated cone), while the upper part of it is the area of stability (outside of the cone).

Thus, using the Samuelson-Hicks model supplemented by an inflation factor, we have the mathematical model of sustainable development of a regional economy built in 3D.

4 Conclusion

This model of sustainable development of a regional economy helps one calculate the marginal factors impacting the economic situation in a region. If the total annual GRP incremental growth is spent on investment, and no savings remain available, then the state of the economy is designated as unstable. To return the economy to stable condition the produced GRP must be in excess of the total value of investment. For this calculation one has to solve an inverse problem, i.e. to change the input data across the whole process of analysis from the result to its correction, by values defined by the Bellman method.

As a result, in the course of a study of sustainable development of a regional economy we have built mathematical economic models where GRP = max, GRP = 0, GRP < 0, GRP > 0.

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9.5 A Case Study: Feasibility and Economic Analysis for Advanced Automation in Spoke Rim Assembly for Motorcycle Towards Sustainability

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Abstract

A full automated system for assembly of spoke rim for motorcycle is difficult to realize, rather more manual and hybrid system until now, because of tight joining tolerance, increased complexities during assembly operation and wide diversity of variants. Due to recent increasing trends in labour cost and sustainability aspect advanced automation become more and more necessary. An industrial case study which deals with different improvement concepts for an economical feasible and technical realizable advanced automation of a motorcycle spoke rim assembly line is conducted. This paper presents a comprehensive analysis of the current implementation, a systematic approach to design the advanced automation concepts and a sustainable evaluation method in selecting the most feasible and realizable concept that ensures profitability and continuity.

Keywords:

Spoke rim assembly, Automation, Concept design, Economic analysis, Sustainability

1 Introduction

Assembly operations have traditionally been performed manually, either at single assembly workstations or on assembly lines with multiple stations. Owing to the high cost of manual labour, greater attention has been given in recent years to the use of automation for assembly work [1]. For products with large quantities, small size and simple design, automation assembly is generally required.

The main aim of automation in assembly processes is increasing productivity, better product quality, reducing factory lead times and reducing personal expenditures. However, it is also well known that, compared with a manual assembly system, highly automated system often causes high capital expenditure required to invest in automation, including design, fabricating and installing, higher level of maintenance and lower degree of flexibility.

Sustainability has become an urgent requirement and challenge for mankind's survival on earth and for their future development, considering the limits of resources and growth and the unequal distribution of wealth. Therefore industries need to consider sustainability aspect in development of their processes and products. Sustainability here is interpreted in ecological, economic and social dimensions. Advanced automation offers a comprehensive approach to meeting the sustainability objectives. This objective is, however, multi-faceted [2]:

i. The solutions need to be sustainable from an economical point of view, because the company need not only acquire the assembly technology, but also maintain it.
ii. Ecological aspect linked to sustainability: minimise use of resources, waste disposal, CO_2 emission, etc.
iii. Social aspect must also be taken into account, because the technology needs to support and sustain the societies and economies being affected by them.

Motorcycle rims need to be tough and rigid to support passengers and the weight of the motorcycle. However, the rims also need to be light in order to minimize the fuel consumptions. To obtain these criteria, most of the motorcycle manufacturers will use spoke rim for their product [3].

A motorcycle spoke rim basically consists of a rim, spokes, hubs and nipples. A spoke rim usually has 36 or 40 spokes, whose main function is to provide structural strength to the rim. Rim is connected to the hub and holes in the rim at an angle by several spokes under tension. This angle is a function of the cross-pattern used to spoke the wheel, the diameter of the hub flanges, and the width of the hub at the flanges. The spoke on the set of the spoked motorcycle will absorb impact more effectively than the solid rims. Nipple is used to connect the spoke to the hub with the main function of adjusting the tension in the spoke and locking the spoke to the hub.

A spoke rim assembly joins a rim, a plurality of spokes with connecting portions and a hub together. Spokes extend from the connecting portion and terminate in nipples. Each spoke has an upper connecting portion, a deformed portion, and a distal portion terminating in the nipple. A hub has a pair of symmetrical slots to receive the deformed portions of the spokes. In that way, spokes are located to pass through the rim, extend across a pair of adjacent slots, and be locked with the nipples [4].

A full automation system for assembly of spoke rim as a part of motorcycle assembly is hard to be realized. The required flexibility and dexterity can be obtained easily by manual assembly systems. Automated handling of spoke rim, however, due to their various shapes and tolerance requirements, is difficult to be putted in practice.

This paper is based on an industrial case study in a motorcycle manufacturer company. The company is

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producing varies type of motorcycles through several processes such as machining, assembly, packaging and shipping.

The paper is structured as follows: Chap. 2 will describe about the case study followed by Chap. 3 which explain the approaches used in it. Chapter 4 will present the AS-IS state analysis. The concept development and evaluation will then be presented at Chaps. 5 and 6 will the conclusion for this study.

2 Description of the Case Study

Global demand for motorcycles is forecasted to increase 7.6% per year through 2013, spurred by rising standards of living in developing parts of the world, which are making motorcycles a more affordable alternative to walking, bicycling or using mass transit. The demand is expected to remain healthy for all categories of motorcycles [5].

To meet this demand, motorcycle manufacturers need to increase their productivity. More and more products need to be produced in a given time frame which leads the manufacturer to reduce their total production time. Assembly processes which most of the processes have been conducted manual nowadays in motorcycle industries show a lot of potential for time reduction.

Automation was introduced to increase the quantity by reducing processing time, to reduce the rate of waste and to reach a steady and higher product quality. However higher automation to increase productivity is limited because of complex assembly processes and problems with variants and numbers. Therefore, manual assembly is still the best practice in motorcycle industries.

Based on the difficulties in implementing automation into motorcycle assembly processes, a study named “Feasibility and economic analysis for advanced automation in spoke rim assembly for motorcycle” has been conducted by Department of Assembly Technology and Factory Management, Technical University Berlin with one of motorcycle manufacturer in Berlin. The objective of this study is to propose and develop automation concepts that minimizing the process time of the spoke rims assembly processes and meet the sustainability objectives. In order to achieve that, their economic feasibility, technical realizable, impact on environments and ease-of-use are analysed.

The main features of complex assembly systems which need to be analysed include business processes, their organisation, the resources used, and the outcomes. Seliger [6] introduces the factors of value creation networks as product, processes, equipment, organisation and people. In the scope of this study, spokes rims present the products that need to be assembled. Assembly processes cover all the assembly activities from the components till becoming a spoke rim. Resources and materials are used as equipment in the assembly processes. The organisation is planning and control of the assembly processes and qualification level and number of employees are considerably influence the performance of the assembly processes.

3 Systematic Approach

In developing concepts for the assembly of motorcycle spoke rim process that considered sustainability aspect, some methods are used to get an overall systematic approach, which include basic methods for general systematic approach, value benefit analysis for defining automation potentials and Methods-Time Measurement (MTM) for calculating number of workers.

3.1 General Systematic Approach

Pahl and Beitz methodology is chosen to be used as the baseline method, which is commonly accepted as a systematic design approach to concept evaluation. However, based on the original form, some augmentations are required to make it suitable for developing advanced automation concepts based on the existing assembly cell. Pahl and Beitz method consists of four primary phases: planning and clarification of task, conceptual design, embodiment design, detail design and overall design [7]. Within each phase, various steps are to be followed to properly complete the phase.

In order to make the approach suit the case study, only requirements list, function structures, working principles, working structures, concept design and evaluation process are chosen to be addressed. The systematic approach used in the advanced automation concepts development in spoke rim assembly is shown in Table 9.5.1 and described below.

i. Clarification of task

   The case study starts with AS-IS state analysis. Current assembly cell is clearly analysed based on process time, cost, working load and productivity. Based on that, the automation potential for each process will be given. Then the requirements list can be generated to define the goal in this case study.

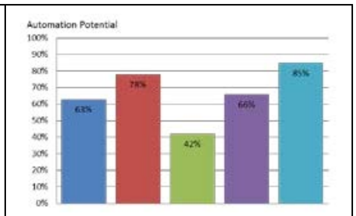
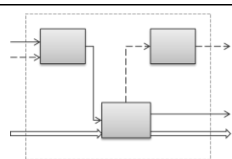
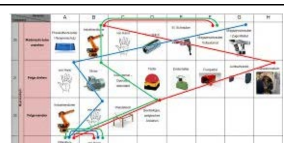
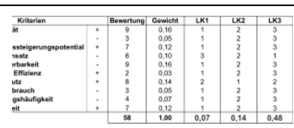
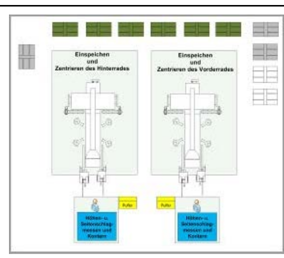
ii. Conceptual design

   Once the overall problem has been formulated, an overall function can be indicated based on the flow of energy, material and signal with the use of block diagram, which expressing the solution-neutral relationship between inputs and outputs. Subfunctions will be determined to facilitate the subsequent searching for solutions. The function structure of the assembly process is consisted with overall function and subfunctions. Preliminary concepts are formulated which base on AS-IS state analysis and focus on improving productivity. Based on the three preliminary concepts, probable working principles are searched for each function. With a logically and physically possible function structure, a combination of working principle can be made for each concept, ensuring the physical and geometrical compatibility. After firmed up into principle solution variants to satisfy the condition, an evaluation of the three concepts can be created based first on requirements list and then technical and economic criteria.

iii. Embodiment design

   From the chosen concept, a preliminary layout with machine placement and general material flow is developed, which leads directly to production.

Table 9.5.1 Systematic approach used in the case study

Clarification of task	AS-IS state analysis	
	Requirements list	
Conceptual design	Function structure	
	Working principles	
	Concepts working structures	
	Concept design and evaluation	
Embodiment design	Preliminary layout	

3.2 Value Benefit Analysis

As a multidimensional method integrating different perspectives, value benefit analysis is a useful tool for preparing systematic decisions. It integrates non-quantitative, so called soft, criterions which measure rather the effectiveness than efficiency of a solution [8]. In terms of this case study, such a method can be applied to analyse AS-IS state.

Eight criteria are used to evaluate the automation potential of each process: repeat accuracy (RA), positioning accuracy (PA), number of repeats (NR), current automation degree (AD), process complexity (PC), parts geometry (PG), parts orientation (PO) and parts mass (PM). The weights of each criterion will be established during the matrix in Table 9.5.2.

Table 9.5.2 Weights of criteria for value benefit analysis

	RA	PA	NR	…	PO	PM	Total number	Weight
RA	–	0.5	1.0	…	0.5	0.5	2.5	0.09
PA	0.5	–	0.0	…	0.5	0.5	2.0	0.07
NR	0.0	1.0	–	…	1.0	1.0	4.5	0.16
AD	1.0	1.0	0.5	…	1.0	1.0	6.0	0.21
PC	1.0	1.0	1.0	…	1.0	1.0	6.5	0.23
PG	1.0	0.5	0.0	…	0.5	1.0	3.0	0.11
PO	0.5	0.5	0.0	…	–	1.0	2.5	0.09
PM	0.5	0.5	0.0	…	0.0	–	1.0	0.04
						∑	28	1.00

Legend:

1.0	more important
0.5	equal
0.0	less important

3.3 Method-Time Measurement

As one of the motivation in this case study, increasing in labour cost has become a big challenge in current spoke rim assembly processes. For this reason, the number of workers is essential to be defined. Methods-Time Measurement (MTM) is a predetermined motion time system that used to perform the manual operation or task in the industry by means of analysing any manual operation into basic motions required to perform it and assigning to each motion a predetermined time standard which is determined by the nature of the motion and the conditions under which it is made [9].

Combined with the goal of increasing productivity, MTM-Analysis is used as the way to calculate the numbers of workers involved in the assembly process, see Fig. 9.5.1.

The number of workers calculation should be on the basis of both analysis of current working load and the prognoses of productivity increasing.

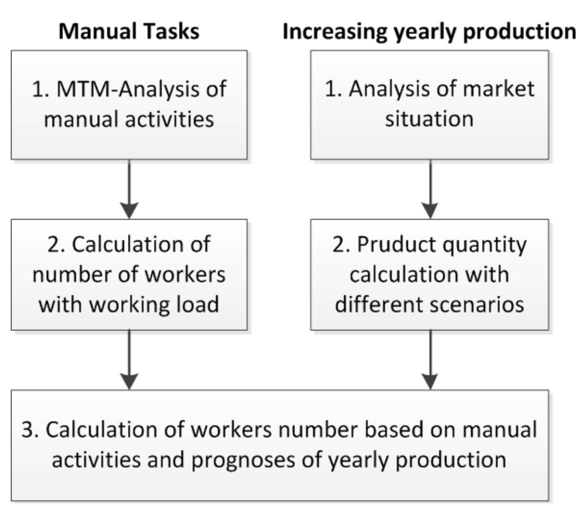


Fig. 9.5.1 Steps for defining the no. of workers with MTM

4 AS-IS State Analysis

For the analysis of the process flow in the case study, the data of the assembly processes is taken. The volume of activities and their times is analysed in detail for the current spokes rim assembly processes. Besides several visits to the assembly cell are done to have better understanding with the process. In order to simplify the complexity of the case study, a survey of some system features is helpful.

This can be done with the value creation factors introduced in Chap. 2 using the question method: where (assembly cell), what (spokes rim), how (assembly processes), when (date), and who (employees).

With a production number and demand around 17,000 rims per year, there are two size of rim assemble by the manufacturer. Size of 19” is for the front wheel and 17” size for the rear wheel. The spokes rim consists of five main components. The main components are rim, hub, spokes, nipples and stud screws as shown in Fig. 9.5.2 and Table 9.5.3. Both rims have 40 spokes, nipples and stud screws.

Fig. 9.5.2 Spoke rim components

There are four main processes in spokes rims assembly which are spoking, centring, testing and countering. The assembly process starts with spoking. Spoking is the process where all spokes are placed at the rim and connected to the hub. The placements of the spokes are done one another and alternately with screwing the nipples into it. The nipples are tightened at the centring process. During this process the same pressure is given to each nipple for making the rim centre.

Table 9.5.3 Spoke rim structure

Name	Wheel rim			
	Front wheel		Rear wheel	
	Size	Amount	Size	Amount
Rim	19”	1	17”	1
Hub		1		1
Spoke	19”	40	17”	40
Nipple	M4	40	M4	40
Stud screw	M4x5	40	M4x5	40

The centeredness of the spokes rim will then be tested. Testing process is done by using information technology (IT) system and sensors. Rework has to be done for a not centred rim. After completing the testing process, countering process will take place. During this process the stud screws are place inside nipples and be tighten. The complete rim will then transfer for the final assembly process. The overall spoke rim assembly processes are picture in Fig. 9.5.3.

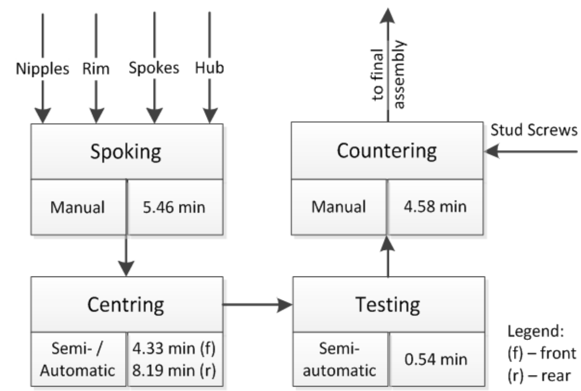


Fig. 9.5.3 Flowchart of the spoke rims assembly process

The entire process is located at the assembly cell area with 100 m^2 and contains eight working areas for the different process and activities of the assembly. Between 3 and 7 workers are assigned for the entire process depend on the demands and productivity. There are two parallel stations for each process. One station for the 19” rim and another station for 17” rim. Spoking process is done manually for both rim and takes 5.46 min. By centring process, the 19” rim is done by fully automated machine but the 17” rim using semi-automated machine. As a result the 19” rim needs 4.33 min for centring and 17” rim needs 8.19 min with one worker. This is the only process with different process times but if the centring process for 17” rim is done by 2 workers, the similar times will be gotten.

Testing process for quality control check just take less than a minute for both rim. This process is semi-automated process which is done by a worker with the help of IT system and mechanical sensors. Rims that pass the testing process will then go to the final process which is countering. At this process, a worker will places the stud screws ant tighten it up using counter principle. It takes 4.58 min for each rim. In total 14.91 min is need for assembly the front wheel 19” rim and 18.77 min for the rear wheel 17” rim.

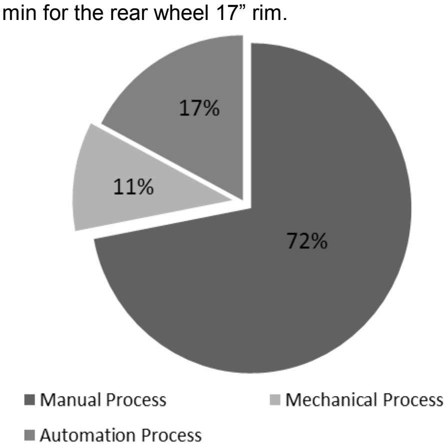


Fig. 9.5.4 Degree of automation in spoke rim assembly process

An analysis is done to define the degree of automation implemented in the current process. For this analysis the processes are breaking down into activities and the percentage of automated, manual and mechanical activities are calculated. Based on the calculation only 17% of the total assembly activities are done automatically. 11% are coming from mechanical assembly activities and the rest which is 72% are manual assembly activities. The degree of automation in current spoke rim assembly process is shown in Fig. 9.5.4.

By 72% of assembly activities are still manually operated, the chances for improvement are high. Two potential processes for the improvement which contribute more for total assembly time are spoking and countering processes. In terms of process complexity, spoking process has more complicated assembly activities compared to countering process. This left countering as the most potential process to be automated.

To support the statement above, a value benefit analysis is done based on criteria and weights explained in Chap. 3. The weight is given to each criterion by taking into account their importance from perspective of manufacturer and theoretical. Rating scale is established and fulfilments of the criterions for each process are evaluated. Then the value of benefit for each process is determined. The outcome from value benefit analysis is shown in Fig. 9.5.5.

Obviously, countering process is the most potential process to be automated. This is followed by centring process by semi-automated machine, testing process, spoking process and centring by automated process.

Referring to analysis done for AS-IS state, three concepts are developed and proposed. The feasibility of each concept will be analysed by economic and technical perspective. Estimation of investment and Return on Investment (ROI) will then be presented and explained.

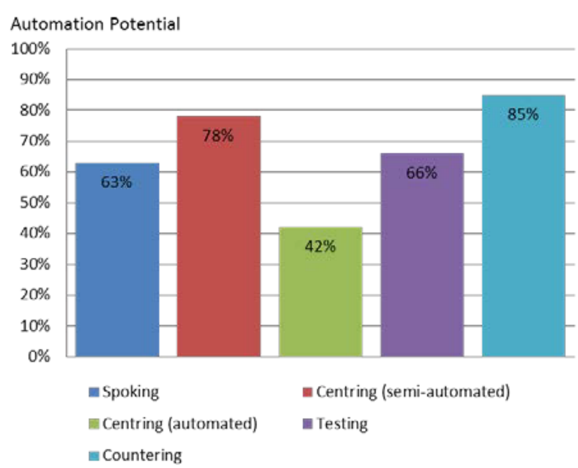


Fig. 9.5.5 Outcome from network analysis for spoke rim assembly process

5 Concepts Development and Evaluation

Concept development and evaluation process involve defining function structure, searching for possible working principles, combining suitable principles into concepts based working structures, concept design and preliminary layout.

After developing function structure and possible working principles and working structure, which are addressed in Table 9.5.1, three concepts will are proposed as follows.

Concept 1 aims at improving countering process, which has the highest automation potential according to AS-IS state analysis. According to the working principle selection, countering process can be fully automated instead of current fully manual operation by 4 measurements: purchasing a new full-automated countering machine, using automated spike to fix the rim in the new machine, assembling stub screws with robot and pasting the labels with labelling machine. Some small improvements are also applied to make the process much easier and more quickly, such as implementing a quick fixer to help fixing the nipples in spoking process, also using spike to fix the rim in both centring machines, that are all based on the working principles.

Concept 2 takes into account of the first two most potential processes, countering process and semi-automated centring process. With the main idea of rebuilding the semi-automated centring machine to an automated countering machine, the countering process will be improved into semi-automated process. The measurements in manual part of countering process are using strain-relieved screwdriver with magnetic attachment and automated screw feeder. Meanwhile, a new automated centring machine is purchased for rear rim. As the same improvement for other processes in concept 1, some small changes of processes will also be used, like implementing quick fixer to fix the nipples in spoking process. This concept focuses on using existing machine to reduce the cost of rebuilt and meanwhile increases automation degree to improve the productivity.

Concept 3 focuses on joining testing process with both front and rear rim centring processes. Process time will be highly reduced and thus productivity can be increased by purchasing a new automated centring machine with testing and after-centring function for front rim and upgrading the existing automated centring machine with testing and after-centring function for rear rim. Also, some other improvement will be implemented such as fixture the rim with spike in centring machine.

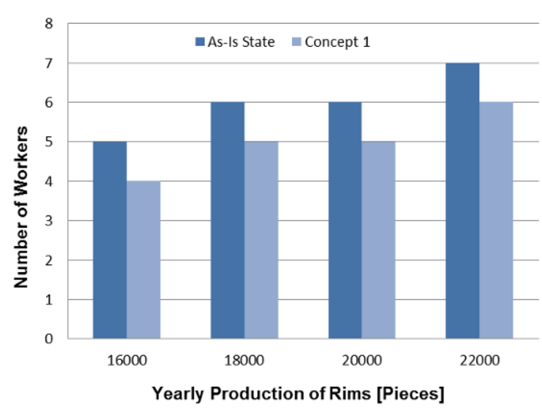


Fig. 9.5.6 Required workers according to yearly production

As addressed in Chap. 3, MTM is used to define the number of workers that combined with production quantity. The comparison of AS-IS state and concept 1 along the change of yearly production as an example is shown in Fig. 9.5.6.

With these 3 concepts, process time and working time will surely be shorter than current assembly process. The exact time of reduction for the whole process during each concept is estimated, this will lead to a reduction of production cost. Fleschutz [10] demonstrates that the energy consumption during use phase of an articulated robot system contributes about 90% to the global warming, while in assembly automate system it only take up 20% of the potential. With ecological view of point, robot system has much worse influence to the environment. Totally, the benefits of these measurements from the 3 concepts can be summarized in Table 9.5.4 below.

Table 9.5.4 Summary of 3 concepts

		Criteria	Concept 1	Concept 2	Concept 3
Sustainability aspect	Economy	Reduction of workers	1	2	1
		Reduction of cost [€/year]	180,000	360,000	180,000
		Reduction of working time	26%	48%	29%
		Reduction of process time	16.14% (f.) 16.76% (r.)	8.36%	9.12%
		Estimated investment [1000 €]	500–600	800–900	1,100–1,200
		Period of amortization [year]	3	2.3	6.2
	Ecology	Global warming potential	Medium	High	Low
	Society	Ease-of-use	Medium	Low	High

Evaluation of these three concepts is based on the sustainability requirements. As addressed before, evaluation should lay on economic feasibility, technical realizable, impact on environments and ease-of-use. From the summary of proposed concepts, the largest reduction of cost comes from concept 2, even it has the lowest reduction of process time. For the estimated investment, concept 2 doesn't have too much superiority as concept 1. But with the shortest period of amortization of 2.3 years, concept 2 will be the best choice from economic aspect. From ecological view point, concept 2 will contribute more to the global warming because of the use of robot. The ease-of-use aspect is evaluated according to the professional requirement of testing and countering process.

6 Conclusion and Future Work

Motorcycle spoke rim assemblies depend more on manual work than automation. With the challenges of rising labour cost and productivity requirements, automation technology is needed. Based on the case study "Feasibility and economic analysis for advanced automation in spoke rim assembly for motorcycle", a systematic approach is presented in this paper to develop the concepts and evaluation in selecting the most feasible, realizable and sustainable concept. The concepts are developed to ensure profitability and continuity of the company. Referring to the AS-IS state analysis of spoke rim assembly cell, three concepts with detailed implementation methods are proposed with systematic approach, value benefit analysis and Method-Time Measurement. After an evaluation based on the sustainability requirements the most feasible and realizable concept is proposed for motorcycle spoke rim assembly. Future work will concentrate on the detailed evaluation of the concepts, e.g. weight of criteria, exact cost of investment.

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9.6 Energy and Cost Efficiency in CNC Machining from a Process Planning Perspective

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Abstract
The role of process planning as an enabler for cost efficient and environmentally benign CNC machining is investigated in the paper. Specific energy is used as the principal indicator of energy efficient machining and different methods to calculate and estimate the specific energy is exemplified and discussed. The interrelation between process planning decisions and production outcome is sketched and how process capability can be considered as one factor of green machining is assessed. A correlation between total machining cost and total energy use is presented for an experimental machining case. A general conclusion is that in order to be able to draw general conclusions, the importance of having reliable data during process planning to make effective decisions is essential.

Keywords:
Cost efficiency, Energy efficiency, CNC machining, Green manufacturing, Process planning

1 Introduction

Changing demands and requirements from customers, governmental regulations and changing competition impose partly new areas of competition for many companies. Today not only quality, flexibility, time and cost requirements are to be met, but also increasing demands on environmental impact. To achieve sustainable production, both demands of traditional economic focus as well as environmental must be fulfilled. For economic performance a variety of indicators are used based on cost, time and quality on different levels in the production system. It is essential to define criteria, indicators and methods to enable more environmentally benign production, in this work focused to CNC machining. Basically environmental improvements of CNC machining can be achieved through technology development or through the use of more effective methodologies. Process planning is vital for this move to take place. Zein et al. [1] listed 124 improvement measure for making energy saving in CNC machining. Forty percent of these relate to improved machine tool design while 22% measures relate to energy demand reduction through improved process design [1]. It is the latter 22% that relates to process planning and consequently being investigated in this work.

Decisions made during process planning, to a large extent dictates the production outcome, such as lead times, quality levels, process capability, but also energy use and the environmental impact of the goods production. Herrmann et al. [2] states that both green manufacturing and lean production share many similar basics, where the elimination of waste is the major commonality. Waste can basically be regarded as a consequence from low process capability.

Process planning is a key function to realise products that fulfil defined requirements. However, it is important to provide the right knowledge to process planners. It can be in the form of analytical models, data, experience, which can be spread through the use of best practice cases or workshops.

However, to achieve advancements that results in real reduction of environmental impacts, methods and strategies must be developed and communicated. It is in this aspect also important to add the economic aspects as well, to gain industrial acceptance. A previous study presented the effects that increasing electrical energy prices potentially can have on the total cost of CNC machining [3]. It concluded that electrical prices are not high enough to pose any particular need for making radical energy savings in CNC machining. However, real cost savings can be made as a consequence from time savings. If production output can be increased due to optimised machining parameters, cost and energy savings can concurrently follow. However, depending on the need for manual work in CNC machining, future increased costs of electricity can play an increasingly important role of the total machining cost. The trend towards increased automation (and the use of FMSs etc.) will accordingly cause cost of energy to stand for a larger proportion of the total machining cost.

1.1 Process Planning for Sustainable CNC Machining

Sustainable production can in general be considered to include the following aspects, which in a significant way are influenced by decisions made during process planning:

- Cost (Labour, machine tools, cutting tools—as function of machining time)
- Environment (Energy use, materials and process emissions from usage of cutting fluids)
- Quality (Process capability, scrap rate, in process control needs etc.)
- Lead time (Material removal rates, reduced set-up times—hence decreased standby times)
- Flexibility (Routines, KBE, competence)

It is important to understand the interrelation between different machining factors, decisions, constraints etc. and their respective influence on the machining outcome.

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1.2 Research Questions

The following questions are investigated and discussed is this paper:

- How can lyprocess planning create more environmental friendly machining operations, in terms of energy use?
- Which are the main factors and what is their respective importance when designing CNC machining processes for energy efficiency?
- What are the analogies between process designs for cost efficiency versus energy efficient CNC machining with respect to machining parameters?

2 Specific Energy as Energy Efficiency Measure

There are principally two types of specific energy; one is the direct specific energy to remove material, which can be named *specific energy on process level*. This value describes the energy per volume unit required to physically form a chip and thus remove the material. Data on this specific energy can be found in handbooks, calculated analytically or measured by using piezo-electric dynamometers directly mounted on the cutting tool holder in turning operations or on the work table in a milling and drilling machines. In order to get a realistic energy use of the machine tool, this value must be corrected by assigning a corresponding specific energy or the efficiency (η) for the machine tool. The specific energy on process level is calculated using Eq. 9.6.1, where F_C is the cutting force, b width of cut and t the undeformed chip thickness (function of feed rate and entering angle).

However, the specific energy can also describe the energy that must be fed to the machine tool to remove material. Equation 9.6.2 expresses the specific energy when the machine tool power, P is used. P is divided with the MRR for the current operation. One problem with this value is that only the machining activities are regarded. Non-removing work (MRR = 0) is not captured, which makes this measure most suitable to use when different operations are evaluated against each other.

To find the effective specific energy, that most comprehensively describe the whole machining process, the total energy, E (as can be extracted from a power/time plot) can be used, which is related to the total volume of removed material. This value will include all non-value adding activities necessary to machine the component (e.g. spindle start, repositioning of tool, enter and exit of cut etc.), see Eq. 9.6.3.

$$u_1 = \frac{F_C}{b \cdot t} \quad (9.6.1), \quad u_2 = \frac{P}{MRR} \quad (9.6.2), \text{ or } \quad u_3 = \frac{E}{V} \quad (9.6.3)$$

Figure 9.6.1 provides an overview of the different methods to use in order to calculate the specific energy. Most relevant from an environmental perspective is to calculate the total energy use required to machine the intended feature. This means that only studying the cutting process isolated from other factors (i.e. machine, auxiliary systems) will not be sufficient. If the power is measured directly in the process (as described above), the value must be corrected to the specific machine specifications, which requires measured values of machine efficiency, machine supplier data on efficiency or estimates from tables or analytically derived. Kara and Li [4] developed machine tool models for different machine tools, which predicts the specific energy as a function of MRR. These models can be useful to estimate the actual energy use of a machining process during process planning to evaluate different machining strategies. However, since machine tools are complex, with many subsystems, a generic machine tool model is difficult to derive. To this adds the many possible combinations of materials, machining parameters, use of different amounts of cutting fluids etc., which makes modelling complex.

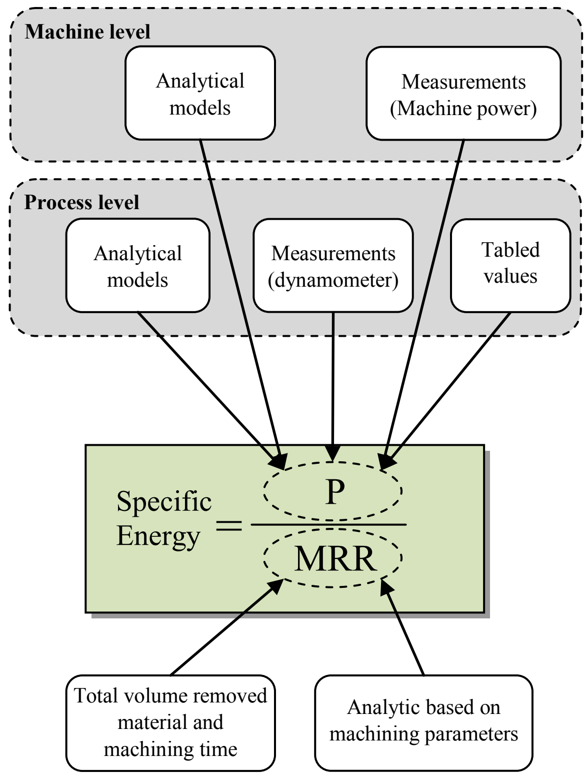

Fig. 9.6.1 Overview of different methods to calculate specific energy

Roughing (and roughing with surface finish demands) and finishing influence the possibilities for green machining, since surface roughness requirements constrain the machining process, i.e. higher MRRs are not allowed, especially high feed rates. Due to the behaviour of the specific energy as a function of MRR, where the hyperbola curve converges towards higher MRR, the full potential of machining with high MRR and limiting the increase rate of specific energy cannot be utilised. It is however difficult to generalise the possibilities, since it depends on the actual surface finish requirements and the governing parameters of specific energy.

3 Results and Discussion

From a process planning perspective it is efficient to have reliable knowledge repositories where data regarding tooling, machining parameters, machine capability, and in a green machining perspective also data regarding machine tool power profile, material data (specific energy), embodied cutting tool energy to be able to make effective and informed decisions. Process planning performed by humans, which is the dominating mode in the industry does not differ from more computer-based approached to process planning (e.g. CAPP), since no matter what mode of process planning, the need for accurate and reliable data is the fundament to enable effective decisions.

The most effective indicator of green machining is the total energy used by the machine tool and necessary auxiliary equipment in relation to the volume of total removed material volume, which in effect is specific energy.

As discussed in the introduction, to be able to make effective decisions during process planning it is vital to have accurate data and information. The following sections aim at highlighting a few areas which are of importance, where results are achieved, but more research activities are needed as well so that generic conclusions can be drawn.

3.1 Results from Modelling Machining Cost and Energy Use

Results from the experiments (shortly described hereunder) to test the machining cost model (see Ref. [5]) showed that it is not the cost of energy that is governing energy efficiency improvements, but better utilisation of the machine and increased production rate. These are important learnings for the process planner when optimising the machining process for environmental impact as well as minimised production costs. The model is based on handbook formulas for machining cost estimations, but extended with costs for direct and indirect energy consumption. Experimental data was gathered from turning a simple part of mild carbon steel using different machining strategies, where the machine power and tool wear were measured. The different strategies include alternated feed rates and depths of cuts. The model and results are more in depth presented in Ref. [5].

The same model is used here as the fundament for the analysis, but extended to also include the embodied energy use for manufacturing the cutting tool insert, which was omitted in the first study. The first study gave the result that the most energy efficient machining was found towards higher MRR, no local minimum was found to exist as was for the machining cost. This analysis perspective can be defended since it corresponds to the situation where the workshop itself is isolated from the overall supply chain, where the energy use is quantified only based on the electric power from the socket. In order to widen the scope to also study the general environmental impact from machining operations, this approach has its limits, since the environmental aspect of tool wear must be included as well, since excessive tool wear must be considered to constitute a negative impact on the environment, not only cost. The total embodied energy in cutting tools was modelled by using figures from Dahmus and Gutowski [6] where the carbide production was stated to require 400 MJ/kg and different coating techniques (PVD, PCD) require 1–2 MJ per coating process and insert. With a weight of 4.0 g for the insert used in the experiments, the

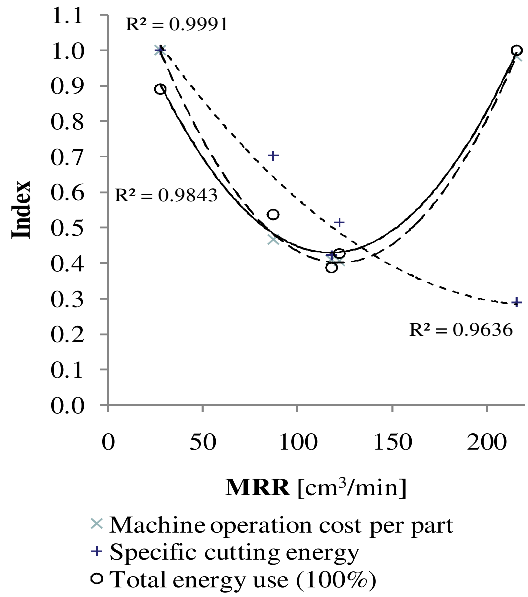

Fig. 9.6.2 Relation between machining cost, total environmental energy use, specific cutting energy

embodied energy in the cutting tool is found to be 0.60 kJ/edge (with an insert of six cutting edges and if the higher value is used). The result is plotted in Fig. 9.6.2. With increasing embodied energy in relation to MRR, the optimum of the *total electrical energy use* curve will move towards the left side. With decreasing embodied energy, and possibilities for higher MRR, the optimum will instead move towards the right, more resembling the specific energy curve of machining operations.

3.2 Capability and Level of Quality

The level of quality is vital for the overall environmental impact of machining operations. A scrap rate of 10%, will lead to an overproduction of the same proportion, with all the environmental impact that the machining operation has. Quality problems in machining operations stem form a number of causes, e.g. excessive tool wear, chip breaking, vibrations etc. Astakhov [11] states that ensuring reliability of cutting tools are important from a cost perspective, since it reduces cycle times, human errors and need for rework. The same holds true from an environmental perspective as well.

As was stated in the introduction, waste is the result of poor process capability and can be caused by inappropriate machine choice for the current part, tooling, machining parameters, clamping etc. All of these factors results in unnecessarily high scrap rates or rework rates. In this perspective the use of process capability indices (PCIs), such as C_p and C_{pk} can be indicators of environmental performance alongside quality levels and performance of the production system.

Figure 9.6.3 illustrates the relations between different aspects of machining outcome in relation to process planning decisions on machine tool, tooling, machining parameters. It is clear from this figure that many aspects of machining are interrelated. Where e.g. low process capability definitely influences both quality levels, overall

Table 9.6.1 Machining factors and their relative importance on energy use (values are based on handbooks, scientific papers etc. and formatted to fit the unit kJ/cm^3)

Factor specific energy	Machine tool	Workpiece material	Machining parameters	Cutting tool	Auxiliary equipment
Factor ratio (max/min of nominal values)	~7	~7	~3	~2	~10
Observed typical nominal values	0.74–5.45 (kJ/cm^3) (standby milling) Ref. [4]	2.1–2.8 (kJ/cm^3) (low alloy steel) Ref. [7]	1.5–4.0 (kJ/cm^3) (SS 1450) Ref. [7]	4.8–7.3 (kJ/cm^3) (diff. rake angles) Ref. [8]	1–10 (kJ/cm^3) (5.6–9.5 (kW) sum aux. syst.) Ref. [9]
	1.16–1.77 (kJ/cm^3) (standby lathes) Ref. [4]	1.1–1.8 (kJ/cm^3) (cast iron) Ref. [7]	1.9–4.8 (kJ/cm^3) (SS 2244) Ref. [7]	20.8–23.3 (kJ/cm^3) (micro milling) Ref. [10]	
		2.3–3.0 (kJ/cm^3) (stainless steel) Ref. [7]	1.8–3.2 (kJ/cm^3) (SS 1550) Ref. [7]		
		3.0–3.7(kJ/cm^3) (heat res. alloys) Ref. [7]			
		0.5–1.0 (kJ/cm^3) (Aluminium) Ref. [7]			

process cost as well as the environmental impact. More in depth analysis of process capability from a process planning is found in Anderberg et al. [12].

3.3 Different Machining Factors' Impact on Specific Energy

As mentioned in the introduction, specific energy is chosen as an indicator of environmental performance of machining operations. However, it can be confusing and difficult to relate various factors influence of the total specific energy for a certain machining operation. Table 9.6.1 compiles values of the most important factors governing the magnitude of the total specific energy. The objective of the table is to create an overview of the ruling factors and their variation in contributing to the magnitude of the specific energy, which can be helpful when different options are being considered during process planning. It also aims at illustrating the complexity and the importance of having reliable data for the current machining set-up, since the resulting process can require a significantly higher energy use if some the factors are overlooked. As seen, to only regard the machine tool and neglect the workpiece material can lead to erroneous decisions, since the specific energy to remove different types of materials can approximately vary by a factor 7. Likewise to neglect machining parameters' influence on specific energy can lead to poor process designs, both from cost and energy efficiency perspectives.

Interesting to note is that extremely high values of specific energies can be reached when machining at extremely low MRR. This is the case for micro machining [10] and machining of difficult materials such as Inconel 718, which could generate 12 fold ratios (as is seen in Beno et al. [13]).

The values in the table are based on published works and the compilation should by no means be considered complete. However, the tendencies should be representative for the actual situation. The factor ratio describes the uncertainty and can be interpreted as a worst case scenario that if the factor is overlooked, its intrinsic effect can change by a factor (e.g. 2, 3 or 7). The respective importance of each factor's influence of the total specific energy use for a specific operation is difficult to generalise, since it depends on the type of operation (micro machining, finishing, roughing etc.) where the machine tool in some of these cases stands for the proportionally large part. The factor ratio is calculated as the ratio between the largest and smallest value in each respective column. Each column describes typical values for each factor, where for the workpiece material states different materials, and within each type of material the typical specific energy values are stated, e.g. low alloy steels nominally range between 2.1 and 2.8 kJ/cm^3.

From the above, the conclusion can be drawn, that in order to make effective decision during process planning, accurate data is important. Otherwise, faulty decisions are likely.

3.4 A Green Machining Strategy

In order for the industry and the individual company to advance towards more environmental friendly production, a green machining strategy should be developed. Figure 9.6.4 shows how such a strategy can be designed and here illustrated for the industry at large in the perspective of process planning and research and development initiatives both in academia and industry. The parameters that can be influenced mainly by the process planner are located on the left side. To work with these aspects is more of picking the low hanging fruit, but as shown in various models and experiments, the achievements can be considerable; hence these efforts should not be overlooked. Towards the right side of Fig. 9.6.4, more research and development of equipment must be carried out in order to achieve results.

Some activities are joint efforts, as can be seen by the overlaps and some results are more immediate, whereas other can only be acquired through future development work. As has been highlighted in this paper and other papers on the topic, there are many things to do as a process planner to move towards green machining, which do not require extensive efforts to be achieved.

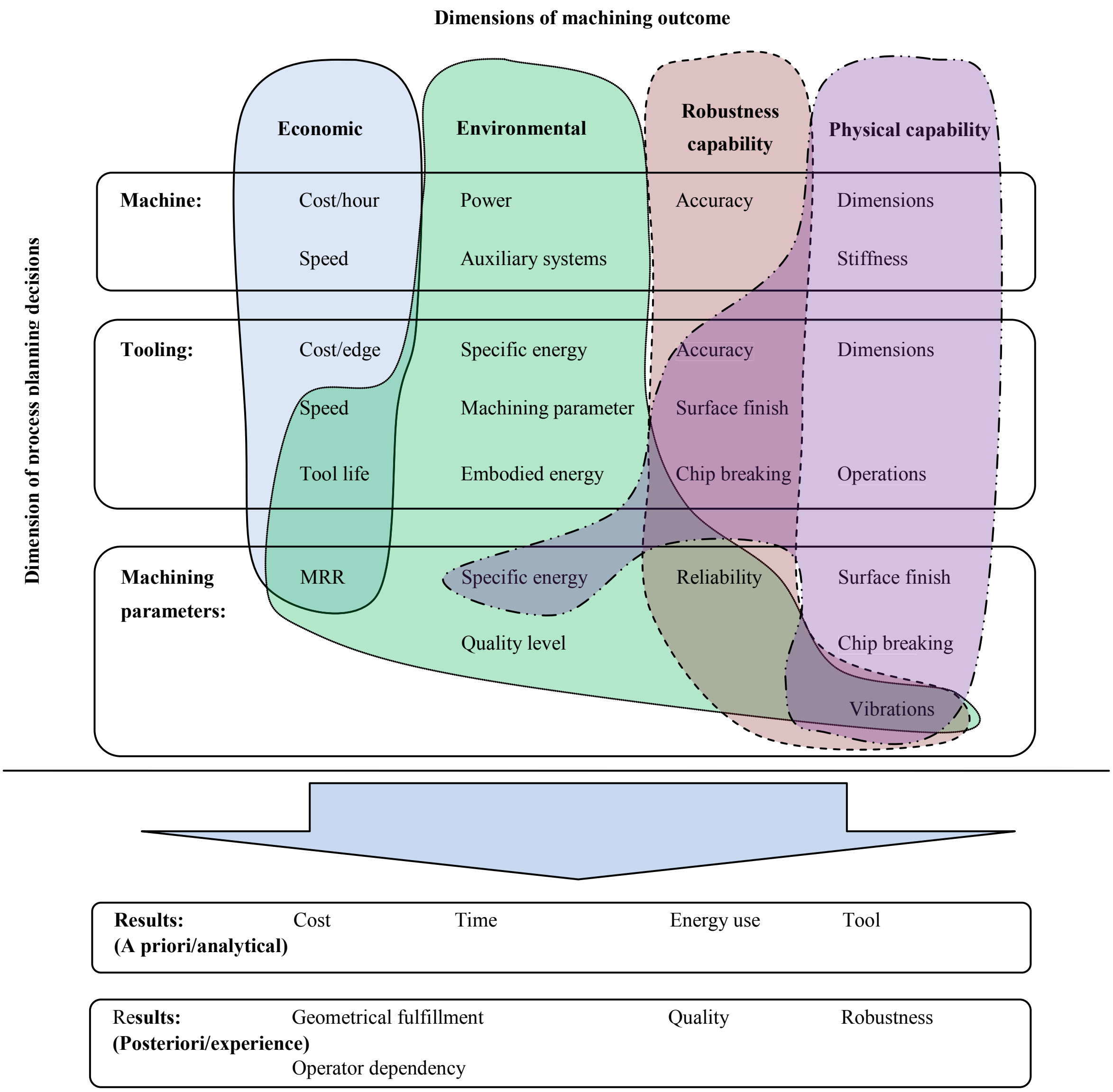

Fig. 9.6.3 Relations between process planning decisions and machining outcome

3.5 Further Research Efforts

From the above reasoning, a number of difficulties were discussed, which need further research efforts before effective solutions can be presented:

- More accurate data on the factors that constitute the specific energy are needed, which can be based on experimental data or analytical models (which today are often complex and non-generic).
- Material databases (specific energy as a function of machining parameters, preferably in the form of 3D surfaces for feed and cutting speed as presented in [13])
- Dry and near dry machining solutions can potentially decrease the specific energy, but further work is needed to understand the real savings (environmental and cost wise) and which are the trade-offs in the form of surface roughness problems, tool wear, process capability etc.

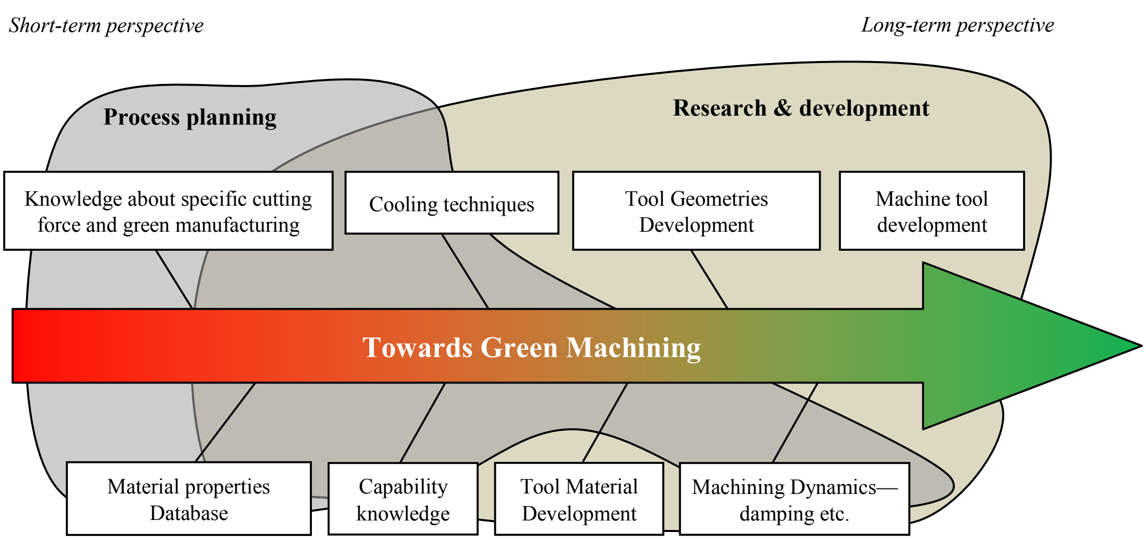

Fig. 9.6.4 A green machining strategy

4 Conclusions

A number of areas of CNC machining for cost and energy efficiency have been highlighted and discussed from mainly a process planning perspective. Specific energy was used as the principal indicator of energy efficiency and greenness of machining operations. The following issues were raised in the paper:

- The relations between different machining outcomes in relation to process planning decisions.
- A correlation between total machining cost and total energy use was shown for an experimental case.
- The importance of having reliable data to predict machining outcome, which was indicated by compiling observed values of specific energy in relation to different influencing factors.
- The process capability's influence on green machining.
- A green machining strategy was presented as a mean to enable a move towards more environmentally benign machining.

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9.7 The Pricing in Mobile Phone Networks and its Implementation in Russian Practice

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Abstract
It's obvious, that conscious implementation of a pricing systems can lead to the prosperity of a company. The aim of this work is to show that the pricing can be considered as a good thing for the society as well. The tariff policy of one of the key Russian mobile providers was analyzed. The paper contains the contemplation of eight current tariffs of the provider Beeline which operate on the territory of St. Petersburg and Leningrad region. Considering such needs as: frequent long conversations for students or inexpensive sms-communication for people with limited hearing abilities Beeline offers attractive and reasonable tariffs. Establishing various prices for one minute or message, not only does Beeline try to maximize the profit but it also identifies its customers. That is why prices absolutely do not need to be the same for all consumers, because equality is not always the advantage.

Keywords:
Pricing, Mobile phone networks, Beeline

1 Introduction

Being successful on the market means to win the competition. It is not easy nowadays, so companies try hard using variety of methods and strategies. Pricing is essential and one of the most fundamental ways a company uses to affect the market situation. So it is obvious, that effective implementation of a pricing systems can lead to the prosperity of a company. However the aim of this work is to show that the pricing can give advantages to the society as well.

In order to achieve this goal the work contains the analysis of pricing policy of the provider Beeline, which is one of the leaders in the mobile market in Russia. The eight current tariffs operating on the territory of St. Petersburg and Leningrad region were considered. Each of them is meant to satisfy the needs of a particular group of consumers.

2 The Tariff Analysis

The first one is called «Универ», which in Russian means «The University», so it is to be focused on students and their demands. The main issue of the tariff is that the one-minute price depends upon the whole length of your conversation. This means that the 1st minute costs 1, 5 Ruble, but from 2nd to 30th minute you are to pay only 15 Kopeks (1Ruble = 100 Kopeks).

Being a student I can definitely say that Beeline estimates our lifestyle right, because our everyday calls are supposed to be frequent and rather lasting, far longer than 1 min for sure. However for the provider such pricing also makes sense, as from the 31st minute the customers have to pay 1, 5 Ruble per minute again [1].

So we can see that this pricing is reasonable for both sides: for the company and for the customer.

What also makes this tariff interesting to analyze is the fact that becoming the consumer of the product is possible only for students. The procedure of buying requires documents proving that you are a real student. It was made likely to fulfill company's interests more than customers, but it doesn't make the tariff less desirable for students.

The second tariff that was found is called «Областной» reflects the needs of people who live in suburbs not far from the St. Petersburg. For them calling from the Leningrad region is much cheaper than calling from the city, which is doubtlessly a benefit for this group of customers. That it is: suburb calls costs 45 Kopeks per minute whereas city ones—1.45 Rubles [2].

In this case we see exactly the same situation as in the previous example. Beeline differentiates the market according the particular customer demands and provides them with the appropriate supplies.

The money you pay for the mobile communication can also depends upon the destination. The tariff named «Международный» («The International one») provides variety of prices. So if you call European countries you are to

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pay 7, 95 Rubles. Countries like Canada, USA, Turkey, India, China, Israel, Egypt, Vietnam, Cambodia and SNG Group countries cost you 4, 95 Rubles. However the most expensive calls waits for you if you call so-called «Rest countries», because 1 minute is 40 Rubles [3].

So we can see that this tariff might be useful for businessmen or travelers, who need to be on the phone no matter where they are.

Children are considered as children only by their parents. For the market they are only special consumers with their special requirements. In this way the tariff «Детский» («The one for a child») should be mentioned. This one is interesting because it offers a range of unusual opportunities.

For example, if your mobile account goes below zero you still can make calls, until it reaches −30 Rubles. For children it's rather reasonable because they cannot always count money well, may forget, etc.

Another opportunity is that for each incoming call your account gets 30 Kopeks as a bonus [4].

Someone might say that it is too cynical to involve children into market, but nowadays it happens all the time. We can see that in the tariff their needs represented well. So if through this the company expands its customers, it only means it has done a good job.

The very special feature of modern communication is the communication through sms equally loved by teenagers and grown-ups. To meet this interest Beeline uses the practice of «SMS-boxes» almost in every tariff. For example tariff «Свободный стиль» («Free style») [5].

The amounts of the «boxes» are standard: 25, 50, 100, 300 and 1,000 smses. The reason to buy one is that the bigger your box is the less you have to pay for each sms.

However not for all people sms communication is just the favorite activity, for some it is a real necessity. There is a special tariff called «Со-общение» («Communication») for physically challenged people who have hearing problems. This tariff is oriented on sending sms, so they are the cheapest of all. The first 1,000 sms of month cost 45 Kopeks per one message, from 1,001—cost 2 Rubles [6]. It's important to highlight that establishing such tariff, not only does the company expand the customer field, but also resolves the social issue helping people who need support from the society.

The last two tariffs analyzed may appear to have no special customers as all previous ones, but it is not that simple. They are «Просто» and «Монстр общения 2011» («The simple one» and « The Monster of communication 2011») [7]. The point is that they contain no particular features representing the needs of a narrow group of customers. They can be called universal as they offer value for money in calling for people who do it quite often.

Having this sort of tariffs allows Beeline to cover the rest of the market niche; that is customer group without any kind of specific demands. As a rule there are many consumers who cannot be fitted exactly in any group. That is why the offer of such tariffs is rather sensible.

3 Summary

In conclusion of the work it is necessary to say that for Beeline the idea of flexibility and adoptability in pricing really makes sense. Through effective pricing differentiation it identifies more and more customers. Someone might say that it is unfair practice of price discrimination. However the only answer to them is that consumers receive their bonuses and eventually win together with the company. So we can see that in this case pricing is the form of a successful agreement between the society and the company. That is why prices absolutely do not need to be the same for all consumers, because equality is not always the advantage.

4 References

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