EcoProduction.
Environmental Issues in Logistics and Manufacturing

Pawel Pawlewski
Allen Greenwood *Editors*

Process Simulation and Optimization in Sustainable Logistics and Manufacturing

Springer

EcoProduction

Environmental Issues in Logistics and Manufacturing

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The EcoProduction Series is a forum for presenting emerging environmental issues in Logistics and Manufacturing. Its main objective is a multidisciplinary approach to link the scientific activities in various manufacturing and logistics fields with the sustainability research. It encompasses topical monographs and selected conference proceedings, authored or edited by leading experts as well as by promising young scientists. The Series aims to provide the impulse for new ideas by reporting on the state-of-the-art and motivating for the future development of sustainable manufacturing systems, environmentally conscious operations management and reverse or closed loop logistics.

It aims to bring together academic, industry and government personnel from various countries to present and discuss the challenges for implementation of sustainable policy in the field of production and logistics.

Pawel Pawlewski · Allen Greenwood
Editors

Process Simulation and Optimization in Sustainable Logistics and Manufacturing

Springer

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Preface

In order to succeed in today's highly competitive business environment, organizations strive to effectively balance financial and social performance. Oftentimes, they do this by improving the design and operation of key processes in manufacturing, service, logistics, and basic business functions. These changes need to be evaluated based on both shareholder needs and those of society.

Making these change decisions involve understanding both the organization, which is a complex and dynamic system, and the environment in which the organization must function—also complex, dynamic, competitive, and oftentimes global. One means to help organizations cope with complexity, better understand their system, and make better decisions is through the use of models, such as simulation and optimization models. Model-based decision making enables the testing of ideas and alternatives virtually—this provides an understanding of the consequences of a decision before it is implemented. The use of models also expands the decision space, and is not disruptive to the real system.

Simulation involves developing a model or representation of a real system, using the model to conduct experiments and analyzing the impact of proposed changes on system performance. Simulation is oftentimes used to assess performance before the system actually exists. By its very nature the process of simulation is sustainable in that it conserves resources and reduces risks. However, simulation by itself, and when coupled with optimization, provides a powerful means to understand a system's behavior and performance, the interactions of its components, its dynamics, the influence of variability, and the effects of changes in system parameters, policies, and the environment.

This monograph brings together a cross-section of articles that present ideas and applications of how simulation and optimization effectively support the design, analysis, and management of sustainable manufacturing and logistics systems. It is composed of 12 reviewed chapters divided into four parts.

Part I includes six chapters that illustrate how simulation modeling supports the analysis of sustainability in manufacturing systems including: the design of a new production facility considering safety, environmental protection, and cost; the definition and evaluation of a variety of measures of production-logistics systems; a methodology that is validated and evaluated through simulation for analyzing alternative strategies in organizations that offer a wide variety of products and employ diversified customer services; a study, through the use of simulation, of the effects of key parameters of an order-leveling technique (Heijunka, intending to reduce fluctuations in the productions process); the analysis and assessment of stability and risk in production systems through modeling and simulation; and, the optimization, through simulation, of the operation of a production process with a focus on energy consumption.

Part II includes two chapters on other types of production systems. The first chapter illustrates how simulation can be used to address transportation concerns in the mining industry; the second chapter describes the formulation and use of an optimization model to aid with biomass co-firing decisions in coal plants considering emissions, plant efficiency, logistics costs, and capital investments.

Part III also includes two chapters—they describe how simulation and optimization can be used to address issues, including sustainability, beyond the enterprise—to the supply chain. The first chapter uses simulation to study the effect of the level of supplier flexibility on total order lead time and variability in total lead time; the second chapter assesses the effect of various types of disturbances or interferences (e.g., related to means of transport, route, driver) on the functionality and sustainability of supply chains.

The final part describes two cross-disciplinary methodologies that support the use of simulation to analyze and enhance production and logistics systems. The first chapter uses the IDEF0 methodology to enhance the general simulation modeling and analysis process; the approach is demonstrated through a healthcare application example. The second chapter describes an approach that has effectively been used to transform university-based student simulation projects in manufacturing and logistics into business projects.

We are indebted to our authors and reviewers for their outstanding contributions and assistance in preparing this work.

Pawel Pawlewski
Allen Greenwood

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Part I
Manufacturing Operations

Simulation Method for the Benefits of a Small Business in Sustainable World

Grzegorz Wróbel and Joanna Oleśków-Szłapka

Abstract This chapter presents a process of modeling and designing a new manufacturing for a small business by means of simulation methods. Legal regulations are used to develop the principles of work organization, production processes and plant layout. The project also used simulation standards resulting from the family of ISO 14000 standards on environmental management. The objective is to explain if investor is moving to a new facility he will be able to find out new opportunities of operations in a new place under certain financial, technical and legal constraints. The simulation refers to the production and storage areas in given company. The project was also to identify those areas where there is a risk of incurring very high costs and the formation of waste arising. Simulation work and design of production activities identified areas of possible limitations of cost and waste and propose how to solve these problems.

Keywords Manufacturing system • Simulation • Environmental requirements • Health and safety

1 Introduction

The construction of a new industrial plant and expansion of existing operations is a challenge for a small business. It is necessary to focus on issues and problems that have not been considered in the current activity. These are issues related to both

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the organization of production in the industry covering the functions of production, storage, transportation and administration as well as the related requirements and concepts in the field of environmental protection and work safety.

By increasing the scale of the business venture investor often is unaware of these requirements and problems that may surprise him within ongoing transformation. Patternmaker and process analyst helping entrepreneurs should therefore pay attention to the aspects of environmental protection and safety at work in the newly planned industrial environment, in order to avoid unnecessary problems during audits. First of all they must prevent dangerous incidents affecting the environment and human security.

Versatility and variants of design and production planning issues makes it possible to reduce costs and increase the competitiveness of the system using modeling and simulation techniques (Zarządzanie produkcją 2006).

The advantages of using simulation are contained in four categories: feasibility, cost avoidance, design details and operational activities (Beaverstock et al. 2013).

Thus the questions of environmental protection and Health and Safety identified in the process of modeling and analysis assume the nature of the benefits associated primarily with avoiding the costs of accidents at work and penalties for environmental pollution.

Hereby article describes a process of preparing and execution of the project for a new manufacturing hall for a small entrepreneur by means of simulation methods including above mentioned norms and instructions.

2 The Basic Requirements of an Environmental Protection and Work Safety in the Manufacturing Company

The requirements for an environmental protection and work safety are rooted both in the regulations of the European Union and in the current Polish regulations among other things related to:

- The need to meet emission standards with respect to the amount and type of pollutants produced in industrial processes;
- The dealing with disturbances and breakdowns in processes or operation of protective devices;
- Cases where it is necessary to conduct measurements of concentrations of pollutants in waste gases and the scope of these measurements.
- In terms of national rules and regulations main the following:
- The Regulation of the Minister of Labour and Social Policy on 26th of September, 1997 on the general safety and health at work[1];

[1] Journal of Laws from 2003.

- The Regulations of the Minister of Infrastructure on the technical conditions to be met by buildings and their location—as amended.[2, 3, 4, 5]

Above guidelines and regulations have been used to develop the principles of work organization, production processes and plant layout. In addition, the project also used simulation standards resulting from the family of ISO 14000 standards on environmental management generally understood in relation to the activities of the company and the product and services.

The most important of above comprise:

- ISO 14001:2004 Environmental management systems—Requirements with guidance for their use International Standards ISO 1400 (2004),
- ISO 14004:2004 Environmental management systems—General guidelines on principles, systems and supporting techniques International Standards ISO 1400 (2004),
- ISO 19011:2002 Guidelines for auditing quality management systems and/or environmental management International Standards ISO 19011 (2002).

3 The Background of a Simulation Project, Objectives and Measures

The investor has a backyard manufacture, which produces the product on the two production lines. The first is associated with a range of XXX brand products, comprising seven articles, the second one refers to other materials which support sales POS/POP—cabinets, counters, cubes for perfume. Production is located in a home garages, workshops and rooms and it is not explicitly ordered. The investor came to the conclusion that at this stage of its activity, an investment is needed in the construction of a new production hall on the plot that he has already bought. Investor copes with the existing orders, oversees all operations on a regular basis, but he has no central information about a course of manufacturing processes and material flow as well as work in progress. Employment in the plant finds several people. Manufacturing area is not stable, and when it is necessary machines and people are moved into another place or on other work stations. When investor is moving to a new facility he would not like to know whether he is able to find out new opportunities of operations in a new place under certain financial, technical and legal constraints rather than to present a current scale of them. An investor using the fact of moving to a new location would organize a new production process according to the best standards, which at increasing the scale of purchases

[2] Journal of Laws No 56, item 461 from 2009.

[3] Journal of Laws No 75, item 690 from 2002.

[4] Journal of Laws No 201, item 1238.

[5] Journal of Laws No 228, item 1514.

will help him in the ongoing monitoring of manufacturing processes, production planning and reducing the cost of waste.

The objective of simulation modeling in hereby project were:

- propose to the investor the project layout design for the new facility on the surface of the new plot, remembering all the restrictions of given land and environmental requirements;
- propose to the investor the positions and working areas (layout) in the first version of the new facility pointing to the advantages and disadvantages of such solution and the requirements for an environmental protection and safety;
- indicate of investor areas and places where there is a risk of pollution, accidents at work and waste and capacity limitations of the production process which will result in reduction of system performance and increase operating costs (costs of eliminating pollution, penalties, damages), as well as system bottlenecks and resource constraints;
- check the manufacturing capabilities give him the previous human resources and machinery, and if such reserves exist, what production lines they refers to, and how large they are.

Therefore a simulation aimed at limiting the risk of making wrong decisions and organizational infrastructure associated with the construction and commissioning of the new plant in the production activities with environmental aspects, safety and dispelling doubts concerning the organization of the production system.

Indicators that are used to measure the improvement and optimization are:

- Number of products manufactured in the calendar year in respect of the quantities forecasted to be produced in a calendar year (efficiency of the production system—summary of execution of production plans in relation to the procurement plan);
- Effectiveness of machinery and equipment and productivity of a human labor (degree of efficient use of labor resources);
- Time spent in the system (Work in Progress) is the amount of work in progress in the timeline;

Defined variables that were crucial in making decisions relating to issues of simulation

- Procurement plans for the specific groups of products;
- The transportation batch sizes on the production;
  Number of employees and structure of their assignment to jobs/production areas.

The simulation covered the production and storage areas within the following limits and operating assumptions

- Limitations: all operations from the date of entry of the detail to the production area and its transport to the first position to forward it to the storage area.
- Limit Assumptions: Products in the containers or POS/POSM modules needed to assembly the product as a whole come into a production area at a specific time as a result of the average frequency of orders.

Operational assumptions:

- Operators and forklifts are always available during their working time (8 h work day—one shift).
- Machines and equipment are always available and there is no unplanned downtime due to the need for repair or maintenance.
- Empty containers are always available.
- Storage space is always ready for the final products of the manufacturing process.

3.1 Description of the Modeled System and the Problems of Environmental Protection and Work Safety

There are some popular simulation applications in the market. Clear analysis and discuss about several methodological issues and survey of different types of simulation for supply chain management are presented in the article Supply chain simulation tools and techniques: a survey by Jack (Kleijnen 2005).

Planning, implementation, and operation of cut to size plants are very costly and time consuming processes. Therefore to simulate the environment described in the previous chapter, authors based their efforts on experience and guidance from similar projects (Schoech et al. 2013).

Characteristics of the simulated system depends on the type of product. Two groups of products have been determined jointly with the investor. They are produced in the two 'agreed upon' production lines.

In the case of brand products XXX worker goes to the sawmill and selects the material (wood), then he brings it to the company where there is a re-inspection of its quality. Afterwards a material passes on the production when staves are carved out and cutting down angles, drilling, milling shapes, grinding cleaning, then the product goes to the paint shop—painting (2 or 3 times), product returns to production for re-cleaning after painting, paint shop again goes to where it is in clear or color is applied.

Finally, the product is transferred to the dryer, and passes to the finishing (printing, gluing surfaces, strings). After a treatment products are packed in individually and transported on the storage shelves. Packaging for shipment of products is executed after the customer orders and shipments are received by a courier with an already printed courier waybill.

The second production line are the products of POS/POP. Given that these are the products of roasting-inputs, dedicated-contract to individual order—you cannot determine the order of the route and uniform processes—it all depends on the particular project. Most are processes in the field of woodworking, MDF, plywood, etc. on conventional machines and CNC. The manufacturer gets a request, he performs the valuation, the prototype, followed by manufacturing and shipping.

Products POS/POP exposure in addition to the ankles perfumes are rather bulky products (cabinet shelves) and require for their processing machines with extendable tables.

The main environmental problems faced by the trader stood in the organization of a new production system are as follows:

- storage and export of waste products,
- drainage systems of dust from selected areas of machining and installation of dust filters,
- construction of a dedicated area and the organization of work for paint stand,
- storage, storage, use and recycling of waste and containers of paint.
- spatial design of the building site with the required buffer distances from its borders.

The problems of occupational safety and health protection of workers includes mainly:

- secure the organization of work with for regulation distances from the walls of the building and other positions,
- organization of locations for intermediate storage areas,
- design of appropriately wide communication routes within the factory floor, in the warehouse and surface maneuvering square,
- design of transportation mode of bulky workpieces,
- protection of protective clothing, masks, eye protection and foot,
- organization of high-bay warehouse storage.

Today, many of these issues are unresolved. Photo presents the problem of storage and deportations, possibly further processing of waste from the production of POS/POP (Figs. 1 and 2).

3.2 The Logic of the Production System Operation

All machines must be able to change the time of their work, depending on the product being processed on them and depending on the stage of the technological route. Some of the products are returned to the same machine several times at different stages of their processing e.g. the position of paint. Employees, in a situation when they do not work on a given machine and there is a need for human labor for another post, they pass on it. The company does not operate the system time and there is no standardization of work entered. This meant that the calculation time of processing as time averages (average) based on the number of work processes.

The final proposal of the production lines for improving the existing production technology (process technology) has been designed taking into account the requirements (or constraints) legal and regulatory, technology implementation, financial and spatial.

Fig. 1 Wastes at the saw SCM (*Source* own study)

Fig. 2 Press not used for a current production (*Source* own study)

So far, some of these requirements have not been met. They constituted the basic assumptions in the modeling of the new system.

The limitations resulting from the regulations and standards in the area of production lay down, among other things:

- The discharge of dust from process operations;
- Minimum width of pedestrian traffic and mechanized routes;
- The availability of workstations and escape routes;
- The minimum distance between the machines and the internal and external walls;
- Availability of transport and transshipment on the production floor and in the warehouse;
- Distances of high storage racks from the walls and each other, and the width of the shelves.

The limitations resulting from the implementation of the technology imposed the need to include in the project:

- Maintenance the minimum distance from the center point position machine parameters on the workstation (XYZ) to other posts or walls—allowing for hassle-free use of the machine functions (extendable tables for cutting and milling);
- Separation of a spray booth;
- Maintenance enough space to locate the intermediate storage areas for the operating position—resulting from parameters of details that are herein processed;
- The deployment of production zones in accordance with the technological route and manufacturing process of the product.

The limitations resulting from the financial aspects were defined investment opportunities entrepreneur, which defined the maximum area built hall in the stage of development of factory and additional expenditures for equipment and supplies (spray booth, storage racks, forklift, tool cabinets, electrical equipment and filters). Moreover, not all machines were used in the same way. In the system there are areas where the main work takes one position, while next to it is the device used occasionally or for example for small series. Justify the assignment of a particular type of machine to one dedicated area.

3.3 Main Issues

The investor in the form of a preliminary verification of the project and during validation meeting formulated some basic questions on which he wants to get a response after the project simulation:

1. What should be the layout of the rooms (the first version), and production areas in the newly built factory hall meeting the requirements of environmental protection and safety at work?
2. In what place should be located a new plant within the area of the building plot?

3. Will the plan a layout of production lines using all existing machines and equipment at the investor's financial constraints translate into maximum surfaces hall built in the first stage of development of the company?
4. Will the new system of production lines and organization of work allow for completion of the annual procurement plan (execution of the production plan and capacity of the system)?
5. Will the new system of production lines reduce operating costs? If so in what areas?
6. Does the proposed layout of the production area make possible to increase the productivity of the system by extending the production orders (realization of increased annual production plan)?
7. Where in the proposed system are bottlenecks, critical areas that determine the capacity of the system and to which you should pay the most attention?
8. What are the possibilities of efficient use of machine and human resources in ordes to further increase the scale of operations?
9. What kind of additional investments and the methods of organization of production should be introduced after the transfer of operations to the new hall to facilitate the ongoing monitoring and management in the field of manufacturing?

Thus questions relate to two problem areas:

- tasks associated with the design layout and the location of the building on the plot and positions within the production area
- task of simulation processes based on the designed layout in order to investigate the efficiency of the system and its production reserves.

In one and in the second case the project must comprise both legal and standardized environmental standards and safety.

4 The Design of the Production System

Model of the system in which it is included as required by law or regulated by the ISO standards requirements of work safety and environmental protection has been subjected to experiments.

These requirements generally refer to:

- minimum or maximum distance at operational stands and between them
- minimum distance from the walls of the building,
- minimum distance from the boundaries of the building site,
- width of the traffic routes and pedestrian traffic,
- identify and secure of storage sites,
- designation of a network of filters and dust extraction,
- the equipment necessary for the safe operation of the work in the warehouse handling and maneuvering,

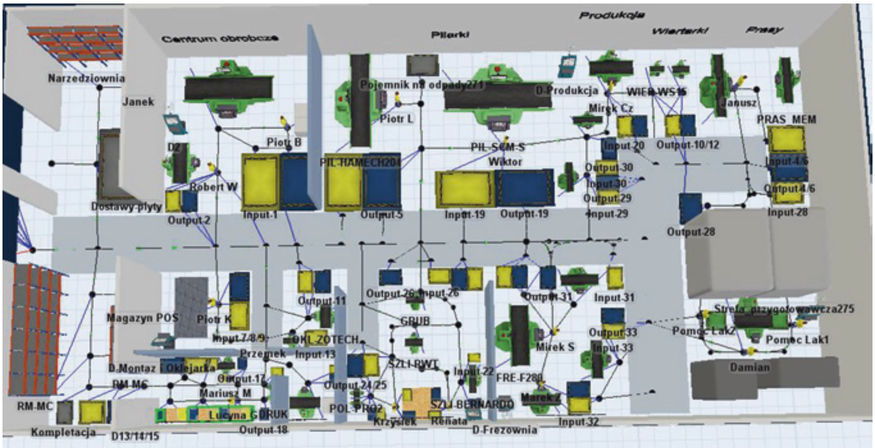

Fig. 3 Proposed organized of the production hall and warehouse (*Source* own study)

At the stage of experiment used pre-defined performance metrics:

- Execution rate of orders—production orders (% realized annual production plan),
- Indicator of the efficiency of machinery and equipment (% nominal operating time),
- Productivity ratio of operators (% nominal operating time),
- The production index in progress (work in Progress)—the number of containers with details XXX and modules POS/POP currently processed in the production area of the timeline,
- Parameter length of displacement operators within the hall (km/day).

The final version of model has been executed based on classic schedule of subsequent tasks usually comprised by each simulation model. This version presents a proposal to the layout of workstations and machinery and equipment in the newly designed production hall investor (entrepreneur). This model was developed using specialized software for simulation analysis of manufacturing processes FlexSim and used for experiments of different variants of diagnostic systems workstations and assign them to employees. The final layout of the proposed system is shown in the Fig. 3.

Across the hall, separating it into two pages proceeds communication route with access to all major intermediate storage areas (outside stands of polishing and grinding to fine detail and final assembly for XXX). Route communication breaks at the end of the hall at the positions of paint. Layout positions complies with layout of the main workshop (production in work centres) due to:

- the specific nature of their operations,
- processing technique resulting in such a large formation of dust and the need to separate the positions of other areas
- a large fluctuation of operators between positions. About 10 operators is shared between the production area (saws, drills and presses) milling and assembly.

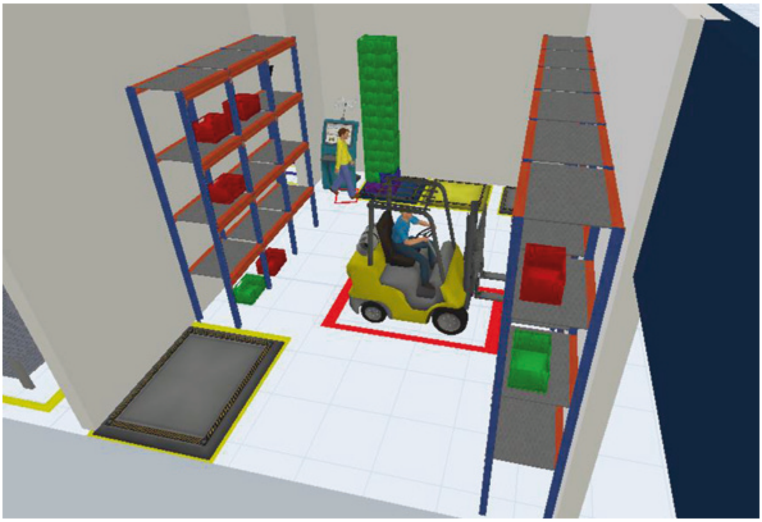

Fig. 4 Warehouse of finished goods (*Source* own study)

The current production system was complicated and ambiguous due to fact that it was based on the use of the room backyard and garage with no clear separation of production areas and communication routes power and the material of positions. In these areas there are also frequent movements of machines, workstations and operators under the current needs and available space. Paint shop was to be a special place in the new hall in view of the pollution and the key aspects of the production process. It was designed according to the dimensions of the modules enclosed drawing. It consists of three parts: preparation, proper paint shop and dryer. In the design a new building was proposed to the investor a storage space approximately 140 m^2 divided by the main communication route into two zones with similar cubature and surfaces:

- the receipt zone of materials and equipment for the production, within which will be shelving for supplies, abrasives and other tools and intermediate storage areas of 12 m^2 for bulky materials (plates)
- the dispatch zone of finished goods within which there will be two high storage racks containing up to 45 EUR pallets are stacked 3 layers allowing containers with details of 4 in each layer.

Shelves on the racks have dimensions adjusted to EUR palette manipulation. Distribution zone also includes a place for the order picking area of 2 EUR pallets and palletizing place coming down from the production line containers with details also an area of 2 EUR pallets (Fig. 4).

The area is also a place for empty industrial containers to be used in a Kanban system as a signal to start production of the given detail resulting from the customer order. Handling operations in the warehouse as well as loading and unloading tasks in the two docks are performed warehouse worker by means of a forklift truck. In addition to the project organization within the body of the building line

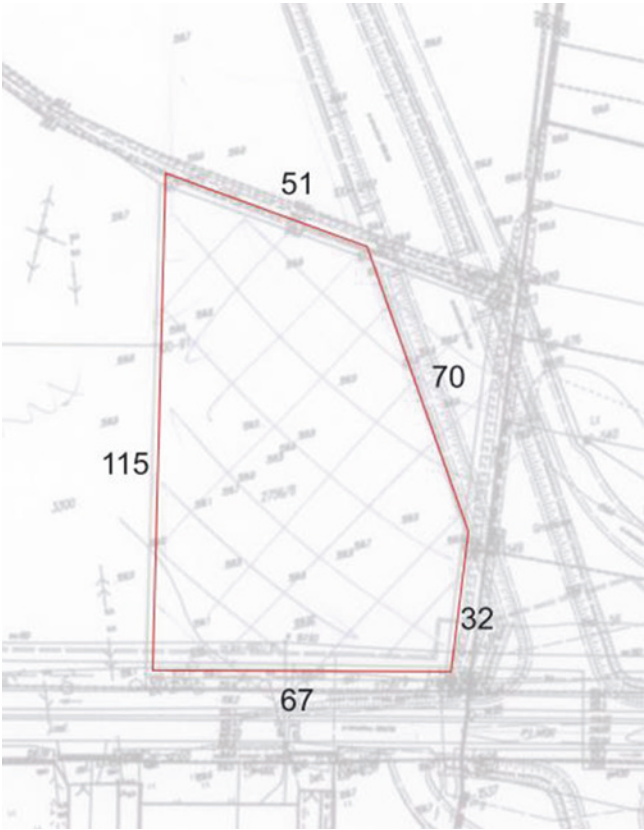

Fig. 5 Orthogonal projection on the outline of the building site (*Source* own study)

should design the same arrangement of buildings on a plot construction. Its outline and arrangement shown in the drawings (Figs. 5, 6 and 7).

The drawing shows a modular layout of the production hall and office spaces along with administrative and social system forming the letter L. The block of production hall meets the essential distance requirements from the boundaries of the parcel and environmental regulations. The entrance to the plot is located on the left side of the drawing and continues on the road along the fence to another parcel adjacent to the present. The access road is planned 7 m in width to facilitate the passing of two tractors. On the left side of the building is designed maneuvering for 3 sets of tractor plus a standard trailer on the surface approx. 600 m^2 intended also to car park staff. Square layout allows for safe maneuvering sets during loading and unloading operations.

Given the limitations of a financial nature and spatial proposed in the first stage of the expansion of the plant building area of 1,506 m^2 including:

- production and warehouse building with an area of 1,250 m^2 (approx. 150 m^2 warehouse and production hall about 1,100 m^2)
- Some administrative office and a two-storey social area of 256 m^2.

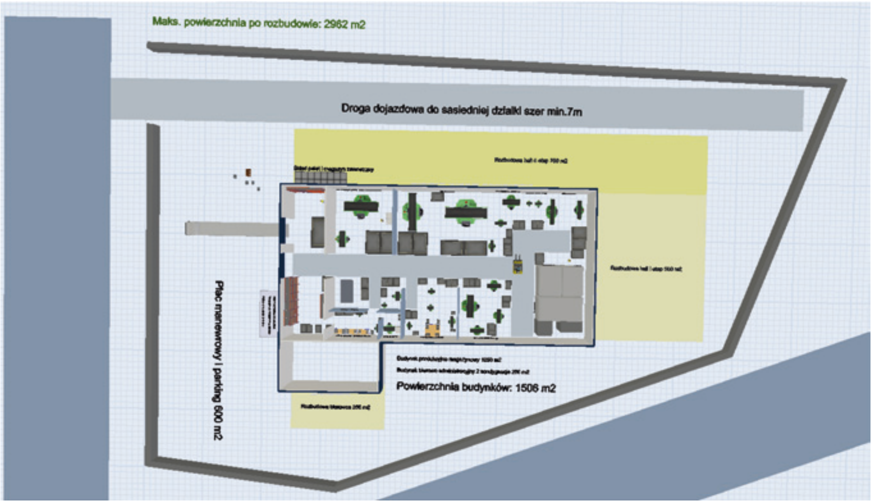

Fig. 6 General view on building arrangements and organization of manufacturing lines inside (*Source* own study)

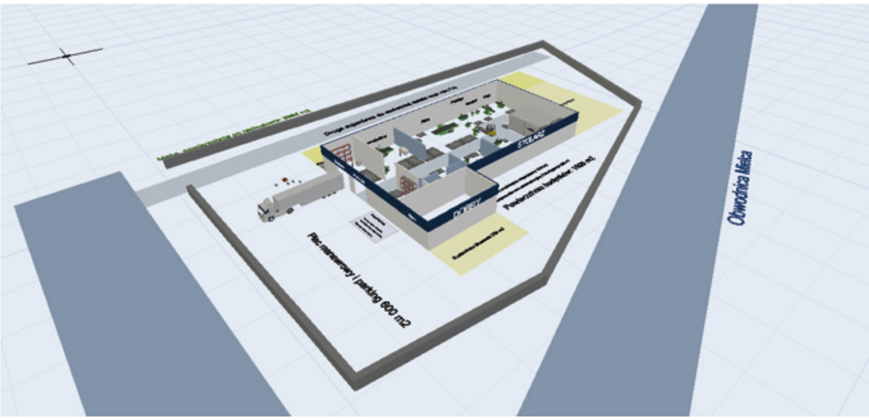

Fig. 7 Perspective on the layout of the building on the plot (*Source* own study)

This area will allow for the deployment of all current production stands along with maintaining adequate patency of the communication and accessibility, and intermediate storage areas for each operating position using the existing equipment and the introduction of new ones. In addition, spatial layout and organization of production lines was created in accordance with the principle of modularity, i.e. in the subsequent stages of the investment can be easily "move" or extended by compact modules: warehouse, manufacturing, office. The yellow color illustrates suggestions for further expansion of the building in the subsequent stages of increasing:

- Double-office area on the ground floor and creating such showroom;
- 50 % of the production area in the first stage
- 100 % of existing production areas and expanding to 700 m^2 warehouse.

4.1 The Results of the Simulation and Analysis of Experiments

As a result of the fulfillment of the above requirements and also take into account the constraints obtained in the simulation experiments, compared to the existing data of the present organization of the production of the following effects and advantages:

1. *Indicators of machines and equipment productivity* set by the proposed layout allow for processing almost all production orders (current implementation of the annual sales plan 99 %) at a fairly average level of use. There is therefore the possibility of either increasing the scale of production of existing products or introduce new product lines using existing machinery.
2. *Performance indicators of employed operators* working on the lines show a high variability depending on the person while their relatively low level in comparison with other parameters. This demonstrates the large unused production capacity of existing human resources and part of the machinery.
3. *Improvement of the spatial organization of production processes*; taking into account the specific manufacturing technology The best solution turned out to be the production in work centers (machines with similar functions are clustered in the so-called. manufacturing sites such as milling machines, cutters, presses, paint shop, etc.). Logistic function takes over the warehouse worker (forklift operator) for the transport of heavy or bulky work pieces and selected operators. The work centers with usage of "milk runner: function will enable to increase a productivity of operators and decrease losses and waste. Moreover there is an increasing awareness of positioning each operation throughout the manufacturing process for both the operators and the head of production;
4. *Improved visualization of manufacturing processes and the possibility of monitoring, verification, improvement*; Model simulation model is the basis for building architectural drawings, technical—mapping in AUTOCAD and future simulation process in the second and third stage of the expansion of the plant.
5. *Meeting the requirements and production and environmental standards and health and safety requirements*; Existing organization of work particularly addresses the factor of available space of small rooms, in which were located the appropriate machine, the cost of compliance with operational standards. The proposed solution to the organization of production space includes these conditions.
6. *Improving the implementation of the warehouse functions including the manipulation and storage of tooling*; For POS/POSM products as well as for XXX

For POS/POP and XXX detail introduced the right size storage areas of type INPUT OUTPUT improve safety, reduce the risk of material damage and improve workflow management for production. So far not been unambiguously places, mainly for reasons of space limitations. In addition, the new proposal appears in a separate storage space (not yet lack thereof) divided into two zones: the warehouse of finished products and raw materials storage and instrumentation as well as additional space for the assembly.In addition to the storage area proposed two purchasement-distribution docks with parameters adapted to enter the rear of the standard operation of loading the trailer. The proposed maneuvering also allows these operations when unloading side (semi-curtain).

7. *Introducing a system of internal transport.* So far, due to the locations of the production system was not executed. Introduced classic linear main route with access to intermediate storage areas of all production stations, two-way mechanized vehicles (trolleys and forklifts) including pedestrians way and several access roads to stations that meet the parameters of mechanized transportation one-way.
8. Visualization of a stage development of the plant on the accessible surface of the plot. Model gives an investor a view to possible further variants of plant expansion:

- Additional area production hall of 500 m^2, in the second stage of expansion
- Additional office and social space (plus showroom) —256 m^2
- Additional warehouse and production in the second stage of expansion—700 m^2

9. Proposed also to investor the introduction of a standardized industrial container to detail the brand XXX and XXX ankle, which in addition to the security detail would perform the function of the transport container with dimensions of 40/60/30.

Therefore it would meet the most of the logistical functions of the packaging of the product in the course of its preparation (a protective, storage, transport and information) (Szymonik et al. 2012). It also would allow:

- Unification of the unit load transport internal to the line (1 box/container).
- Manipulation picking products for EUR pallet containing up to 12 containers stacked in three layers.
- The organization of production flow. The container will function as a production order—will be a Kanban signal. This proposal will significantly improve existing unmonitored flow of work in progress on the line, will allow for the management of work in progress and rapid analysis of inventory and optimally use the available (proposed) storage space. Shelves and storage racks adapted to the parameters of the proposed EUR pallets and container.

4.2 Reducing Costs and Waste

The project was also to identify those areas of investor's activity and the project to build a new production plant, where there is a risk of incurring very high costs and the formation of waste arising, inter alia, of the evil system workstations and operating parameters used in the system resources as well as from non-organization jobs to the requirements of environmental protection and health and safety regulations.

As a result of simulation work and the creation of spatial layout design production activities of the investor has identified the following areas of possible limitations of cost and waste, and proposes a way to solve these problems:

- Costs of storage and use of existing production space for the storage of finished products or work in progress—*the introduction of storage and handling space.*
- The costs of shortages, errors or damages arising from the lack of INPUT/OUTPUT intermediate storage areas, visual management and unambiguous system of the production system. Today, each room and free space can be used for virtually any purpose, and the only limitation is equipment and ventilation infrastructure—*introducing of intermediate storage points and the location of work stands in the separate production areas in accordance with the proposed layout;*
- The costs of inefficient use of purchased (owned) machinery and equipment arising from the mismatch between the structure of production orders or lack of current service (waiting for the operator) and the lack of monitoring of performance indicators machines—*designing spatial availability of each machine, the introduction of intermediate storage areas and internal logistics functions (service maintenance), measuring and monitoring of indicators to manage a production course;*
- Process costs resulting from frequent changes in positioning functions and manufacturing operations—the introduction of the first version of the complete layout the entire production line based on the principle of production in work centers;
- Costs of waiting for detail resulting from the lack or ambiguously defined and cargo transport unit production—the introduction of a unified unit load in internal transport and the store;
- The costs of incorrect arrangement of production positions, improvement of architectural projects—the actual distribution of the machines and the optimal variant of simulation in the project;
- The costs of the lack of opportunities for further expansion of the plant or the need for its reconstruction as a result of an incorrect layout of buildings on the accessible surface of the plot without function analysis of manufacturing processes, types of materials used, the parameters of machines and equipment, the additional requirements (paint), and manipulation-transport features-take into account the spatial position and the size of the proposed building the plant and its layout on the surface of the building site.

5 Final Conclusions

Given the above achieved results, and referring to the key investor's questions, there has been formulated recommendations and conclusions based on findings from the simulation model:

- The layout of production areas and rooms should be modular in nature allowing for a development of the infrastructure in the factory in stages. Inside the shop floor should be separated production areas (work centers), and the organization of production shall move existing operations and its planning into the new building.

- In what place should be located a building? In their proposal the location of building a new plant within the plot construction should be placed in a central place with the possibility of further expansion in three directions with the scheduled training yard and access road to the adjacent land investor. In this way, the easiest way will be met all the requirements of construction and environmental protection infrastructure treatment and discharge of industrial dusts.
- The layout of production lines also reflecting any spatial requirements of health and safety plan will be using all existing machines and devices at the same time the investor's financial constraints translate into maximum surfaces hall built in the first stage of development of the company. Show that the simulation results with several scenarios of business situation.
- The proposed system production positions gives you the current sales plan.
- A ten-fold increase in the production plan POS/POP is also real but then would only solve the problem of the bottleneck of the system—the paint shop. As a result of experiments with two-and three-time all orders increased investor will not be able to increase the scale of production line XXX (the current assignment operators, processing times and route). In this case, the annual plan will not be realized. Implementation of POS/POP can be further increased so until the occurrence of a bottleneck on the bench paint shop. It is estimated that it occurs at a 5–6 fold increase in orders for these products.
- The new layout of production lines will reduce the cost of operations in the areas discussed above.
- The proposed layout of the production area will increase the productivity of the system by increasing the production orders (realization of increased annual production plan). But here is a prerequisite is a performance and capacity analysis of the paint shop and a greater diversification of staggered contracts (often, without necessarily changing their size). Simulation adopted for uniform distribution of orders resulting in the fact that there were periods of work and periods of maximum utilization of machinery and equipment. There is also a possibility of further optimization because despite execution state analysis to use them effectively is far from optimal (productivity at the level of 50–60 % of production capacity. Suggested solutions in order to enhance the productivity is the choice of the optimal size of production units (in the variant is 1 container), the introduction of several automatic work stations, assignment operators to other positions. It is also suggested to check the system performance in a situation of different distribution of incoming orders. If it solved the problem should hire a planner or create a post production that sets the order in a specific queue to execute adequate for the effective use of resources.
- Bottlenecks, critical areas that determine the capacity of the system and which should be paid the most attention are: the position of the paint shop in the implementation of all existing plans and plans to increase POS/POP. Bottlenecks also occur in the product line XXX (Procher polisher, final assembly position), despite the fact that the capacity of the system is average

and could produce more. As mentioned above, the main reasons for this are: the accumulation of production at one time, non-optimal distribution of the operators.
- The possibility of efficient use of resources and human machine to further increase the scale of operations are very large and have not yet used. Evidenced by the relatively low rate of productivity (productive work during an 8 h shift) as well as high expectations for the operator. The problem bottlenecks and limit system performance in a year is not clear from the lack of capacity unless the uniform use of machinery and to ensure ongoing support for him (without waiting for the operator). However, the simulation indicates a much greater opportunities (at existing resources) to increase the scale of production of POS/POP than brand XXX.
- Additional investments and methods of organizing the production that should be made after the transfer of operations to the new hall to facilitate the ongoing monitoring and management in the area of manufacturing is primarily buying and putting on productions shipping container serving as a loading unit for fine detail. Furthermore, the purchase and installation of air conditioning and air purification, sewage paint, buy high storage racks, the purchase of a forklift with an increased production of POS/POP. Suggested methods of production organization is first a kanban production control system, personnel training and introduction to the culture of the organization of the fundamental principles of Kaizen–Lean: standardization, 5S, awareness MUDA (waste: over-production, waiting, defects and deficiencies, additional transportation, reprocessing), visual management. There is also a need for organizational standards according to ISO standards for the protection of the environment (ISO 14000 series) and safety (ISO 18000 series). These standards are in fact a means of preventing errors and minimizing variability (Imai et al. 2006).

The simulation model implemented in this project did not answer, of course, for all the doubts and generated all possible variants of action. He defined the scope and objectives. However, it realized both analysts and modelers investor attention to a variety of regulations and standardization related to environmental protection and work safety.

These occurred mainly in the design of the organization of the production system and distribution system construction of buildings on the plot. In part, this consciousness has sung the analysis of existing business entrepreneur who either downplayed these issues, either not aware of the risk of an accident or pollution. In the design process of simulation, however, these problems were identified and addressed in a spatial model, suggesting additional measures of organizational (labor standards, inspections, maintenance, protective clothing, etc.).

Checking other policy options, particularly those that relate to another distribution recommendations, another assignment operators to positions, partial automation or batch size production of transport require additional work modeling, analysis and experiment, which the project due to the time frame and scope not included.

References

Beaverstock M, Greenwood A, Lavery E, Nordgren W (2013) Symulacja stosowana. Modelowanie i analiza przy użyciu FlexSim, przekład Wróbel G, Wydawnictwo Cempel Consulting, Kraków, pp s25

Imai M, Gemba K, Biznes MT, Warszawa (2006) pp s97

International Standards ISO 14001:2004 (2004) Environmental management systems—requirements with guidance for their use, International Organization for Standardization, Geneva

International Standards ISO 14004:2004 (2004) Environmental management systems—general guidelines on principles, systems and supporting techniques, International Organization for Standardization, Geneva (reviewed 2008)

International Standards ISO 19011:2002 (2004) Guidelines for auditing quality management systems and/or environmental management, International Organization for Standardization, Geneva (reviewed 2008)

Kleijnen J (2005) Supply chain simulation tools and techniques: a survey. Int J Simul Process Model 1(½):pp 82–89

Pająk E (2006) Zarządzanie produkcją, PWN, Warszawa, pp s57

Schoech R, Schmid S, Hillbrand C, Fleisch R (2013) Optimising plant layout decisions based on emulation models—technical framework and practical insights. J Simul Process Model 8(2/3):92–103

Szymonik A (2012) Logistyka produkcji, Wydawnictwo Difin, Warszawa, pp s200

Operational Measurements for Evaluating the Transformation of Production-Logistics System and Their Reflecting in Simulation Software

Piotr Cyplik, Lukasz Hadas and Pawel Pawlewski

Abstract The aim of the article is to present performance metrics and indicators of a production-logistics system at the operational level and their use for evaluation purposes in simulation experiments carried out in Simulation Software. The authors reviewed logistics and production system performance metrics and indicators as arranged in the category of flow and stock management. A survey questionnaires served as a basis for investigating the evaluation of logistics and performance systems (a system of metrics and indicators) with a view to identifying the ways in which the requirements of companies could be met in this respect, i.e. how they have a real impact on the decision-making process (research sample—372 enterprises surveyed on the operational and tactical level). The final part of the chapter demonstrates the authors' evaluation system its and modeling in Simulation Software. In the conclusion, the authors offer guidelines on how to capture and analyze the results of simulation experiments to be able to satisfy the requirements of competition-driven market.

Keywords Transformation of production-logistics systems • Simulation software • Metrics and indicators for evaluation purposes • Operational level

1 Introduction

The process of creating goods and/or services through combination of material, work, and capital is called production. Production can be anything from production of customer goods, service production in consultancy company, music or energy production (Bellgran and Safsten 2010).

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DOI: 10.1007/978-3-319-07347-7_2,

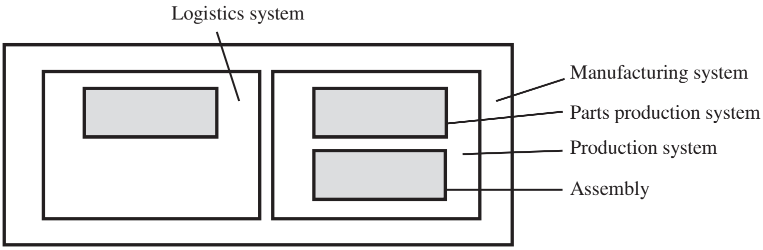

Fig. 1 A hierarchical respective on production system (*Source* Rogalski 2011)

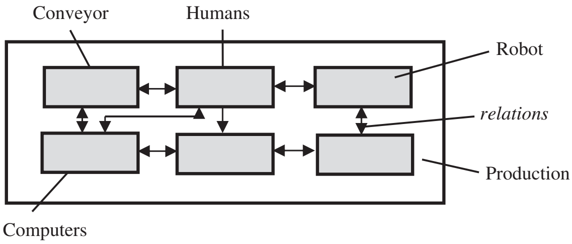

Fig. 2 Example of elements in production system (a structural perspective *Source* Rogalski 2011)

There is clear connection between production of goods and services. Consumption constitutes superior driving force for all production. Produced goods must in some way be distributed for consumption. Production of goods is therefore often of no interest, if not combined with production of services, as for example within the area of logistics (Rogalski 2011).

Production system is often used as synonymous with manufacturing system and assembly system. The Authors of this chapter assume a hierarchical perspective on the production system put forward by Bellgran and Safsten (Bellgran and Safsten 2010), as presented in Fig. 1.

Production system can be defined as by Eversheim (Eversheim 1992) as an "independent allocation of potential and resource factors for production purpose", which in addition to the elements of the technical production process, also includes organizational elements for the planning and controlling of the production process. Accordingly, it has a specific system organization that creates specific links between the elements of a production system in order to achieve the optimal factors combinations to complete the task (Kern 1980).

A production system comprise a number of elements between which there are reciprocal relations. Commonly mentioned elements are premises, humans, machines, and equipment (Löfgren 1983). Software and procedures might be added to the listed system elements according to Chapanis (Chapanis 1996). A structural perspective of a production system can be used to describe the different system elements and their relations, see Fig. 2.

Yet another dimension can be added to the description of a production system, namely a decision-making process. The decision-making process for a production

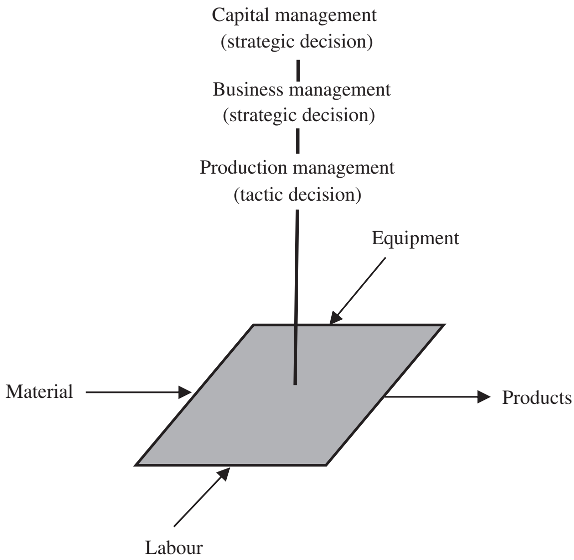

Fig. 3 Model of a production system including the decision making process (*Source* Rogalski 2011)

system adds capital management (owners), business management and production management to the description of a production system (Rogalski 2011), see Fig. 3.

Logistics activities in manufacturing companies can be divided into three fields: procurement logistics (in-bound), production logistics (in-plant) and distribution logistics (out-bound) (Baudin 2004).

The activities of production logistics are from dock to dock, meaning all activities from the receipt of goods to the dispatch. Its main purpose is to offer an efficient logistical support for production through material planning, i.e. planning, execution and control of material flows (Bullinger and Lung 1994).

Hence, efficient production logistics secures minimal inventory levels, short lead times, high flexibility of production and consistent (internal) customer orientation. Synchronization, flow and tact orientation, as well as the consideration of customer needs, are key requirements for eliminating wastes in form of excess inventory or waiting times due to material shortages (Droste and Deuse 2012).

On the tactical level a strong feedback between the production and logistics systems exists in each enterprise. A logistics system is a peer for a production system. They must both exhibit great similarities. Especially strong similarities ought to come into play in the area of planning. Irrespective of individual solutions applied in the field of production and logistics, both the systems are supposed to base their functioning on the same planning standard. This raises the problem of selecting a logistics strategy, understood as a general model of the functioning of the logistics system in an enterprise (Fertsch et al. 2010).

Based on these deliberations the authors assume that production-logistics system will be constructed as a set of elements of a production system, composed of premises, humans, machines, and equipment, software, procedures and the decision-making process, linked by mutual interrelations with a view to executing a logistics strategy and logistics system is understood by the authors as changes which are process and/or structural in nature. Process changes denote a modification in the operation of a production and logistics system as regards the mechanisms in control of material streams flow in order to meet the objectives of the logistics strategy which had been implemented. Structural changes denote a change in: type, number, location (arrangement into a layout) or capacity (throughput) of particular resources combining into production-logistics system. Structural changes are initiated by process changes (processes require resources) depending on the scope of individual works in process over time and their specialization (Boszko 1973).

Basic prerequisites for achieving an efficient production-logistics system are stability, transparency and standardization of processes (Droste and Deuse 2012). A multimodal modelling approach to manufacturing processes is an example of a major impact exerted by logistics processes on production processes. This concept defines a multi-layered model of behavior of a system of concurrent cyclic processes (Pawlewski 2014). Each process is "carried" by a physical system—in our case a logistics and production system.

A strong focus of production managers on logistics customer service as well as on lean and flexible qualities of internal and external supply chains along with cost pressures mean that at the operational level these managers evaluate production processes using measurement systems consisting of a set of both production and logistics metrics. This chapter demonstrates a selection of such metrics and indicators based on the study of the requirements of production company managers as well as a project involving mapping them in computer simulations.

2 Ratio Analysis

The main idea behind the ratio analysis is to measure the efficiency of the process. Process measurement may apply to three key elements

- input—information and materials on input,
- resources—resources used in the course of the process,
- results—the information and materials on output.

Ratio analysis is used for evaluating each of the above-mentioned attributes and process elements. The structure of metrics and ratios enables such an operation. Input data for calculating the value of a given metrics or ratio determine which process attribute will be evaluated.

Twarog (Twarog 2003) defines a metric as an economic and logistics category reflecting the events and facts pertaining to the company management and its environment, as expressed in certain units of measurement. In other words, a metric is a measure which characterizes a given phenomenon. Another definition Twarog (Twarog 2003) puts forward for a metric is that it is an economic category reflecting the events and facts pertaining to the flow of materials and related information in the company's logistics system and in the supply chain. A metric is a relative number expressing a variable ratio of certain statistical values. From the point of view of logistics, metrics are used for measuring performance efficiency of logistics systems and for a quantitative determination of objectives. According to Kisperska-Moron (Kisperska-Moroń 2000), ratio analysis consisting in the use of logistics factors in measuring the performance of processes in enterprises or in supply chains requires defining a framework for measuring and analyzing the efficiency of logistics systems (the production system is included in the logistics system). The ratios should have an appropriate structure so that described results could be achieved. The features of a well-structured metric are as follows (Twarog 2003):

- adequacy—a metric should clearly reflect the situation in the organization,
- validity—a measurement should be valid in terms of time,
- relevance—information given by ratios should be relevant from the point of view of the organization,
- accuracy—the results of ratio analysis should provide the grounds for measuring processes and the system and for making decisions on this basis,
- scope—should include the highest number of states within the organization,
- comprehensiveness—should enable the evaluation of the system and processes right from their start (input) to the end (output),
- comparability—ratios should enable the comparison of processes over time,
- unification—ratios should be identical for as many processes in the supply chain as possible,
- comprehensibility—ratios should be understandable by both their authors and the reviewers,
- compatibility—ratios should enable the creation of a system of indicators,
- costs and profits—the costs of establishing the value of metrics should be justified in the terms of the metric's objective.

A system of logistics metrics and indicators must be created with the use of logistics approach. It must also reflect the essence of logistics. It is therefore necessary to connect the metrics in an arithmetical or logical way. The cross-referencing of indicators may occur on two planes (Pfohl 1998).

- phase—based on material flow phases (supply, production, distribution),
- systemic—based on logistics systems (inventory management, warehouse management).

3 Basic Operational Metrics and Indicators of a Production-Logistics System: Selection Method

The Authors suggested a three-staged method of selecting production-logistics system metrics and indicators for evaluating the system transformation:

1. Stage one—questionnaire survey on the use (if any) of production-logistics evaluation systems in enterprises—along with the extent to which they meet the expectations set for them (and have a real impact on decision-making).

Table 1 Number and volume of fractions in individual layers for surveyed enterprises from Group C—processing industry (based on the basic classification of activities employed by Central Statistical Office)

No. of subsets	Subset feature (employment)	Subset size (Nh) (number of enterprises)	Number of sample elements (nh)
1	0–9	282,839	121
2	10–49	26,025	11
3	50–249	6,461	3
4	≥250	1,466	1
In total		316,791	136

2. Stage two—expert selection of operational metrics for an in-depth study.
3. Stage three—carrying out an in-depth study of the relevance of individual metrics in the process of transforming a production-logistics system.

3.1 Stage One: Questionnaire Survey

The first stage involved conducting a questionnaire survey among production enterprises based in Poland. This phase was intended to identify state-of-the-art and relevant fact pertaining to the area under investigation. The scope of study is outlined below:

Objective scope of the study was to determine the extent, to which production-logistics evaluation systems are applied in enterprises along with the extent to which they meet the expectations set for them (and have a real impact on decision-making).

Subjective scope of the study—the survey was conducted among Polish enterprises belonging to Group C (processing industry), according to the Polish Classification of Activity employed by the Polish Central Statistical Office (GUS). The enterprises subject to the survey would be small, medium and large companies (as classified by GUS based on the number of employees).

Geographical scope—the Authors of this chapter were interested in Polish enterprises. The survey covered entire Poland.

Timeline—the first half-year of 2013.

The survey involved 372 enterprises, although the minimum size of the sample (with the maximum error of estimate at 10 % and confidence coefficient set at 98 %) was 136 enterprises, as divided into fractions presented in Table 1.

Table 2 answers to what extent the existing system for evaluating the production and logistics area in the enterprise (a system of performance metrics and indicators) meets its requirements—namely what is its real impact on the decision-making process at the operational level of management (impact on the daily performance specific functions).

The most common answers given by respondents to these questions was: I have no such knowledge (35.2 % of answers). It is an evidence of a lack or a gap

Table 2 To what extent the existing system for evaluating the logistics and production area (a system of metrics and indicators) meets the requirements imposed on it—namely what is its real impact on the process of decision-making at the operational level of management (daily performance of specific functions)

No.	Possible answer	Number of answers	Percentage of answers
1	Complete overview of the situation in the context of pursued strategy (global and functional) and the extent to which resources are engaged (machinery and human) as well as their costs (arranged into categories)	51	13.7
2	Knowledge on process total costs	42	11.3
3	Knowledge on the process results (the status/extent of on-time order delivery expressed as %: shipments, service, etc.)	52	14.0
4	General knowledge on the extent to which the resources are engaged (machinery and human resources)	57	15.3
5	No knowledge on the performance efficiency of executed processes at this level—no metrics and ratios clearly assigned to this level	22	5.9
6	No access to this management level	131	35.2
7	Not met at all, because there is no formalized evaluation system for this area from a strategic point of view	17	4.6
	Total	372	100

in knowledge on management systems at enterprises. General knowledge on the extent to which resources are used (machinery and human resources) was reported in 15.3 % of cases. 14 % of respondents has general knowledge on the results of realized processes (the status/extent of order delivery expressed as percentage of on-time shipments, service, etc.). A comprehensive view of the situation as regards the strategy implementation (global and functional strategies) and the extent to which available resources are engaged (machinery and employees) as well as the costs (arranged into categories) is held in 14 % of cases. Knowledge on the total costs of the process was reported by 11 % of companies. It should be stressed at this point that 4.6 % of respondents declared that no formalized evaluation system had been put in place for this area in their enterprise and 5.9 % of respondents lack any knowledge on the performance efficiency of the processes realized at this level—there are no performance metrics and indicators have been clearly assigned. The level of knowledge of surveyed enterprises regarding the evaluation system in the area of production and logistics is nowhere near satisfactory.

Another question concerned the tools and techniques applied in the enterprise for the purpose of assessing the production-logistics system. An analysis of the findings (Table 3) suggests that every fifth enterprise (72 of 372) has no formalized evaluation system deployed for this area.

Table 3 What tools and techniques are used by enterprises for evaluating the logistics and production system?

No.	Possible answer	Number of answers	Percentage of answers
1	SCOR model	10	1.5
2	Balanced scorecard (BSC)	34	5.2
3	Cost centre analysis (MPK)	235	35.7
4	Activity based costing (ABC)	32	4.9
5	Simulation tools	13	2.0
6	Internal system dedicated for process evaluation	248	37.6
7	None—no formalized evaluation system deployed in the company	72	10.9
8	Other	15	2.3
	Total	659[a]	100

[a]respondents could choose more than one tool or technique

In other enterprises an internal system dedicated for process evaluation is used in 37 % of cases, yet such solutions are not treated as objective. As regards other tools, the analysis of cost centers is quite popular (27 % of answers). The remaining tools and techniques can be regarded as being at the preliminary stage of implementation. What also comes to the forefront as regards the survey results is the popularity (between 10 and 20 %) of ABC method (16 %) and simulation processes (22 %) compared with SCOR (11 %) and BSC (9 %).

3.2 Stage Two: In-depth Study

The results obtained in the first phase had an impact on the second phase. Hundreds of performance indicators of the production-logistics system discussed in the literature on the subject (Supply Chain Operations Reference (SCOR®) Model, Overview—version 10.0, Supply Chain Council. http://supply-chain.org/f/SCOR-Overview-Web.pdf. Access April 2012) were analyzed based on interviews with managers (at companies having production and logistics evaluation systems put in place); as many as 46 indicators were shortlisted for further in-depth study. This phase was intended to provide a detailed (precise) picture of subject of study along with its distinctive features and situations.

The aim of the in-depth study conducted by the authors of this chapter on a group of 30 production and logistics managers working in the sector of machine production was to identify key performance assessment indicators currently used to assess the production-logistics system. The second aim of the study was to find out which of the indicators would production managers opt for if they had appropriate information and technological tools at their disposal. Yet another goal of the study was to answer the following question: changing the value of which indicators will directly affect corrective measures introduced by production managers? The research was based on basic assumptions of the Delphi method. The Delphi method is based on a structured process for collecting and distilling knowledge from a group of experts by means of a series of questionnaires interspersed with controlled opinion feedback (Adler and Ziglio 1996). Linstone and Turoff (Linstone and Turoff 1975) say that Delphi may be characterized as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem. The method takes its name from the Oracle at Delphi, an ancient Greek soothsayer able to predict the future, and was originally developed at the RAND Corporation by Dalkey and Helmer (Dalkey and Helmer 1963) as a tool for forecasting likely inventions, new technologies and the social and economic impact of technological change.

The members of the expert team were not selected randomly. The authors of the research turned for help to experienced production managers (with a minimum of three years of experience in a managing position). The subjects analyzed were six big businesses, 18 small and medium-sized businesses, and six microbusinesses (in these cases of which the owners of the businesses were interviewed).

In order to conduct a study based on an in-depth interview, a study questionnaire was prepared. Considering the aim of the study, the most important part of the questionnaire was a table presenting the use of specific assessment indicators of production-logistics system (see Table 4).

Every manager was to be interviewed about 46 performance assessment indicators of the production-logistics system. The preliminary list of indicators had been prepared by the authors with reference to the literature (Twarog 2003) of the subject and their personal experience in this area. While preparing the list of indicators, proper care was taken to eliminate indicators of similar value (e.g. only one indicator was selected from a group containing Perfect Order, Vendor Delivery Performance, On Time In Full).

Descriptions of all listed indicators that were used in the questionnaire included a name of an indicator, its verbal definition and its calculation formula. Additionally, the managers determined how changes of the indicators currently used in their companies affected the decisions concerning implementing corrective measures into the production-logistics system. The authors of the study also analyzed the experts' opinions on the role of indicators, which are not currently used in the company, but which should be used according to the respondents.

After gathering research results from all the experts, steps to judge conformity of experts' opinions were taken (compare Table 5). With this end in view relative classification dispersion rate was used. The following formula depicts it (Martino 1970):

$$\mathrm{h_r} = \frac{\mathrm{k}}{\mathrm{k}-1}\left(1-\sum_{\mathrm{j}=1}^{\mathrm{k}} f_{rj}^2\right) \quad 0 \le \mathrm{h_r} \le 1, \tag{1}$$

where:

k Number of categories distinguished in the rth question
$\mathrm{f_{rj}}$ Frequency of occurring the jth category in the rth question

The formula measures conformity of experts' opinions, the closer h is to 0, the higher is conformity of experts' opinions.

Table 4 A sample table presenting the use of specific performance assessment indicators of the production-logistics system, completed by experts

Indicator: (name)					
Definition					
Formula					
	The influence of the indicator value on introducing adjustment procedures in the production- logistics system				
	None—the indicator in not used	Rather small—indicator of local importance, useless for decision making	Quite big—indicator helpful for decision making	Big—indicator impor- tant but not critical for decision making	Very big—key indicator for decision making
Currently used					x
To be used in the future					x

Table 5 Results of the expert opinion analysis for the vendor delivery performance (VDP) indicator

Indicator: Vendor delivery performance					
Definition: shows the percentage of order completed on the first confirmed delivery date and in full					
Formula: the number of orders completed on the first confirmed date and in full/the number of all orders to be completed within a specific period of time					
	The influence of the indicator value on introducing adjustment procedures in the production-logistics system				
	None—the indicator in not used	Rather small	Quite big	Big	Very big
Currently used		1	3	2	24
To be used in the future			2	2	26

By judging experts' opinions conformity for VDP, relative classification dispersion rates were calculated in the following way:

$$h_{VDP,\,(1)} = \frac{5}{4}\left[1 - \left(\left(\frac{0}{30}\right)^2 + \left(\frac{1}{30}\right)^2 + \left(\frac{3}{30}\right)^2 + \left(\frac{2}{30}\right)^2 + \left(\frac{24}{30}\right)^2\right)\right] = 0.43 \quad (2)$$

$$h_{VDP,\,(2)} = \frac{5}{4}\left[1 - \left(\left(\frac{0}{30}\right)^2 + \left(\frac{0}{30}\right)^2 + \left(\frac{2}{30}\right)^2 + \left(\frac{2}{30}\right)^2 + \left(\frac{26}{30}\right)^2\right)\right] = 0.3 \quad (3)$$

These rates were calculated in an identical way for other indicators as well. Table 6 presents the classification of results for 46 selected indicators arranged according to the criterion of the impact of the indicator's value on introducing corrective measures into the production-logistics system. The table contains the most frequent experts' responses and the dispersion indicator value. Wherever two values are assigned to one indicator, it means that the number of experts' responses to the two criteria were identical.

The observations prove previous research that large enterprises use the most complex structure of performance assessment indicators of the production-logistics system, whereas the structure used by microenterprises is the least complex. It needs to be kept in mind, however, that for the first 15 indicators, managers of SMEs, as well as microenterprises considered the introduction of these indicators as necessary in the future. Relative classification dispersion rate is included in the range of $\langle 0,\, 1\rangle$. The lower its value, the greater the conformity of the advisors' opinions. The authors' conclusion based on the results is that for the first four indicators the compliance level concerning the significance of impact of the indicator value on introducing corrective measures in the production-logistics system is big. For the next 11 indicators, however, the compliance level proves to be acceptable (the dispersion rate for their use in the future is lower than 0.75).

Table 6 Results of a pilot study of preferences of the Polish production managers concerning the choice of performance assessment indicators of the production-logistics system

No.	Indicator	Currently used/to be used in the future	None—this indicator is not used	Rather small	Quite big	Big	Very big
1	Single order lead time	Currently used					0.43
		To be used in the future					**0.23**
2	Timeliness of the production process (Vendor Delivery Performance)	Currently used					0.43
		To be used in the future					**0.3**
3	OEE—overall equipment effectiveness	Currently used					0.46
		To be used in the future					**0.37**
4	DDT—Dock to Dock time	Currently used					0.49
		To be used in the future					**0.37**
5	Precision (quality of production planning)	Currently used					0.53
		To be used in the future					**0.49**
6	Stock intensity, namely the level of work-in-progress	Currently used					0.53
		To be used in the future					**0.53**
7	Cost of processing incoming order	Currently used					0.82
		To be used in the future					**0.58**
8	Cost of wrong deliveries or complaints caused by a wrong instruction	Currently used					0.74
		To be used in the future					**0.58**
9	Finished goods inventory turnover	Currently used				0.71	
		To be used in the future					**0.63**
10	WIP inventory turnover	Currently used					0.77
		To be used in the future					**0.68**
11	Inventory—percentage > X days	Currently used	0.81				
		To be used in the future					**0.68**
12	Obsolete inventory—%	Currently used	0.34				
		To be used in the future					**0.7**

(continued)

Table 6 (continued)

No.	Indicator	Currently used/to be used in the future	None—this indicator is not used	Rather small	Quite big	Big	Very big
13	Production process throughput	Currently used	0.85				
		To be used in the future				**0.7**	
14	Tact time	Currently used		0.85			
		To be used in the future				**0.73**	
15	Efficiency (intensity) of the flow	Currently used	0.88				
		To be used in the future				**0.73**	
…	…	…	…	…	…	…	…
46	Share of LT in DDT	Currently used	**0.80**				
		To be used in the future	**0.86**				

Table 7 Analysis of logistics states and of the entire production-logistics system

Performance measures/ratios	Logistics states		Entire production-logistics system (a mix of logistics states)
	Movement (flow)	Stock	
Reliability (timeliness of the production process)	√	X	√
Responsiveness (single order lead time)	√	√	√
Cost of processing incoming order	√	√	√
Stock intensity, namely the level of WIP inventory	X	√	√
Cost of wrong deliveries or complaints caused by a wrong instruction	√	√	√
Precision (quality) of production planning	√	√	√
Finished goods inventory turnover	X	√	√
Obsolete inventory—percentage	X	√	√
WIP inventory turnover	√	√	√
Production process throughput	√	X	√
Tact time	√	X	√
Dock to dock = lead time	√	X	√
OEE—overall equipment efficiency	√	X	√
Flow efficiency (intensity)	√	X	√

3.3 *Stage Three: The Use of Logistics and Production System Performance Measures and Indicators for Analyzing Logistics States*

A production and logistics of an enterprise with a diversified production structure, a wide range of products and multi-variant customer service strategy can be described by way of a combination of logistics states such as stock (warehousing) and movement (flow). Planning and shop floor control systems developed based on the planning logic such as MRP, JIT or TOC are also such a combination (Hadaś and Cyplik 2010) of the flow logic (push, pull) and buffering (stock buffer and time buffer), creating the company's manufacturing system. The system of metrics and indicators should enable a comprehensive analysis of logistics states in the course of the transformation of the production-logistics system with a view to enhancing its efficiency in using the resources (production criterion) and the level of customer service (logistics criterion) (see Table 7).

Performance measures and indicators differ in character; some of them refer only to "flow" or "stock" states and some of them apply to both. All of the metrics and ratios brought together evaluate the mix of logistics states in a logistics and production system of an enterprise.

4 Project of Reflecting Measures and Indicators of Efficiency of Production-Logistics Process in a Simulation Model

The Authors of this chapter developed a simulation model of an enterprise with a multi-divisional production structure, capable of processing a number of value streams (group technology) and pursuing a diversified customer service strategy. Simulation works were performed with the use of Simulation Software tool. Simulation Software is an advanced tool, which enables the execution of simulation experiments, which are a valuable source of information on the behaviour of dynamic production-logistics systems. Analysis methodology for such a production-logistics system was based on short-listed metrics and indicators selected by the managers at production companies. The project of reflecting all of the measures and indicators selected at the research level by the Authors required:

- Defining key input data (variable for particular simulation scenarios),
- The scope of mapping analyzed processes in the simulation model,
- The scope and logic of monitoring simulation parameters,
- The scope of reporting or calculating final performance measures and indicators (based on input and output data from Excel and Simulation Software).

Of course there are alternative methods of reflecting the parameters which describe the processes under review. The Table 8 shows the project of reflecting measures and indicators of efficiency of production-logistics process in a simulation model.

5 Summary

This chapter was aimed at presenting a set of performance metrics and indicators for evaluating the performance of a production-logistics system and showing a method of their mapping in the simulation environment. The data contained in Table 7 confirm that this objective has been accomplished. The set of performance metrics and indicators provides the basis for analyzing, in line with standard requirements, the application of a simulation tool in business practice for the purpose of analyzing the production-logistics systems in market conditions.

Further study will involve working on the results of the simulation of the behavior of a logistics and production system under transformation. The data contained in Tables 7 and 8 was used for simulation experiments mapping production-logistics processes; the following assumptions have been made for the purpose of further analysis:

- the results of the transformation of the production-logistics system states are known on a fixed control date (among others the status of production orders, the number of available machines, the size of work station buffer, etc.),
- states of production-logistics systems on fixed control dates are clearly defined, namely measurable.

Table 8 The project reflecting measures and indicators of efficiency of production-logistics process used for analyzing a production-logistics system in Simulation Software for the developed simulation model

Metric/indicator	Key input data	Key mapping in the simulation tool	Scope and logic of monitoring simulation parameters	Reporting and calculation
	Input data	Simulation program	Simulation program	Excel report
Single order lead time	Technological route, setup and process time	Production structure, parameters of production and logistics resources	Identification of the flow and storage of a single batch, lead time report for a single order	Archiving
Cost of processing incoming order	Cost data: Hourly rate of working and idle time of production and logistics resources	Production and logistics structure of an item under investigation	Resource working time (work, transport, changeover, etc.) Resource idle time (waiting to be processed)	Calculation in excel according to assumed settlement system of fixed and variable costs
Stock intensity, namely WIP inventory level	Key phases of the flow—"phases" of value stream, incrementing of the stream value	Production and logistics structure of entity under investigation	Identification of the value of input, output, length of stay (duration of) a given flow phase of the value stream for allocated streams	Calculation according to assumed unit of time (time scales), calculation according to incrementing value of inventory for respective phases
Value of wrong deliveries or complaints caused by wrong order instruction	Characteristics of probability distribution for individual phases of the decision-making processes	Expanding the flow model by a logical decision-making structure of order instruction & feedback	Monitoring the selection of paths with a specification inconsistent with deviation threshold	Percentage analysis of the selection of decision-making paths
Precision (quality) of production planning	Order schedule (quantity and right-hand deadline)	Production and logistics structure of a given entity	Monitoring order receipt time from production phases—inventory level	Calculation—value of order release time from right hand-side deadline

(continued)

Table 8 (continued)

Metric/indicator	Key input data	Key mapping in the simulation tool	Scope and logic of monitoring simulation parameters	Reporting and calculation
	Input data	Simulation program	Simulation program	Excel report
Finished product inventory turnover	Value of individual finished goods Schedule or probability distribution of the release of finished goods	Generator of the release from finished goods warehouse	Inventory level per individual finished goods	Calculation of the value of inventory level/sales figure
Obsolete inventory—%	Order schedule, schedule or probability distribution of release from finished goods warehouse, value of individual finished goods	Generator of the release from finished goods warehouse	Inventory level per individual finished goods Warehouse receipt time	Calculation, validity period, report date, warehouse receipt date, number of SKUs, value of SKU
Inventory—% > X days	Order schedule > X days	Generator of the release from finished goods warehouse	Inventory level per individual finished goods, Warehouse receipt time	Term input in warehouse, >X days
WIP inventory turnover	Order schedule, raw material value	Generator of the release from finished goods warehouse	Volume of release from finished goods warehouse	Calculation. Order schedule * value of raw materials/ volume of release * value of raw material
Timeliness of the production process	Order schedule (volume and right hand-side deadline)	Production and logistics structure of entity under review	Warehouse receipt time	Calculation—% number of orders with a "positive" receipt at the warehouse
Production process throughput	Mark-up	Production and logistics structure of an entity under review	Product units generated per hour	Mark-up * number of units / generated per h

(continued)

Table 8 (continued)

Metric/indicator	Key input data	Key mapping in the simulation tool	Scope and logic of monitoring simulation parameters	Reporting and calculation
	Input data	Simulation program	Simulation program	Excel report
Tact time	Technological route, setup and process time, time fund, order schedule	Production and logistics structure of an entity under review	Average work station time (cycle time)	Order schedule/time fund, tact time/cycle time
Dock to dock = lead time	Order schedule	Production and logistics structure of the entity under review	Warehouse release and receipt of material for an order	Archiving
OEE—overall equipment efficiency	Probability distribution of breakdown, shortage ratio	Production and logistics structure of the entity under review	Idle time, process time, setup time, break time	OEE calculation
Flow efficiency (intensity)	Technological route, setup and process time, order schedule	Production and logistics structure of the entity under review	Process time, setup time, Idle time, lead time	Process time total, setup time, per order/lead time

Based on the above mentioned assumptions for each predefined state of system on transformation control dates selected performance measures and indicators of the production-logistics system will be reviewed with the use of an expert method. The dispersion factor will be put to use after the review process—from the perspective of individual ratios. The aspects measured will be the relationship between the measure returned by an indicator on a fixed control date and the real state of the production-logistics system (this state is known thanks to designed simulation scenarios). The evaluation of the transformation process is equally important. It will be also possible to evaluate the effectiveness of suggested changes to the production-logistics system. Such a solution enables the creation of the final list of measures identifying the production-logistics system as well as its transformation efficiency.

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References

Adler M, Ziglio E (eds) (1996) Gazing into the oracle: the Delphi method and its application to social policy and public health. Jessica Kingsley Publishers, London

Baudin M (2004) Lean logistics. The nuts and bolts of delivering materials and goods. Productivity Press, New York

Bellgran S, Safsten K (2010) Production development: design and operation of production systems. Springer, Berlin Heidelberg

Boszko J (1973) Struktura organizacyjna przedsiębiorstwa i drogi jej optymalizacji. WNT, Warszawa

Bullinger H-J, Lung M (1994) Planung der Materialbereitstellung in der Montage (Planning assembly material provision). Teubner, Stuttgart

Chapanis A (1996) Human factors in systems engineering. Wiley, New York

Dalkey N, Helmer O (1963) An experimental application of the Delphi method to the use of experts. Manage Sci 9:458–467

Droste M., Deuse J., (2012) Enabling manufacturing competitiveness and economic sustainability, pp 604–610

Eversheim W (1992) Flexible Produktionssysteme. In: Frese E (ed) Handwoerterbuch der Organisation. Poeschel-Verlag, Stuttgart

Fertsch M, Cyplik P, Hadas L (eds) (2010) Logistyka Produkcji—Teoria i praktyka. Biblioteka Logistyka, Poznan (in Polish)

Hadaś Ł, Cyplik P (2010) Hybrid production planning system in make-to-order company—case study. LogForum 6(4), No 5

Kern W (1980) Industrielle Produktionswirtschaft ueberarbeitete, vol 3. Poeschel Verlag, Stuttgart

Kisperska-Moroń D (2000) Wpływ tendencji integracyjnych na rozwój zarządzania logistycznego. Prace naukowe AE, Katowice

Linstone HA, Turoff M (eds) (1975) The Delphi method: techniques and applications. Addison-Wesley Publishing Company, Reading

Löfgren K-G (1983) Produktion—teknik och ekonomi. LiberHermods, Malmö (in Swedish)
Martino JP (1970) The precision of Delphi estimates. Technol Forecast 1(3):293–299
Pawlewski P (2014) Multimodal approach to modelling of manufacturing processes, variety management in manufacturing. In: Proceedings of the 47th CIRP conference on manufacturing systems
Pfohl H-Ch (1998) Zarządzania logistyką, Funkcje i instrumenty. ILiM, Poznań (in Polish)
Rogalski S (2011) Flexibility measurement in production systems: handling uncertainties in industrial production. Springer, Berlin Heidelberg
Supply Chain Operations Reference (SCOR®) Model, Overview—version 10.0, Supply Chain Council. http://supply-chain.org/f/SCOR-Overview-Web.pdf. Access April 2012
Twarog J (2003) Mierniki i wskaźniki logistyczne. Biblioteka logistyka, Poznań (in Polish)

Methodology of Assortment Analysis in Companies with a Wide Range of Products for Building the Flexibility of Customer Service

Łukasz Hadaś, Pawel Pawlewski, Karolina Werner-Lewandowska and Piotr Cyplik

Abstract The aim of the chapter is to present the methodology of the analysis of assortment in companies with a wide range of products and diversified customer service strategies (Make to order, Make to stock, Assembly to order). The authors performed ABC/XYZ analysis (logistical criteria of the segmentation), analysis of technological similarity coefficient in terms of process times in both horizontal and vertical terms. A statistical software has been used for analysis purposes. Then the selected data have been used in the simulation of production-logistics process (FlexSim 7 Simulation Software) for multi-department companies with diversified customer service strategies. The validation of the methodology was based on an analysis of the correlation between the indicators adopted for the evaluation of simulation results with the results of statistical analysis. The chapter ends with general conclusions on the results of the work and the comments on their application in business practice.

Keywords Wide range of products • MTO • MTS • Production system transformation • Flexibility of customer service

1 Introduction: Production Environment Characteristics

The works presented in this chapter have been inspired by the need for supporting the business practitioners as regards the management of material stream flows in multi-divisional companies having a broad range of products on offer. Production and logistics managers in those systems struggle with the performance of classical

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management tasks or with a timely order execution while staying within the desired operational parameters (such as machine load, timely performance of tasks, the level of work in progress or lead time); this problem is much more pronounced than in the case of regular production systems.

It is a group of production enterprises which are characterized by:

- Lack of ability to single out value streams having a common production tact and a stable machine load,
- Much longer production cycles compared with the theoretical cycle,
- Major changes to the production program in the planning period,
- Major fluctuations of technological parameters of the process.

Creating stable value streams as a precondition for implementing lean production (Liker 2004) is hampered under such circumstances. Product range analysis in keeping with *Technological and organizational similarity coefficient* (Domanski and Hadas 2008), which serves as a basis for identifying value streams with a highly diversified product range, proves to be insufficient, because the similarity is much below the expectations set for flow shop units.

Material stream flow typology is represented by the so-called "V" plant (Umble 1992), where we usually deal with products manufactured from a small number of diversified output materials, which become more diversified during the production process with a wide variety of finished products as a result. The representatives of such a "topography" of material stream flow are enterprises from, for example, machine-building, textile or metallurgic industry (American Production and Inventory Control Society 2008). Generally speaking, in the case of "V" structure, the production process for all products follows the same sequence. Machine changeover time for another type of production as well as production lead time are extremely long.

In the area of customer service, with the possible solutions MTS—make to stock, MTO—make to order and ATO—assembly to order. More importantly, this arrangement is often not fixed both for groups of products and individual product items, but variable, depending on the customer class or current terms of contract. It makes management even more difficult due to the growth of the system dynamics. Such a high dynamics of a production and logistics system is one of the key reasons for the use of a simulation application.

2 Statistical Indicators and Measures

Statistical methods are used for analysing the data which describes mass phenomena and constitute a set of statistical tools developed based on mathematical sciences, mainly probability theory (Turek and Michalak 2009). Statistical methods are focused on the analysis of the variability of data and are also used for measuring, describing and interpreting this variability (Turek and Michalak 2009).

The highest amount of the most accurate data concerning the phenomenon under analysis can be obtained by establishing concrete values of certain functions defined in a set of statistical data, referred to as descriptive characteristics, statistical measures or parameters (Bielecka 2001). They combine into the most analytical tool for presenting the findings of a statistical study.

1. Information on the distribution of the population feature—we distinguish the following statistics measures:
   - value measures,
   - dispersion measures,
   - skewness measures,
   - peakedness measures;
2. Information on the scope of data:
   - classical measures,
   - position measures.

The following statistical measures have been used in the presented analysis of cycle times for individual operations on details:

- arithmetic mean, a level measure, classified as classical measure,
- standard deviation, classified as dispersion measure,
- coefficient of variation, classified as dispersion measure.

Table 1 presents the basic descriptive characteristics taking into account two distribution criteria:

Arithmetic mean, as is the case with the remaining average measures, represents an average level of the study feature. Arithmetic mean is a sum of the values of all statistical units in the population, divided by the sum of all of the units in a given population (Ignatczyk and Chromińska 2004; Luderer et al. 2010).

Standard deviation, is the basic measure of variability of the results under observation. It shows how the results "change", namely how big is the dispersion or variation from the average. **Standard deviation** is a common measure used for statistical inference concerning the probability of obtaining certain results. Standard deviation is a common phrase in the "language" of statistics. It measures the distance of individual results from the average. The greater the deviation from the average as expressed in deviation, the more non-standard the result. The following formula for calculating the standard deviation was used for the analysis purposes:

$$\delta_x = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N}} \tag{1}$$

where:
δ_x A symbol of standard deviation.

Standard deviation is often sued for summarizing the distribution of the data from a given sample (Cleophas and Zwinderman 2011). Standard deviation is a

Table 1 Classification of statistical measures (*Source* own study)

Types of measures	Classical		Position	
Level measures	Absolute Arithmetic mean Geometric mean		 Dominant Median Quartiles	
Dispersion measures	Absolute Variance Standard deviation Average deviation	Relative Classical coefficient of variance	Absolute Scope Interquartile deviation	Relative Classical coefficient of variance
Asymmetric measures	Absolute / direction/ Classical asymmetric measure	Relative/ direction and force/ Classical asymmetric measure Value range (−2; +2)	Absolute/ direction/ Position asymmetric measure	Relative/ direction and force/ Position asymmetric measure Value range (−1; +1)
Peakedness measures	Absolute Peakedness measure	Relative Peakedness coefficient		

sensitive measure of dispersion, yet it cannot be used as an absolute measure in the comparative analysis of dispersion in several populations or for several features in one population. Every comparative evaluation of dispersion requires applying a relative measure. The key to developing a relative measure is to relate an absolute measure of variability to the central tendency—arithmetic mean, median (Ignatczyk and Chromińska 2004). A relative measure of dispersions is referred to as the coefficient of variability. The **coefficient of variation**, is the ratio of the standard or average deviation to the arithmetic mean (Lemaire 1995), expressed by the following formula:

$$Vx = \frac{\delta_x}{\bar{x}} \cdot 100\,\% \tag{2}$$

The coefficient of variation is characterised by a more pronounced occurrence of incidental causes compared with principal causes.

An advantage of this statistical measure is that it enables the evaluation of an average parameter (Ignatczyk and Chromińska 2004), when:

- $V_x \leq 35\ \%$ means that dispersion level is low, arithmetic mean represents well the average level of the phenomenon under study; the population can be considered homogeneous.
- $35\ \% < V_x \leq 60\ \%$, means that dispersion level is moderate, arithmetic mean represents the average level of the phenomenon under study quite well.

- $60 < V_x \leq 75$ %, means that dispersion level is high, arithmetic mean is of little cognitive value.
- $75 < V_x \leq 100$ %, means that dispersion level is very high, arithmetic mean does not represent the central tendency very well.
- $V_x > 100$ %, means that dispersion level is very high, arithmetic mean does not represent the central tendency.

The coefficient of variation facilitates the comparison of the degree of dispersion of the variable feature in several as well as in one population. On top of the above it enables the evaluation of the population's level of homogeneity, which is crucial for the accuracy of the statistical analysis.

Statistical measures mentioned above describe the structure of the study population. However, the units combining into the statistical population are usually characterised by more than one feature. These features are mutually conditioning. The relationship between the features of the study population is investigated based on interdependence analysis, which is used for determining correlation. Correlation measures the relationship between two or more variables.

The statistical study involved the application of correlation interdependence, which is a special case of stochastic interdependence. Specific values of one variable correspond to strictly defined average values of another variable. It is possible to determine how the value of dependent variable Y changes (on average) along with the changes in the value of independent variable X.

Correlation coefficients assume the values ranging from −1.00 to +1.00. The value −1.00 represents an excellent negative correlation, whereas value +1.00 represents an excellent positive correlation. Value 0.00 means that there is no correlation (Pederse et al. 2010).

3 The Logic of Validation Experiments in the Methodology of Selecting a Product Range

In management systems (ISO) validation means the confirmation through investigating and presenting objective evidence which proves that the requirements regarding the intended use (Norma ISO 9001: 2000) have been met. In computer simulations, on the other hand, is the process of determining the degree to which the model represents the real system from an assumed point of view (Hartley 1997). The evaluation of the model adequacy is a factor deciding on its usefulness for solving the problem in question. Two approaches can be taken as regards validation. The first one is based on a simultaneous work of the validation team and the system designers aligned with the current evaluation of the model's adequacy.

The second approach implies the validation and verification of the simulation system after the work on the model has been completed (Sargent 2001).

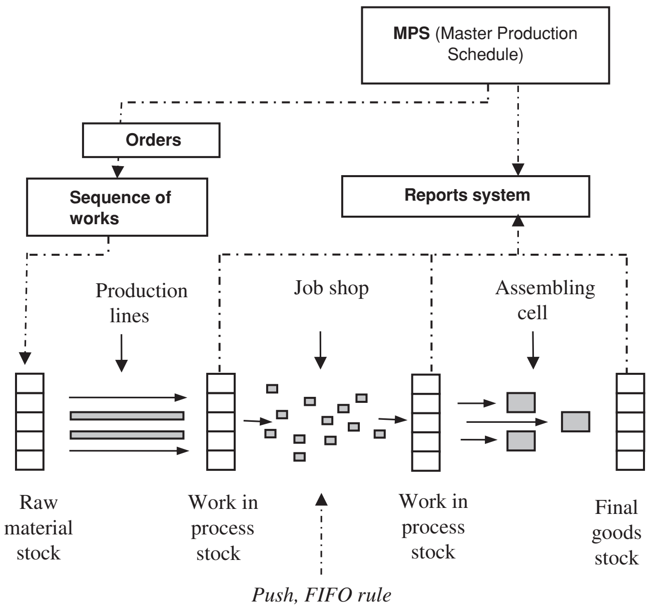

Fig. 1 Production structure chart pertaining to the class of enterprises under analysis (*Source* own study)

Table 2 Input data and the results of statistical analysis (*Source* own study)

No.	Route	Prevailing arithmetic average	Prevailing standard deviation	Prevailing coefficient of variation (%)
Vertical section				
1	Route_E1_S1	9.00	0.00	0.00
2	Route_E1_S2	5.50	0.55	9.96
3	Route_E1_S3	5.83	0.75	12.90
4	Route_E1_S4	5.83	0.75	12.90
5	Route_E1_S5	6.00	1.79	29.83
Horizontal section				
1	Route_E1_S1	9.00	0.00	0.00
2	Route_E1_S2	5.71	0.53	8.54
3	Route_E1_S3	8.00	0.79	14.12
4	Route_E1_S4	5.86	1.35	22.97
5	Route_E1_S5	6.29	1.80	28.62

In the case study presented in the article validation pertains to verifying the efficiency of the methodology for analyzing the product range for specific conditions (a broad range of products with a low level of technological and organizational similarity) with a view to improving the preferred operational parameters of the flow of material streams (see Fig. 1).

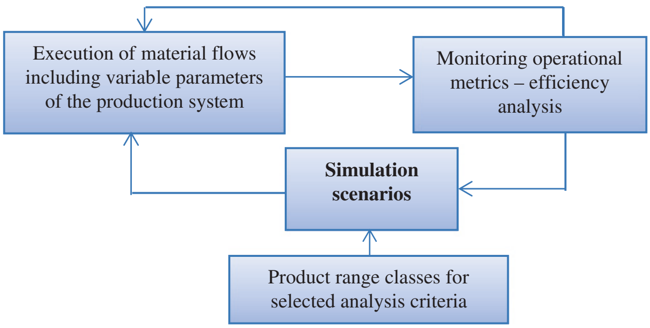

Fig. 2 The diagram representing the logic of validation experiments of the selection of the product group in FlexSim (*Source* own study)

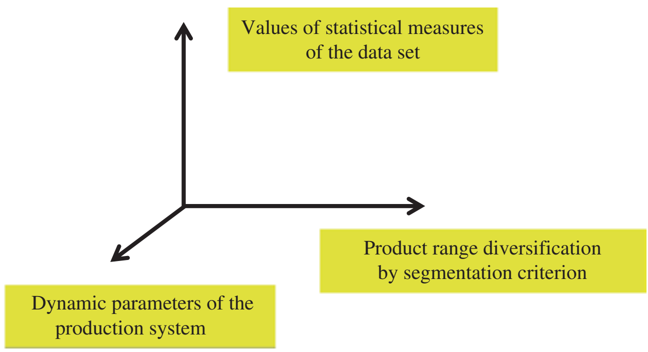

Fig. 3 Three-dimensional space of validation experiments (*Source* own study)

In order to analyses the results of simulation experiments a group of performance metrics was identified (see Table 2).

The next step involved defining the required “validation experiment space” so that the scope of the study could overlap with “decision-making space” available in the enterprise under observation (Fig. 2). “Validation experiment space” consists of three dimensions (see Fig. 3). The “values of statistical measures of the data set” and “product range diversification by segmentation criterion” are dimensions related with the adopted methods for assortment analysis. The “dynamic parameters of the production system” dimension, on the other hand, represents the features of the production system impacting the simulation results. They involve: process time fluctuations, the level of disturbance and the level of machine load.

The production system model was developed in FlexSim 7 simulation program (Fig. 4).

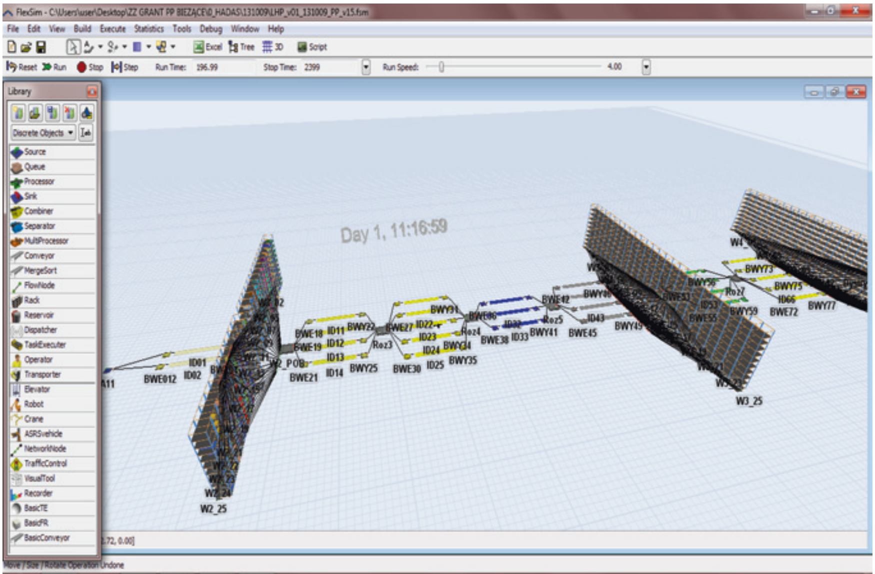

Fig. 4 FlexSim—simulation model screenshot (*Source* own study)

4 The Analysis of Results: Correlation Analysis

4.1 Framework Methodology for Validating Product Range Analysis

Validation methodology for investigating the product range in keeping with the needs of enterprises having a broad range of products and a diversified customer service strategy is based on a group of analyses and the study of correlations between them, which give rise to making general inferences. The importance of the range of finished products is determined based on ABC/XYZ analyses, which are commonplace in business practice, and executed based on the value as well as demand regularity criteria. On the one hand, it is a classification method for defining product range class, numbers and frequency. On the other hand, these analyses are a point of departure for **defining customer service priorities** and, thus, for modelling an internal order portfolio (along with demand management).

These analyses are aimed at adopting the right **market service strategy**, taking into account operational results of an enterprise, which is expected to be the basis for a sustainable decision-making process.

Statistical analyses, on the other hand, are an attempt at **evaluating the method of selecting the product range** in view of its similarities crucial for **the efficiency of the flow of material streams**. These are multi-aspect analyses, investigating the similarity in line with the criteria that had been adopted, and describing these

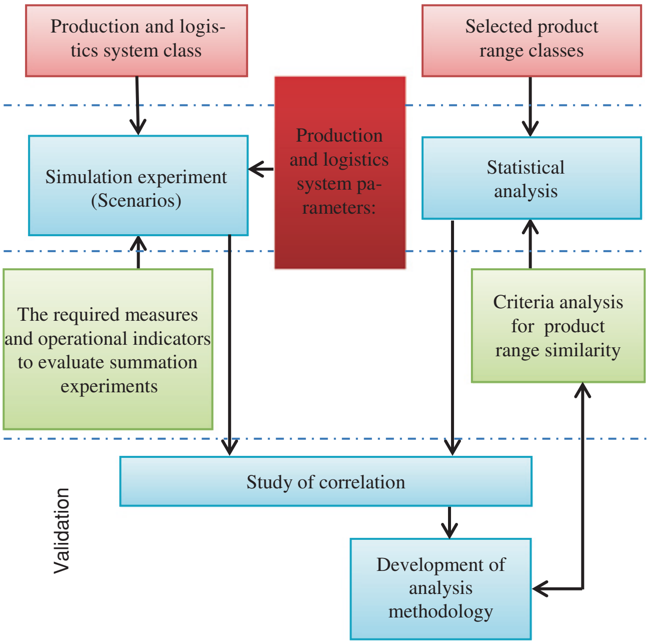

Fig. 5 Framework validation methodology for analyzing product range in a multi-divisional enterprise with a wide range of products (*Source* own study)

similarities with the use of statistical measures (central tendency and dispersion measures—see Chap. 2).

The subject matter of study is the result of simulation conducted in the developed model of a multi-divisional enterprise, which are based on the prepared experiment and individual scenarios. Simulations scenarios are intended to enhance the credibility of the results in the context of random variables of production system parameters. The first type of parameters is **independent of the physical production system**, but dependent on the planning logic (average machine load). The second type of parameters depends on the stability of the production process (machine breakdown rate and production failure rate, time fluctuations). The basic interdependencies are shown in Fig. 5.

The modelling of other parameters is not mapped in the scenarios, which is intentional. These parameters include, among others: the flow logic, processing priorities and time or stock buffers (along with their location). This is due to the fact that the chief purpose here is investigating the intensity of the flow in the conditions which are possibly "pure", namely free from any flow management aspects (for the clarity of inference). Investigating the management aspects of material stream flow is the subject of further works on the production system transformation model (Hadas et al. 2009; Hadas and Cyplik 2010).

The final stage of this part of work is the study of correlation between simulation results and statistical analysis results. Potential strong correlations suggest that statistical analysis identifies the impact of assortment selection on the efficiency of material stream flows and, in view of the above, may become an important constituent element of planning and shop floor control system.

4.2 Results of Descriptive Statistical Analysis of Input Data

The scope of descriptive statistical analysis of input data includes cycle times of individual operations performed on the product group. Statistical measures such as: arithmetic mean, standard deviation and the coefficient of variation were determined in two sections:

- vertical, with statistical measures for individual work stations obtained as a result,
- horizontal, with statistical measures for individual details in the assortment-group obtained as a result.

The analyses have been conducted from the perspective of 5 technological routes. The most common measures have been used for this purpose, such as arithmetic mean, standard deviation and the coefficient of variation. Input data and the results of descriptive statistical analysis are presented in Table 2.

Statistical analyses reveal that in both vertical and horizontal sections, the coefficient of variation regarding cycle times for operations in the technological route assumes the value of $V_x \leq 35\ \%$. It means that dispersion is low and the arithmetic mean characterizes the average level of the phenomenon under investigation very well; it can be assumed that the study population homogeneous.

4.3 Results of Descriptive Statistical Analysis

The correlation analysis was conducted in three cross-sections, covering the following data:

- vertical section, the investigation of the interdependence between the cycle time coefficient of variation of the operation performed on a given work station, which is the most common for a given technological route, and the technological process metrics as delivered by simulation experiments, among others: WIP, LT, idle, processing and coefficient,
- horizontal section, the investigation of the interdependence between the cycle time coefficient of variation of the operations performed on a given detail within the technological route and the technological process metrics, as delivered by simulation experiments, among others: WIP, LT, idle, processing and coefficient.
- the investigation of the interdependency between the degree to which technological route is covered and technological process metrics delivered by simulation experiments, such as: WIP, LT, idle, processing and coefficient.

Table 3 Correlation analysis results (*Source* own study)

	WIP	Lead time	Idle	Processing	Coefficient of flow
Vertical layout					
Coefficient of variation	0.95	0.97	−0.07	−0.68	0.72
Horizontal layout					
Coefficient of variation	0.89	0.94	0.91	0.38	0.95
Degree to which route is covered	−0.76	−0.80	−0.96	−0.14	−0.96

4.3.1 Correlation Analysis Results

The correlation analysis and coefficient values that have been obtained as their result imply that (Table 3):

1. There is a strong positive interdependence between the coefficient of variation of cycle times of operations performed on the work station and WIP and lead time indicator. The correlation coefficient is close to 1.00, which is indicative of an almost linear interdependence. A positive value of the correlation coefficient suggests that the greater the coefficient of variation, the greater the value of WIP and LT. It means that in order to reduce WIP and LT we should bring down the value of the coefficient of variation, namely reduce the diversity of cycle times for operations on the work station.
2. There is a very weak negative interdependence between the coefficient of variation of cycle times of operations performed on the work station and the idle indicator. The correlation coefficient is close to 0.00, which is indicative of a scant interdependence between the variables under investigation. It means that the coefficient of variation of unit operations on a given work station has a marginal impact on idle times.
3. There is a strong positive interdependence between the coefficient of variation of cycle times of operations performed on the detail and WIP as well as lead time, idle and coefficient. The correlation coefficient is close to 1.00, which is indicative of an almost linear interdependence. A positive value of the correlation coefficient suggests that the greater the coefficient of variation, the greater the value of WIP and LT, idle and coefficient. It means that in order to reduce the value of these indicators we should bring down the value of the coefficient of variation, namely reduce the diversity of cycle times for operations performed on a given detail.
4. There is a negative interdependence between the degree to which the technological route is covered and the idle and coefficient indicators. The correlation coefficient is close to 1.00, which is indicative of an almost linear interdependence. A negative value of the coefficient of correlation suggests that the greater the degree to which technological route is covered, the lower the value of idle and coefficient indicators. It means that in order to reduce the value of idle and coefficient we should increase the degree to which the technological route is covered.

5. There is a very weak negative interdependence between the degree to which the technological route is covered and the processing indicator. The indicator of correlation is close to 0.00, which is indicative of a scant interdependence between the variables under investigation. It means that the degree to which the technological route is covered has a marginal impact on processing.

5 Product Range Segmentation Model in the Enterprises with Wide Range of Products

Production planning and shop floor control under the conditions of a large fluctuation of assortment and diversified customer service strategy must be capable of implementing many diversified production orders (Fig. 6).

The production orders are generated on the basis of orders and/or forecasts, each for a separate assortment groups, these are approached on the following levels respectively: long, medium and short term (see Fig. 5) depending on the applied customer service strategy (location of a *decoupling point*). Therefore it is a classical production planning system with two balancing levels and an executive level. The executive level includes a multi departmental production structure (see Fig. 1) with multiple value streams. The assortment analysis and segmentation module contains of two levels (level 1—segmentation and level 2—operational planning support) and performs a supply role for the production planning system. The support of the planning system is based on providing information on:

- assortment group (and the logic of order planning),
- possibility of allocation of assortment to particular value streams,
- size of the stock buffer and time buffer required for the assumed logistics level of service.

  Level 1—segmentation uses the following managerial analysis:
- ABC (according to the flow value, for the selecting of dominant assortment flows),
- XYZ (according to the regularity of requirements and the forecast correctness criteria, for the selection of MTS, ATO and MTO groups),
- Customer Value Added (CVA)—(according to the importance of an assortment and customer, for the verification of the level of service and localisation of the decoupling point—i.e. their conformity with marketing strategy and customer category).

Level 2—operational planning support uses statistical analysis of an assortment for the supporting of balancing of tasks and calibration of time and stock buffers. And so for example MTS—OTB—assortments from this group are available "off the shelf". The demand profile of such an assortment forces the collection of stock enabling intensified sales in the latter part of the month (a diagnosed end of month syndrome). The MTS group—Buffer—assortments from this group are available "off the shelf". The size of a time buffer equals the maximum usage during stock

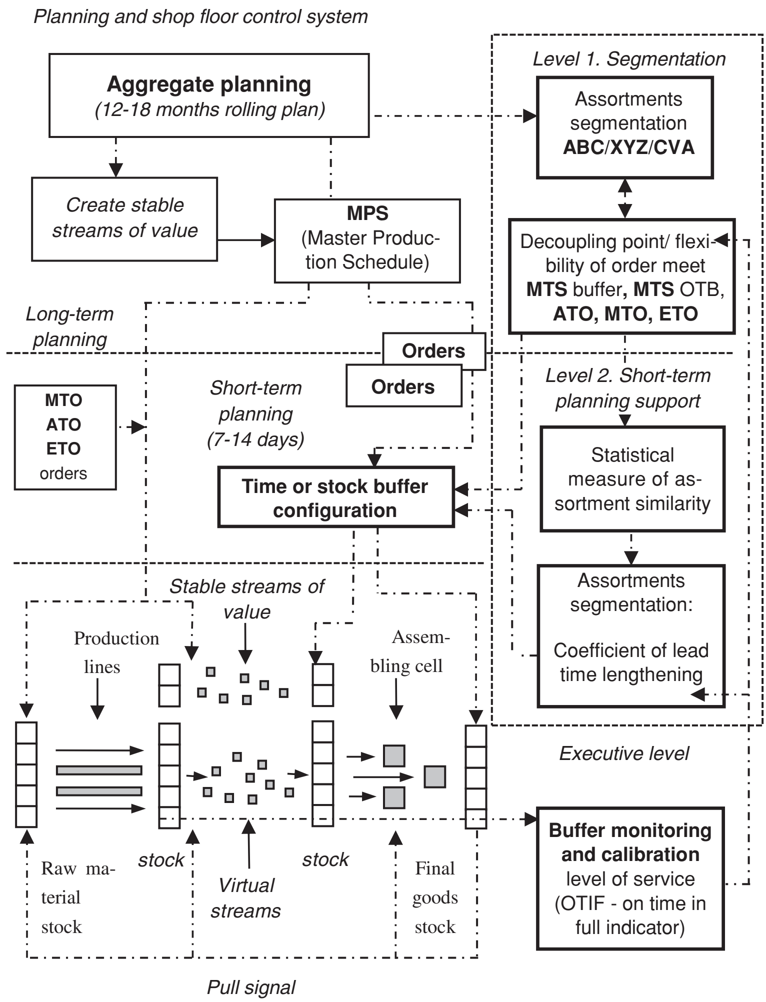

Fig. 6 Construction of the production planning system together with the multi-criteria analysis and assortment segmentation module (*Source* own study)

replenishment (7 days at the assembly department) or the value stemming from the assumed customer service level. Such positions require time buffer management. The ATO group—the order implementation deadline for an ATO group assortment order is 14 days. It is assumed that the time of the assembly cycle at the assembly department is 7 days. A buffer is maintained in the storage sections in which the stock replenishment cycle is longer than 7 days. These positions require stock and time buffers to be managed.

Similarity classes, which enable the allocation of orders to alternative value flows, are created on the basis of statistical analysis of an assortment (load balancing support important in case of large demand fluctuation). Each of assortment classes includes information on the production cycle lengthening ratio (strong correlation detected in the conditions of dynamic parameters of the production system). The research performed by the authors based both on a wide statistical group of managers and the previous works on dedicated planning and production steering systems indicate that the changing of the production system duration is a key planning aspect (in the analysed industrial conditions). Therefore credible information in this area is an important factor of planning process support.

6 Conclusion

The proposed method of assortment segmentation fits in the company planning system in the conditions of high assortment fluctuation and differentiated customer service strategy supporting the process of balancing and adjustment of time and stock buffers which is made possible by the strong correlation between probability (according to the appointed analysis criteria) and operational outcomes (received from the simulations of material flows).

At the same time the research that was carried out does not cover the issue of using statistical analysis of assortment as a support for production planning and steering in the functions described. Further research will be directed at analysing linear regression within the framework of assortment similarity, dynamic parameters of a production system (machine load, time fluctuation and disturbances) as well as the extent of their influence on the lengthening of a production cycle and other operational indicators. The outcomes of the analysis will be used to accurately adjust the stock buffer or time buffer in the conditions of a changing assortment, which does not allow for an effective adjustment to be performed by successive iterations.

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References

American Production and Inventory Control Society (2008) American Production and Inventory Control Society Dictionary, 14th edn. American Production and Control Society, Inc., Falls Church

Bielecka A (2001) Statystyka w zarządzaniu: opis statystyczny, Wyższa Szkoła Przedsiębiorczości i Zarządzania

Cleophas TJ, Zwinderman AH (2011) Statistical analysis of clinical data on a pocket calculator. Springer Science Business Media B.V, The Netherlands

Domanski R, Hadas L Technological and organizational similarity coefficient (α) as a basis for value streams in lean production. http://www.logforum.net/vol4/issue2/no4/4_2_4_2008.html

Hadas L, Cyplik P, Fertsch M (2009) Method of buffering critical resources in make-to-order shop floor control in manufacturing complex product. Int J Prod Res 47(8, 15):2125–2139

Hadas L, Cyplik P (2010) Hybrid production planning system in make-to-order company—case study. Log Forum 6(4), No 5. http://www.logforum.net/vol6/issue4/no5

Hartley DS III (1997) Verification and validation in military simulations. In: Proceedings of the 1997 winter simulation conference (WSC)

Ignatczyk W, Chromińska M (2004) Statystyka: teoria i zastosowanie. WSB, Poznań

Lemaire J (ed.) (1995) Bonus-malus systems in a Uiomobile insurance. Springer Science+Business Media, New York

Liker JK (2004) The Toyota way—14 management principles from the world's greatest manufacturer. McGraw-Hill, New York

Luderer B, Volker N, Vetters K (2010) Mathematical formulas for economists. Springer, Berlin, Heidelberg

Norma ISO 9001:2000—validation of process for production and service provision (7.5.2)

Pedersen TB, Mohania MK, Tjoa AM (eds) (2010) Data warehousing and knowledge discovery. In: 12th International conference, DaWaK 2010 Bilbao, Aug/Sept 2010, Proceedings. Springer, Berlin, Heidelberg

Sargent RG (2001) Some approaches and paradigms for verifying and validating simulation models. In: Proceedings of the 2001 winter simulation conference (WSC)

Turek M, Michalak A (2009) Zasady, tryb przygotowania, przeprowadzenia oraz finansowania przewodów doktorskich i habilitacyjnych, Wyd. Politechniki Śląskiej, Gliwice

Umble M (1992) Analyzing manufacturing problems using V-A-T analysis. Prod Inventory Manag J 33(2):55–60

Global Sensitivity Analysis of Heijunka Controlled Assembly Line

Przemyslaw Korytkowski

Abstract Heijunka (production leveling) is a technique that is associated with lean management, and is responsible for reducing the bullwhip effect. With Heijunka, fluctuations in customer orders are not transferred directly to the manufacturing system, which permits a smoother production and better production capacity utilization. A variance-based Sobol method was used to conduct the global sensitivity analysis. Discrete-event simulation was used to carry out experiments on random data-sets. Through this analysis it was determined that the most influential parameter was lot size, followed by change over time, and variation of technological operation duration.

Keywords Lean management • Heijunka • Production leveling • Simulation • Sensitivity analysis

1 Introduction

Fluctuations in manufacturing environments are one of the causes of increased waste. This is especially true in a multi product manufacturing systems where a particular product mix must be efficiently manufactured. Traditional approaches to product mix management tend to compact orders into large batches of the same product. This leads to changeover and set-up time reductions, but at the same time usually results in lengthening lead times, increased inventories, excessive overtime and/or idle time (Liker 2004). It creates variable production schedules, which can be stressful and can lead to mistakes. The objective of heijunka is to avoid peaks and valleys in the production schedule.

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In a case where demand is variable, two approaches are possible: demand leveling and production leveling. Demand leveling is a role of marketing and sales departments, while production leveling is done by the manufacturing department. Let's focus here on production leveling, which in Japanese is called heijunka. Heijunka is the even distribution of production volume and mix over time (Dennis 2007). It is a core concept that helps bring stability to a manufacturing process. Heijunka converts uneven customer demand into an even and predictable manufacturing process. Fluctuations in demand are often highly amplified and delayed throughout the supply chain and can result in increased overtime or idle time. Heijunka is a type of cyclic scheduling. The repetition of intrinsic to cyclic schedules offers advantages both for shop floor activities and for planning. It may help to detect disturbances earlier and reduce set up time and costs (Bocewicz and Banaszak 2013). Heijunka requires that the company has already introduced other lean management tools such as: takt time, kanban planning, SMED (reduction of changeover and set-up times). Introducing heijunka requires determination of a base period called EPEI (Every Part Every Interval) (Rother and Harris 2002). During the base period the entire mix of products has to be produced.

In literature, it has been demonstrated that Heijunka improves operational efficiency in several objectives related to flexibility, speed, cost, quality and level of customer service. Matzka et al. (2012) modeled a heijunka-controlled kanban manufacturing system as a queuing network with synchronization stations in order to find optimal buffer capacities. The arriving demands were controlled and limited by a kanban loop. The formation of product families for leveling are presented in Bohnen et al. (2011), where clustering techniques were used to subsume the large number of product types into a manageable number of product families.

In a previous work, a multivariate analysis of a heijunka controlled assembly line (Korytkowski et al. 2013) showed that the proper selection of heijunka composition (cyclic schedule) influences work-in-progress and throughput and improve system performance by as much as 10 %. Similar conclusions could be drawn from Huttmeir et al. (2009) who compared heijunka and just-in-sequence on an example of engine production. The presented analyses showed that a proper construction of heijunka was very important to achieve production goals, in that case WIP.

In this chapter a further step in the analysis of heijunka is made by applying variance-based sensitivity analysis, in particular the Sobol indices approach (Saltelli et al. 2008). The question is how stochastic disturbances translate into fluctuations in a heijunka controlled production capacity. Three parameters were investigated: lot size, changeover time, and variability in technological operation duration. A group of experiments was carried out on a simulation model of a real-life microelectronic assembly line.

This chapter is further organized as follows. The following Sect. 2 presents a variance-based sensitivity analysis methodology. The subsequent Sect. 3 describes the case study of a microelectronics manufacturing system, followed by an analysis of the results (Sect. 4). The final Sect. 5 concludes the chapter with a summary and some further issues.

2 Variance-Based Global Sensitivity Analysis

Sensitivity Analysis provides insights into system behavior and reliability, and is used to increase confidence in its predictions. Saltelli et al. (2004) describe Sensitivity Analysis as "The study of how uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input". This is useful as a guiding tool when the model is under development, as well as to understand model behavior when it is used for prediction or for decision support.

Two types of sensitivity analysis are distinguished: local and global. The goal of local sensitivity analysis is to measure the local impact of factors on the model outputs and is performed by computing partial derivatives of the output variables with respect to the input factors. Here the factors are allowed to vary within small intervals around expected values. These intervals are not related to uncertainty in the factor values. Global sensitivity analysis tries to measure the importance of individual factors with respect to the uncertainty. This provides a more realistic view of the model behavior when used in practice. Global sensitivity analysis consists of: defining the distributions of the input factors, generating scenarios of input factors and computing output variables for each scenario, with the final step consisting of calculating a sensitivity index for each factor (Monod et al. 2006). These indices are computed while varying the factors over their uncertainty ranges.

The first step of sensitivity analysis is to define a proper probability distribution. Uniform distribution, the most widely used, puts equal weight on each value in the uncertainty range. In most cases, however, the extreme values of the uncertainty ranges are less likely than the middle values. Among symmetric distributions, the truncated Gaussian distribution or symmetric beta distributions for asymmetric, log-normal, gamma or beta distributions offer a large range of possibilities. The next step is to draw representative samples from these distributions. Here Monte Carlo sampling and Latin Hyper Cube are the most popular methods. Monte Carlo sampling provides unbiased estimates of the expectation and variance of each output variable. Once the samples of factor values have been generated, the corresponding model output values must be computed. The last step of the analysis is to compute sensitivity indices.

There are several methods to perform global sensitivity analysis. In this chapter we focus on variance-based methods as they study how the variance of the output depends on uncertain input factors, and can be decomposed accordingly. Using variance is recommend as a summary measure of uncertainty whenever the application allows it. The advantages of this class of methods are as follows (Saltelli et al. 2008): the sensitivity measure is model-free; capacity to capture the influence of the full range of variation of each input factor; appreciation of interaction effects between input factors; capacity to tackle groups of input factors. The drawback of variance-based measures is the computational cost.

Let's analyze the sensitivity of the following generic model:

$$Y = \mathrm{f(X)} = f(X_1, X_2, \ldots, X_k) \tag{1}$$

where input factors are $X = X_1, X_2, \ldots, X_k$ and the model response (output variable) is Y. For simplicity let's assume that the model has just a single output variable. We don't need to know the functional form of the model to perform the analysis. Each X has a non-null variation. If we fix factor X_i at a particular value x_i^* the resulting variance of Y would be $V_{X\sim i}(Y|X_i = x_i^*)$ taken over all factors apart from X_i. If we take the average of this measure over all possible points x_i^* we get $E_{X_i}(V_{X\sim i}(Y|X_i))$, which is always lower or equal to $V(Y)$,

$$E_{X_i}(V_{X\sim i}(Y|X_i)) + V_{X_i}(E_{X\sim i}(Y|X_i)) = V(Y) \tag{2}$$

Thus a small $E_{X_i}(V_{X\sim i}(Y|X_i))$ or large $V_{X_i}(E_{X\sim i}(Y|X_i))$ will imply that X_i is an important factor. The conditional variance $V_{X_i}(E_{X\sim i}(Y|X_i))$ is called the first-order effect of X_i on Y and the sensitivity measure, known as the first-order sensitivity index, is:

$$S_i = \frac{V_{X_i}(E_{X\sim i}(Y|X_i))}{V(Y)} \tag{3}$$

S_i is a number always between 0 and 1.

A high value indicates an important factor. Higher-order indices, also known as interaction effects, are calculated based on a high dimensional model representation decomposition, so named ANOVA-HDMR. Let $V_i = V(E(Y|X_i))$ and $V_{ij} = V\left(E\left(Y|X_i, X_j\right)\right) - V(E(Y|X_i)) - V\left(E\left(Y|X_j\right)\right)$.

$V\left(E\left(Y|X_i, X_j\right)\right)$ measures the joint effect of the pair $\left(X_i, X_j\right)$ on Y. Higher order variances could be written analogously. The ANOVA-HDMR decomposition could be written as:

$$V(Y) = \sum_{i=1}^{k} V_i + \sum_{i=1, j>i}^{k} V_{ij} + \cdots + V_{12\ldots k}. \tag{4}$$

The 'total effect index' accounts for the total contribution to the output variation from factor X_i, i.e. its first-order effect, plus all higher order effects due to interactions. Total effects are a consequence of the variance decomposition approach and are calculated as:

$$S_{Ti} = S_i + \sum_{j \neq i} S_{ij} + \cdots + S_{12\ldots k}. \tag{5}$$

The first method of variance-based sensitivity analysis was Fourier Amplitude Sensitivity Test Description (FAST) developed by Cukier et al. (1973). This was later improved by Saltelli (1999) and called Extended Fourier Amplitude Sensitivity Test Description, and allows the estimation of first order and total sensitivity indices for all the factors at a total cost of $n \times p$ simulations, where p is the number of factors.

Another way to compute sensitivity indices is to use a Monte Carlo estimation (Saltelli et al. 2010), which allows computing first-order and total indices at a total cost of $N \times (p + 2)$ simulations, where N is the number of random experimental points and p is the number of factors. All first-order indices could be calculated using a Monod scheme (Monod et al. 2006) at a cost of $N \times (p + 1)$ simulations. In this chapter a Monod scheme here will be applied for the sensitivity analysis of a heijunka controlled assembly line.

The basic idea behind the Monod scheme is to evaluate the model response at N randomly sampled scenarios $sc_{A,n}$ and $sc_{B,n}$, where $n = 1, \ldots, N$, defined by

$$sc_{A,n} = \left(x_{n,1}, \ldots, x_{n,i-1}, x_{n,i}, x_{n,i+1}, \ldots, x_{n,k}\right), \tag{6}$$

$$sc_{B,n} = \left(x'_{n,1}, \ldots x'_{n,i-1} x_{n,i}, x'_{n,i+1}, \ldots x'_{n,k}\right), \tag{7}$$

with the same level $x_{n,i}$ of X_i and all other levels sampled independently.

Then calculating;

$$\hat{y}_0 = \frac{1}{2N} \sum_{n=1}^{N} \left(f\left(sc_{A,n}\right) + f\left(sc_{B,n}\right)\right) \tag{8}$$

$$\hat{D} = \frac{1}{2N} \sum_{n=1}^{N} \left(f\left(sc_{A,n}\right)^2 + f\left(sc_{B,n}\right)^2\right) - \hat{y}_0^2 \tag{9}$$

$$\hat{D}_i = \frac{1}{2N} \sum_{n=1}^{N} f\left(sc_{A,n}\right) \times f\left(sc_{B,n}\right) - \hat{y}_0^2 \tag{10}$$

where $\hat{D}$ is the total and $\hat{D}_i$ is the main-effect of X_i variance estimators. The first-order sensitivity index is calculated as follows

$$\hat{S}_i = \frac{\hat{D}_i}{\hat{D}}. \tag{11}$$

To calculate the sensitivity indices, the R environment (3.0.2) will be used with a Sensitivity package version 1.7 (Package Sensitivity 2014). The Monod scheme is applied in the “sobolEff” function.

3 Microelectronic Assembly Line

This section introduces the case study plant, which is a microelectronics assembly line that produces potentiometers used to adjust sound levels. There are four main classes of product (A, B, C and D). Class B includes three sub-classes (B1, B2, B3) and class C two subclasses (C1, C2). Average customer demand is about 50,000 pieces per month and distribution by product is as follows: A—50 %, B—35 %, C—14 % and D—1 %. The maximum production capacity is about 60,000 pieces, working in two 7 h shifts, 5 days a week, with a maximum scrap

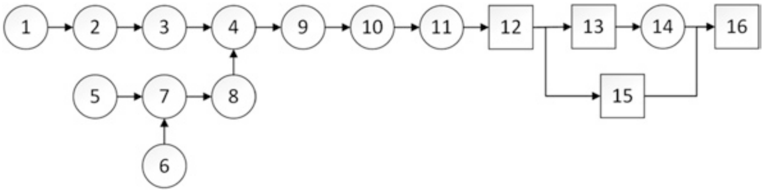

Fig. 1 Microelectronics assembly line (*Source* own study)

Table 1 Production process

Workstation	Description	Time per pcs (s)
1	Assembly 1	3.2
2	Lubrication	2.5
3	Assembly 2	11.8
4	Final assembly	6.8
5	Assembly 3	4.7
6	Bending	4.3
7	Assembly and lubrication	6.5
8	Riveting	17.3
9	Setup	1.0
10	Gluing	5.8
11	Front and back marking	2.4
12	Mechanical inspection	2.9
13	Electrical inspection	5.0
14	Packing	2.4
15	Electrical inspection + packing	6.3
16	Final inspection	1.5

Source own study

level of 6 %. Order size has the great variability. The minimum order size is 100 pieces and the maximum 1,000 pieces, with an average about 500. Processing times and setup times vary between products.

The processes for this product family consist of manual and semi-automatic assembly, and several quality control operations. In Fig. 1 and Table 1 a production process is presented, made up of 28 workstations of 16 types. Some workstations are multiplied and are working in parallel. Between all production steps there are buffers for 24 pieces. Semi-finished products are transported manually between workstations in batches of 12 pieces. In the assembly line, pull production is organized with fixed capacity buffers between workstations. Workstations 12, 13, 15, and 16 are mechanical, electrical and final inspections.

Arriving orders are scheduled using a heijunka reflecting averaged demand. Heijunka has several compartments (pitches) where orders are stored according to a predefined schema. In one compartment only one order can be stored. For each compartment the kind of order which can fall into it is defined. In some cases it is defined that only one type of order can be stored in a compartment, and for others a list of possible order types is defined. Orders for production are executed in a sequence resulting from the heijunka.

The aim of this study is to determine how a heijunka controlled production system is vulnerable to distortions and how universal this approach is.

4 Sensitivity Analysis of a Heijunka Controlled Assembly Line

The assembly line described in the previous section was modeled in an Arena discrete-event simulation system from Rockwell Automation. The simulation length was set to one week, comprised of 5 working days with two shifts of seven hours of effective work. A week was a planning period at the factory. A warm-up period ensuring steady-state statistics gathered was set at 7 h. Arena uses a common random number approach as a method of variance reduction, meaning that experiments start with the same random numbers. This feature is desirable when comparing different variants of the same system, but in this case independent and identically distributed random variables were required to compute the sensitivity indices. In Arena, a new replication of the same experiment uses the last random number from the previous replication as a seed. This propriety in combination with Visual Basic was used to ensure case independent and identically distributed random numbers.

Experiments were carried out on a simulation model with a production process controlled by the heijunka sequence A–B–BCD–A–A–B–BCD–A–A–B. Here A, B, C and D stand for the product type, and BCD means that any order of types B, C or D can fall into the heijunka pitch. This was a standard heijunka configuration working everyday in this assembly line.

Three parameters are investigated in this study: lot size (X_1), changeover time (X_2) and variation of technological operation duration (X_3). Lot size and change over time are closely related, and the lean management approach advises shortening both. This should result in shorter throughput time and lower inventory levels. Sensitivity analysis will provide answers to questions like: how vulnerable is the selected heijunka configuration when not everything goes smoothly on the production floor. Moreover we would like to investigate whether randomness in the technological operation duration will affect the efficiency of the assembly line. Responses of the model were measured by the output capacity (Y).

A Monod scheme (Monod et al. 2006) was used to calculate first order sensitivity indices. 1,024 Monte Carlo points were generated (see Fig. 2): $\boldsymbol{X_1 = UNIF(100, 1{,}000)}$, $\boldsymbol{X_2 = UNIF(10, 100)}$,$\boldsymbol{X_3 = UNIF(0, 0.3333)}$, where UNIF stands for continuous uniform distribution. For three input variables, the Monod scheme requires $\boldsymbol{N \times (p + 1) = 1{,}024 \times (3 + 1) = 4{,}096}$ simulation runs to calculate indices S_1, S_2 and S_3 respectively for: lot size (X_1), changeover time (X_2) and variation of technological operation duration (X_3).

After finishing all experiments, the average output capacity was 58,410 with median equal to 58,880, first quantile equal to 57,850 and third quantile equal to 59,640. The minimal value was 48,340 and maximal 60,940. The distribution of output capacities is shown in Fig. 3.

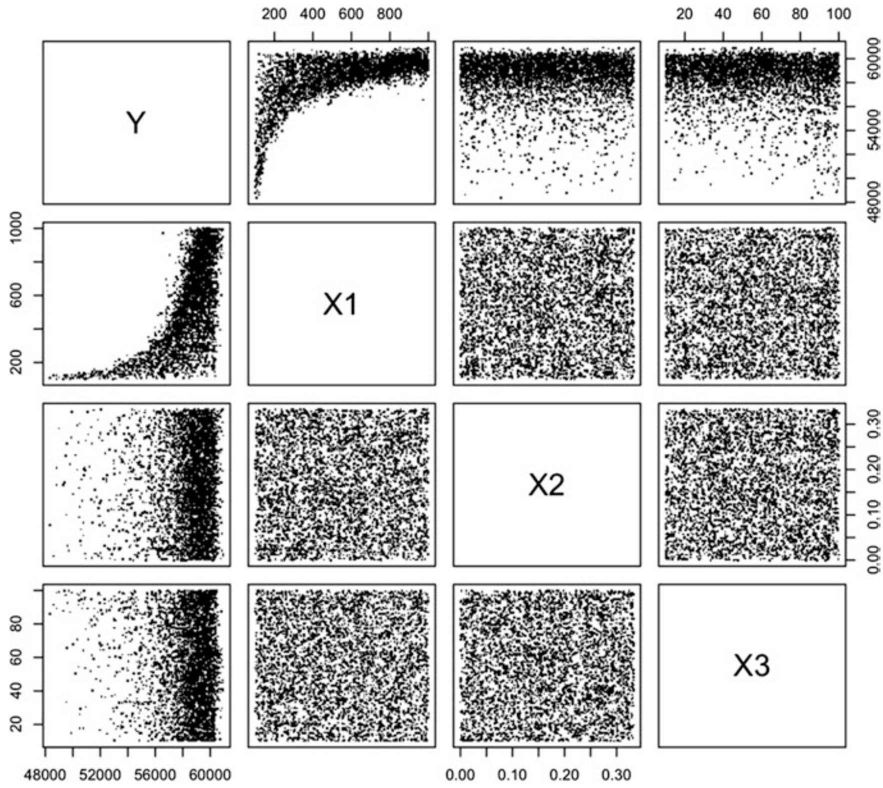

Fig. 2 Scatter plots for input and output variables (*Source* own study)

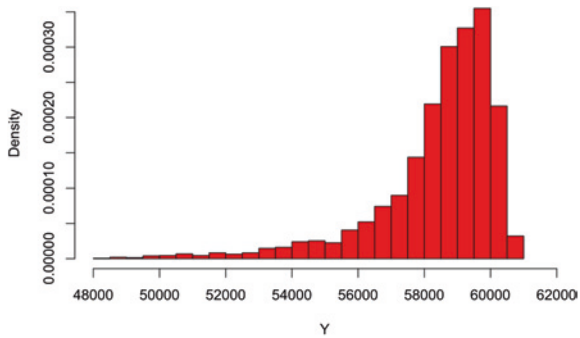

Fig. 3 Production capacity (*Source* own study)

Figure 2 shows the strong dependence of output capacity (Y) upon lot size (X1). The bigger the lot size, the more the average production capacity increases until it reaches the maximal level, with dispersion decreasing at the same time.

Table 2 Estimation of first order sensitivity indices

Index name	Value	95 % confidence interval
S_1	0.8797	$(0.8559, 0.9081)$
S_2	0.0490	$(-0.0177, 0.1145)$
S_3	0.0806	$(-0.0008, 0.1618)$

Source own study

Two other parameters (X2 and X3) do not show so any strong relation with output capacity.

Estimations of first order sensitivity indices are presented in Table 2. S_1 has the biggest value, almost 0.88 with a quite narrow 95 % confidence interval, indicating that variation in lot size had a great impact on the variability of output capacity. The S_2 index with a value close to 0.05 and the little higher S_3 index suggest that changeover time and variation of technological operation duration do not have a big influence on the variability of output capacity.

The above presented results suggest that variations in technology operation duration have a small impact on the output capacity of a production line controlled by the heijunka. This is good information for managers as they do not have to pay a lot of attention to ensure exact information about such variations. The variation of changeover time seems to not have a great impact on output capacity. This is a strong argument for implementing heijunka in a production environment.

With lot size versus output capacity, the scatterplot (Fig. 2) shows that when the lot size is about 400 or higher, variation of output capacity is quite stable and is gradually decreasing. The situation is completely different for smaller lot sizes where variation is strongly increasing as lot size is decreasing. This suggests that lot sizes below 400 are not well managed by heijunka in this assembly line.

5 Conclusions

In this chapter we have presented a sensitivity analysis of one particular assembly line. Three input parameters were considered and one output variable. This analysis could be easily applied to many different production systems controlled by heijunka.

The obtained results show that heijunka is quite robust with respect to variation in operation time duration and changeover time duration. Attention needs to be placed on selecting the lot size, as this factor strongly influences the variance in output capacity.

References

Bocewicz G, Banaszak Z (2013) Declarative approach to cyclic steady states space refinement: periodic processes scheduling. Int J Adv Manuf Technol 67(1–4):137–155

Bohnen F, Maschek T, Deuse J (2011) Leveling of low volume and high mix production based on a group technology approach. CIRP J Manuf Sci Technol 4(3):247–251

Cukier RI, Fortuin CM, Schuler KE, Petschek AG, Schaibly JH (1973) Study of the sensitivity of coupled reaction systems to uncertainties in rate coefficients. J Chem Phys 59:3873–3878
Dennis P (2007) Lean production simplified, 2nd edn. Productivity Press, New York
Hüttmeir A, de Treville S, van Ackere A, Monnier L, Prenninger J (2009) Trading off between heijunka and just-in-sequence. Int J Prod Econ 118(2):501–507
Korytkowski P, Wiśniewski T, Rymaszewski S (2013) Multivariate simulation analysis of production leveling (heijunka)—a case study. In: Proceedings of IFAC conference on manufacturing modelling, management and control, Saint Petersburg, Russia, 19–21 June 2013
Liker JK (2004) The Toyota way, 14 management principles from the worlds greatest manufacturer, 1st edn. McGraw-Hill, New York
Matzka J, Di Mascolo M, Furmans K (2012) Buffer sizing of a Heijunka Kanban system. J Intell Manuf 23(1):49–60
Monod H, Naud C, Makowski D (2006) Uncertainty and sensitivity analysis for crop models in working with dynamic crop models. In: Evaluation, analysis, parameterization, and applications, Elsevier, Amsterdam
Package Sensitivity, download from http://cran.r-project.org/web/packages/sensitivity/. Access 10.01.2014
Rother R, Harris M (2002) Creating continuous flow: an action guide for managers, engineers and production associates. Lean Enterprise Institute (LEI)
Saltelli A, Tarantola S, Chan K (1999) A quantitative, model independent method for global sensitivity analysis of model output. Technometrics 41:39–56
Saltelli A, Tarantola S, Campolongo F, Ratto M (2004) Sensitivity analysis in practice: a guide to assessing scientific models. Wiley, London
Saltelli A, Ratto M, Andres T, Campolongo F, Cariboni J, Gatelli D, Tarantola S (2008) Global sensitivity analysis. The Primer. Wiley, London
Saltelli A, Annoni P, Azzini I, Campolongo F, Ratto M, Tarantola S (2010) Variance based sensitivity analysis of model output. Design and estimator for the total sensitivity index. Comput Phys Commun 181:259–270

Stability Analysis of the Production System Using Simulation Models

Anna Burduk

Abstract In order to ensure smooth functioning of a production system, the stability of its processes must be guaranteed, while on the other hand it must be possible to make quick decisions encumbered with the lowest possible risk. Innovations concerning products or processes constitute a necessary condition to remain on the market, but they always carry the risk of losing the stability. The risk results from the uncertainty associated with making decisions as to the future, as well as from the fact that the implementation of innovations is one of the factors that disturb the current manner of the company's operation. There are many methods and techniques for system modelling, while a broad range of advanced IT packages for process modelling is available in the market. Production system modelling allows ensuring the stability of a production system through: understanding and assessing the impact of the decisions made on the production system and its various functional areas. The problem of the stability of the production system has been considered in the context of its current functioning (operation) and development (reorganization).

Keywords Stability of a production system • Modelling and simulation

1 Introduction

In order to ensure smooth functioning of a production system, the stability of its processes must be guaranteed, while on the other hand it must be possible to make quick decisions encumbered with the lowest possible risk. Innovations concerning

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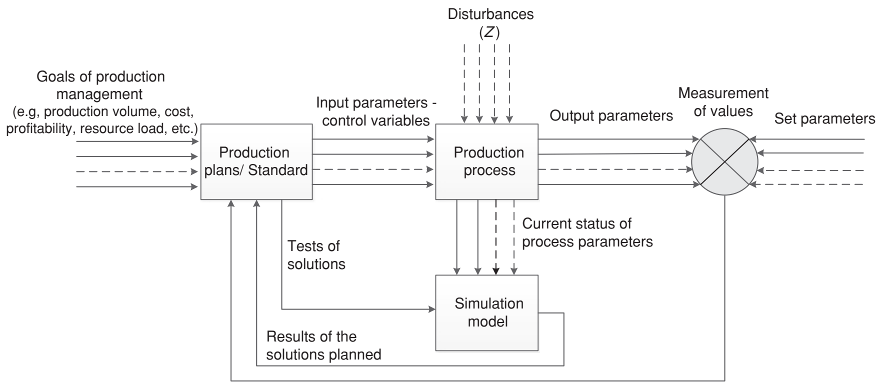

Fig. 1 Method for managing and optimizing a production process using a computer model (*Source* Own study)

products or processes are a necessary condition to remain on the market, but they always carry the risk of losing the stability. The risk results from the uncertainty associated with making decisions as to the future, as well as from the fact that the implementation of innovations is one of the factors that disturb the current manner of the company's operation.

The concept of stability is derived from the systems theory. Several different definitions of the system stability can be found in the literature. Most of them refer to the concept of the point/state of balance and define the stability of a system as its ability to return to the state of balance after the disturbances that caused the instability have ceased. The stability of a control system is its most important feature—it characterises the ability to accomplish the tasks, for which it has been built. If there is a standard, the process control boils down to approximating the functioning of the process to the standard using feedbacks. Feedbacks allow comparing the actual states of the system with the desired states (standards), and then correcting the deviations found.

In the case of production processes, the standard is typically established by the production plan for final products, which specifies parameters or criteria and an appropriate time scale. However, the production practice is always accompanied by disturbances known as risk factors (r_i), which cause that the system becomes out of balance (Burduk 2011).

The stability of a production system will be understood as maintaining the steady state of the system for a certain assumed period. In order to ensure the stability, on the one hand an appropriate control is needed, while on the other hand it is necessary to analyse, evaluate and eliminate the random factors causing the disturbances (risk factors). Control in the context of production systems means making decisions based on the information or data coming from the controlled system. The impact of single- or multi-criteria decisions on the production system can be verified very well on a model that contains selected elements important in a given context, their parameters and the relationships between them. Figure 1 presents a schematic overview of a method for managing a production system with the use of a computer model.

A computer model of a production system offers the possibility of controlling the production system by selecting the parameters of system inputs in such a way, so that the planned values of the parameters of system outputs are ensured.

2 The Role of Production Systems Modelling in Ensuring the Stability

Operations performed on a model instead of the actual production system do not disturb the stability of production processes. Treating a model as a duplicate of the actual system enables, inter alia, the transfer of the conclusions from the studies performed on the computer model to the actual production system. Modelling and computer simulation allow verifying solutions being introduced before their actual implementation, which is not possible in the case of conventional methods of conducting design work (Abu-Taieh and El Sheikh 2007). An additional advantage is a reduction in the costs of the changes made on the basis of the simulations carried out at the beginning of the project implementation. The changes, which have been foreseen and planned at the beginning of the project, cost significantly less than in the later stages and they disturb the functioning and stability of the system to a lesser extent (Krenczyk et al. 2012; Zdanowicz 2007).

There are many methods and techniques for system modelling, while a broad range of advanced IT packages for process modelling is available in the market. Production system modelling allows ensuring the stability of a production system due to the possibility of:

- understanding and assessing the impact of the decisions made on the production system including its various functional areas,
- designing or reorganizing the production system in a manner that does not disturb its current and future functioning,
- controlling the production system by selecting the parameters of system inputs in such a way, so that the planned values of the parameters of system outputs are ensured,
- identifying, assessing and eliminating the effect of factors disturbing the correct functioning of the production system.

Usability of models is influenced by their accuracy, possibility of populating them with reliable data, and a short time of building them. It is possible thanks to the progressing unification, standardization and parameterization of production processes and products. Standardization, apart from shortening the time needed to build a model, also lowers the costs of product or production process development.

Thanks to the use of IT systems, models can be populated with appropriate data from an actual system. Modern production systems are measured and monitored to a higher and higher degree. Many organizational, process-related, cost-related

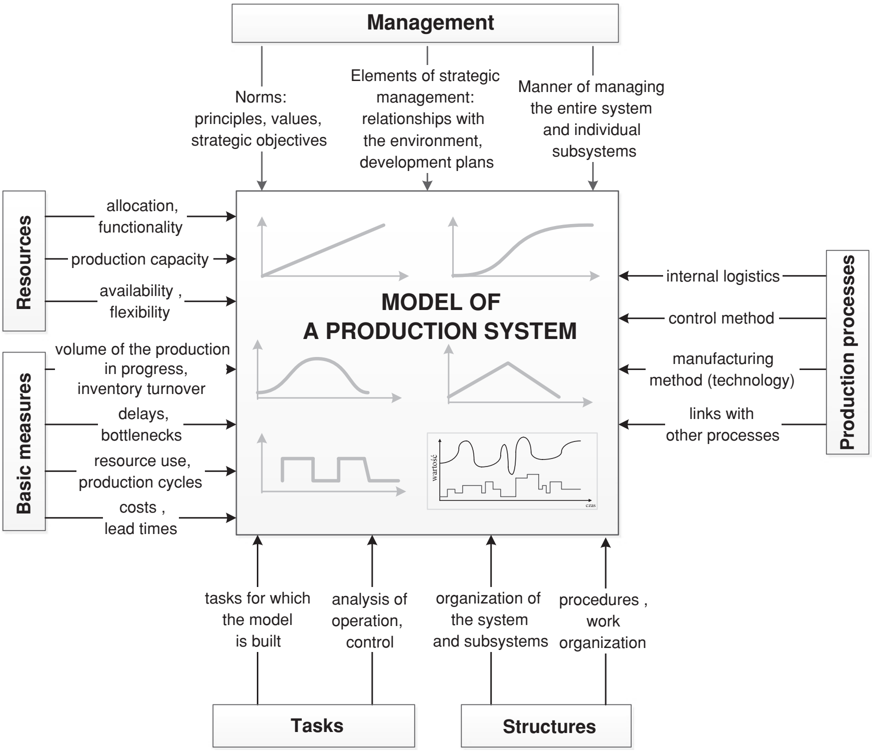

Fig. 2 Production system modelling usually takes account of parameters, an aggregated model of a production company, as well as selected components (*Source* Own study)

and other data are stored every day in databases of IT systems. The problem of the contemporary enterprises is not a lack of data, but rather their excess. This problem often boils down to adequate data acquisition, processing them, and generating a model. The experiments conducted on models do not disturb the functioning of the actual system and thus allow predicting the effects as well as selecting an optimal variant of decisions on the parameters and types of inputs to the system (Korytkowski and Wisniewski 2012).

In order to be able to make right decisions based on a model, it must include the company's aspects adequate to the scope of the studies. When modelling production systems, regardless of the purpose of modelling and the optimization criteria adopted, generally six aspect of a company are taken into account: management, structures, resources, production processes, basic manufacturing measures and tasks of the production system (Abu-Taieh and El Sheikh 2007; Nowosielski 2011). Figure 2 shows the aforementioned aspects along with the elements that are most commonly used in the manufacturing process modelling.

Different types of models are used at different levels and stages of the production system management process (Vinodh 2011) Fig. 3. The illustrates the

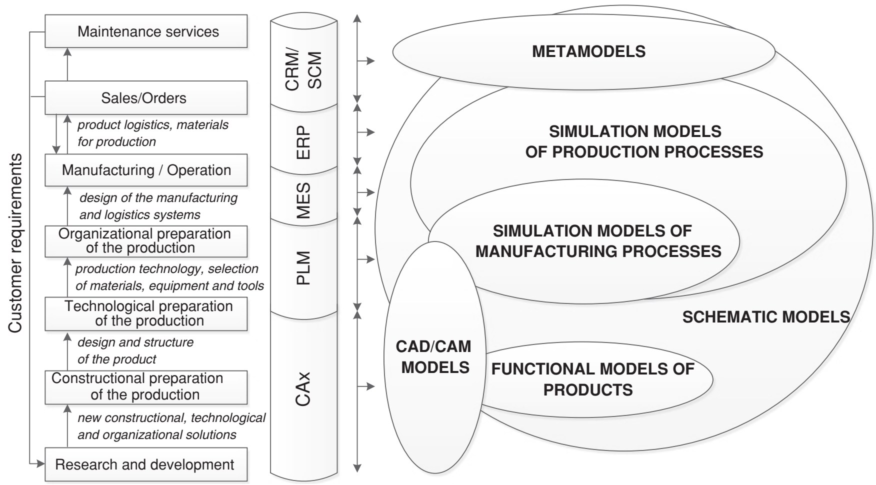

Fig. 3 The application of different types of models at selected stages of the production system management process (*Source* Own study)

application of different types of models at various stages of the production system management process.

So called metamodels are used at the strategic level. They describe a company at the highest level of generality. Metamodels contain specifications of goals, plans, methods of operation, resources etc. Schematic models are the ones that are most versatile and commonly used at all levels of management. They are used mainly to analyse a problem and to select elements for further modelling work or for establishing a procedure. Simulation models constitute the largest group. Simulation experiments can be carried out on them using computers and the planned decisions can be verified.

3 Simulation Modelling of Production Systems

Computer simulation and modelling methods are used when obtaining a solution by analytical methods is too complicated, while direct experiments on the actual system consume too much time or cannot be carried out. Modelling and simulation of manufacturing processes make it possible to analyse them and trace the way they have been functioning, sometimes for many years, in just a few min. This allows verifying the assumptions made before, as well as identifying the irregularities that may occur during the operation, particularly the weaknesses of a production system, which is being designed or improved.

Simulation models belong to the group of symbolic models based on mathematical notation, in which the reality is represented with the use of symbols and mathematical relations (Gutenbaum 2003). Mathematical notation describing the structure and behaviour of a system makes it possible to verify the correctness of the representation and conduct studies on the model built in such a way. Therefore, mathematical modelling consists of two stages: building a model and experimenting on it.

Serious difficulties are encountered in the classical mathematical modelling of production systems. Process parameters are changing dynamically and depend on many variable factors originating in the environment. In addition, modern production systems are very complex and complicated. All these facts cause that mathematical models require the use of a compiled mathematical apparatus, which in turn translates into the time needed for building them.

If a model of a production system is to be used for decision making, it should include all the elements and parameters important from the viewpoint of the decision problem. Most dynamic phenomena observed in production systems result from many partial events that take place in various functional areas at different organizational levels, often at different time instants. The phenomena occurring in one area of a production system affect also other functional areas of the system. In the case of such complex and integrated production systems, mathematical formulas must be considerably expanded, while the time needed for building them is significantly increased.

In such a situation, it is helpful to build computer models of production systems. A computer model is a mathematical model recorded in the computer memory with the use of a programming language or in a special computer program (package) (Roux et al. 2008). There are many packages for modelling and simulation of production systems available in the market. These programs are based on a symbolic language of notation and allow building models from ready-made, pre-defined objects like from blocks. A user defines only the relationships between the objects, the initial parameters and the logic of the process course.

Due to the fact that production systems are very complex and vary in individual industries, as well as due to different applications for computer simulations of production systems, there is no single, universal software that could be deemed to be the best in the market. An appropriate package should be selected each time depending on the purpose of modelling and the type of the system analysed. Figure 4 shows the percentage of the use of computer modelling and simulation methods in selected areas of production system management. The most commonly used commercial computer tools were assigned to each area.

A computer simulation of a production system or process consists in building a computer model of the system or process to be analysed, and then examining, with the use of simulation experiments, the influence of input parameters (signals) on the behaviour of the model. Typically, many simulation experiments are carried out on the model for different sets of input parameter values. The results are obtained in the form of simulation reports. An analysis of the reports allows selecting the best (optimal) input parameters from the viewpoint of building a model of a set of input parameters. In addition, the model can be improved and further simulations may be carried out for different variants of the model. Having simulation

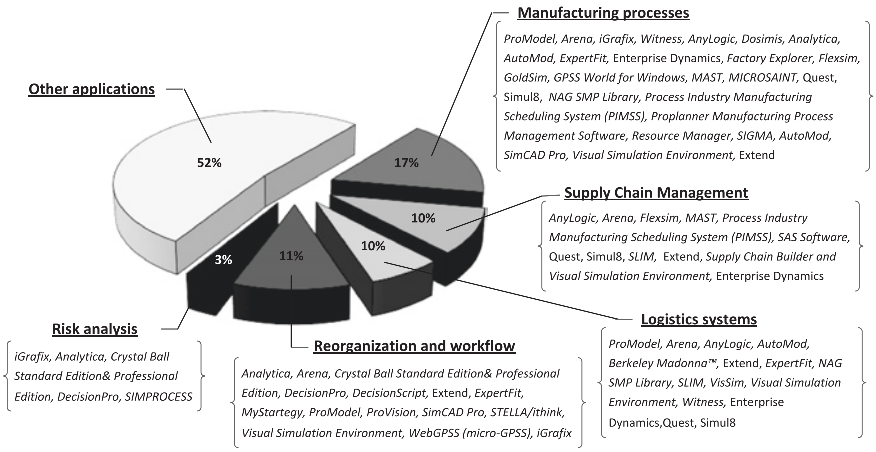

Fig. 4 Application of computer modelling and simulation methods in selected areas of production system management and the commercial tools that are most commonly used in these areas (*Source* Abu-Taieh and El Sheikh 2007; Tewoldeberhan et al. 2002)

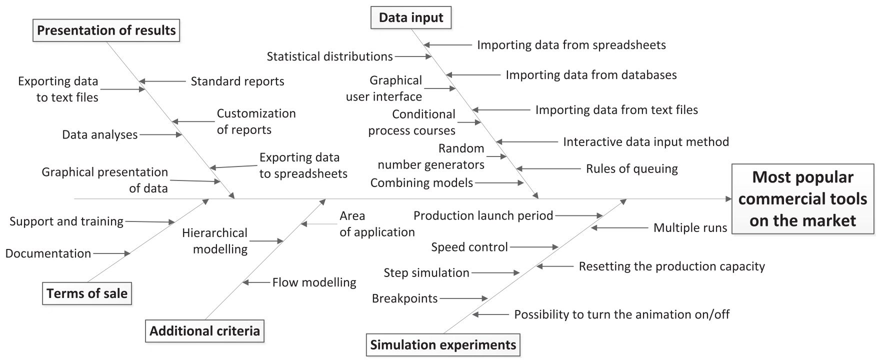

Fig. 5 The most important criteria taken into account when choosing a modelling and simulation program (*Source* Tewoldeberhan et al. 2002)

models of a production system significantly reduces the time needed to make decisions concerning its development. Another advantage is the possibility to select the best decision that will be burdened with the least risk due to the ability to predict future states of the analysed system, which in turn translates into ensuring the stability of the system being reorganised.

The period of implementation of a simulation project is affected by the selection of software to be used for building the model and then conducting simulation experiments. The basic requirement to be met by the modelling and simulation software is of course the logical and mathematical correctness, but the users pay more and more attention to additional features when choosing commercial packages. Figure 5 shows the most important criteria taken into account when selecting a commercial program to be used for modelling and simulation. These criteria were indicated on the basis of the results obtained from surveys conducted among teams of experts in the field of modelling and simulation, who worked in large international corporations (Tewoldeberhan et al. 2002). The surveys included over fifty commercial programs for modelling and simulation. Figure 5 shows only five out of eight categories of functional features of the programs included in the surveys, however only these features were taken into account, which obtained the highest number of points in the experts' assessment.

As shown in Fig. 5, the function of import and export of data to external files has a large impact on the selection of a modelling and simulation program. Such a function is very useful due to the widespread use of CAx, PLM, MES, MRP II/ERP, CRM and SCM systems in production companies. The possibility of importing data to a simulation program significantly reduces the time required to build a model and allows updating them on a current basis in the developed model. In turn, the data export allows updating the documentation of the production system analysed and enables the flexibility in presenting the results.

4 Reorganization and Optimization of a Production System with the Use of Simulation Models

The results of a project implemented in the Wroclaw branch of an international corporation will be used an example illustrating the possibility of using computer modelling and simulation methods for reorganizing and optimizing a production system. The plant produces bogie frames for locomotives, as well as freight and passenger cars. At the time, when the project was implementation, the plant produced 19 types of bogie frames. Each type of frame is manufactured on a separate production line (bay). The aim of the project was to increase the capacity of the production line of the BR 185.2 bogie frame from 3 to 5 pcs per week.

In order to achieve this aim, organizational changes increasing the production capacity should be proposed, while the impact of risk factors on the stability of the reorganised production system should be assessed and reduced. This aim was accomplished with the use of the ProModel 2002 system for computer modelling and simulation.

4.1 Characteristics of the Production System

The design of the BR 185.2 bogie frame is a strategic product of the company due to a large number of finished products contracted under long-term agreements with customers from Western Europe. The manufacturing processes that take place in the entire factory include welding operations of individual elements making up the product structure and fitting operations. The structure of the BR 185.2 bogie frame is presented in Fig. 6.

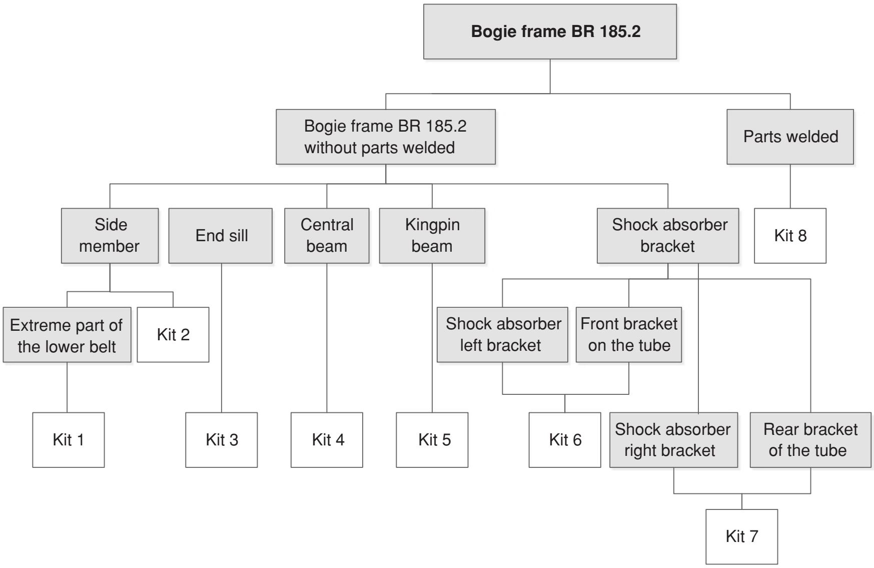

Fig. 6 Diagram showing the structure of the BR 185.2 bogie frame (*Source* Own study)

Due to a large size and weight of the semi-finished products, assembly stations are equipped with special devices for fastening and positioning the workpieces. Individual manufacturing operations are controlled with the use of KITS, i.e. kits of finished parts prepared and distributed in the warehouse and then delivered to the allocated places at the production line. In addition, the company uses a Kanban system in the form of boards that indicate the inventory balance of materials. The production process consists of the following main stages:

- completing KITS in the warehouse and delivering them to the production line,
- delivery of sheet metal to the production line,
- production process,
- quality control.

The flow of materials and semi-finished products inside all production lines takes place with the use of overhead cranes and forklift trucks. The original production line layout for the analysed product is shown in Fig. 7.

Cycle times of welding and fitting operations include the times of additional transport between stations of the production line, workpiece handling operations, as well as control and measuring work at the stations.

The research consisted in building several versions of layout models for the analysed product (using ProModel 2002 simulation package), carrying out their simulation and analysing the results obtained. A screen capture of the production line is shown in Fig. 8.

Using the simulation models of the manufacturing process, there were analysed different variants of the workstations layout, extensions of operation times of the

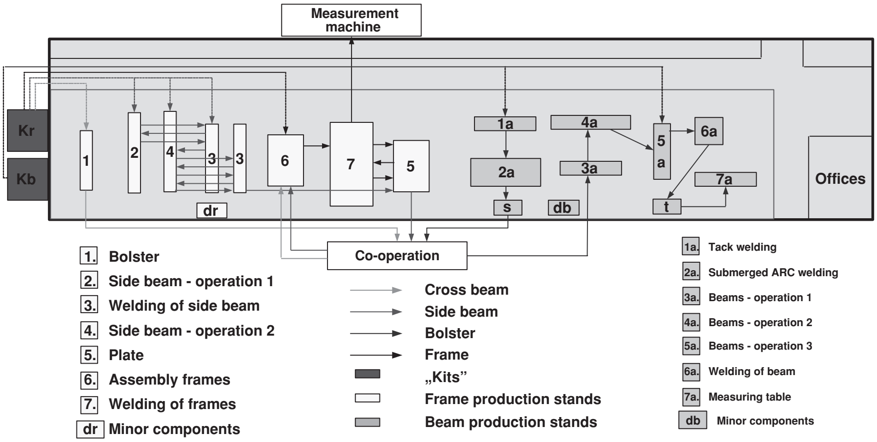

Fig. 7 Original layout of the production line for the analysed product (*Source* Own study)

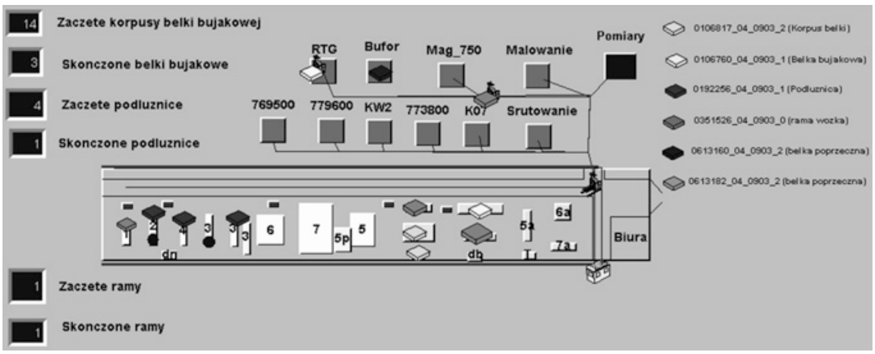

Fig. 8 The simulation model of the production line (*Source* Own study)

stations that constitute bottlenecks, and the employment of an additional number of workers. However, significant differences between the times recorded in the process documentation and the actual times were observed during the implementation of the project.

The target time of manufacturing one piece of the BR 185.2 bogie frame is approx. 187 h. On the basis of data obtained from the monitoring of the actual time of the operations with the analysed product over a period of 5 months, it can be concluded that the average time needed for manufacturing one frame is longer by 19 h than the time assumed in the process documentation. Figure 9 shows a comparison between the actual times of individual operations and the number of hours planned in the process documentation for their execution.

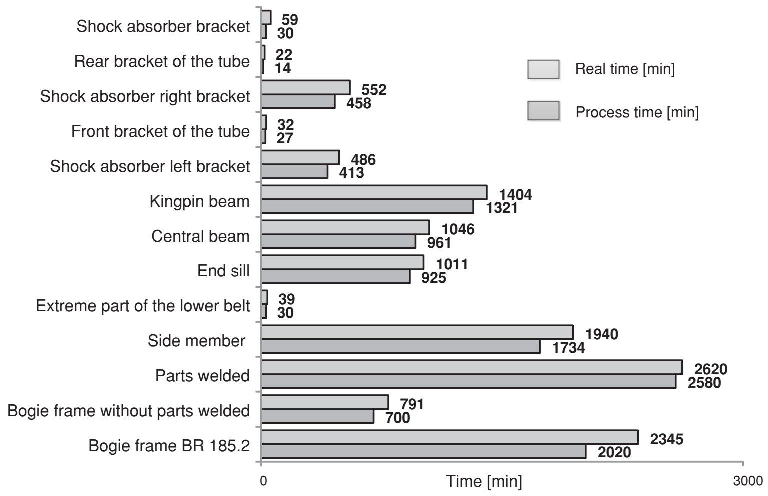

Fig. 9 Differences between the process times and actual times (*Source* Own study)

Considering the fact that the weekly production volume of the 185.2 BR bogie frame is constant (5 frames/week), which results from the demand in the production plan, it should be concluded that a higher number of hours allocated for manufacturing one frame will cause a delay in the realization of the weekly production plan. Therefore, a decision was made that the impact of risk factors on the production system should be identified and examined in the next stage.

4.2 Assessment and Minimization of the Risk Level in the Production Line

The risk factors were isolated on the basis of direct observations, an analysis of the documentation of the orders executed earlier, measurements of the process times, as well as consultations and interviews with employees of different organizational units involved in the production process. Table 1 contains information on the identified risk factors.

The risk factors determined in Table 1 were introduced into the simulation model in order to assess their impact on the production system. A period of 3 months was adopted for the analysis. Thanks to that, the losses of production times caused by the occurrence of risk factors were estimated (Fig. 10).

The results of the simulation show that along with the introduction of risk factors to the model, the productivity decreases and the time of production of the assumed number of products increases. On this basis it can be stated that there is an increase in the probability of not achieving the target assumed for the system, i.e. manufacturing 5 pieces of the BR 185.2 frame per week.

Table 1 Description of the risk factors identified in the production system

Risk factor (r_i)	Description of the impact of risk on the production system
Customer (r_1)	Customer-specific requirements mean that the customer may demand introduction of constructional and process changes in the product. In the analysed period, this factor applied to 30 % of the products and caused an extension of the production process by 6 h for 1 piece
Sheet metal supply (r_2)	The analysis included the actual quantities and times of deliveries. Because the delays in sheet metal delivery are random, average times and standard deviations were determined for individual deliveries
Cooperation (r_3)	This factor results from delays and poor quality of the components delivered by cooperating partners. The characteristics were determined on the basis of the data from rejects sheets and downtime sheets
Production process (r_4)	An observation was made that there are significant differences between the actual times and the process times. This is caused mainly by faulty holding devices, failures of overhead cranes, and the time of waiting for the transport of elements. The characteristics were determined on the basis of an analysis of the production documentation, as well as the observations and time measurements performed at the production line
Quality control (r_5)	An analysis of the process showed that 7 % of the manufactured elements had to be repaired, while 3 % were scrapped. The time of repair ranges from 10 min to the actual time of the operation. Since this time is not constant, the analysis assumes that it has a normal distribution

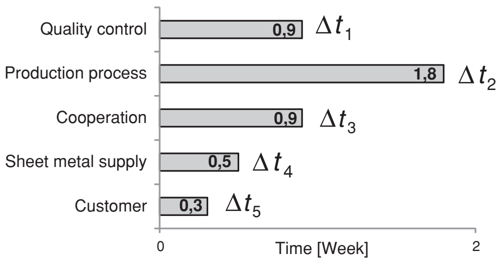

Fig. 10 Time losses in individual areas caused by the occurrence of risk factors (*Source* Own study)

5 Assessment of the Stability of the Production System

Because risk factors are of random nature, it is not known when and in what combinations they will occur. The stability of the process of manufacturing the BR 185.2 frame will be assessed by examining the impact of disturbances, which result from the occurrence of a single risk factor and multiple risk factors, on the goal of the production process. This goal was to manufacture 60 ± 10 % frames within 3 months. A simulation model without risk factors (base model) was used to analyse the stability of the production system.

Table 2 List of models used for analysing the stability of the production system depending on the occurrence of a single risk factor

Model name	Model description
Model 1. "Customer"	Impact of the risk of customer-specific requirements
Model 2. "Sheet metal supply"	Impact of the risk of delays and poor quality of the sheet metal supplied
Model 3. "Cooperation"	Impact of the risk of delays and poor quality of sheet metal from cooperating partners
Model 4. "Production process"	Impact of the risk of differences between the process times and actual times, and the risk of failures
Model 5. "Quality control"	Impact of the risk of manufacturing defective products

Source Own study

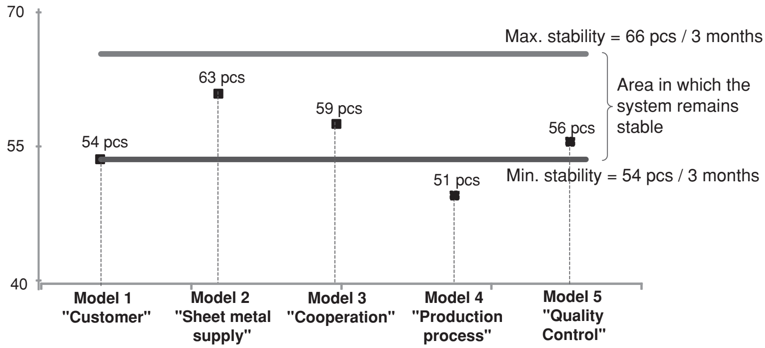

Fig. 11 Impact of a single risk factor on the analysed production system (*Source* Own study)

This analysis was to assess the stability of the production system in the event of the occurrence of a single risk factor. Characteristics of different types of the risk factors identified were introduced to the base model. In this way, 5 simulation models were created to assess the influence of risk factors on the analysed production system. Description of the models built is given in Table 2.

The results obtained from the experiments with the use of the models presented in Table 2 are shown in Fig. 11.

As shown in Fig. 11, if risk factors occur one at time, the system will lose its stability only in the case of the risk associated with the differences between the process times and actual times, as well as in the case of risk of machine failures. In such an event it will not be able to produce the quantity of products assumed in the production plan.

The next step involved examining the stability of the production system in the event of occurrence of two risk factors. As in the case of the analysis of a single risk factor, the base model was used, but it was modified with the characteristics of two types of risk factors. The risk factors associated with the production process and the customer were excluded from the examinations, because, as it appears

Table 3 List of models used for analysing the stability of the production system depending on the occurrence of two risk factors

	Model name
Base model	Model 1. "Sheet metal supply + cooperation" Model 2. "Quality control + cooperation" Model 3. "Sheet metal supply + quality control"

Source Own study

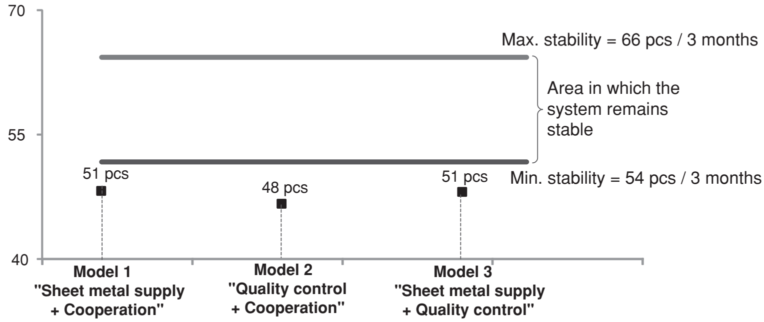

Fig. 12 Impact of a combination of two risk factors on the analysed production system (*Source* Own study)

from previous studies (Fig. 6), a single occurrence of these risk factors results in the loss of production system's stability. The models built and the types of risk factors are presented in Table 3.

The results obtained from the experiments with the use of the models presented in Table 3 are shown in Fig. 12.

As is appears from Fig. 12, if any combination of two risk factors occurs, the analysed production system will become out of balance. As can be seen, if the production organization level is not improved, the risk factors present in the system will prevent the accomplishment of the assumed goal.

References

Abu-Taieh E, El Sheikh A (2007) Commercial simulation packages: a comparative study. Int J Simul 8(2):66–76

Burduk A (2011) Methods of production risk assessment. PRINTPAP Publishing House, Łódź

Gutenbaum J (2003) Modelowanie matematyczne systemów. Exit Publishing House, Warszawa

Korytkowski P, Wisniewski T (2012) Simulation-based optimisation of inspection stations allocation in multi-product manufacturing systems. Int J Adv Oper Manage 4(1–2):105–123

Krenczyk D, Kalinowski K, Grabowik C (2012) Integration production planning and scheduling systems for determination of transitional phases in repetitive production, hybrid artificial intelligent systems, vol 7209. Springer, Berlin

Nowosielski S (2011) Modelowanie procesów gospodarczych w literaturze i praktyce, podejście naukowe w organizacjach. Publishing House of the Wroclaw University of Economics, Wrocław

Roux O, Jamali M, Kadi D, Chatelet E (2008) Development of simulation and optimization platform to analyse maintenance policies performance for manufacturing systems. Int J Comput Integr Manuf 21:407–414

Tewoldeberhan T, Verbraeck A, Valentin E (2002) An evaluation and selection methodology for discrete-event simulation software. In: Proceedings of the winter simulation conference, Michigan

Vinodh S (2011) Axiomatic modelling of agile production system design. Int J Prod Res 49(11):3251–3269

Zdanowicz R (2007) Modelowanie i symulacja procesów wytwarzania. Publishing House of the Silesian University of Technology, Gliwice

Simulation Modeling of Acrylic Bathtubs Production Using Task-Oriented Approaches as a Tool to Improve Energy Efficiency of Thermoforming Process

Witold A. Cempel, Dawid Dąbal and Mateusz Nogły

Abstract Small industrial companies often struggle with production process organization and maintaining its energy efficiency. Even a small variability in the number of operators on the production line could disturb the process thus making it chaotic and inefficient. This happens especially when each operator is working on multiple stations or is performing multiple tasks. In the course of the research the simulation model was created using the task-oriented approach to provide the tools for the quick and efficient organization of such a process. The main variable for this model was the number of operators at each process stage. FlexSim General Purpose software was used to create a model and for its optimization. The model has provided the company with optimal process organization for improving energy efficiency of the thermoforming process. The company can now use the simulation model in day-to-day management of the production process thanks to the integration with MS Excel data spreadsheet.

Keywords Simulation • Modeling • Task-oriented approach • Energy efficiency

1 Introduction

The management of the production process in small companies can be a very difficult task, especially when a variety of products is mainly directed for the service of current orders. Long-term planning may be impossible to conduct due to the large changes in demand lack of steady orders and other nondeterministic factors (Karkula et al. 2013). The process of production organization itself can also be problematic. The fluctuating number of employees caused by sick-leaves or holidays can result in the decrease of efficiency of the whole production system.

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Usually the main principle of people responsible for the organization of the production process is the achievement of the greatest productivity. However, what they do not realize is that this sort of approach is not always profitable from the economic point of view. There could be processes in the system which low efficiency will generate higher expenses than the potential profit gained from the increased production volume. An example of this sort of process may be thermoforming which is conducted in special gas or electrical furnaces.

Consequently, the question arises of how to organize the production process in order to ensure the highest possible energy efficiency.

2 Aim of the Simulation Model

A model can be described as "a symbolic representation of a set of objects, their relationships and their allowable motions" (François 1997). It is a tool to support and extend the power of thinking (Pidd 2003).

Simulation is a one of the methods that is "used to find the model's global behavior base of knowledge of an initial condition and the locally acting constrains" (Barto 1978). Generally, simulation is aimed at the prediction of the behavior of the simulated process or systems. The results, however, can never be fully guaranteed due to the number of practical and conceptual reasons (François 1997).

The aim of simulation modeling in this case was to create such an organization of the acrylic bathtubs production process in order to obtain a high energy efficiency (Pawlewski and Borucki 2011) of the thermoforming process obtained by reducing the power usage for production of a single bathtub.

The thermoforming process takes place using an electrical furnace which results in high energy costs of its use. Multiple switching the furnace off and on during the change of workers is unprofitable as the furnace must be heated to the appropriate temperature before thermoforming can resume.

The following was taken into consideration in the model:

- The number of operators on specific stages of production;
- Process time of specific operations;
- The number of operators needed to execute specific operations;
- The distance between specific workstations and warehouses;
- Limitations in the possibilities of introducing improvements resulting from the specifics of the production process as well as available company resources.

3 Methodology

Simulation modeling was chosen as a tool for this research because its ability to analyze complex dynamic and stochastic production systems and its usefulness in understanding issues in organization of such systems (Petropoulakis and Giacomini 1997). Simulation models can be divided into three basic groups: discrete event simulation, continuous variable simulation and hybrid simulation systems

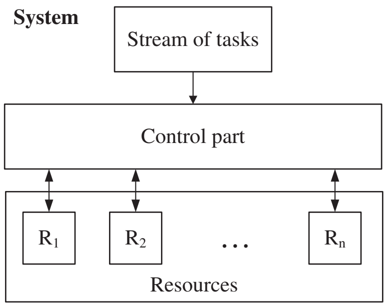

Fig. 1 Task-oriented view of the modeled system (*Source* Ochmanska 2002)

(Petropoulakis and Giacomini 1997). In this particular case discrete event simulation was used because of the following characteristics of the given production system:

- Components within a system are subject to their own random events;
- Random events in the environment impact the system;
- System behavior is time dependent;
- System components have complex interactions, and thus there are many connecting paths within a system.

In addition to discrete event simulation, the task-oriented approach was used. This approach propagates tasks arriving to modeled systems, which are then executed in one of possible ways according to the current state of the system, task executers and fixed resources (Ochmanska 2002). Thanks to these assumptions, it is possible to create models which very precisely simulate the work organization of operators in the production system and additionally take into account tasks that need to be performed in order to meet certain goals (Fig. 1).

This particular production system consist of many stochastic elements and discrete operations that occur randomly thus describing it using mathematical model would be impractical (Wang and Chatwin 2005).

FlexSim General Purpose software was chosen due to its capabilities when it comes to the discrete simulation process and tools which enable the implementing of the task-oriented approach (Beaverstock et al. 2011). Simulation analysis can be used as a tool of day-to-day management of the production process. Thanks to the integration of simulation models with excel and ODBC, they can cooperate and support other tools used in companies. (Fig. 2).

Taking the above issues into consideration, the methodology of a simulation modeling using the task-oriented approach for improving the organization of the production process was formulated (Fig. 3).

4 Course of Research

The main aim of the research was to create such an organization of the production process which would ensure the achievement of the greatest energy efficiency of the thermoforming process. The simulation model's aim is to define the ways of

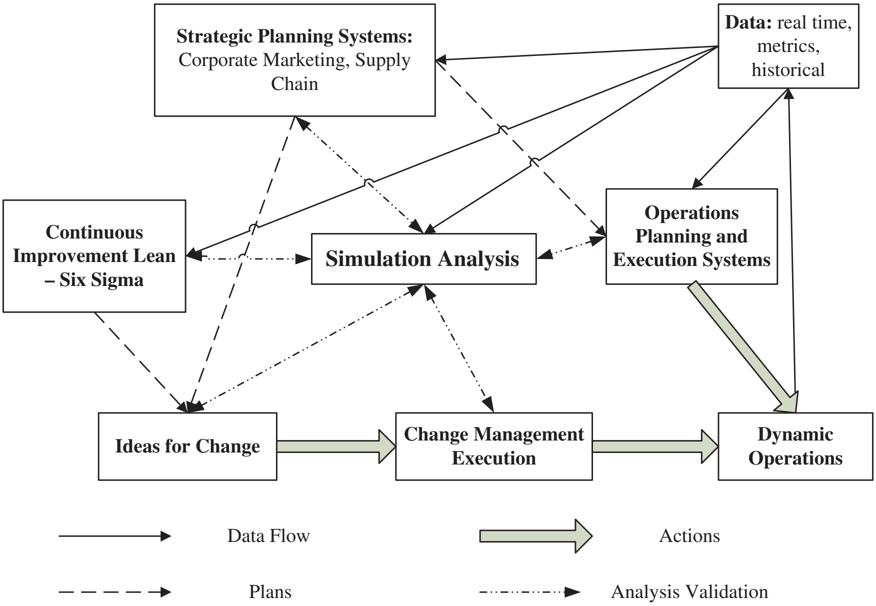

Fig. 2 Interaction between simulation and other applications (*Source* Beaverstock et al. 2011)

organization, number of employees, and work share at each production stage as well as defining the productivity during one work shift.

In order to properly simulate the production facility, the design of the facilities was obtained and implemented into the FlexSim General Purpose. Objects which represented the positioning of specific work stations, warehouse storage as well as places of realization of the production process were placed on the design of the production facility.

The realization time of specific operations was defined on the basis of Time-Study analysis and their analysis was conducted using ExpertFit in order to determine their statistical distribution.

Consultations were conducted with managerial staff in order to acquire a greater knowledge of the production process as well as of the capabilities and range of possible improvements.

The way in which production processes were organized in the real production system can be described as follows:

Specific employees had the skills required for performing operations on most work-stations;

- There were large reserves right after the thermoforming process and before successive operations connected with the epoxide application;
- During the change of shifts there were frequent changes in the organization of the production process depending on the efficiency of the given production stage;
- Processes in the organization are defined without having any constant designated employee while being performed by any employee which is currently available;

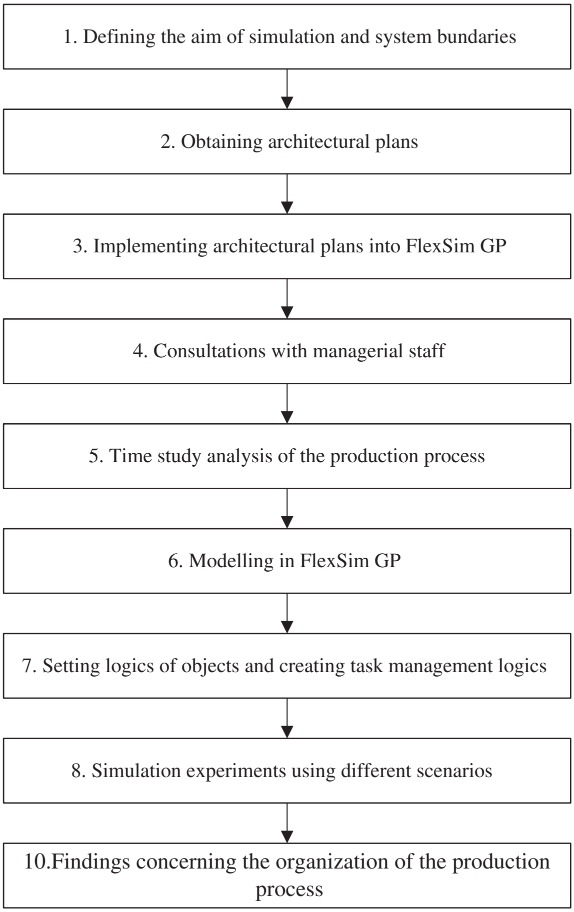

Fig. 3 Simulation modeling using the task-oriented approach for improving the organization production process, originated from Mikulik et al. (2014)

- In the case of a smaller number of staff, they are allocated in the later stages of the production process in order to maintain the daily productivity goals, at the cost of increased inter-operational reserves.

Daily usage of energy in the process of thermoforming is about 1,98 MWh, during one shift about 70 bathtubs are produced. No matter what the amount of produced bathtubs is, the furnace works for the whole 8 h period and the average efficiency is about 69 %. Increasing the energetic efficiency was the main aim of the created simulation model and it could be achieved by the increase of productivity of the thermoforming process.

The main variables in the simulation model were:

- Number of groups of operation;
- Assigning each operation to one group respectively;
- Number of operators in each group.

This production process was divided into 21 operations performed by 10 operators. The model was built using basic object classes from FlexSim General Purpose:

- Source—resource used to generate flowitems—simple objects that will travel through the model;
- Processor—object used to simulate basic processes in the model;
- Combiner—resource used to simulate processes of grouping (packing) and joining flow items together;
- Separator—resource in opposite to combiner, it is used to separate flowitems into multiple parts and to unpacking them;
- Conveyor—object used to move items through the model;
- Dispatcher—resource used for controlling multiple task executers, for example operators, forklift trucks and etc.;
- Queue—the place for storing flowitems and is used as a buffer when downstream objects cannot accept them yet;
- Rack—the place for storing flowitems, representation of warehouse rack;
- Operator—task executer, in this case a worker;
- Sink—the termination point for flowitems in the model.

Task executer means the resource which can perform tasks resulting from the production process. Certain fixed resources of the simulation model will create tasks for given task executers, which in turn will create a task queue from them to execute.

The logic of task queuing can have any form, both the easier first-in-first-out as well as the more complex customizable logics. In the moment when the object creates a task it gives it a priority and then sends it to the task executer which is chosen according to the given logic. The tasks are set in a line in relation to the decreasing priority with the exception of the task which has already been started. If two tasks have the same priority, then their time of queuing will decide about their place in the queue.

The task executer may discontinue a previously started task in place for another, more important task. An example of this kind of situation may be the malfunction of a machine, when a worker must discontinue the task which is currently being realized and immediately begin repair work. Preempting may be useful while modeling additional tasks for employees, which should be completed in the time when the worker has already finished his main tasks and we do not want to allow delays in their resuming.

In FlexSim there are four possible preempting variants:

- No Preempting—the task is added to the end of the queue;
- Only Preempting—after receiving this task the task executer discontinues the execution of the current task and begins the execution of another task which is more important. The discontinued task will be set as the next one to be executed;
- Preempting and aborting active task—after receiving this task the task executer will discontinue the task which is currently being executed and permanently removes it from the queue of tasks to be executed. This means that after

executing the new task, the task executor will not go back to the one that was discontinued;
- Preempting and aborting all tasks—in this case the task executer discontinues the task which is currently being executed and deletes it together with the whole queue of tasks to be executed.

In the case when the task executer is just executing a preempting task and it receives a new preempting task, then it is the priority which decides about which task is realized first. If the task currently being executed has a higher or equal priority then it is added to the queue as a new task. When the priority of the new task is higher, the current task is discontinued accordingly to the rules of the accepted variant.

Another way of simulating the ways of task execution by employees is creating whole sequences of tasks. In the task queue such sequences are treated the same as single tasks which means that a sequence built of, for example, 5 tasks will have its own priority and its own preemption rule. A task sequence may be created, among others, from different types of tasks:

- Travel—for ordering task executer to go to a given location;
- Load—causes task executer to load an item from an object;
- Utilize—causes task executer to go into a given state for example: utilize, busy, lunch;
- Send message—task executer will send message to a given object;
- Destroy object—causes task executer to destroy flowitem;
- And others used for modeling specific tasks.

The formation of a task sequence inside an already existing sequence of tasks may be done in two ways, sub-task which guarantee the later execution of a discontinued task and break task—which deletes a task from sequences in which it appeared (Fig. 4, Table 1).

During the formation of the simulation model, charts including priorities for particular tasks received by the task executor were created. Other sets of priorities were put in particular columns, in turn forming particular scenarios which will later be used during the simulation-experiments-phase. These processes were modeled without using task sequences, the dispatcher manages task executers. By applying this approach, each operation consists of two tasks: the transport task and the proper operation which can be given different priorities

The final stage of the process was modeled using task sequences. A logic of the choice of prioritized operations was formed and operators were assigned to tasks. This data was saved in a chart, the particular variants of column 3 and 4 are the following scenarios of simulation experiments. Each row is assigned to a task sequence. Particular columns mean:

- Call—1 means that the task sequence which was induced by a given operation is waiting in line to be executed, 0 no task;
- Service—1 means that the given sequence of tasks is currently being executed, 0 the task isn't being executed;
- Priority—the priority value of a given task sequence;

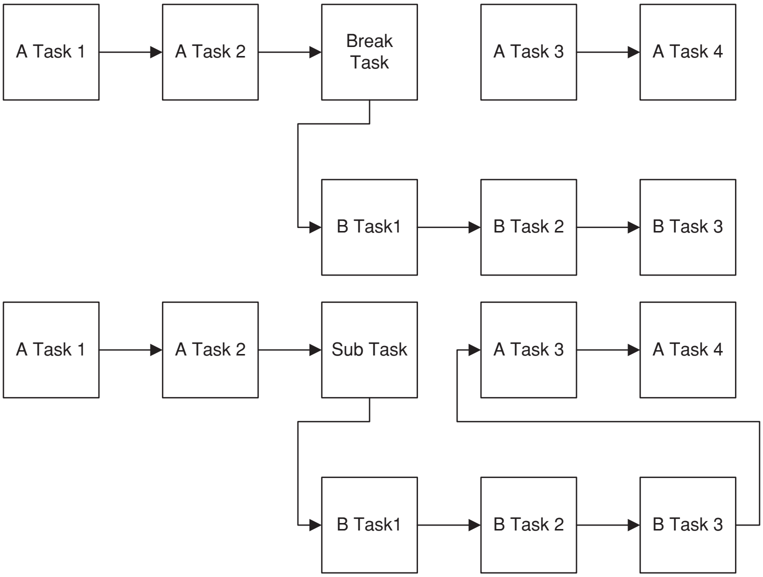

Fig. 4 Available variants of creating task sequence inside of the task sequence (*Source* own study)

Table 1 One of the priority tables used in the simulation model (*Source* own study)

Task	Priority
OP_20_1a_processpriority	1
OP_20_1a_transportpriority	2
OP_20_2a_processpriority	3
OP_20_2a_transportpriority	4
OP_20_3a_processpriority	5
OP_20_3a_transportpriority	6
OP_20_4a_processpriority	7
OP_20_4a_transportpriority	14
OP_20_5_thermoforming_processpriority	0
OP_20_5_thermoforming_transportpriority	15
OP_20_6a_processpriority	8
OP_20_6a_transportpriority	9
OP_20_7a_processpriority	10
OP_20_7a_transportpriority	11
OP_20_8a_processpriority	12
OP_20_8a_transportpriority	13

- Worker ID—operator assigned to a given operation, 0 means that the given operation may be executed by any operator.

In the case of the occurrence of a greater number of calls than there is available operators, the algorithm will choose tasks of the highest priority to be executed (Table 2).

Table 2 Table of the last stage of the process used for task sequence management (*Source* own study)

Task sequence	Call	Service	Priority	Worker ID
OP_50	0	0	1	0
OP_60_1	0	0	2	1
OP_60_2	0	0	3	1
OP_70	0	0	4	2
OP_80_1	0	0	5	2
OP_80_2	0	0	6	2
OP_80_3	0	0	7	3
OP_90	0	0	8	3

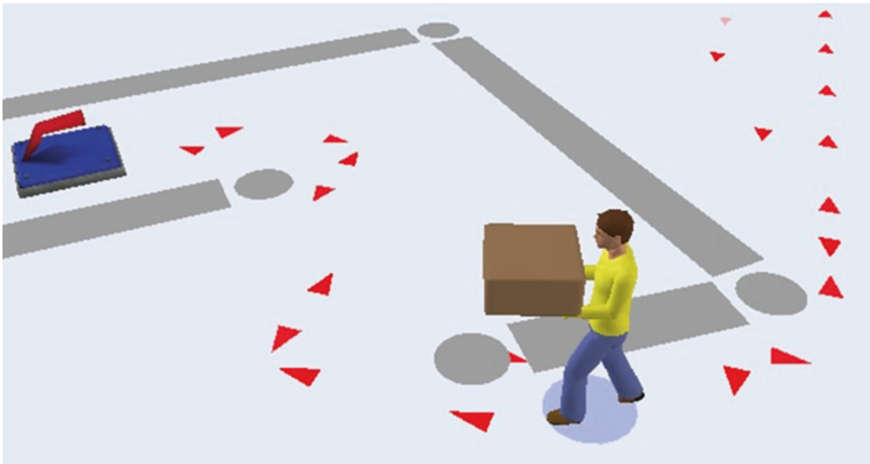

Fig. 5 A* module path finding in FlexSim model (*Source* own study)

Additionally, the module A* was applied, which was used to define the paths of movement of the operators in the production process. By introducing barriers such as walls, shelves, and areas without entrance, the time of passage and transportation which is as close to reality as possible was established, assuming that the task executer will always be moving about using the shortest possible way between two points. (Dechter and Pearl 1985) (Fig. 5).

The model of production organization was created in this way in order to obtain an easy possibility of building and implementing different possible working organization scenarios. Simulation experiments were conducted on the basis of several scenarios which differed from each other in the way of assigning priorities to different tasks, distribution of tasks amongst particular groups of operators and the number of operators in particular stages of the production process (Figs. 6, 7 and 8).

After analyzing the results of the conducted simulation experiments, a way of work organization was chosen which would guarantee the highest

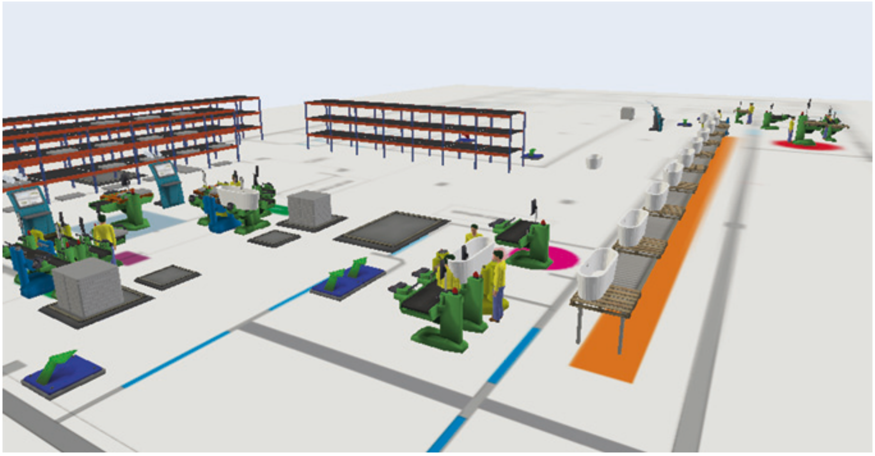

Fig. 6 Simulation model of acrylic bathtubs production (*Source* own study)

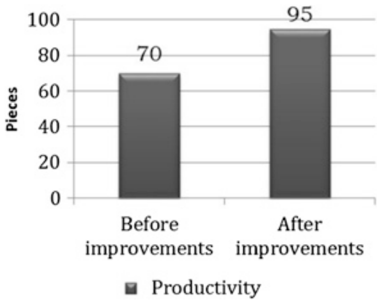

Fig. 7 Productivity before and after improvements (*Source* own study)

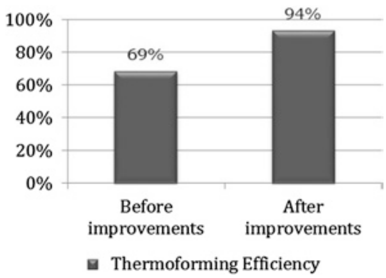

Fig. 8 Thermoforming efficiency before and after improvements (*Source* own study)

energy efficiency of the thermoforming process. It would have the following characteristics:

- The thermoforming process will be a process with the highest priority with the preempting-only variant. It will consist of: putting the form together with the acrylic sheet into the furnace as well as taking it out;

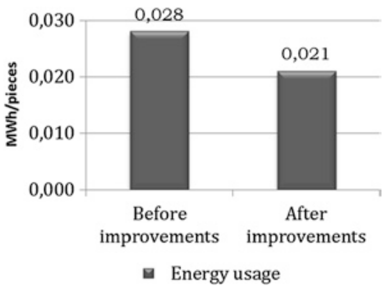

Fig. 9 Energy usage before and after improvements (*Source* own study)

- The delay of taking the form out of the furnace does not occur as thermoforming for too long a time may cause distortion of the acrylic surface;
- Operations supporting the production process were assigned to specific groups of operators; their priority changes in a dynamic way depending on the situation, for example on the current size of warehouse supply;
- Priorities of the rest of the operations were compiled in such a way as to allow the highest possible productivity;
- The thermoforming process should be resilience to the fluctuation of the number of employees.

Introducing the new work organization will allow a considerable increase in the degree of making use of the thermoforming process to up to 94 %, which took place as a result of increasing production to about 95 bathtubs.

Moreover, the new method of work organization ensured the decrease of inter-operational reserve and introduced a greater resistance of the whole system to the fluctuation of the number of employees. In the new method of organization, all the operations which are included in the thermoforming process are executed by one completely delegated employee.

The proposed organization causes a decrease in the consumption of electrical energy during the production of one acrylic bathtub from 0,028 MWh to 0,021 MWh, which considerably increases the energy efficiency of the thermoforming process (Fig. 9).

In the case of a change of the number of employees, which may result from lay-offs or illness, the model may be used each time to define the optimal distribution of the work-load in particular stages of production.

5 Conclusions

The use of simulation modeling with the task-oriented approach allowed us to create a new method of acrylic bathtub production organization, which will increase energy efficiency of the thermoforming process.

An increase in productivity of the whole system as well as creating a precise distribution of operations among operators were additional advantages. This led to a considerably greater smoothness in the process, which resulted in the decrease of reserves between particular stages of production.

The use of the task-oriented approach allowed the precise simulation of the logic of choosing operations executed by employees and also enabled the creation of process organization which takes into consideration other aims besides only productivity. The placement of key variables in tables allows easier integration of the model with MS excel. Thanks to this, people who do not have the skills of using simulation software can also use the model. Further work will have the aim of creating a model which will also take into account the development of employee skills, for example how process familiarity will influence the time of particular operations.

References

Barto AG (1978) Discrete and continuous models. Int J Gen Syst 4:163–177

Beaverstock M, Greenwood AG, Lavery E, Nordgren B, Warr S (2011) Applied simulation: modeling and analysis using flexsim. Flexsim Software Products Incorporated, Orem

Dechter R, Pearl J (1985) Generalized best-first search strategies and the optimality of A*. J ACM 32:505–536

François C (1997) International encyclopedia of systems and cybernetics. K. G. Saur Verlag, GmbH

Karkula M, Jurczyk K, Bukowski L (2013) Nondeterministic factors in simulation models of logistics processes. CLC’2012: carpathian logistics congress: Nov 7th–9th 2012, Jeseník, Czech Republic, congress proceedings (reviewed version). Czech Republic, TANGER Ltd, pp s529–535

Mikulik J, Cempel W, Kracik S, Dąbal D (2014) A simulation model for emergency evacuation time and low-cost improvements of a hospital facility using flexsim healthcare: a case study. In: Korbicz J, Kowal M (eds) Intelligent systems in technical and medical diagnostics SE—28. Springer, Berlin, pp 333–342

Ochmanska E (2002) Task-Oriented petri net models for discrete event simulation. In: Sloot PA, Hoekstra A, Tan CJK, Dongarra J (eds) Computational science—ICCS 2002 SE—106. Springer, Berlin, pp 1049–1057

Pawlewski P, Borucki J (2011) Green possibilities of simulation software for production and logistics: a survey. In: Golinska P, Fertsch M, Marx-Gómez J (eds) Information technologies in environmental engineering SE—52. Springer, Berlin, pp 675–688

Petropoulakis L, Giacomini L (1997) A hybrid simulation system for manufacturing processes. Integr Manuf Syst 8(4):189–194

Pidd M (2003) Tools for thinking modeling in management science. Wiley, Chichester

Wang Q, Chatwin CR (2005) Key issues and developments in modelling and simulation-based methodologies for manufacturing systems analysis, design and performance evaluation. Int J Adv Manuf Technol 25:1254–1265

Part II
Production Operations

Simulation Analysis of Traffic Congestion in Mineral Mining Transport

Sebastian Chęciński

Abstract This chapter presents a simulation analysis of several mining transport problems, carried out using the FlexSim software. A method of defining a mining production specification is described and ways of building and importing 3D mining models are shown. Special attention is paid to the formation of heavy vehicle streams and to truck traffic concentration points. Simulations, involving changes in the number of mines and in the levels of their production and showing their direct consequences, were run. The usefulness of computer simulations, especially for mineral market management, transport control and transport network transformation, is demonstrated.

Keywords FlexSim • Simulation model • Traffic analysis • Vehicle movement intensity • Mining transport

1 Introduction

Lower Silesia with its attractive geological structure is one of the most important mineral mining centres in Poland (Institute for Territorial Development 2009a). Because of the types of minerals occurring here and the transport network conditions, heavy trucks need to be used for transport (Nowakowski et al. 2010). The dispersion of mineral deposits and fluctuations in demand for mineral products create local traffic concentrations, disrupting the continuous flow of trucks. The higher intensity of mining truck traffic on particular routes adversely affects the surrounding areas, degrading the road network condition and the quality of life of the inhabitants and devastating the natural environment (Institute for Territorial Development 2012; Supreme Audit Office 2011).

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In order to counteract the adverse effects it is necessary to pinpoint the locations of mining transport traffic jams. Because of the lack of tools which could be used for this purpose (Institute for Territorial Development 2009a), studies on a method of modelling and simulating the flow of mining vehicles were undertaken at Wrocław University of Technology. The aim was to locate the areas adversely affected by transport as a result of the changing levels of mining production and to transform the road network geometry.

The defined issue is basically a starting point for a discussion about the effective balancing of the mining transport impact with environmental protection while sustaining industrial functionality and development. This issue features prominently in the 2020 Development Strategy for the Lower Silesia Voivodeship and the Voivodeship authorities intend to modify the transport system in order to reduce its negative impacts (Institute for Territorial Development 2009b; The 2020 Development Strategy). The issue is highly important not only because of public interest, but also for mining industry sustainability (The 2020 Development Strategy).

Since the mining industry processes and the spatial structure were to be studied the FlexSim software was chosen for the analysis and solution finding. The choice was determined mostly by the functionality of this application (Garrido 2009; Pawlewski et al. 2012), which enables one to easily define all the mining production parameters and shows the results in 3D.

2 Modelling Framework

The model was to show how the mining transport intensification points are created for the specific mining route-destination geometrical structure. The use of simulation techniques for the presentation of transport processes in a specific spatial environment is attractive mainly because of the low costs (Pawlewski and Borucki 2011). The possibility of running simulations of transport impact changeability for different input parameters and network geometry transformations enables one to search for optimal solutions.

At the modelling stage several theoretical assumptions were made, especially to simplify the vehicle flow problem. The first assumption consisted in defining the study area by means of a circle with a given diameter. According to the second assumption, minerals are transported to the outside of a given area. As a result, it is easier to define the maximum number of transport routes from a mining facility. This is done by indicating the starting point (the mine location) and the end points (the intersections of the circle perimeter and the road network).

In order to carry out such an analysis for a specific area, it is necessary to input spatial data showing the shape of the available transport network. For this purpose a satellite orthoimage from the Google Earth application was used (Fig. 2). From this picture one can determine not only the transport infrastructure geometry, but also the locations of mining excavations and their elements. This greatly helped in defining the starting points of the transport routes.

Table 1 Rock material deposit resource data for Kostrza Village area

Deposit name	Mineral type	Exploitation level (thousands tones annually)	Geological resources (thousands tones)	Industrial resources (thousands tones)	Estimated numbers of vehicles (cars daily)
Borów	Mineral aggregates	232	138,035	57,748	33
Borów 17	Mineral aggregates	135	32,868	32,868	19
Kostrza	Mineral aggregates	66	4,800	3,938	10
Kostrza-Wanda	Mineral aggregates	42	8,373	8,373	6
Kostrza-Lubicz	Mineral aggregates	18	8,402	3,034	3
Kostrza-Piekiełko	Mineral aggregates	16	17,027	17,027	3

Source (Polish Geological Institute, National Research Institute 2012)

The satellite picture also enables one to create a three-dimensional terrain representation (Fig. 2) with specified mine shapes and environment elements (buildings, forests, etc.).

The number of vehicles (N) used for mining transport was estimated (Eq. 1) from the available balance data (Polish Geological Institute 2012) describing the annual mineral production (W, Table 1) for every mineral deposit in Poland. Assuming an average number of working days in a year ($d = 240$ days) and average truck tonnage ($l = 30$ tons), the approximate number of vehicles driving from the mines was calculated. The calculated truck quantities were connected to the routes generated for every mining facility in the studied area.

$$N = \frac{\mathrm{w}}{\mathrm{d} - 1} \quad (1)$$

3 Building FlexSim Model

Because of the very easy and fast modelling process and the FlexSim producer recommendations to use simplified 3D objects, Trimble SketchUp application was used to create mining vehicle models (Fig. 1) (FlexSim Users Manual 2014). In order to increase their attractiveness the models were subjected to the shading process in the Blender 3D Studio application and then exported to a FlexSim recognizable file format.

The terrain model was prepared in a similar way (Fig. 2), using the satellite orthoimage as a realistic surface texture.

From the functional point of view it was essential to define the model structure correctly and select proper FlexSim tools. Standard objects representing cargo flow elements in a delivery chain process were used in the analysis (Pawlewski and Pasek 2009).

Fig. 1 3D mining vehicle models (*Source* Own study)

Fig. 2 Satellite orthoimage of Kostrza Village (*left*) and 3D model (*right*) (*Source* Own study)

The basic classes used for constructing the model elements were (FlexSim Users Manual 2014):

- sources,
- queues,
- transporters,
- sinks,
- network nodes.

Since mining transport processes take place in a specific infrastructure environment, it was necessary to construct a vector transport network on which vehicles would drive. FlexSim network tools enable one to manipulate network nodes in three dimensions, whereby a faithful representation of the expected network shape can be created. It was also possible to define flow directions for the network branches (sections with one or two directions) and include them in the transport

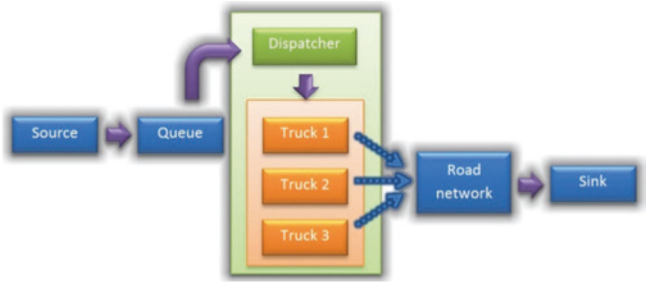

Fig. 3 Schematic diagram of transport sequence (*Source* Own study)

model. All of the elements were connected in accordance with the FlexSim application functionality (Fig. 3) which directly shows how to form mineral transport processes.

A traffic control mechanism (FlexSim Users Manual 2014) was built into the network structure to indicate the locations of bottlenecks in the transport of minerals (Fig. 4). This solution makes it possible to show the proper way in which mining vehicles should pass through crossroads. Additionally, some extra nodes were attached to the network branches. The nodes were provided with a script blocking the possibility of driving when another car is standing in front of the mining vehicle (Fig. 4).

Additional nodes were attached to the network also to define the mining transport flow intensity. The nodes performing the function of measuring devices were provided with a counting script[1] and an increment label to specify the number of trucks passing through them (Fig. 4).

4 Kostrza Village Case Study

It is essential to select a proper terrain in order to test the functionalities. Because of the peculiar layout of the mine and the available documentation, the Kostrza Village area was chosen as most suitable for this purpose. The place is located in the direct neighbourhood of nine open pit mines whose annual production amounts to 897 thousand tones. The geometry of the road network is such that the haulage routes intersect in the village area, which predisposes Kostrza to analysis even more.

Because of the preliminary character of the analysis, only six mines most closely located (Table 1) were used in vehicle flow calculations. The mines were: Borów, Borów 17, Kostrza, Kostrza-Wanda, Kostrza-Piekiełko and Kostrza-Lubicz.

1 www.flexsim.com/community/forum/. Approach 8 March 2012.

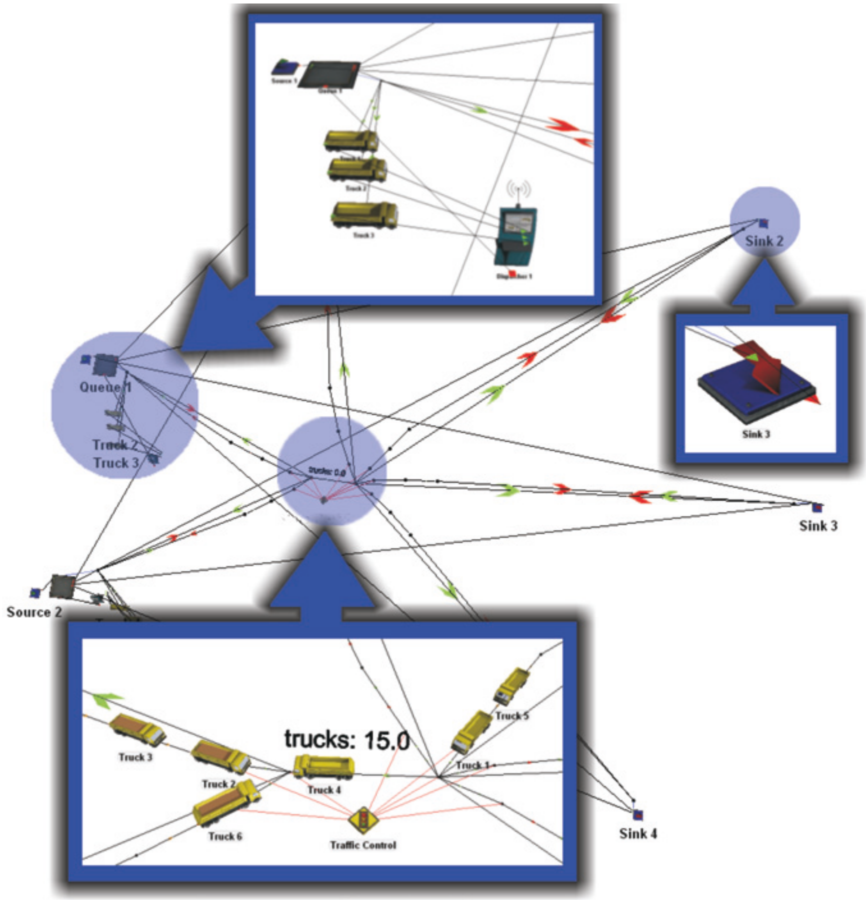

Fig. 4 Transport network model built in FlexSim application (*Source* Own study)

When building a 3D model of the Kostrza Village area with the identified existing road network (Fig. 5), it became apparent that the analysis should focus on 18 road sections. Initially, only three objects generating vehicle flows were created. Two of them reflected the total production of two mine facilities located very closely to each other.

The daily number of cars was calculated from Eq. 1. On this basis material production time intervals were defined and assigned to each of the source objects. Proportional transport to every delivery place was assumed for the basic analysis.

5 Results of Analysis

The analytical results show that the different network segments are characterized by different intensity values (Fig. 6) depending on the number of junctions between them and the starting points, and on the production levels. In the analysed case

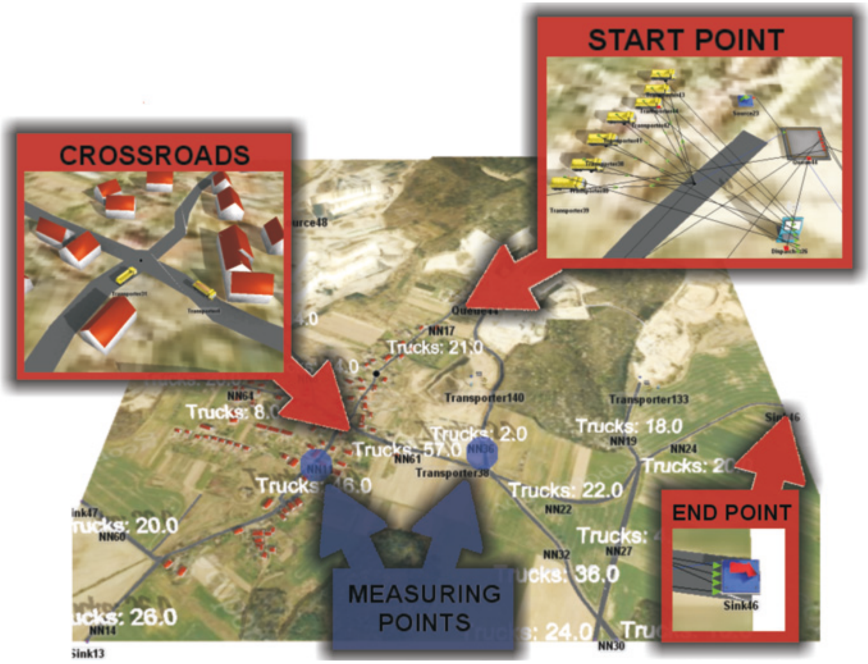

Fig. 5 Kostrza Village FlexSim model (*Source* Own study)

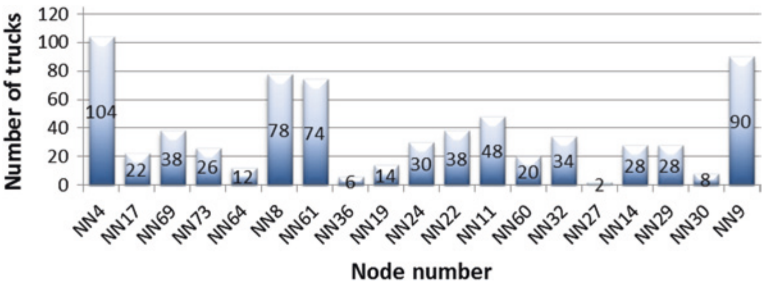

Fig. 6 Number of vehicles detected in network measuring points (*Source* Own study)

the most burdened segment was NN4 (104 vehicles), mainly because it is the first transport section from the closely located Borów and Borów 17 deposits which generate the highest volume of production. The second most overloaded segment was NN9 (90 vehicles), which is typical of almost every considered transport route.

By connecting the FlexSim object labels to the Excel Spreadsheet it is possible to show the recorded values in the GIS application (Fig. 7). Using the tool for generating a spatial representation of the density of objects[2] it was possible to present the simulation measurement results as a colour map of transport intensity.

[2] www.esri.com. Approach 20 Feb 2014.

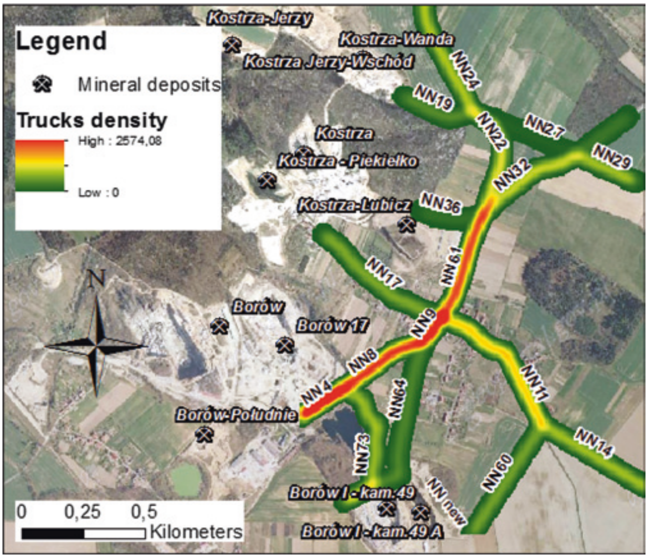

Fig. 7 GIS representation of mining vehicles density (*Source* Own study)

As expected, it is the mines with the highest volume of production that are most responsible for creating vehicle flows and their haulage routes contribute most to transport intensification. The highest intensity values were recorded in the Kostrza Village centre, mainly because it is the place where almost all of the mining routes intersect. Because of the network geometry, it is also the first place where the routes are divided according to their final directions and so the input number of vehicles is the highest there.

Since it is possible to monitor process time, it is easy to determine process changeability (Fig. 8). Hourly frequency distributions of the number of vehicles which drive through the measuring points can show the transport characteristic with reference to the lengths of the routes. The particular time ranges are characterized by a different number of trucks, which is mostly due to transport schedules. Taking into consideration the fact that destination points for the particular mines are chosen randomly, it is certain that the actual time changeability characteristic can be determined after several simulations by comparing the similarities between them. The best results were obtained using the actual mine schedule data whereby not only the locations of transport intensity, but also the times when the latter occurs were precisely determined.

For the testing of the model capacity several scenarios of possible transport condition changes were prepared. Since the simulation results should be readable and easy to interpret, the implemented changes were related to the mine with the highest level of production (the Borów deposit). The first case involved the transformation of the network geometry—an extra connection was attached near the place where the Borów deposit is located. The second case involved changing the

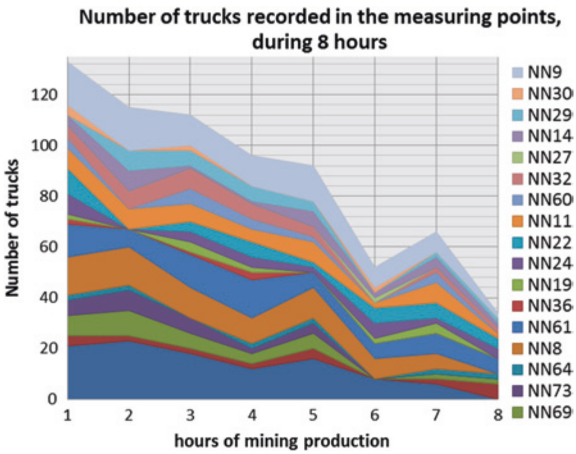

Fig. 8 Hourly distribution of number of trucks (*Source* Own study)

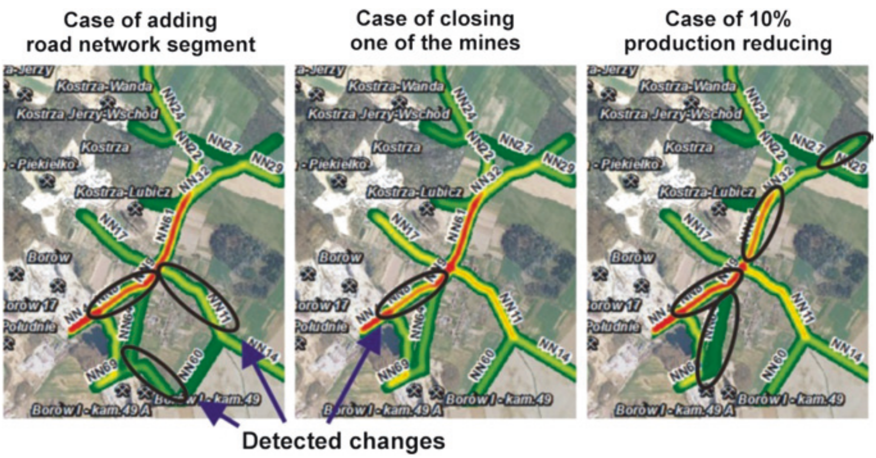

Fig. 9 Transport intensity changes for different analytical conditions (*Source* Own study)

number of mine facilities (the Borów deposit was deleted). In the third case, the levels of production (−10 %) were changed for each considered mine.

The simulation results were compared with the reference situation (Fig. 7) in order to determine the hypothetical differences between them (Fig. 9). As it was easy to predict, the changes that took place were concentrated in the road segments connected with the designated mine (Table 2). In the first case, the cars leaving the Borów deposit area took the shortest route by choosing the newly created road segment. This situation occurred only for the destination to which the new route leads. In the second case, visible differences on the segments used by the Borów mining transport (nodes NN4, NN8, NN9) become apparent. The

Table 2 Biggest changes in truck intensity detected in network nodes

Node	Numbers of trucks (cars daily)			
	Base	Case 1	Case 2	Case 3
NN4	104	104 (0 %)	64 (−38 %)	94 (−10 %)
NN8	78	68 (−13 %)	44 (−44 %)	66 (−15 %)
NN9	90	80 (−11 %)	58 (−36 %)	70 (−22 %)
NN60	20	4 (−80 %)	14 (−30 %)	18 (−10 %)

Source Own study

third case shows the same changes as in the second case, but with some other differences detected on the segments where transport routes from several mine facilities (node NN9) converge.

It has been demonstrated that the possibility of running various simulations can be helpful in determining how mine facilities are responsible for the formation of vehicle flows. It is possible not only to show transport intensity locations, but also to define several changes in the transport process and see their direct consequences. Thanks to the FlexSim software application, especially owing to the possibility of using various control parameters, both industrial processes and their environmental impact can be comprehensively modelled.

6 Conclusion

An analysis as the one presented in this chapter makes it possible to discover how road network segments are used for the transport of minerals near mining areas. Besides showing the highest transport intensities for the particular time intervals, it also indicates the level of facility participation in the creation of flows of mining vehicles.

The analytical mechanism enables the automatic definition and quick execution of specific model variants and scenarios. The different cases can be related to production levels and to the number of mines involved. The presented tools make it possible to take into account transport directions and to carry out simulations of vehicle flow changeability for the different road directions.

The 3D environment unconditionally visualizes the mining vehicle flow creation process and its direct locations. When vehicle detectors are added and a traffic logic is defined, the model shows the intensity of the traffic of mining trucks and the locations of bottlenecks.

The presented solution forms an effective basis for carrying out further research aimed at defining possible changes in network geometry and formulating a transport policy programme which will include the heavy vehicle aspects.

Because of the limited spatial scope of this analysis made using the prototypical modelling mechanism no definite conclusions about the road situation in the study area can be drawn. Only a full analysis covering all the mining facilities and the precisely defined transport directions will show the real mining vehicle flow conditions in the region.

Thanks to the possibility of combining the FlexSim application with other analytical tools (GIS) more complex spatial analyses based on industrial process modelling and simulations can be carried out.

References

FlexSim Users Manual (2014). www.flexsim.com. Approach 20 Feb 2014

Garrido JM (2009) Object oriented simulation: a modelling and programming perspective. Springer, New York

Institute for Territorial Development, Wrocław, Raport (2009a) Studium wydobycia i transportu surowców skalnych na Dolnym Śląsku. Stan i perspektywy

Institute for Territorial Development, Wrocław, Raport (2009b) Wytyczne kierunkowe do kształtowania sieci drogowej i kolejowej w województwie dolnośląskim

Institute for Territorial Development, Wrocław, Raport (2012) Studium wydobycia i transportu surowców skalnych na Dolnym Śląsku. Stan i perspektywy. Edycja druga

Nowakowski T, Kwaśniowski S, Zając M (2010) Problemy logistyczne wywozu surowców skalnych z rejonu Dolnego Śląska a idea komodalności, vol 4, Logistyka, CD-CD

Pawlewski P, Borucki J (2011) "Green" possibilities of simulation software for production and logistics—a survey

Pawlewski P, Pasek ZJ (2009) Use of distributed IT tools for assessment of manufacturing processes. In: Distributed computing, artificial intelligence, bioinformatics, soft computing, and ambient assisted living, vol 5518, pp 350–357

Pawlewski P, Dossou P-E, Golinska P (2012) Using simulation based on agents (ABS) and DES in enterprise integration modelling concepts. Trends Pract Appl Agents Multiagent Syst 157:75–83

Polish Geological Institute, National Research Institute (2012) Minerals Yearbook of Poland 2012

Supreme Audit Office, Raport (2011) Informacja o wynikach kontroli ochrony dróg przed niszczeniem przez przeciążone pojazdy

The 2020 development strategy for the Lower Silesia Voivodeship (official document)

An Optimization Model in Support of Biomass Co-firing Decisions in Coal Fired Power Plants

Sandra D. Eksioglu and Hadi Karimi

Abstract This chapter provides an optimization model to aid with biomass co-firing decisions in coal fired power plants. Co-firing is a strategy that can be used to reduce greenhouse gas emissions at coal plants. Co-firing is a practice that impacts logistics-related costs, capital investments, plant efficiency, and tax credit collected. The linear mixed-integer programming model we present captures the relationship that exists between biomass usage and the corresponding costs and savings due to production of renewable electricity. We test the performance of the model proposed on a case study developed using data from the State of Mississippi. We perform a sensitivity analyses in order to evaluate the impact of biomass purchasing costs, biomass transportation costs, investment costs, and production tax credit on the cost of renewable electricity.

Keywords Biomass supply chain • Mixed integer programming • Co-firing

1 Introduction

The work presented in this chapter is motivated by the increasing awareness about the impact that greenhouse gas (GHG) emissions have on the quality of the air, and consequently the quality of our lives. Figure 1 presents projections of the world-wide CO_2 emissions (International Energy Agency 2009). It is clear from the figure that the major contributors to GHG emissions are the power generation and energy sectors.

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DOI: 10.1007/978-3-319-07347-7_8,

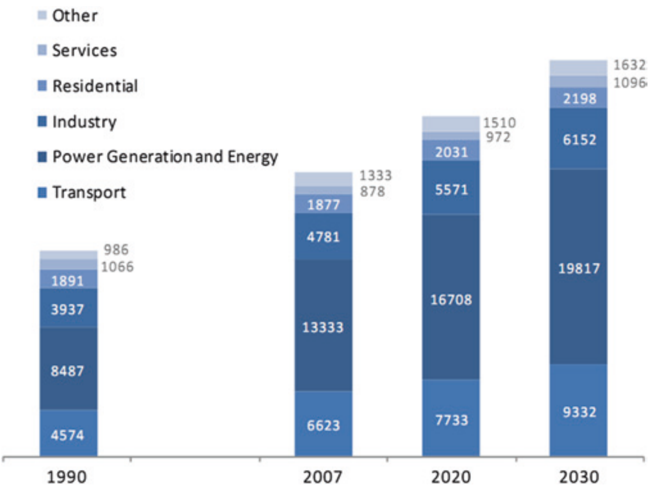

Fig. 1 Projected world energy-related CO_2 emissions [*Source* (International Energy Agency 2009)]

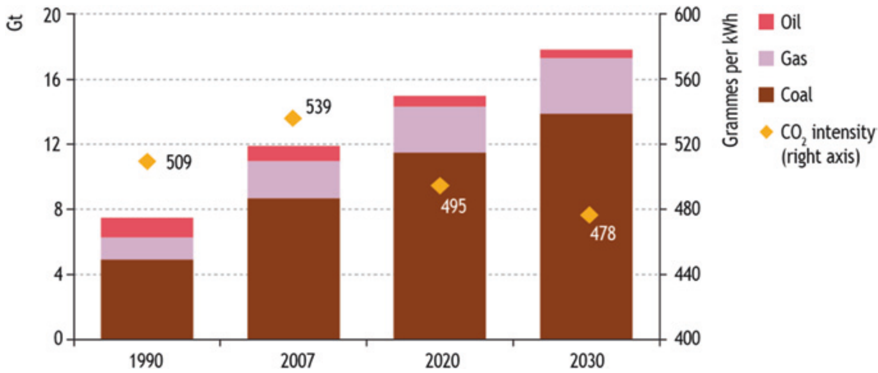

Fig. 2 World energy-related CO_2 emissions from the power sector and CO_2 intensity [*Source* (International Energy Agency 2009)]

Figure 2 provides details about the CO_2 emissions and CO_2 intensity from the power sector. Emissions in the power generation sector are expected to increase by 26 % between 2007 and 2020, and in 2030 they will reach 50 % above today's levels. This increase is driven from the growth in demand for electricity, and consequently the increased use of coal, and fossil fuels.

Co-firing biomass in coal plants is a practice that has been investigated and implemented (Tillman 2000). Using biomass to co-fire can reduce GHG emissions due to displacing coal for biomass, a product which has theoretically zero net GHG emissions during its life cycle. In order to increase the use of biomass for the purpose of power generation, the federal government has provisioned incentives, such as, the renewable electricity production tax credit (PTC). PTC provides an income tax credit of 2.3 cents/kWh. At the State level, policies, such as, the

California's RPS "requires investor-owned utilities, electric service providers, and community choice aggregators to increase procurement from eligible renewable energy resources to 33 % of total procurement by 2020." As of January 2012, 30 States and the District of Columbia have enforceable RPS or other mandated renewable capacity policies (Energy Information Administration 2013a, b, c).

Co-firing biomass impacts the performance of coal plants in several ways. Co-firing reduces boilers efficiency and as a consequence, reduces overall system efficiency. Biomass co-firing requires additional investments in the coal feeding system of the plant in order to facilitate the process of co-firing. Co-firing requires additional transportation costs because biomass, different from coal, is widely dispersed geographically, and has lower heating values and density per unit (International Energy Agency 2009). While co-firing implies additional investment and processing costs, it does result in additional savings. These savings result from reducing the amount of coal purchased, and from the renewable electricity PTC.

This chapter provides a linear mixed-integer programming model that aids coal fired power plants with biomass co-firing decisions. The model maximizes profits due to co-firing subject to biomass availability and other operational constraints at a power plant. The model captures the relationships that exist between the percentage of coal displaced, and the amount of biomass required (by mass), the loss of plant efficiency, the investments and processing costs. The model integrates processing and investment costs with logistics costs required to deliver biomass to coal plants and savings due to production tax credits. The results of our sensitivity analyses are very insightful and would help plant managers with decisions about biomass co-firing. The model itself can be used by decision makers at the State and Federal government to evaluate the economic feasibility of producing renewable electricity through co-firing, and, consequently, to design regulations.

2 Problem Description

In this section we describe the problem, and provide insight about the equations developed in order to identify the relationship that exists between biomass co-fired and the resulting cost/savings in a coal plant. We focus only on the additional costs and savings that result from co-firing. Costs are due to the additional investments in the coal plant in order to facilitate co-firing, purchase biomass and transport biomass to coal plants. Savings are due to the renewable electricity production tax credit, and due to reducing the amount of coal purchased and used.

2.1 Biomass Co-firing: Estimating Biomass Usage

Biomass has a lower heating value as compared to coal. Additionally, biomass usage decreases the efficiency of the boilers used in a coal plant. Thus, co-firing as much biomass as the amount of coal displaced will negatively impact the amount of energy produced. The objective of this section is to determine the relationship that exists between the amount of coal displaced and the amount of biomass to co-fire in order to maintain the same energy output at a coal plant. The equations presented in this section are mainly derived from De and Assadi (2009). A full list of notations used here on is presented in Table 2 in the Appendix.

The amount of coal that a coal plant uses $\left(M_j^{coal}\right)$ is a function of its annual energy input rate $\left(Q_j^0\right)$, number of operating hours $\left(OH_j\right)$, and lower heating value of coal $\left(LHV_j^{coal}\right)$. Equation (1) presents this relationship.

$$M_j^{coal} = \frac{Q_j^0 * OH_j * C^{wb}}{LHV_j^{coal}} \tag{1}$$

When biomass is co-fired with coal, then the amount of biomass (by mass) required to displace β_j % of coal of plant j is calculated as follows:

$$M_j^{bm} = \frac{M_j^{coal}}{1/\beta_j - \alpha_j} = \frac{1}{1/\beta_j - \alpha_j} * \frac{Q_j^0 * OH_j * C^{wb}}{LHV_j^{coal}} \tag{2}$$

where, $\alpha_j = 1 - \frac{LHV_j^{coal}}{LHV_j^{bm}}$. Equation (2) assumes that there is no efficiency loss in the boilers due to using biomass instead of coal. Tillman (2000) presents the efficiency loss due to displacing β_j % of coal using the following equation:

$$EL_j = 0.0044\beta_j^2 + 0.0055 \tag{3}$$

Therefore, plant efficiency during co-firing becomes $\rho_j = \left(\rho_j^b - EL\right) * \rho_j^{rp}$. Where, ρ_j^b is the efficiency rate of boilers, and ρ_j^{rp} is the efficiency rate of the rest of the plant. Equation (4) calculates the amount of biomass required for co-firing when efficiency loss is considered:

$$M_j^{bm} = \frac{1}{1/\beta_j - \alpha_j} * \frac{Q_j^0 * OH_j * C^{wb}}{LHV_j^{coal}} * \frac{\rho_j^b}{\rho_j^b - EL_j} \tag{4}$$

2.2 Biomass Co-firing: Estimating Costs and Savings

Plant investment costs: Sondreal et al. (2001) show that, when β_j % $\leq$ 4 %, the existing fuel feeding system can be used for co-fire, and therefore, investment costs are only \$50 per kW of power generated from biomass. Investment costs are calculated as follows:

$$\boldsymbol{I_j^{CAP}} = \boldsymbol{I_j^{cap}} * \frac{\boldsymbol{\beta_j}}{1 - \boldsymbol{\beta_j}}. \tag{5}$$

where, $I_j^{cap} = 50{,}000 * TC_j * f_j * \frac{LHV_j^{bm}}{LHV_j^{coal}}$ and it is a constant.

Caputo et al. (2005) show that, when $\beta_j \,\% > 4\,\%$, the capital costs are much higher due to the necessary investments for biomass storage $\left(I_j^S\right)$, biomass handling $\left(I_j^H\right)$, and compressors and dryers $\left(\boldsymbol{I_j^{CD}}\right)$. Investment costs are calculated as follows.

Biomass storage:

$$I_j^S = I_j^s * \left(\frac{\beta_j}{1-\beta_j}\right)^{0.5575}. \tag{6}$$

Biomass handling:

$$I_j^H = I_j^h * \left(\frac{\beta_j}{1-\beta_j}\right)^{0.9554}. \tag{7}$$

Compressors and dryers costs:

$$I_j^{CD} = I_j^{cd} * \left(\frac{\beta_j}{1-\beta_j}\right)^{0.5575}. \tag{8}$$

where,

$$I_j^s = 136{,}578 * \left(TC_j * f_j * \frac{LHV_j^{bm}}{LHV_j^{coal}}\right)^{0.5575}, I_j^h = 55{,}780 * \left(TC_j * f_j * \frac{LHV_j^{bm}}{LHV_j^{coal}}\right)^{0.9554}$$

and

$$I_j^{CD} = 13{,}646 * \left(TC_j * f_j * \frac{LHV_j^{bm}}{LHV_j^{coal}}\right)^{0.5575}. \tag{9}$$

Operating Costs: These costs consist of the cost of purchasing and transporting biomass. Let $\boldsymbol{c_i^{bm}}$ denote the unit purchase cost of biomass (in \$/ton) from supplier i, and let S denote the set of biomass supplier. Then, biomass purchasing costs at plant j are:

$$\sum_{\boldsymbol{i \in S}} \boldsymbol{c_i^{bm} M_j^{bm}}. \tag{10}$$

Transportation costs consist of the truck costs necessary to deliver biomass to coal plants. The delivery cost from supplier i to plant j is denoted by c_{ij}^t. Biomass transportation costs to plant j are:

$$\sum_{i \in S} c_{ij}^t M_j^{bm}. \tag{11}$$

Savings: Some of the savings are due to the displacement of coal. If plant j displaces ΔM_j^{coal} tons of coal, at a unit purchase cost of c_j^{coal} (in \$/ton), then these savings are: $S_j^p = \sigma_j^p * M_j^{bm}$. Where,

$$\sigma_j^p = c_j^{coal} * \frac{LHV_j^{bm}}{LHV_j^{coal}}. \quad (12)$$

Other savings are due to renewable electricity production tax credits which are 2.3 cents/kWh. If M_j^{bm} is the amount of biomass used (in tons), then the corresponding savings are: $S_j^{tax} = \sigma_j^t * M_j^{bm}$. Where,

$$\sigma_j^t = 23 * \frac{LHV_j^{bm}}{C^{wb}}. \quad (13)$$

2.3 Mathematical Problem Formulation

Next we present a linear mixed-integer programming model to identify how much coal to displace from power plants in order to maximize profits from co-firing. We discretize the problem as described below in an effort to model this problem as a linear mixed-integer linear program. Consider that plant j could displace coal (by mass) either at a rate of $\beta_j = 1$, or 2, or 3 %, etc. We denote the finite set of all potential values that β_j can take by L. Let l = 1, …, |L| index this set, and let Ll denote the l—the element of this set. We declare Y_{lj} to be a binary variable which takes the value 1 if facility j displaces Ll = β % coal, and takes the value 0 otherwise. Let X_{ij} be a decision variable which represents the amount of biomass delivered from supplier i to coal plant j.

We use Eq. (9) in order to calculate the value of σ_j^p for different facilities. We use Eq. (10) in order to calculate the value of σ_j^t for different facilities. The units for σ_j^p and σ_j^t are given in \$/ton of biomass delivered. Thus, for coal plant *j*, the following equation presents the annual savings due to tax credits and due to reductions of coal purchases: $\left(\sigma_j^p + \sigma_j^t\right) * \sum_{i \in S} X_{ij}$.

The amount of biomass delivered to a coal plant depends on the amount of coal displaced. Let M_{lj}^{bm} denote the amount of biomass delivered when facility *j* displaces $L_l = \beta_j$ % coal. We assume that a coal plant would pursue a single coal displacement strategy (would select a single β_j). Then, the total amount of biomass delivered to coal plant *j* is equal to $M_j^{bm} = \sum_{l \in L} M_{lj}^{bm} Y_{lj} = \sum_{i \in S} X_{ij}$. Then, the annual biomass transportation and purchasing costs for plant *j* are: $\left(c_{ij}^t + c_i^{bm}\right) * \sum_{i \in S} X_{ij}$.

Investment costs depend on the value of β_j. For $\beta_j \le 4$ % we use Eq. (5) to calculate investment costs at plant *j* (I_j^{CAP}) for different values of β_j. We denote these values by I_{lj}. Similarly, when $\beta_j > 4$ % we use Eqs. (6)–(8) to estimate storage, inventory holding and compressors/driers costs. We denote these values by I_{lj}.

The following is a linear mixed integer programming formulation which we will be referring to as formulation (Q).

$$\text{Max: } Z = \sum_{j \in C} \left(\left(\sigma_j^p + \sigma_j^t\right) \sum_{i \in S} X_{ij} \right) - \sum_{i \in S, j \in C} \left(c_{ij}^t + c_i^{bm}\right) X_{ij} - \sum_{l \in L} \sum_{j \in C} I_{lj} Y_{lj} \quad (14)$$

Subject to:

$$\sum_{j \in C} X_{ij} \leq s_i \quad \text{for all} \quad i \in S \tag{15}$$

$$\sum_{i \in S} X_{ij} \leq \sum_{l \in L} M_{lj}^{bm} Y_{lj} \quad \text{for all} \quad j \in C \tag{16}$$

$$\sum_{l \in L} Y_{lj} \leq 1 \quad \text{for all} \quad j \in C \tag{17}$$

$$X_{ij} \in R^{+} \quad \text{for all} \quad i \in S, j \in C \tag{18}$$

$$Y_{lj} \in \{0, 1\} \quad \text{for all} \quad l \in L, j \in C \tag{19}$$

The objective of (Q) is to identify the amount of biomass to co-fire in a coal fired power plant so that the total profit due to co-firing is maximized. These profits are calculated as the difference between savings and cost. The costs considered are plant investment costs, biomass purchasing and transportation costs. Savings are due to tax credits and due to reducing the amount of coal purchased/processed. Constraints (11) show that the amount of biomass shipped is limited by biomass availability (s_i) at supplier i. Constraints (12) indicate that the amount of biomass required in a coal plant is a function of plant capacity, efficiency and the percentage of biomass co-fired. Constraints (13) indicate that at most one co-firing strategy is employed at a particular plant. Constraints (14) are the non-negativity constrains, (16) are the binary constraints.

3 Numerical Analysis

3.1 Data Collection

Biomass supply: Biomass availability data by state and county is extracted from the Knowledge Discovery Framework (KDF) (2013) database, an outcome of the US Billion Ton Study led by the Oak Ridge National Laboratory. This database provides the amount of biomass available at the county level in the form of forest products, forest residues, agricultural products, agricultural residues, energy plants, etc. The database provides the amount of biomass available at different target price for the 2012–2030 period.

From this data set we extracted and used data about forest products and residues. We focus the analyses on these products only, because, research has shown that these products are low in sulfur, as well as, chemicals such as, chlorine, potassium and nitrogen. Table 1 presents a summary of the data we use in the experimentations. The table provides the total biomass available in Mississippi in 2012

Table 1 Biomass availability as a function of target price

Price (in \$/ton)	Biomass available (in tons)	Price (in \$/ton)	Biomass available (in tons)
50	25,900	130	5,551,100
60	258,800	140	6,208,000
70	793,000	150	6,754,900
80	1,601,700	160	7,507,400
90	2,523,400	170	8,046,500
100	3,434,500	180	8,657,800
110	4,107,100	190	9,220,600
120	4,781,400	200	9,687,500

for different price targets. The amount of biomass available increases as a coal plant is willing to pay a higher price for purchasing biomass.

Coal plants: The data about coal-fired power plant locations, nameplate capacities, types of coal used, utilization rates, and annual heat input rates, is collected from the National Energy Technology Laboratory (2005). This study only considers power plants with capacity larger than 1 MW. This resulted in a total of 632 coal-fired power plants across the USA, with an overall production capacity of about 380,000 MW.

Truck transportation costs: In order to estimate costs for truck transportation of biomass, we use the data provided by Searcy et al. (2007). They provide two cost components which are the distance variable cost (DVC) and distance fixed cost (DFC). The distance variable cost includes the cost fuel and labor. The distance fixed cost includes the cost of loading and unloading a truck. These costs were provided for different types of biomass, such as, woodchips, straw and stover. We used the data provided for woodchips. The DVC of woodchips is estimated \$0.112/(tons mile) and DFC is estimated \$3.01/(tons). Woodchips are shipped using truck with a capacity of 40 tons. This data is used as follows in order to calculate $\boldsymbol{c_{ij}^t}$ (in \$/ton): $\boldsymbol{c_{ij}^t = DFC + DVC * d_{ij}}$, where, $\boldsymbol{d_{ij}}$ is the distance traveled.

3.2 *Experimental Results*

Model (Q) is solved using CPLEX. The experimentations were conducted on a PC with a Dual 2.2 GHz processors and 2 GB of RAM on Windows platform. Figures 3, 4, 5, 6 and 7 summarize the experimental results for the case study.

Figure 3 represents the relationship that exists between the size of set $|L|$ and the objective function value. We focus on strategies where β_j is between 1 and 50 %. As we increase the size of the set, we are exploring additional co-firing strategies within this range. For example, when $|L| = 3$, the only strategies considered are $\beta_j = 0$, 25, and 50 %. When $|L| = 51$, then strategies considered are $\beta_j = 0, 1, 2, \ldots, 49, 50$ %. The goal of these experiments is to evaluate the impact

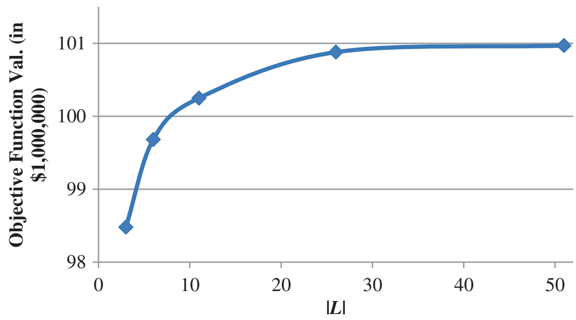

Fig. 3 Relationship between the size of set |L| and the objective function value (*Source* own study)

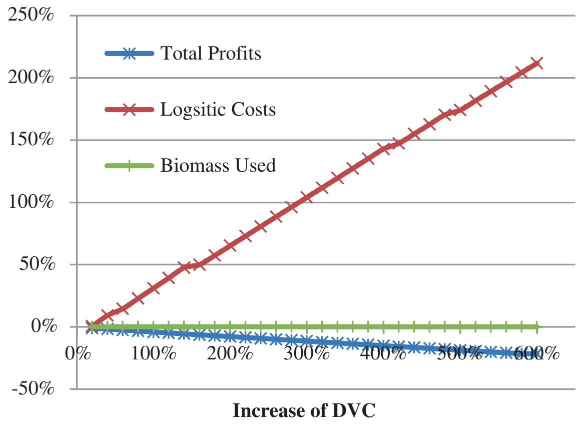

Fig. 4 Relationship between variable transportation costs, logistics costs, profits, biomass use (*Source* own study)

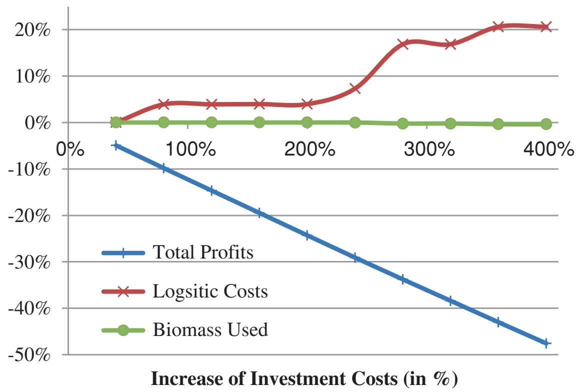

Fig. 5 Relationship between investment costs, logistics costs, profits, biomass use (*Source* own study)

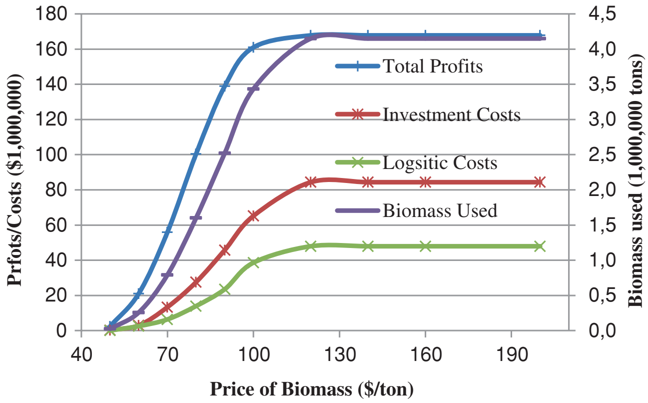

Fig. 6 Relationship between biomass price, investment costs, logistics costs, profits, biomass use (*Source* own study)

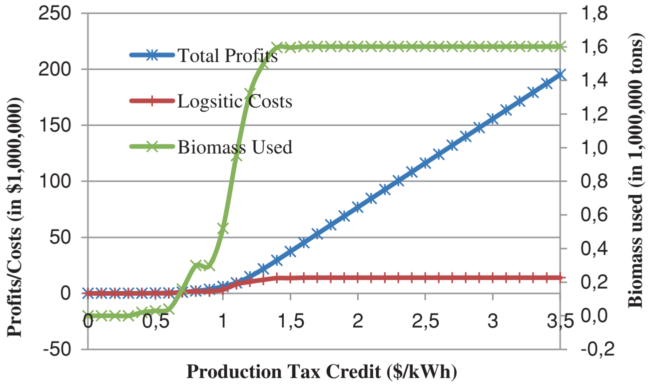

Fig. 7 Relationship between PTC, profits, biomass use (*Source* own study)

of our approximation—that is, not considering all possible values that β_j can take, but instead, investigating only a few options—on the quality of solutions found.

As we increase the size of $|L|$ we are indeed investigating additional co-firing strategies. We did not consider strategies for which $\beta_j > 50\ \%$ since, in all our experimental results, we never observed a plant investing in strategies where $\beta_j > 40\ \%$. As we increase the size of $|L|$, the profits increase. On the other side, as we increase the size of $|L|$, the size of the problem also increases. This in turn impacts the computational time of CLEX. The graph in Fig. 3 shows that the benefits resulting from increasing the size of $|L|$ increase at a decreasing rate. For example, the increase in profits is only 0.09 % when we double the size of $|L|$ from 26 to 51. That means, using $|L| = 51$ in our computational analysis—rather than using a larger value—will modestly impact the quality of the solutions obtained. This is the reason why in the rest of this section we maintain $|L| = 51$.

Figure 4 represents the relationship that exists between the variable transportation cost (DVC) and the corresponding logistics costs, biomass used, profits in the supply chain. While biomass usage is not impacted much by this increase in the value of DVC, the total logistics costs are increased since a higher price is paid per unit shipped. As DVC increases as much as 6 times, the decrease of biomass usage is 0.007 %. The decrease in profits is 22.23 %. However, the total profits remain positive. This is because the PTC of 2.3 cents/kWh is large enough to cover these expenditures.

Figure 5 represents the relationship that exists between the investment costs and the corresponding logistic costs, biomass used, profits in the supply chain. Biomass usage is not impacted much by this increase investment costs. As investment costs increases as much as 4 times, the decrease of biomass usage is 0.37 %. The decrease in profits is 47.58 %. However, the total profits remain positive.

Figure 6 represents the relationship that exists between the biomass price a plant is willing to pay and biomass usage, profits in the supply chain, logistics costs and investment costs. As plants are willing to pay a higher price for biomass, more would be available to them (see Table 1). As a result, biomass usage and renewable energy production would increase. This in turn will increase supply chain profits. Note that, the graphs in this figure flatten out at $100–$110/ton. In order to maintain profits at the maximum, power plants will not be willing to pay a higher price for biomass. That means, when PTC is 2.3 cents/kWh, plants would be willing to pay as much as $100–$110/ton of biomass. Clearly, purchasing biomass at a higher price would not result in losses for the power plants. However, the goal of our model is maximizing profits, and therefore, for a tax credit of 2.3 cents/kWh, purchasing biomass with a price up to $100–$110/ton maximizes profits.

Figure 7 represents the relationship that exists between PTC and biomass usage, profits in the supply chain, and logistics costs. Increasing the value of PTC beyond 1.6 cents/kWh does not result in an increase of biomass usage and renewable energy production. Additionally, when PTC is less than 0.4 cents/kWh no biomass is used. That means, power plants would have no incentive to co-fire unless they are subsidized for their efforts. This is simply because power plants would lose money from co-firing. On the other side, increasing PTC beyond some threshold value would not necessary result in additional renewable energy produced.

4 Conclusions

This chapter presents an optimization model to aid with biomass co-firing decisions in coal fired power plants. We test the performance of the model proposed on a case study developed using data from the State of Mississippi. We perform a sensitivity analyses in order to evaluate the impact of biomass purchasing costs, biomass transportation costs, investment costs, and production tax credit on the cost of renewable electricity.

Our results indicate that transportation costs, investment costs, and biomass price impact profits and consequently impact co-firing decisions in coal fired power plants. Our results indicate that power plants would have no incentive to co-fire unless they are subsidized for their efforts. On the other side, increasing the tax credits beyond some threshold value would not necessary result in additional renewable energy produced. That means, in order to increase the renewable energy production, instead of using a "flat rate" tax credit, a better system would be to make the tax credit a function of the amount of renewable electricity produced.

Acknowledgments This work was supported by NSF grant CMMI 1052671. This support is gratefully acknowledged.

Appendix

See Table 2.

Table 2 Notations

α_j	This is equal to $1 - LHV_j^{coal} \Big/ LHV_j^{bm})$
β_j	The percentage of biomass co-fired in plant j
C	The set of coal plants
c_i^{bm}	The unit purchase cost for biomass from supplier i (in \$/ton)
c_{ij}^t	The unit transportation cost for biomass from supplier i to plant j (in \$/ton)
C^{wb}	The conversion factor from MW to BTU/hour (in BTU/(hour*MW))
d_{ij}	The distance between supplier i and plant j (in miles)
DFC	Distance fixed cost (in \$/ton)
DVC	Distance variable cost (in (\$/(ton*mile)))
EL_j	The efficiency loss of plant j (in %)
f_j	The capacity factor of plant j (in %)
I_j^{CAP}	The investment costs at plant j when $\beta_j \leq 4\,\%$ (in \$)
I_j^{CAP}	Is equal to: $50{,}000 * TC_j * f_j * (LHV_j^{bm}/LHV_j^{coal})$
I_j^H	The investment costs for biomass handling at plant j ($\beta_j > 4\,\%$) (in \$)
I_j^h	Is equal to: $55{,}780 * \left(TC_j * f_j * (LHV_j^{bm}/LHV_j^{coal})\right)^{0.9554}$
I_j^{CD}	The investment costs for compressors and dryers at plant j ($\beta_j > 4\,\%$) (in \$)
I_j^{cd}	Is equal to: $13{,}646 * \left(TC_j * f_j * (LHV_j^{bm}/LHV_j^{coal})\right)^{0.5575}$
I_j^S	The investment costs for biomass storage at plant j ($\beta_j > 4\,\%$) (in \$)
I_j^s	Is equal to: $136{,}578 * \left(TC_j * f_j * (LHV_j^{bm}/LHV_j^{coal})\right)^{0.5575}$
L	The set of all the potential co-firing strategies
l	The index used for set L
LHV_j^{coal}	The lower heating value of coal fired at plant j (in BTU/ton)
LHV_j^{bm}	The lower heating value of biomass fired at plant j (in BTU/ton)
M_j^{bm}	The amount of biomass co-fired in plant j (in tons)

(continued)

Table 2 (continued)

M_j^{bm}	The amount of biomass co-fired in plant j under strategy l (in tons)
M_j^{coal}	The amount of coal co-fired in plant j (in tons)
OH_j	The number of operating hours in plant j (in hours/year)
Q_j^0	The initial (before co-firing) annual heating input of plant j (in MW)
ρ_j	The efficiency rate of plant j (in %)
ρ_j^b	The boiler efficiency rate of plant j (in %)
ρ_j^{rp}	The efficiency rate of the rest of plant j (boilers excluded) (in %)
S	The set of biomass suppliers
s_i	The amount of biomass available for co-fire at supplier i (in tons)
S_i^p	The total savings from reducing the amount of coal purchased in plant j (in $)
S_j^{tax}	The total savings due to PTC in plant j (in $)
σ_j^p	Is equal to: $c_j^{coal} * \left(LHV_j^{bm} \Big/ LHV_j^{coal}\right)$
σ_j^t	Is equal to: $23 * \left(LHV_j^{bm} \Big/ C^{wb}\right)$
TC_j	The nameplate capacity of plant j (in MW)

References

Caputo AC, Palumbo M, Pelagagge PM, Scacchia F (2005) Economics of biomass energy utilization in combustion and gasification plants: effects of logistic variables. Biomass Bioenergy 28:35–51

De S, Assadi M (2009) Impact of cofiring biomass with coal in power plants: a techno-economic assessment. Biomass Bioenergy 33:283–293

Energy Information Administration (2013a) Annual energy outlook 2013. Available on-line at: http://www.eia.gov/forecasts/aeo/MT-electric.cfm#solar−photo

Energy Information Administration (2013b) Annual energy outlook: energy markets summary. Available on-line at: http://www.eia.gov/forecasts/steo/tables/pdf/1tab.pdf

Energy Information Administration (2013c) Most states have renewable portfolio standards. http://www.eia.gov/todayinenergy/detail.cfm?id=4850

International Energy Agency (2009) World energy outlook. Available on-line at: http://www.worldenergyoutlook.org/media/weowebsite/2009/WEO2009.pdf

Knowledge Discovery Framework (2013) U.S. billion ton update. Available on line at: https://bioenergykdf.net/content/billiontonupdate

National Energy Technology Laboratory (2005) Available on-line at: http://www.netl.doe.gov/energyanalyses/hold/technology.html

Searcy E, Flynn P, Ghafoori E, Kumar A (2007) The relative cost of biomass energy transport. Appl Biochem Biotechnol 137:639–652

Sondreal EA, Benson SA, Hurley JP, Mann MD, Pavlish JH, Swanson ML (2001) Review of advances in combustion technology and biomass cofiring. Fuel Process Technol 71:7–38

Tillman DA (2000) Biomass cofiring: the technology, the experience, the combustion consequences. Biomass Bioenergy 19:365–384

Part III
Supply Chain Management

Using Simulation Modeling and Analysis to Assess the Effect of Variability and Flexibility on Supply Chain Lead Time

Seratun Jannat and Allen Greenwood

Abstract In today's highly competitive marketplace, enterprises are in constant need to improve and sustain their existence. Two key supply-chain performance measures are lead time and variability in lead time, both of which affect sustainability of manufacturing and logistics systems. One way that has been proposed to improve both measures is to increase supplier flexibility. Our research focuses on defining the effects of various manufacturing and logistics flexibility-related factors on lead time and its variability. We use simulation modeling and analysis as the basis for studying the impact of both design and system factors on performance. In this chapter, we present our findings on the effect on lead time of supplier flexibility level, proportion of process time that is production and transportation time, and level of variability in process time. We also discuss briefly our flexibility-factor framework and conceptual model for the simulation, as well as its implementation in *FlexSim* simulation software.

Keywords Flexibility • Supply chain • Framework • Conceptual model

1 Introduction

The concept of a flexible supply chain (FSC) is gaining more and more importance since it provides a means to absorb system disturbance or dynamics. In general, the system dynamics comes from uncertainty and variability in operations in the supply chain. This chapter investigates the effect of this variability on FSC performance. It is apparent that supply chain design and analysis that incorporates the consideration of variability is more complicated than the deterministic case. The "best" level

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of flexibility in a supply chain depends on the supply chain structure, the level of variability in the various components of the supply chain, and the operation of key processes. Flexibility can be obtained both internally—e.g. shift arrangements, additional resources (personnel and equipment)—and externally through policies and relationships between suppliers. In this study our focus is on external flexibility where multiple suppliers serve a number of buyers. However, the approach we have developed can be used to address internal factors as well.

Many of the factors we consider in our framework, such as lot size, distance between suppliers, mode of transportation, etc. can be used to make operational and strategic decisions, that consider environmental effects. Also, flexibility provides responsiveness to market dynamics and thus enhances business sustainability.

In this chapter, we consider a supply chain where a number of suppliers perform work for a number of buyers. The basic structure of this flexible supply chain is from Chan at al. (2009) where they considered a cluster of six suppliers supported a single buyer. Their research considers three factors: Supplier Flexibility Level (SFL), Change in Physical Characteristics (CPC), and Time Delay (TD). SFL allows multiple suppliers the opportunity to perform operations on a product. CPC increases the process time for alternative, or non-primary, suppliers. They apply a common percentage increase in process time for the alternative suppliers; however, a more realistic approach is to individually adjust the process times based on user input. This is the approach we have taken in our model—process times depend on the supplier and the product. TD represents the supplier's delay in updating their production information in their online information system. While Chan at al. (2009) use simulation modeling and analysis to analyze the effect of changes in these factors on lead time, they use deterministic process times and consider only a single system configuration.

In order to effectively design flexible supply chains, a number of factors must be considered. Jannat and Greenwood (2014a) identify and define a framework of important factors for flexible supply chain design and analysis. They divide the factors into two broad categories: system factors and design factors. System factors are used to describe the system and provide the foundation for the simulation model. They define the relationships among buyers and suppliers, order characteristics, internal supplier operations, etc. Design factors include decision variables that can be controlled and are used to improve the system; they are divided into two main categories, those internal to a supplier and those internal to a buyer. These, along with other key elements of the modeling and analysis process, are shown in Fig. 1. As shown in the figure, the analyses that are employed to identify and assess ways to improve the operation of a system (e.g. the best level of supplier flexibility) are based on results obtained from experiments performed with a discrete-event simulation (DES) model of the buyer–supplier system.

Figure 1 also shows experimentation factors (e.g. number of replications, stopping criteria) are key inputs to any simulation model. Specification of the variability in the system is also a key input to simulation. It is shown as a major component of the system factors. For the purpose of experimentation and analysis all process times are assumed to be triangularly distributed. We use an approach for specifying the parameters of the triangular distribution that is described in Jannat and Greenwood (2012).

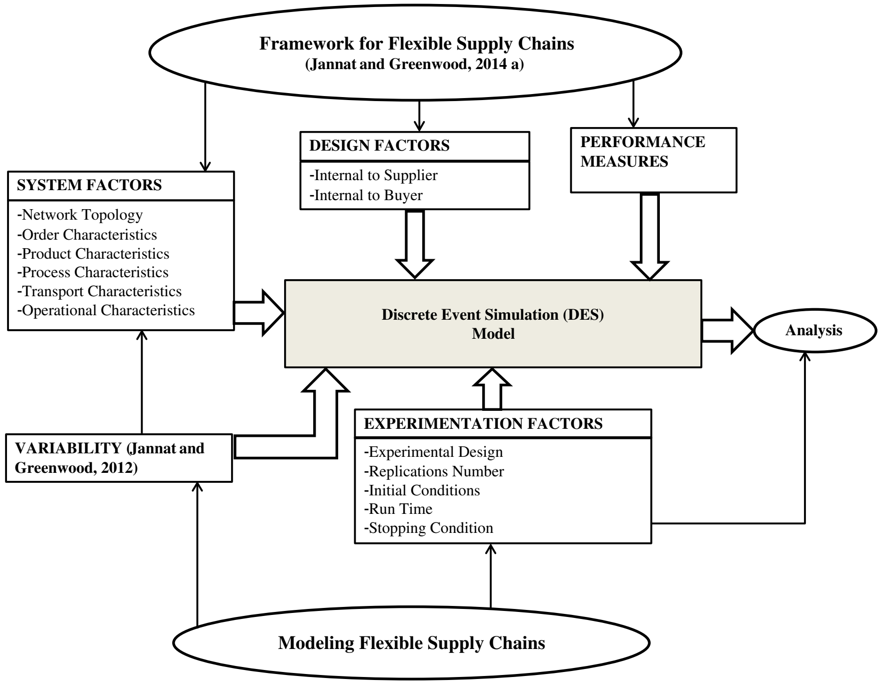

Fig. 1 Process for using simulation modeling and analysis to design flexible supply chains (*Source* Own study)

Jannat and Greenwood's (2012) approach provides an effective means to specify and control variability for experimentation purposes. In this chapter process times are modeled as triangularly distributed random variables with different levels of variation and skewness. The level of variability is specified by the coefficient of variation, denoted as $Cv = \sigma/\mu$, where μ is the mean of the distribution and σ is the standard deviation. Skewness (Sk) measures the symmetry of a distribution and may be positive or negative. In positively skewed distribution, the distribution has a long tail to right; i.e. Mean > Median > Mode. In a negatively-skewed distribution, the distribution has longer tail to the left of the distribution; i.e., Mean < Median < Mode.

As indicated earlier, the basic structure of the supplier–buyer system is as described in Chan at al. (2009). However, we have developed a more comprehensive, flexible, and open model of the system. In general, a cluster of suppliers work together for a buyer. Suppliers receive orders from buyers and process them based on a specified flexibility level. For every operation on every product, up to five suppliers have the capability to perform that operation, thus making the system flexible. Process time for each operation on each product type varies from 40 to 100 time units. Chan at al. (2009) assume transportation time is embedded in the operation time. We believe that to be an overly restrictive assumption; therefore, in this chapter we separate the process time into operation time and transportation time. Also, instead of assuming deterministic process times, we consider variability, specified by the triangular distribution.

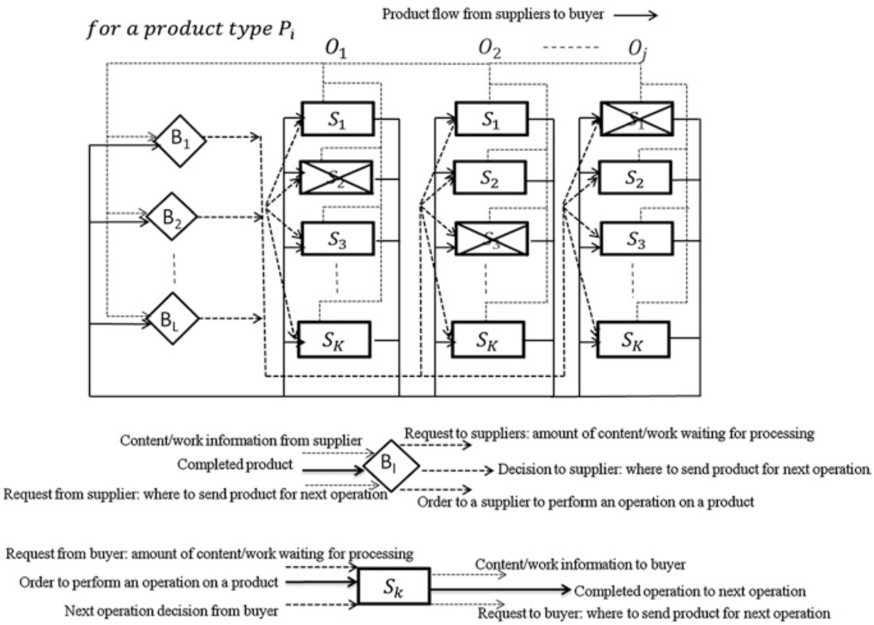

Fig. 2 Product and information flows between buyers and suppliers (*Source* Own study)

2 Conceptual Model and Model Validation

This section provides the conceptual model for developing a simulation of a flexible supply chain. While this generic representation allows the flexible supply chain system to be modeled in any simulation software model, we have developed the model using *FlexSim*. It is briefly described in the next section and further in Jannat and Greenwood (2014b). The model is available from the authors upon request. The conceptual model is presented in Figs. 2 and 3.

Figure 2 provides a high-level representation of the buyer–supplier relationships. The solid lines represent the physical flow of products and the dashed lines represent communication among the elements. (Heavy dashed lines represent information flows from a buyer to a supplier and light dashed lines represent information flows from a supplier to a buyer.) Buyers send orders for products to suppliers. Products vary by the number and sequence of operations required and the process time of the operations. Each operation can be performed by a subset of the suppliers. Initially, product orders (product characteristics and quantity) are generated based on the input parameter values that are supplied by the user. The buyer decides, after each operation, which supplier performs the next operation based on the number of units or the amount of work awaiting processing at each supplier. That is, when an operation O_j needs to be performed on a product P_i a buyer B_l decides which supplier S_k is to perform the operation. The decision process is triggered when a supplier completes an operation—the supplier informs the buyer that it needs to know where to send a product for the next operation. Upon receiving that request, the buyer queries all

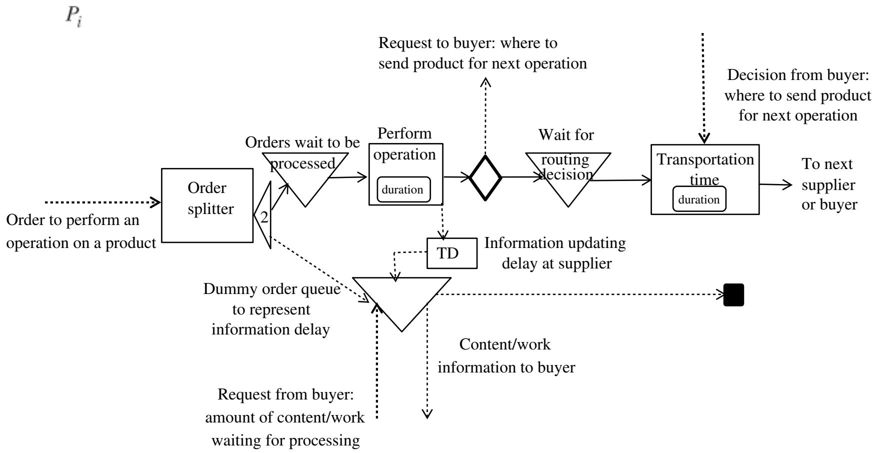

Fig. 3 Conceptual model of the operations within a supplier (*Source* Own study)

suppliers and chooses the one that either has the fewest number of products waiting to be processed or the one with the shortest wait time

The flow of activities that occur within a supplier is shown in Fig. 3. As soon as an order is received at a supplier it is split into two parts—one represents the physical product that is to be produced and the other is a dummy order that is represents an updating delay in the supplier's information system (TD in Fig. 3). This way, when a buyer queries a supplier to obtain information on the number of products waiting or the amount of work waiting to be processed, the information that is obtained is not current. This accounts for delays in updating production information at the supplier and the time to respond to a buyer's query. There may also be a time lag at the buyer to make and respond with the routing decision (TDB in Fig. 3).

3 Application Example and Simulation Results

This example is based on the problem presented in Chan at al. (2009). The six products, their order quantity, number and sequence of operations, mean process times, and supplier preferences are the same. However, we consider two buyers (rather than one), various levels of variability in process times (rather than deterministic), and various operation and transport time ratios (rather than a single all-inclusive process time). Thus, our objective is to assess the effect on mean lead time and lead time variability of four factors from the Jannat and Greenwood's (2014a) framework: Supplier Flexibility Level (SFL), Proportion of Production and Transportation Time (PPTT), and variability in process time (as measured by the coefficient of variation C_V).

We have validated our model with the one described by Chan at al. (2009) and have extended their representation into a more general, flexible, and open simulation model. *FlexSim* simulation software is used to model and analyze flexible supply chains. The model is available from the authors upon request.

Table 1 Product and supplier data for the example

Product	Order quantity	Operation (mean process time)	Suppliers at each flexibility level				
			1	2	3	4	5
P1	50	O1 (40)	S1	S2	S4	S5	S3
		O2 (50)	S3	S5	S2	S1	S4
		O3 (60)	S4	S1	S5	S2	S6
		O4 (70)	S6	S3	S1	S2	S5
P2	50	O1 (40)	S4	S3	S5	S6	S1
		O2 (55)	S2	S1	S3	S4	S5
		O3 (54)	S6	S4	S2	S1	S3
		O4 (95)	S5	S2	S4	S3	S6
P3	50	O1 (60)	S5	S6	S2	S1	S4
		O2 (45)	S1	S4	S6	S5	S2
		O3 (48)	S3	S5	S4	S6	S1
		O4 (65)	S2	S1	S6	S5	S4
		O5 (75)	S4	S6	S1	S2	S3
P4	50	O1 (40)	S2	S1	S3	S4	S5
		O2 (50)	S5	S3	S4	S6	S1
		O3 (50)	S6	S2	S1	S3	S5
		O4 (45)	S3	S6	S5	S4	S1
		O5 (85)	S1	S5	S2	S4	S6
P5	50	O1 (40)	S6	S5	S1	S3	S2
		O2 (45)	S4	S6	S5	S2	S3
		O3 (45)	S2	S3	S6	S4	S5
		O4 (40)	S5	S4	S3	S1	S6
		O5 (55)	S1	S2	S3	S6	S5
		O6 (100)	S3	S1	S6	S5	S4
P6	50	O1 (35)	S3	S4	S6	S2	S5
		O2 (45)	S5	S2	S1	S3	S6
		O3 (100)	S4	S1	S3	S4	S5
		O4 (50)	S1	S5	S2	S6	S3
		O5 (52)	S6	S3	S4	S1	S2
		O6 (75)	S2	S4	S5	S3	S1

Table 1 provides information on each product: quantity ordered, process steps and mean times, and the buyer's supplier preference at each flexibility level. For example, for Product 1 (P1) Operation 1 (O1), the buyer would use Supplier 1 (S1) if Supplier Flexibility Level (SFL) is 1, Suppliers 1 and 2 for SFL = 2, Supplier 1, 2, and 4 (S1, S2, S4) for SFL = 3, etc. In this case all suppliers have the same mean process time, 40 time units. However, our model allows the process time for each product operation to be dependent upon supplier.

Table 2 summarizes the experimental factors that are considered in this example. Our simulation model is capable of handling most of the factors in the framework from Jannat and Greenwood (2014a). However, since the purpose of this example is to illustrate the capability of the model and the value of the analyses that can be performed with the model, we limit the number of factors considered.

Table 2 Experimentation factors and level

Factor name	Factor level	Factor's level explanation
Supplier flexibility level (SFL)	1	1 supplier is available for the operation
	2	2 suppliers are available for the operation
	3	3 suppliers are available for the operation
	4	4 suppliers are available for the operation
	5	5 suppliers are available for the operation
Proportion operation/transportation time (PPTT)	1	100 and 0 % of process time considered as operation and transportation times respectively
	2	75 and 25 % of process time considered as operation and transportation times respectively
	3	50 and 50 % of process time considered as operation and transportation times respectively
	4	25 and 75 % of process time considered as operation and transportation times respectively

		Distribution properties		Triangular distribution location parameters		
		C_v	S_k	Minimum, a	Maximum, b	Mode, m
Process time	1	0.0	0	N/A	N/A	N/A
Distribution	2	0.1	0	0.7551	1.2450	1.0000
Level of variability	3	0.1	0.4	0.8000	1.2732	0.9268
	4	0.1	−0.4	0.7268	1.2000	1.0732
	5	0.2	0	0.5101	1.4899	1.0000
	6	0.2	0.4	0.6000	1.5464	0.8536
	7	0.2	−0.4	0.4536	1.4000	1.1468
	8	0.3	0	0.2652	1.7349	1.0000
	9	0.3	0.4	0.4000	1.8196	0.7804
	10	0.3	−0.4	0.1804	1.6000	1.2196

Each level of each factor is considered a simulation scenario. Each scenario is replicated 10 times in order to obtain a measure of variability in lead time. Lead time is the time for all products to be delivered to the buyer. In this case, 300 products, 50 each of six products. In terms of the starting conditions for each replication, we assume the supplier cluster provides immediate service to the buyer and thus the model starts, and ends, with all work queues at the suppliers empty and all supplier processes idle. This approach is used for simplicity; however, alternative approaches to starting the simulation model include:

1. start with dummy orders at each supplier queue.
2. inject dummy orders to the suppliers at regular intervals but only capture statistics on the set of orders of interest. This reduces the start-up and ending biases.
3. create an initial load at each supplier, with dummy orders, that represent the supplier typical utilization, if it is known.

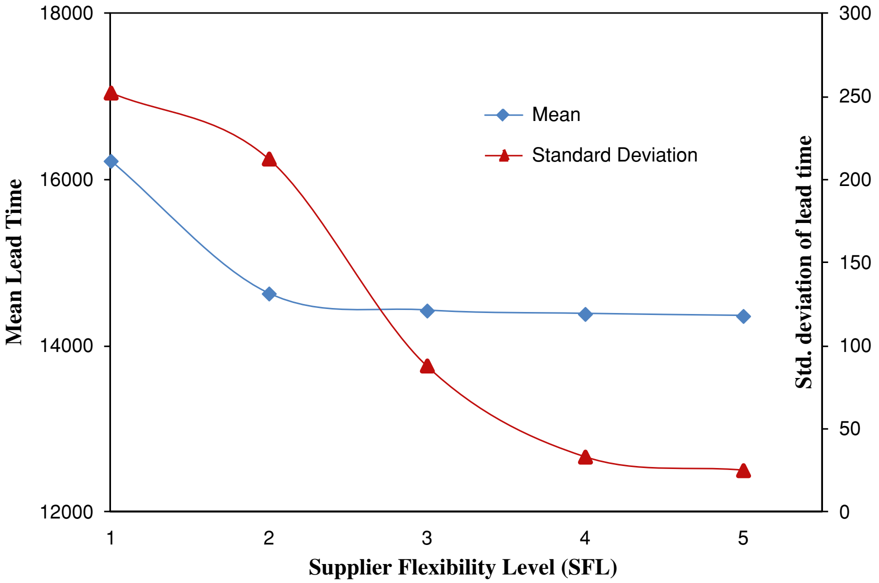

Fig. 4 Mean and standard deviation of lead time at various levels of SFL (PPTT = 0 % transportation time $C_v = 0$) (*Source* own study)

Since the number of factors and levels are relatively few, we use a full-factorial experimental design (Montgomery 2000; Ruiz et al. 2006). This methodology is usually utilized when number of factors and their levels are small or moderate.

4 Simulation Results

One objective of this chapter is to assess the effect of the following factors on lead time and variability in lead time: supplier flexibility level (SFL), proportion of process time that is operations time and transportation time, and the level of variability in process time as specified by a triangular distribution's coefficient of variation C_v and skewness S_k. Based on initial experimentation, it was found that skewness did not have a significant effect on lead time and the variability in lead time. Therefore, the results provided here are all based on symmetric ($S_k = 0$) triangular random variables.

4.1 Effect of SFL on Lead Time

The effect of SFL on lead time is shown in Fig. 4. In this case, all process times are 100 % operations time (0 % transportation time) and have no variability ($Cv = 0$) in process times. As can be seem from the figure, lead time is significantly reduced as SFL increases from 1 to 2, but shows small improvement

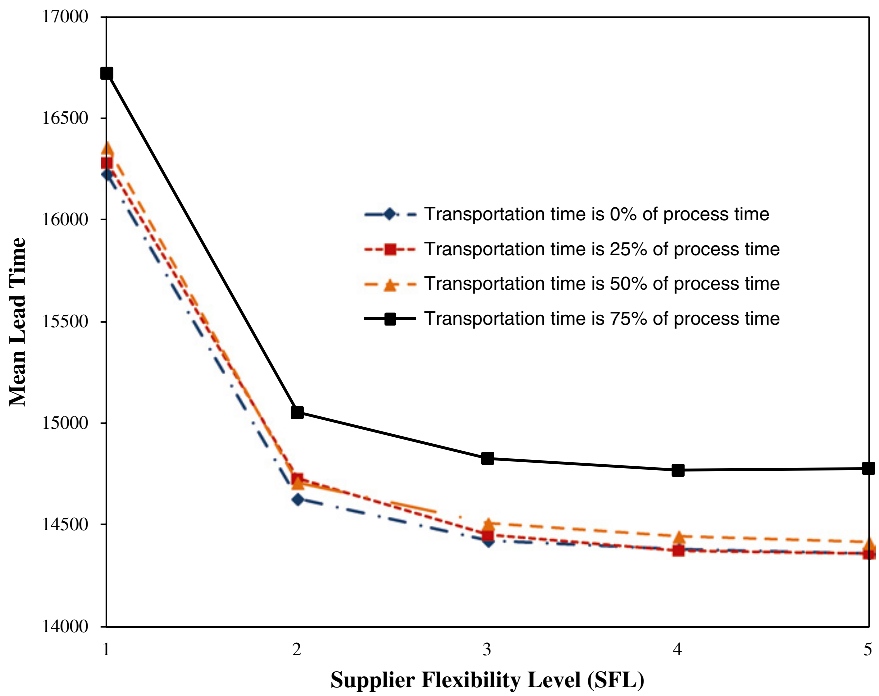

Fig. 5 Mean lead time at various levels of PPTT ($C_V = 0$) (*Source* Own study)

for SFLs above 2. However, variability, as measured by the standard deviation of lead time, continues to drop significantly up to SFL = 4. Therefore, if lead time risk is important to the decision maker, then measures other than the mean need to be considered. Of course, this measure is easy to obtain from simulation model results.

4.2 Effect of PPTT on Lead Time

Figure 5 shows the relationship between SFL and mean lead time at various levels of PPTT (percent of process time that is transportation time). The relationship exhibits a similar pattern to the previous figure, with the largest impact being SFL. However, as the PPTT increases, lead time increases. Recall, the buyer's decision as to which supplier is to produce the next operation is made at the end of the current operation. If PPTT = 0 then the next supplier receives the order immediately and its status (in terms of work in the system) is the same as when the decision is made. However, if there is a long lag between the decision and the arrival of the order, due to transportation time, the supplier status can be quite different when the order actually arrives. For example, if the supplier has a low work content when several buyer decisions are being made, the supplier may receive several orders, but by the time the orders actually arrive there

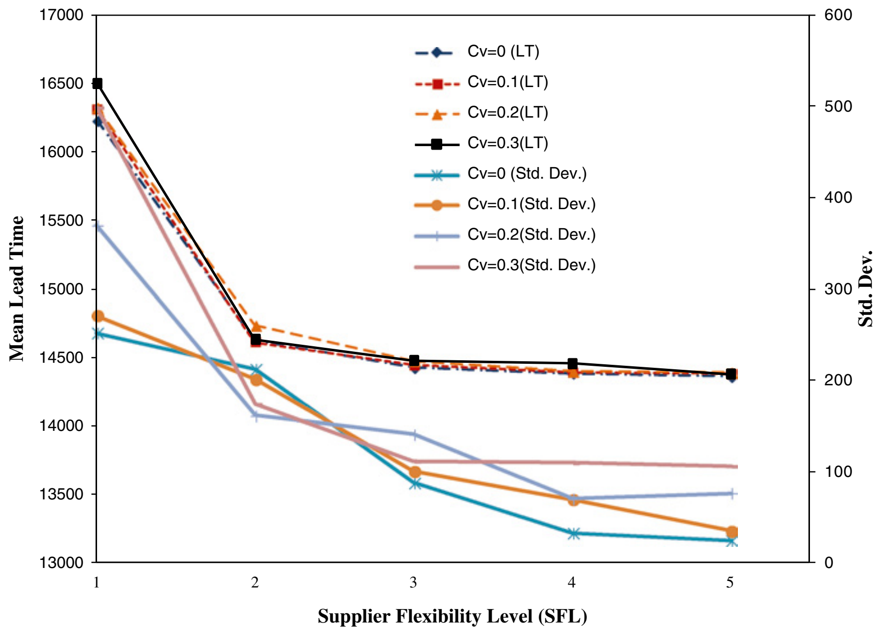

Fig. 6 Mean and standard deviation of lead time at various levels of C_v (PPTT = 0) (*Source* Own study)

could be a lot of work in the supplier's system. A future version of the model may need to include an extension that accounts for this by having the buyer's query based on the content of the orders and not on the work actually in the system.

4.3 Effect of Operations Time Variation on Lead Time

Figure 6 illustrates the effect of variability in operations times, as measured by the coefficient of variation C_v, on lead time. Recall process time is composed of operations time and transportation time and that it is assumed that there is no variability in transportation times. Also, operation time distributions are symmetric triangular distributions with $C_v = 0.0$, 0.1, 0.2, and 0.3. Note that mean lead time follows a similar pattern to that shown in Figs. 4 and 5. However, we also plot the variation in lead time, as measured by the standard deviation of lead time. Generally variability continues to decrease as SFL increases. Of course, within each SFL variability in lead time is affected by the level of variability in operation times. It appears that the effect is quite high when SFL = 1. That is, when SFL = 1, as expected the lowest mean lead time is when $C_v = 0$ and it is highest when $C_v = 0.3$; however, there is considerable affect in the variability of lead time as operation variability increases. Therefore, increasing SFL from 1 to 2 not only greatly reduces mean lead time, but reduces variability in lead time as well.

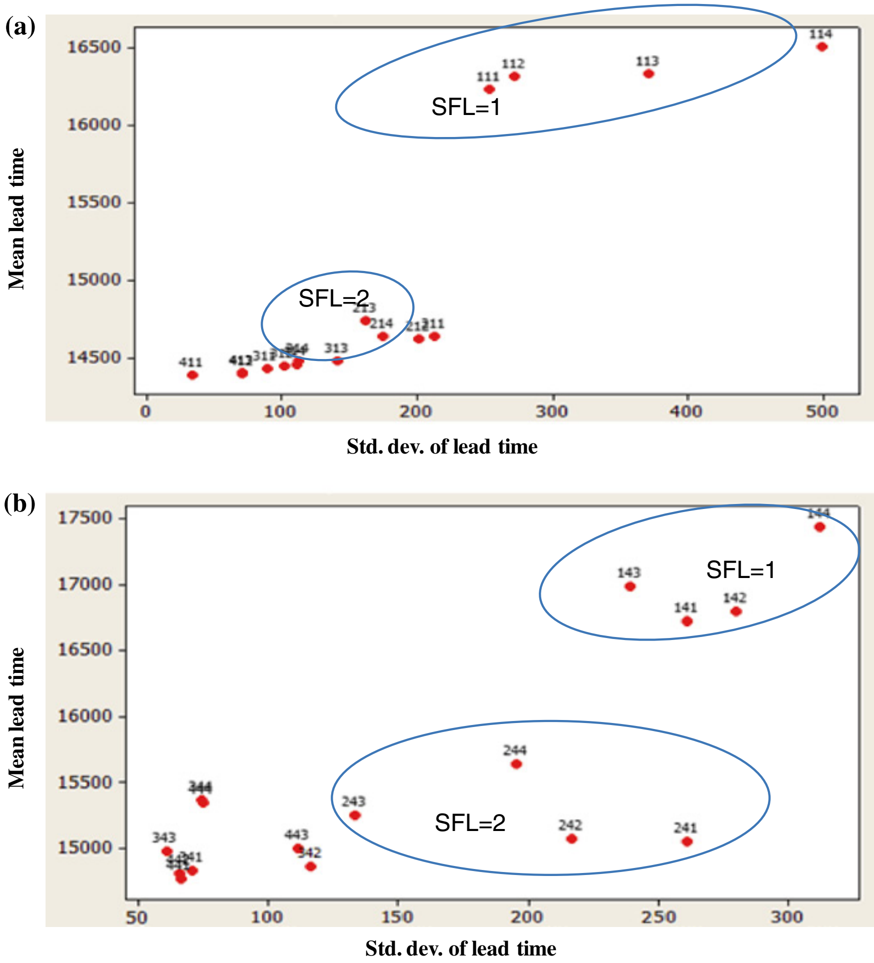

Fig. 7 Scatter plot of mean and variability of lead time considering all factors at all levels (*Source* Own study). **a** Process time = 100 % operation time. **b** Process time = 25 % operation time

4.4 Effect of Factors on Mean Lead Time and Variability in Lead Time

Since Figs. 4 and 6 show that changes in system factors affect both mean lead time and variability in lead time, we examine plots that consider both concurrently at various factor levels. Figure 7 is an example. The notation at each plot point is the factor settings at that point, SFL-PPTT-C_V. For example 143 is SFL = 1, PPTT at level 4 (process time is 75 % transportation time), and C_v at level 4 (C_v = 0.3). Panel (a) is for PPTT = 0 (process times are all (100 %) operations times, no transportation times) and Panel (b) is for PPTT = 0.75 (process times are only 25 % operations time, 75 % transportation time). The improvement in lead time is again evident as SFL increases, as is the diminishing returns in improvement.

These plots also illustrate factor effects when other factors are held constant. For example, in Panel (a) the points highlighted by the oval for SFL = 1 show the effect of increasing operation time variability when process time is all operation time. A similar comparison can be made by considering the points within the oval for SFL = 2. In both cases, when process time is all operation time, increasing the variability in operation time has a similar effect on changing mean lead time, but the effect on lead time variability is much less when SFL = 2 (compared to SFL = 1).

5 Conclusions

This chapter demonstrates that simulation provides an effective means to design and analyze flexible supply chains. The simulation model can address the effect on performance of a number of system and design factors. Those factors and measures are based on a comprehensive framework for modeling and analyzing flexible supply chains. The framework is intentionally general so that it can be used to address a variety of manufacturing and logistical issues. However, the factors and simulation model built considering those factors can be used to address sustainability issues especially regarding transportation.

While the results derived from the example problem considered in this chapter just pertain to its specific problem structure and the values of its system parameters, the example clearly illustrates the value of the approach and the type of insight that can be gleaned. It also clearly illustrates that:

- designing flexible supply chains in a dynamic, stochastic environment is complex and requires the use of sophisticated modeling and analysis tools. Simulation is an effective tool for such analyses.
- a number of system and design factors affect performance and need to be addressed concurrently, not separately or just one at a time. Again, simulation modeling and analysis, along with a good experimental design, provide an effective means to do this.
- in order to design effective flexible supply systems, one must consider not just the mean performance measure, e.g. lead time, but its variability as well, when comparing alternative design and system scenarios.
- there are diminishing returns in increasing supplier flexibility level, but the degree, will vary by measure.

References

Chan FTS, Bhagwat R, Wadhwa S (2009) Study on suppliers' flexibility in supply chains: is real-time control necessary? Int J Prod Res 47(4):965–987

Jannat S, Greenwood A (2012) Estimating parameters of the triangular distribution using non-standard information. In: Proceedings of the 2012 winter simulation conference

Jannat S, Greenwood A (2014a) A conceptual framework for developing a flexible supply chain. Working Paper, Mississippi State University

Jannat S, Greenwood A (2014b) A conceptual model for developing the flexible supply chain simulation models. Working Paper, Mississippi State University

Montgomery DC (2000) Design and analysis of experiments, 5th edn. Wiley, New York

Ruiz R, Maroto C, Alcaraz J (2006) Two new robust genetic algorithms for the flow shop scheduling problem. Omega 34(5):461–476

Models of Organizing Transport Tasks Including Possible Disturbances and Impact of Them on the Sustainability of the Supply Chain

Patrycja Hoffa and Pawel Pawlewski

Abstract Transport organization in the supply chain is a complex issue, which includes a number of factors, like the choice of routes and means of transport or attempt to consolidate loads. In order to improve the functioning of the supply chain, we can analyze realized activities in chain. This allows the evaluation and improvement of selected aspects. When the transport processes are analyzed, it is necessary take into account the factors affecting a sustainability of a supply chain. As in any process, we should consider a wide count of disturbances affecting the effectiveness of the supply chain. Disturbances were divided into 6 groups: about means of transport, about route factors, associated with driver (for example driver's knowledge), resulting from sender fault, resulting from recipient fault and the others factors. Besides, authors determined how a specified disturbance affects a sustainability of supply chain.

Keywords Models of organizing transport tasks • Disturbances • Sustainability

1 Introduction

Supply chain, according to a dictionary of logistics terminology are: "Organizational structure of the group of companies, realizing joint actions necessary to meet the demand for certain products" (Fertsch 2006). Recalling the words of R. Y. K. Fung and T. Chen: supply chain is a worldwide network consisting of suppliers, manufacturers, warehouses, distribution centers and retailers through which raw materials are purchased, transformed and delivered to customers. The

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supply chain is define by the Council of Supply Chain Management Professionals[1] as follows: "Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies. Supply Chain Management is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finance and information technology." So, a supply chain is represented by a number of actors and many factors which have an impact of its functioning.

The concept of sustainable occurs in different meanings depending on a field of knowledge. One of them is the Corporate sustainability (Seuring et al. 2005). We also deal with a concept of sustainable in production (Dettmann et al. 2013; O'Brien 1999; Veleva et al. 2001).

Referring an issue of sustainable to transport should be understood as a concept of sustainability in a supply chain. So focus by companies on a rational use of resources and reducing harmful impact on an environment, while pursuing its objectives. Citing the Qureshi i Huapu: "Sustainable transportation is an expression of sustainable development in the transport sector. A review of the literature has shown a growing emphasis on developing sustainable transportation systems as well as policy-oriented studies to address transportation related negative externalities such as air and noise pollution, accidents, congestion and social exclusion, and to meet current and future mobility and accessibility needs without creating excessive negative externalities" (Qureshi and Huapu 2007).

In recent years, a sustainable transport is a fundamental goal of transport planning and transport policy. The PROSPECTS project for example, proposed five overarching objectives for sustainable transport (Castillo and Pitfield 2010).

- Liveable streets and neighbourhoods;
- Protection of the environment;
- Equity and social inclusion;
- Health and safety;
- Support of a vibrant and efficient economy.

Talking about a sustainability in a supply chain, one of aspects that we should focus is an appropriate way of managing of an entire chain. Depending on a strategy we can achieved varying efficiency of a chain. Is distinguished 5 basic models for organizing transport tasks (Stajniak et al. 2008). These models can be treated as a base to build and create appropriate types of supply chain:

[1] http://cscmp.org/about-us/supply-chain-management-definitions, 2012.

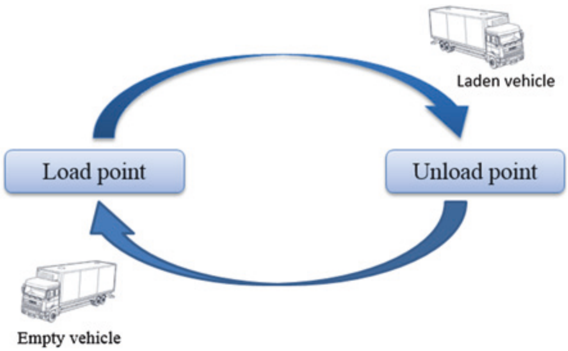

Fig. 1 Swinging model (*Source* own study based on Stajniak et al. 2008)

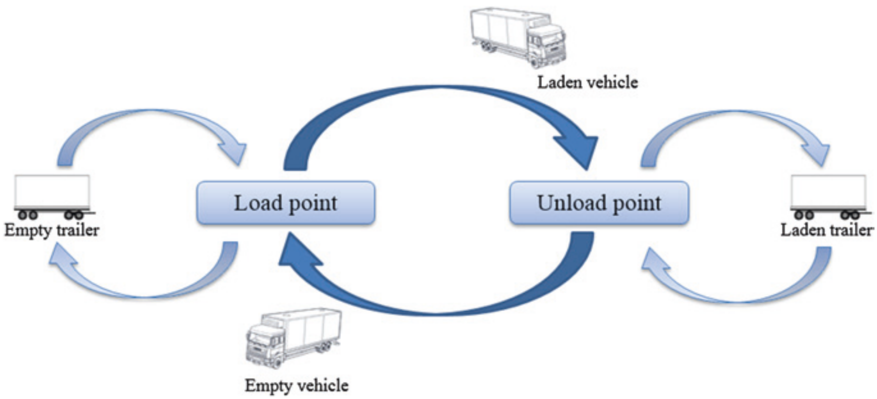

Fig. 2 Swinging-continuous model (*Source* own study based on Stajniak et al. 2008)

- swinging model—in which means of transport runs regularly between two points (loading and unloading); an example of such a model is the daily delivery of fresh meat to the company's butcher shop and then return to the base of an empty vehicle (Stajniak et al. 2008) (Fig. 1);
- swinging-continuous model—in which means of transport are not expected at a loading and unloading point, just getting to these points it takes a loaded or empty trailer and travel to a next designated point; an example of such a model is the delivery of auto parts from subcontractors to the factory. These parts, in order to protect, are often shipped in special box and containers. Subcontractor shall provide to the factory (the place of unloading) a full container of specified elements, and takes empty containers that are transported to the loading place (Stajniak et al. 2008) (Fig. 2);
- radial model—in which means of transport delivers goods from one loading place to number of unloading places, and after unloaded at a given point, a vehicle returns to a place of loading, where it is loading again and it transports

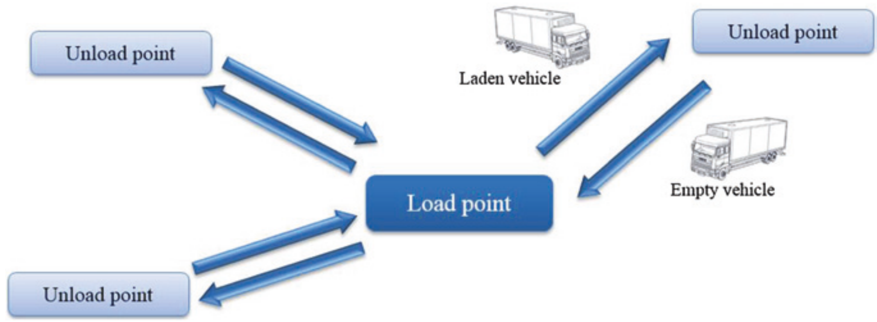

Fig. 3 Radial model (*Source* own study based on Stajniak et al. 2008)

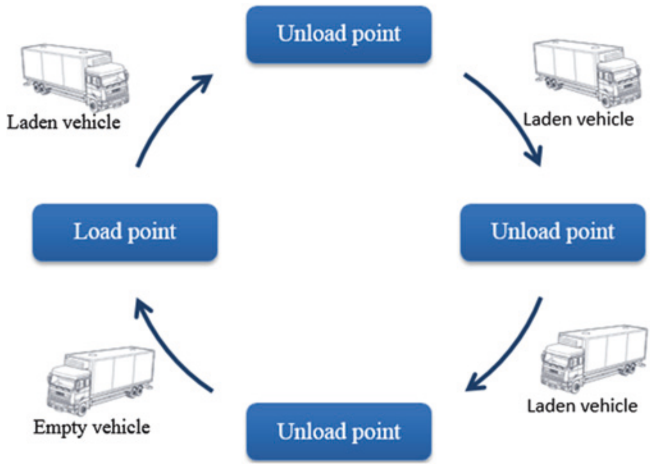

Fig. 4 Circular model (*Source* own study based on Stajniak et al. 2008)

products to other unloading points; an example of such a model is the delivery of products from a central warehouse to regional warehouses, which takes further distribution (Stajniak et al. 2008) (Fig. 3);

- circular model—in which means of transport is loaded at one point and delivers the goods to a next unloading point; it is characteristic for courier and distribution activity (Stajniak et al. 2008) (Fig. 4);
- relay model (call cross-docking too)—where transport is organized from a point of loading to a unloading point with regard to a reloading points; usually goods are delivered to the reloading point in larger batch (by vehicles 33-trucks, trains or ships), and then reloaded on the lower transport means and delivered to the customer (Stajniak et al. 2008) (Fig. 5).

The purpose of this article is to present possible disturbances occurring during the realizing transport tasks and the impact of these disturbances on an efficiency and an sustainability of the supply chain. The chapter consists of 5 sections. Section 1 presents definitions of supply chain and describes models of the organization of

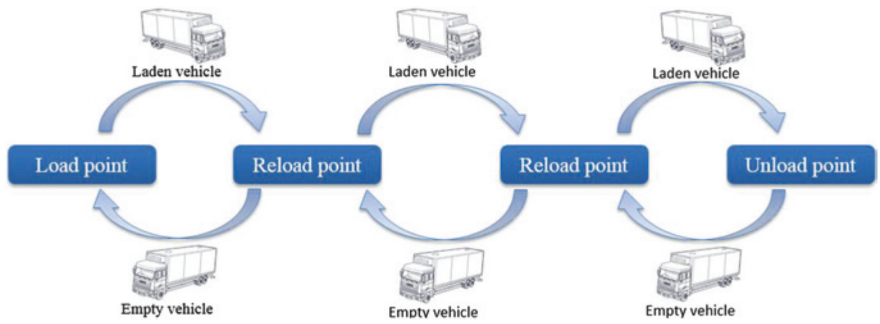

Fig. 5 Relay model (*Source* own study based on Stajniak et al. 2008)

transport tasks. It also shows a different meanings of a concept of sustainable—depending on an area of using. Section 2 contains highlighted by authors disturbances in a context of a supply chain and impact of disturbances to a realization of transport task. Section 3 describes measures by which we can determine the impact of various disturbances on an efficiency of a transport task. Section 4 represent impact of chosen disturbances to an efficiency of a supply chain. Section 5 is part of summarizing the impact of interference on sustainable in a supply chain.

The Research Highlights of performed works are as follows: identify existing in a specific area of supply chain disturbances and their impact on a sustainability of transport and present examples of metrics for evaluating an efficiency of a supply chain.

2 Disturbances in Supply Chain

Referring sustainable to a supply chain, authors decided to focus on an effectiveness of order realization and paying attention to an ecological aspect. Factors affecting an implementation of transport tasks with including basic principles of sustainable development include:

- choice means of transport depending on a planned route (appropriate choice have an impact of a value of generated harmful),
- choice means of transport, depending on a size of the order (an ability to reduce a negative impact on an environment),
- choice routes depending on prevailing conditions on a route (realizing an order without interference increases an efficiency of a process).

As in any process, so in a supply chain can be distinguished number of disturbances which affect an efficiency of processes. Table 1 summarizes possible disturbances and their impact on realization of transport orders, which results into sustainable of a supply chain. These disturbances authors determined based on their own observations and experience. Authors in a supply chain consider not only a route of travel from point A to point B, but also activities carried out at a point of loading and unloading. Because opinion of the authors operations at these

Table 1 Disturbances in supply chain (*Source* own study)

General type	Special type	Description
Related with means of transport	1. Failures of the means of transport	• is associated with a time of waiting for help, and a time required to repair a fault;
	2. Not providing a vehicle on time (e.g. due to theft)	• it results in significant delay in order execution (associated with a search for a replacement car), or failure in order execution;
Related with the route	1. Traffic congestion	• it shortens or extends a duration of a transport order;
	2. Road traffic accidents (so-called "black spots")	• vehicle accident without participation of a vehicle executing a transport order: it is associated with a stoppage at an accident site; • an accident involving a vehicle performing a transport order: it is associated with longer duration;
	3. Weather conditions (sudden bad weather)	• it results in a significant lengthening of order execution (associated with a lower traveling speed);
	4. If a vehicle travels on toll roads, the toll-collection points must be taken into account	• the time of paying a fee should be determined as a variable (depending on a number of cars waiting to pay a toll and an individual characteristics of particular drivers);
Resulting from the fault of the sender	1. The time needed for loading (lengthening related with a limited number of employees)	• depends on a number of employees participating in a loading; • a time of loading may possibly be shortened or lengthened;
	2. Incorrect date or amount of loading	• it results in lengthening a time of loading;
	3. No enough ramps for loading	• a disturbance is of random character, based on historical data it is possible to determine a probability of this disturbance; it results in lengthening a time of loading;
Resulting from the fault of the receiver	1. The time needed for unloading (lengthening associated with a limited number of employees)	• it depends on a number of employees participating in an unloading; • a time of loading may possibly be shortened or lengthened;
	2. Incorrect date of unloading	• it results in lengthening a time of loading;
	3. No enough ramps for unloading	• it results in lengthening a time of loading;
Related with the driver	1. Driver skills	• it affects a traveling speed and a time needed to reach a loading /unloading point;
	2. Driver working time	• breaks in a driver work should be taken into account, as they affect a time of order execution;
Others	1. Natural disasters (hurricanes, floods, etc.) and other situations that slow down traffic on the road (e.g. strikes)	• it results in significant lengthening of order execution (associated with a slower traveling speed), or failure in order execution;
	2. Failure of IT system used by companies to communicate	• it results in significant lengthening of order execution or failure in order execution

points have a very large impact on as realizing a whole transport process (e.g. load a car with a delay associated with failure to achieve order in time).

All these disturbances affect a duration of a transport order. Analyzing more precisely, we can also determine an influence of them of an environmental. For example, a traffic congestion contributes to a higher value of generated emissions of harmful (car moving at a reduced speed ultimately generate more harmful than if they moved at in accordance with assumptions). Also in case of expectation in a place of accident (ignition), we can talk about additional pollution. Talking an issue of rational use of resources we can relate them to use of an appropriate number of employees equipped with a forklift at a point of loading and unloading. Too few staff delays realization of an order process, while too large generates additional costs (this is an irrational exploitation of resources).

When we consider various disturbances in this way, we can see an impact of them to a sustainable of a supply chain.

3 Measures of Supply Chain

We can distinguish a number of indicators to monitor activities highlighted in a supply chain. Due to a huge amount of different indicators, selection of appropriate creates a number of challenges.

Choosing measures should be remember that:

- they should be understood by all people who use them,
- they should provide the most relevant information,
- they should be properly matched to the analyzed process,
- and they should be clearly and explicitly defined, along with the units.

The authors selected, with many proposed by Twaróg (2005), various measures for the evaluation a transport subsystem and an aspect of loading and unloading processes. These indicators representing both time dimension and resource utilization. Because all these factors translates into sustainable.

Selected measures:

- reliability of transport /timeliness of delivery

$$\frac{\textit{the number of operations made on time}}{\textit{total number of operations}} \cdot 100\ [\%] \tag{1}$$

- utilization of the means of transport in terms of time (predisposed time)—both in relation to a truck and forklift truck

$$\frac{\textit{real operating time}}{\textit{predisposed operating time}} \cdot 100\ [\%] \tag{2}$$

- a degree of exploit an opportunities of transport

$$\frac{\textit{real tonnage carried in } t \text{ km}}{\textit{predisposed tonnage carried in } t \text{ km}} \cdot 100\ [\%] \quad (3)$$

- transport time on a 1 transport order.

4 Effect of Selected Disturbances on the Efficiency of the Supply Chain

In each of disturbances affecting an operation of a supply chain. All have influence to a duration of a transport task. Analyzing them accurately we can see additional aspects—such as increasing traffic, generating an additional amount of exhaust, etc. For the purposes of an article four specific disturbances will be presented in detail. The first disturbance is a traffic accident on the planned route of a mean of transport, which realized transport task. Range an impact of this disturbances depends on the seriousness of an accident and traffic at this time (the higher intensity the greater range of occurring congestion or blockage of a road). Extent of distortion is expressed by a circle with a given radius. In the case encountering blocking a road due to a traffic accident, it should be consider additional time required to complete an order (in case of failure to comply with a delivery date can mean a financial penalty), as well as an increase in emissions. A vehicle waiting in traffic (for ignition) will generate additional exhaust. Of course, a driver can switch off a vehicle for some time, but overall should take into account additional generating emissions, and costs associated with spent fuel. Moreover, it may happen that in view of a situation a driver runs out of work—which is an additional disturbance (Fig. 6).

The second disturbance is a not enough free ramps in place of unloading. Therefore, extended time of realization of transport task. It may happen that a car will be too late unloaded—then it is necessary to explain who is at fault—or the fault lies only on a receiver side or perhaps on a people who realized the transport task (which may involve a financial penalty). Lack of free ramps can be caused such a bad time of arrival a car or an absence of a sufficient number of employees at the point of unloading. In a case of this disturbance, vehicle can wait on the parking lot with an engine off—which is not associated with a generation of additional emissions. But again it should be take into account the driver's working time (Fig. 7).

Next disturbance is break in the weather (sudden weather change). This disturbance (like blizzards, downpour, sleet, black ice) can be modeled with using historical data and information obtained from the weather maps. After determining the routes for a transport order, it is possible to check the current weather conditions at certain strategic points (we should divided road for sections, for example about 50 km length). And at these points we can check a weather conditions. The weather break is represented by two areas: a circle with a specified radius, representing the center of change in the weather and a ring (the operating range

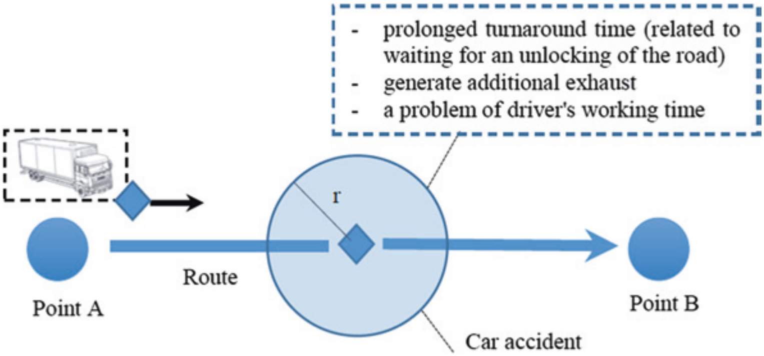

Fig. 6 Impact of one of disturbances like car accident (*Source* own study)

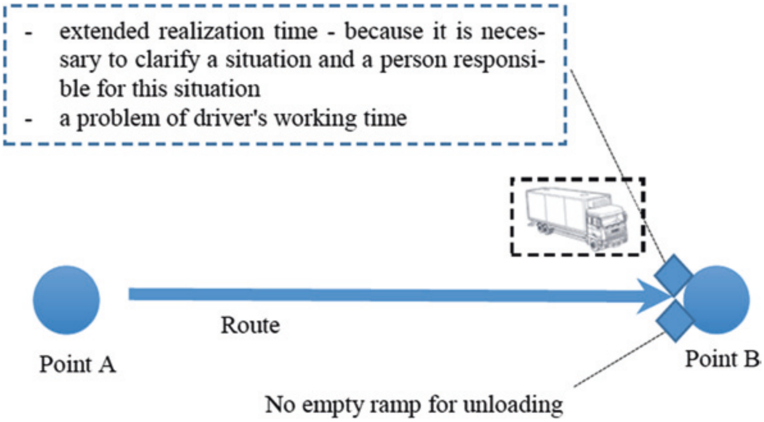

Fig. 7 Impact of one of disturbances like no empty ramp for unloading (*Source* own study)

is defined by two rays), which forms the area surrounding the center. As in case of downpours accompanying the storm—first we find ourselves in the rain, then heavy rain, and again in the rain. According to this approach, this disturbance has two ranges of action, with specific restraints for each of them. It make that speed of transport is lower, so time of travel will be longer. In extreme cases, breakdown weather can have such a large size that will cause a total inability to be traveled a route for a long time (Fig. 8).

Next disturbance is a traffic congestion at a given point. Range an impact of this disturbances depends on the volume of traffic at a given point (representing the statistical distribution of traffic at particular times). Extent of distortion is expressed by a circle with a given radius. Effects of traffic congestion are very similar like a traffic accident In the case of this disturbance, it should be consider additional time required to complete on order. Cost will increase too, because of waiting in traffic with turn on an vehicle's engine. Besides in this case emissions will increase.

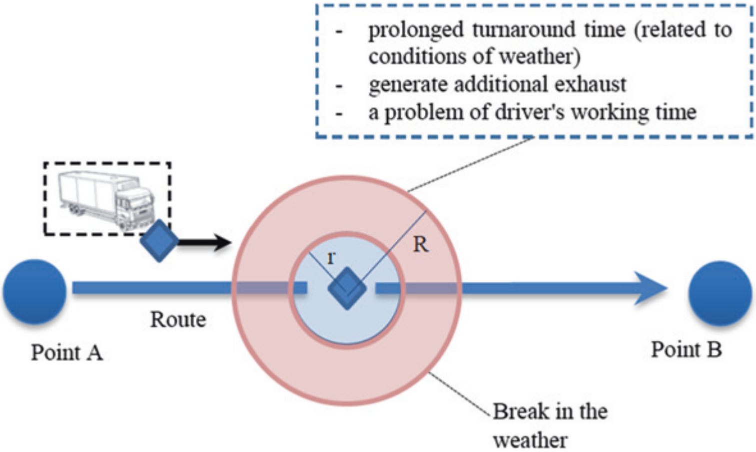

Fig. 8 Impact of a break in the weather (*Source* own study)

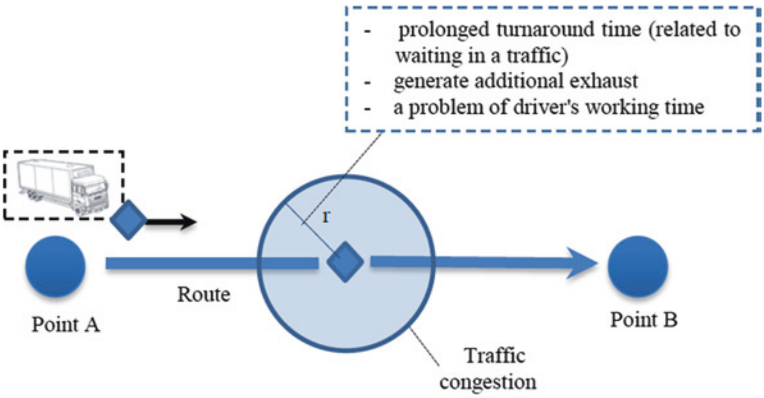

Fig. 9 A traffic congestion represented by an agent—way 1 (*Source* own study)

Other disturbances can be analyzed in a similar way and determine their impact on a realization of transport order. The main measure in the case of a transport order is time, which further translates into cost (Fig. 9).

5 Conclusions and Further Investigations

An article presents an example of interference in a supply chain of a realization of a transport order. In addition, determine their possible impact on an implementation of an analyzed process. In article was defined specific examples of measures to evaluation a supply chain and its effectiveness. For two selected disturbances authors presented in detail their impact on a realization of a transport process. Most disturbance directly affects of a duration of a process. The indirect effect is an increase in the cost of a transport task, for example, associated with a consumption of additional fuel or a payment of penalties incurred due to a breach of a delivery date. An additional aspect that can and should be considered is a use of capacity means of transport. However, this factor should be considered at a level of management and matching transport orders.

Expanding further presented disturbances, for each of them can be specified precise impact on an implementation of a transport order and an environment, in which a process is executed.

Of course we can also define additional measures that allow an evaluation of a sustainable of a supply chain. However, when we made/chose an additional indicators we should remember that more is not always better. Indicators are intended to help at a precise and understandable analysis of a situation, not to describe everything what we can. Therefore it is so important to choose an appropriate measures.

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References

Castillo H, Pitfield DE (2010) ELASTIC: a methodological framework for identifying and selecting sustainable transport indicators. Transp Res Part D 15:179–188

Dettmann T, Andersson C, Andersson J, Skoogh A, Johansson B, Forsbom P-O (2013) Startup methodology for production flow simulation projects assessing environmental sustainability. In: Winter simulation conference, pp 1926–1937

Fertsch M (2006) Słownik terminologii logistycznej. Instytut Logistyki i Magazynowania, Poznań

Fung RYK, Chen T (2004) A multiagent supply chain planning and coordination architecture. Int J Adv Manuf Technol 25(7–8):811–819

O'Brien C (1999) Sustainable production: a new paradigm for a new millennium. Int J Prod Econ 60–61:1–7

Qureshi IA, Huapu LU (2007) Urban transport and sustainable transport strategies: a case study of Karachi, Pakistan. Tsinghua Sci Technol 12(3):309–317

Seuring S, Muller M, Westhaus M, Morana R (2005) Conducting a literature review: the example of sustainability in supply chain. In: Kotzab H, Seuring S, Muller M, Reiner G (eds) Research methodologies in supply chain management. Physica-Verlag, Heidelberg

Stajniak M, Hajdul M, Foltyński M, Krupa A (2008) Transport i spedycja. Podręcznik do kształcenia w zawodzie technik logistyk. Instytut Logistyki i Magazynowania, Poznań

Twaróg J (2005) Mierniki i wskaźniki logistyczne. Biblioteka Logistyka, Poznań

Veleva V, Hart M, Greiner T, Crumbley C (2001) Indicators of sustainable production. J Cleaner Prod 9(5):447–452

Part IV
Cross-Disciplinary Methodologies

IDEF0 as a Project Management Tool in the Simulation Modeling and Analysis Process in Emergency Evacuation from Hospital Facility: A Case Study

Witold A. Cempel and Dawid Dąbal

Abstract Simulation and optimization of sustainability in logistics and manufacturing systems involve the simulation modeling and analysis (SMA) process. The SMA process has an important component "Project Management". In the literature different approaches to project management can be found. Precise definition of what is "input" and "output" at each stage of the SMA process is necessary to lead and execute simulation project effectively. In IDEF0 notation above issues and more (also "control" and "mechanism") are pivotal (ICOM arrows). On that account IDEF0 has been used as a project management tool in SMA process of emergency evacuation of a hospital facility in Krakow (Poland). In this chapter this innovative application of IDEF0 has been described.

Keywords IDEF0 • Simulation modeling and analysis (SMA) • Project management

1 Introduction

A simulation modeling and analysis process (SMA), in the logistics and manufacturing systems (but not only), consist of specific, interrelated blocks of tasks. Usually different actors are involved in this process, as well from lower, as from higher levels of organizational structure and sometimes also from outside an organization. Such specific circumstances requires exact specification of what is input and output from each SMA block of task and also how to execute this and with what resources. Different project management (PM) methodologies are useful to manage SMA process, but the question is how good they support the

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requirement of clear definition of what is input, output, control and mechanism? This is necessary especially when the SMA process at the end has to generate specific results and to has to be conducted effectively. Comparative analysis of frequently used PM methodologies shows lack of precise statement of what is input, output, control and mechanism.

IDEF0 is a function modeling methodology for describing manufacturing functions. This approach contains ICOM cube, which represents input, output, control and mechanism. Attempt to implement IDEF0 in the project management of SMA process of emergency evacuation logistics of a hospital facility in Krakow (Poland) has been conducted. Results are presented in the manuscript.

The chapter is organized as follows. After the introduction section, Sect. 2 presents description of SMA process. Section 3 contains a brief overview of the project management methodologies. In the next section IDEF0 as part of the IDEF family of modeling languages has been presented. Section 5 contains results of comparative analysis of IDEF0 and project management methodologies. Section 6 presents description of application of IDEF0 as a project management tool in SMA process of emergency evacuation from the facility of The Voivodship Centre of Addiction Therapy in Krakow, a part of Dr. Jozef Babinski Hospital in Krakow (Poland). Finally, Sect. 7 concludes the chapter.

2 The SMA Process

A model is (François 1997) "a symbolic representation of a set of objects, their relationships and their allowable motions". Pidd (Pidd 2003) define a model as an external and explicit representation of a part of reality as seen by the people who wish to use the model to understand, to change, to manage and to control that part of reality. Modeling stress or rather the activity of the modeler according to Cempel (Cempel 2008) means searching (and probably finding) a system of compelling attributes and relations in regards to the aim. Simulation (Cempel 2003) means the contraction or expansion of a model's space-time in order to recognize a reality better.

A simulation modeling and analysis process (SMA) consist of tasks grouped into three paths (Beaverstock et al. 2011):

- Define:
  - Statement of objectives
  - Develop project plan
- Build:
  - Model formulation
  - Data preparation
  - Model translation
- Pilot runs:
  - Experiment
  - Design experiments
  - Experimentation.

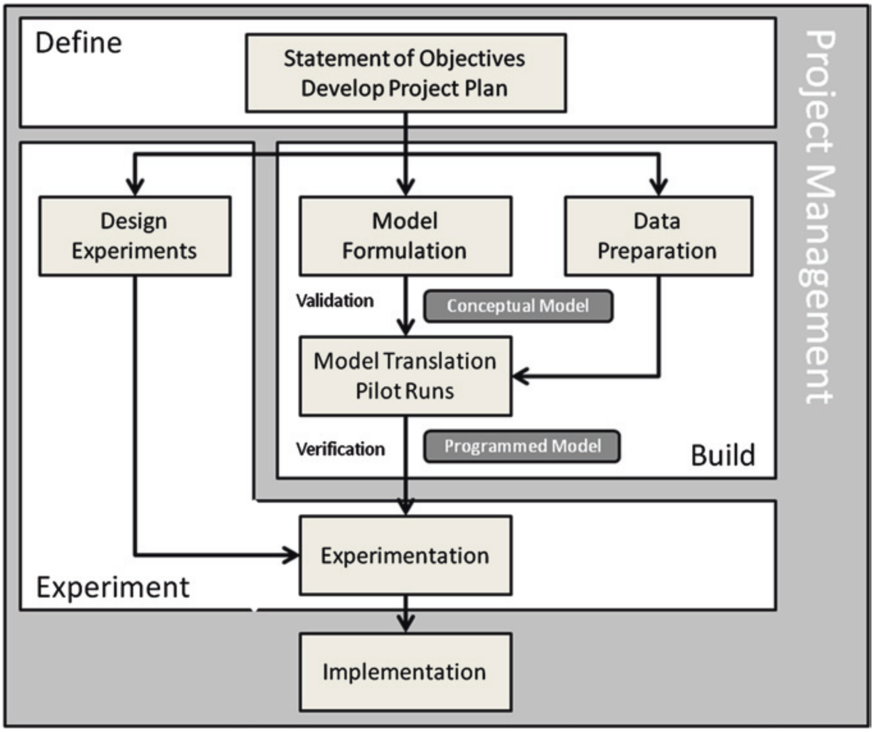

Fig. 1 SMA process (*Source* (Beaverstock et al. 2011))

Relations among above paths and blocks are shown in Fig. 1. The central path is model related and associated with its development (Beaverstock et al. 2011). The two parallel paths are output or analysis related and input or data related respectively. Result of model formulation is the conceptual model. This is a key means of validating the simulation model. Validation determines whether the model is a meaningful and accurate representation of the real system. A translation of the conceptual model into computer-executable form is the programmed model. Prior to experimentation, the programmed model must be verified. It must be determined that the model is working as intended.

The SMA process sometimes is very complex system. One of the factors, which bear on complexity is set of different stakeholders involved into SMA process (Beaverstock et al. 2011):

- Decision makers
- Sponsors
- Domain owners
- Model owners and developers
- Domain experts
- Model users
- Info tech.

Project management braces together SMA issues and helps translate design into actions. Typical project management approach includes key milestones, provides estimates of the duration of each activity, and assigns responsibility (who leads and performs each activity). The SMA process plan usually has graphical representation in a Gantt chart.

3 Project Management Methodologies

In the literature are many approaches to manage projects, but we can distinguish three methodologies, which are used probably the most often:

- PMBOK
- PRINCE2
- SCRUM.

A Guide to the Project Management Body of Knowledge (PMBOK Guide) is a book which presents a set of standard terminology and guidelines for project management. This book was published by the Project Management Institute (PMI). In the PMBOK concept a project management American National Standard: Ansi/Pmi 99-001-2008 (2008) is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements. Project management is accomplished through the appropriate application and integration of the 47 (in 5th edition and 39 in 4th) in logically grouped project management processes comprising the 5 Process Groups. These 5 Process Groups are:

- Initiating
- Planning
- Executing
- Monitoring and Controlling
- Closing.

Structure of Project Time Management in PMBOK concept is depicted on Fig. 2.

Project Time Management is one of ten knowledge areas in PMBOK Guide. All ten areas have been mentioned below:

- Project Integration Management
- Project Scope Management
- Project Time Management
- Project Cost Management
- Project Quality Management
- Project Human Resource Management
- Project Communications Management
- Project Risk Management
- Project Procurement Management
- Project Stakeholders Management (added in 5th edition).

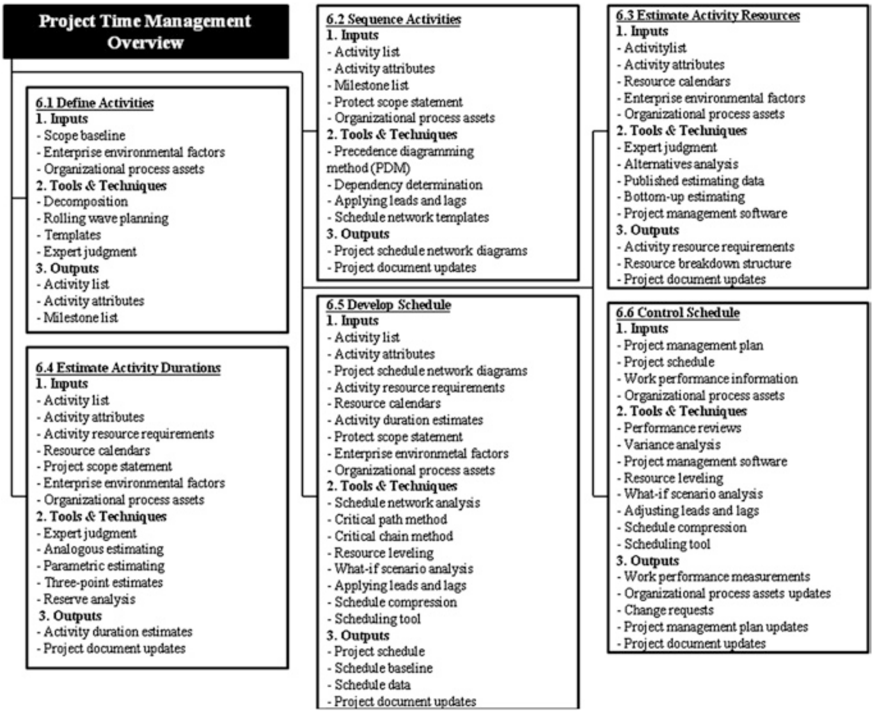

Fig. 2 Project time management overview in PMBOK (*Source* American National Standard: Ansi/Pmi 99-001-2008 (2008))

PRINCE2 is an acronym for Projects in Controlled Environments[1]). This is a project management approach developed by the UK government agency: Office of Government Commerce (OGC). This methodology is used extensively within the UK government as the de facto project management standard for its public projects. The methodology embraces the management, control and organization of a project. PRINCE2 is based on seven principles (continued business justification, learn from experience, defined roles and responsibilities, manage by stages, manage by exception, focus on products, and tailored to suit the project environment), seven themes (business case, organization, quality, plans, risk, change and progress). The principles and themes come into play in the seven processes:

- Directing a project (DP)
- Starting up a project (SU)
- Initiating a project (IP)
- Controlling a stage (CS)
- Managing product delivery (MP)
- Managing stage boundaries (SB)
- Closing a project (CP).

[1] PRINCE2. www.prince-officialsite.com

Processes consist of 40 activities comprising recommended actions (Office of Government Commerce 2009). The PRINCE2 method works with most project management techniques but specifically describes the following:

- Product Based Planning
- Quality Review.

SCRUM (Schwaber and Sutherland 2013) is a framework within which people can address complex adaptive problems, while productively and creatively delivering products of the highest possible value. Scrum is founded on empirical process control theory, or empiricism. Empiricism asserts that knowledge comes from experience and making decisions based on what is known. Scrum employs an iterative, incremental approach to optimize predictability and control risk. Three pillars uphold every implementation of empirical process control:

- Transparency
- Inspection
- Adaptation.

Scrum prescribes four formal events for inspection and adaptation:

- Sprint Planning
- Daily Scrum
- Sprint Review
- Sprint Retrospective.

The Scrum Team consists of a:

- Product Owner
- Development Team
- Scrum Master.

Scrum Teams are self-organizing and cross-functional. Self-organizing teams choose how best to accomplish their work, rather than being directed by others outside the team. Cross-functional teams have all competencies needed to accomplish the work without depending on others not part of the team. The team model in Scrum is designed to optimize flexibility, creativity, and productivity. Scrum Teams deliver products iteratively and incrementally, maximizing opportunities for feedback. Incremental deliveries of “Done” product ensure a potentially useful version of working product is always available.

4 IDEF0

In the literature at least 70 process modeling languages can be found (Pawlewski 2010). According to (Galan et al. 2005) IDEF0 simplifies communication ideas between medical experts and non-medical experts. The models in IDEF0 are easy to build and understand.

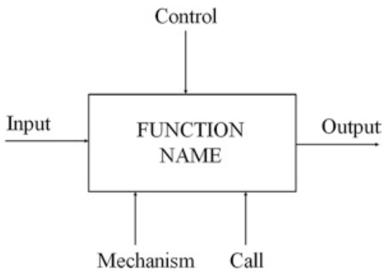

Fig. 3 ICOM in IDEF0 (*Source* (Federal Information Processing Standards Publication 1993))

The name IDEF originates from the Air Force program for Integrated Computer-Aided Manufacturing (ICAM) which developed the first ICAM Definition, or IDEF, methods (Mayer et al. 1995). IDEF0 is a structured representation of the functions, activities or processes within the modeled system or subject area (Federal Information Processing Standards Publication 1993). IDEF0 may be used to define the requirements and specify the functions, and then to design an implementation that meets the requirements and performs the functions. The two primary modeling components in IDEF0 are functions (represented on a diagram by boxes) and the data and objects that inter-relate those functions (represented by arrows). When used in a systematic way, IDEF0 provides a systems engineering approach to (Federal Information Processing Standards Publication 1993):

- Performing systems analysis and design at all levels, for systems composed of people, machines, materials, computers and information of all varieties—the entire enterprise, a system, or a subject area
- Producing reference documentation concurrent with development to serve as a basis for integrating new systems or improving existing systems
- Communicating among analysts, designers, users, and managers
- Allowing coalition team consensus to be achieved by shared understanding
- Managing large and complex projects using qualitative measures of progress
- Providing a reference architecture for enterprise analysis, information engineering and resource management.

IDEF0 models are composed of three types of information: graphic diagrams, text, and glossary. These diagram types are cross-referenced to each other. The graphic diagram is the major component of an IDEF0 model, containing boxes, arrows, box/arrow interconnections and associated relationships. Box and arrows compound ICOM Code, acronym of Input, Control, Output and Mechanism (Fig. 3).

Input Arrow (Federal Information Processing Standards Publication 1993) express IDEF0 Input, i.e., the data or objects that are transformed by the function into output. Mechanism Arrow express IDEF0 Mechanism, i.e., the means used to perform a function (includes the special case of Call Arrow). Output Arrow express IDEF0 Output, i.e., the data or objects produced by a function. Call Arrow: A type of mechanism arrow that enables the sharing of detail between models (linking them together) or within a model. Control Arrow express IDEF0 Control, i.e., conditions required to produce correct output. Data or objects modeled as controls may be transformed by the function, creating output.

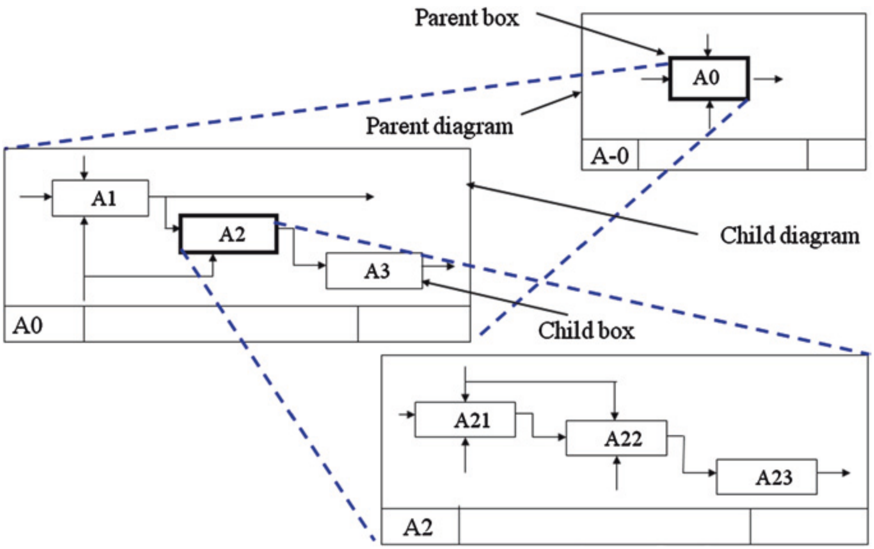

Fig. 4 Decomposition structure (*Source* (Federal Information Processing Standards Publication 1993))

Functions (boxes) are broken down or decomposed into more detailed diagrams, until the subject is described at a level necessary to support the goals of a particular project (Fig. 4).

The top-level diagram in the model provides the most general or abstract description of the subject represented by the model. This diagram is followed by a series of child diagrams providing more detail about the subject.

5 PMBOK, PRINCE2, and SCRUM Comparison in View of ICOM Logical Set

PMBOK approach includes product characteristics, scope, analysis, design, product breakdown, and development. Processes overlap and interact throughout a project or its various phases. Processes are described in terms of American National Standard: Ansi/Pmi 99-001- 2008 (2008):

- Inputs (documents, plans, designs, etc.)
- Tools and Techniques (mechanisms applied to inputs)
- Outputs (documents, products, etc.)

In a PRINCE2 approach Product Based Planning is a core method of identifying all of the products (project deliverables) that make up or contribute to delivering the objectives of the project, and the associated work required to deliver them (see Footnote 1). The Product Flow Diagram (PFD) is a graphical representation of

Table 1 Popular PM methodologies—comparison (*Source* own study)

Task	PMBOK	PRINCE2	SCRUM
Input	✓	✓	–
Output	✓	✓	–
Control	–	–	–
Mechanism	✓	–	–
Typical graphic representation	Data flow diagram Project schedule	Product flow Diagram Product breakdown Structure	Daily estimates

the order by which a sequence of products is created according to Product Based Planning Principles. It is related to the Product Breakdown Structure (PBS).

In SCRUM (Schwaber and Sutherland 2013) the Development Team usually starts by designing the system and the work needed to convert the Product Backlog into a working product Increment. Work may be of varying size, or estimated effort. However, enough work is planned during Sprint Planning for the Development Team to forecast what it believes it can do in the upcoming Sprint. Work planned for the first days of the Sprint by the Development Team is decomposed by the end of this meeting, often to units of one day or less. The Development Team self-organizes to undertake the work in the Sprint Backlog, both during Sprint Planning and as needed throughout the Sprint. The Product Owner can help to clarify the selected Product Backlog items and make trade-offs. The Product Backlog is an ordered list of everything that might be needed in the product and is the single source of requirements for any changes to be made to the product. The Product Backlog lists all features, functions, requirements, enhancements, and fixes that constitute the changes to be made to the product in future releases. Product Backlog items have the attributes of a description, order, estimate and value.

The comparison among PMBOK, PRINCE2, and SCRUM in view of ICOM logical set has been done (Table 1). PMBOK is the most similar approach to ICOM, but finally no one fully correspond with ICOM logical set.

IDEF0 might be used not only to mapping the SMA process but also to managing the SMA project. ICOM Code from IDEF0 has more clear description of what is input, output, control and mechanism, than considered PM methodologies. Such clear description might be useful during conducting project of SMA, especially for those with engineering background.

In the next chapter an attempt to use IDEF0 and ICOM Code as a project management tool will be presented.

6 IDEF0 as a PM Tool in SMA Process in Babinski Hospital

Proper preparation for emergency situation like: terrorist threat, flood, fire, etc., in facilities, especially in hospital, where people entrust their safeness in hands of medical and nonmedical personnel might be an important issue. One of the major

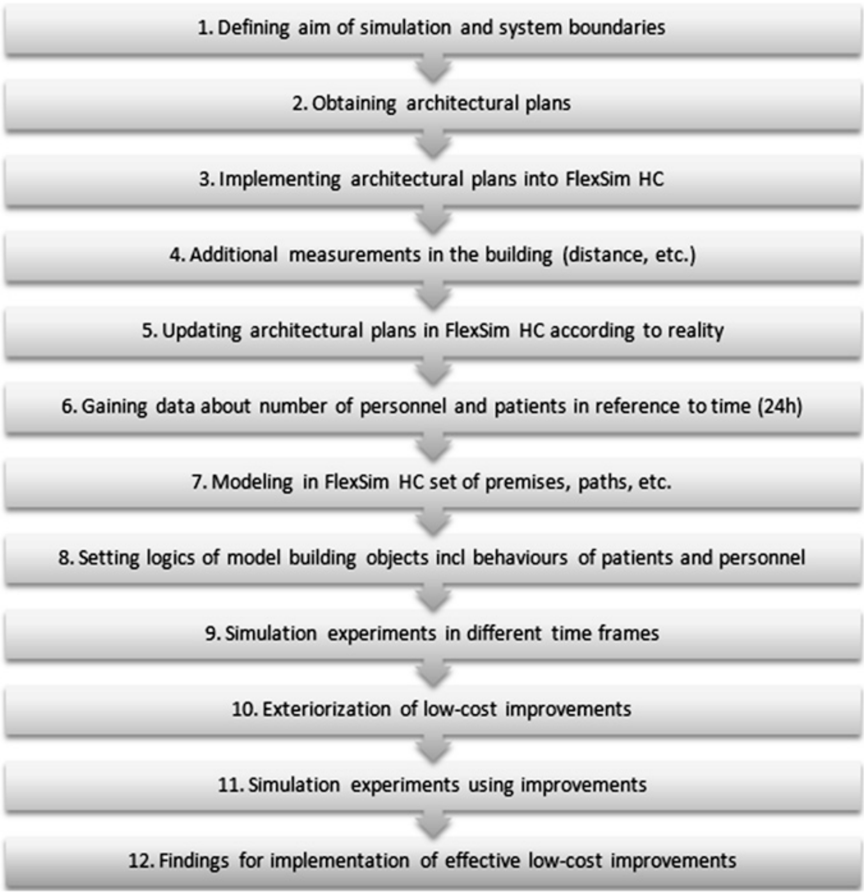

Fig. 5 The methodology of the SMA process of emergency evacuation of a hospital facility (*Source* (Mikulik et al. 2014))

question in such a case is: how much time will it take to leave the building, and what can be done to shorten this time? One of the method is real experiment. It is maybe good solution in case of office building evacuation logistics, but in hospital it is extremely difficult. So, a simulation modeling in computer environment might be the proper solution in such a case. This was the reason why the simulation model of emergency evacuation from the facility of The Voivodship Centre of Addiction Therapy in Krakow, a part of Dr. Jozef Babinski Hospital in Krakow (Poland), has been made (Mikulik et al. 2014).

To run the SMA process the specific methodology of a simulation model of the emergency evacuation time and low-cost improvements of a hospital facility using FlexSim Healthcare was formulated (Fig. 5).

To perform such SMA process with necessary precision, the project management method must respect indications of what functions have to be performed. More-over, what data or objects should be transformed by the function into

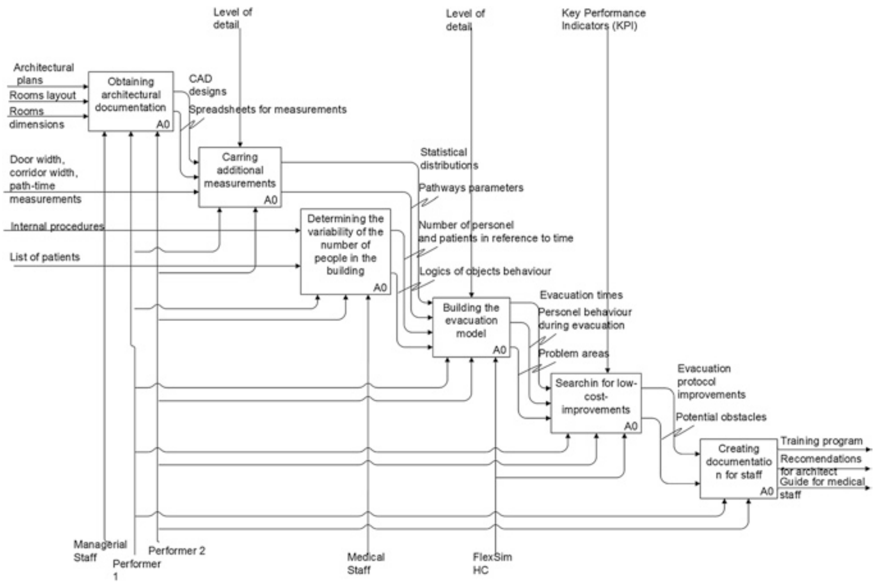

Fig. 6 A0 level of IDEF0 diagram of SMA process of emergency evacuation logistics of a hospital facility (*Source* own study)

output? What means should be used to perform a function? What data or objects should be produced by a function, and what conditions are required to produce correct output?

Taking mentioned issues under consideration the IDEF0 diagram on the A0 level has been created (Fig. 6).

Presented IDEF0 diagram has been used as a project management tool during SMA process. The final products of SMA process (guide for administration and medical staff, recommendations for architect, training program) has been completed on time. More-over following issues have been observed:

- Work to-do well structured
- Easy management of resources
- Precise knowledge about what is necessary to perform the process
- Easy communication among performers and management
- Small quantity of project management documentation
- Easy to understand and use (especially for engineers).

7 Conclusions

Summing-up above issues, legitimacy of usage of IDEF0 approach as a project management tool in the simulation modeling and analysis (SMA) process of evacuation people form facility has been verified and proved.

The IDEF0 seems to be good alternative for project management in SMA process, especially for engineers, and those who are familiar with ICOM Code. Although decisional aspects are not covered in IDEF0 formalism enough deeply. Further works must be conducted to solve those issues.

References

American National Standard: Ansi/Pmi 99-001-2008 (2008) A guide to the project management body of knowledge (Pmbok® Guide)—4th edn. Newtown Square

Beaverstock M, Greenwood AG, Lavery E, Nordgren B, Warr S (2011) Applied simulation: modeling and analysis using FlexSim. Flexsim Software Products, Incorporated

Cempel C (2003) Modern methodological and philosophical issues (Nowoczesne zagadnienia metodologii i filozofii badań). Wydawnictwo Naukowe Instytutu Technologii Eksploatacji, Radom

Cempel C (2008) Systems theory and engineering (Teoria i inżynieria systemów). Wydawnictwo Naukowe Instytutu Technologii Eksploatacji, Radom

Federal Information Processing Standards Publication 183 (1993) The standard for integration definition for function modeling (IDEF0). National Technical Information Service, U.S. Department of Commerce, Springfield

François C (1997) International encyclopedia of systems and cybernetics. K. G. Saur Verlag, GmbH

Galan JC, Marcos M, Reif W, Balser M, Schmitt J (2005) Integrating formal methods in the development process of medical guidelines and protocols. Validated new model of guideline development process. Specific Targeted Research Project Information Society Technologies. IST-FP6-508794. Universitat Jaume I

Mayer RJ, Menzel C, Painter M, de Witte PS, Blinn T, Perakath B (1995) Information integration for concurrent engineering (IICE) IDEF3 process description capture method report

Mikulik J, Cempel W, Kracik S, Dąbal D (2014) A simulation model for emergency evacuation time and low-cost improvements of a hospital facility using FlexSim healthcare: a case study. In: Korbicz J, Kowal M (eds) Intelligent systems in technical and medical diagnostics SE, vol 28. Springer, Berlin, pp 333–342

Office of Government Commerce (2009) Managing successful projects with Prince2. The Stationery Office, London

Pawlewski P (2010) Using Petri nets to model and simulation production systems in process reengineering (case study). In: Pawlewski P (ed) Petri nets: applications. InTech, Olajnica, pp 421–445

Pidd M (2003) Tools for thinking, modeling in management science. Wiley, Chichester

Schwaber K, Sutherland J (2013) The Scrum guide. scrum.org

Transforming a Student Project into a Business Project: Case Study in Use of Simulation Tools

Pawel Pawlewski, Rafał Juraszek, Magdalena Kowalewska and Zbigniew Pasek

Abstract This chapter describes an innovative curriculum developed for a new Logistics Engineering degree programs at the Faculty of Engineering Management of Poznań University of Technology. The core of the program is based on a sequence of four major courses, which focus on the Product Development, Process Analysis and Optimization, Logistic Processes and Service Engineering, respectively. Each course is built around a practical team project. Projects introduce entrepreneurial components, as the teams have to develop their concepts in the context of a start-up company. One key element of all the courses is an emphasis on the use of various simulation tools. These tools may vary from physical mock-ups, through simple Excel spreadsheets to the use of industrial-strength simulation software. One of the courses, offered to the 3rd year students, introduces fundamental concepts related to industrial process analysis and improvement. Students learn necessary data collection and analysis techniques (such as, for example, Value Stream Mapping) and also the basics of process simulation using a commercial software package. Student teams work with industrial sponsors and develop competing innovative ideas for process transformation and improvement. Emphasis is placed on the quality of the student work and final results. Top projects are offered to present at technical conferences, publish their results in technical journals, and also participate in project competitions. Projects focus on the supply chains and logistic processes, assessment of their performance, lifecycle analysis and management. The student group projects are typically carried out in

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an industrial setting, dealing with real-life assignments. The chapter highlights one case of collaboration between University of Technology and commercial business company from aerospace industry. This case is the base for building a reference model of transition from a student project to a business project. The chapter aims to accomplish the following: Point out the gaps in management of logistics-oriented student projects in industry, which rely on use of simulation tools; Identify clearly evolution phases of student projects transitioning into business projects; Share the preliminary project transformation experiences, which may serve as practical foundation to build a reference model for such transitions. The key highlights of presented work consists of the following: Consistent portfolio of courses leveraging student group work; Concept of a transformation model capturing transition from student project to a business project; Use of simulation technologies as an effective means of engagement with industrial partners, in particular when they are neither using nor familiar with simulation tools.

Keywords Simulation • Model • Manufacturing • Education

1 Introduction

Poznan University of Technology (PUT) is a state-run institution of higher education in Poznan, Poland. According to the Webometrics Ranking of World Universities, developed by the Spanish institute Consejo Superior de Investigaciones Científicas, PUT is ranked as the eighth engineering university in Poland and it takes the 856th position among all institutions of higher education in the world.[1] The history of PUT goes back to 1919, however, it was accredited by the Government as higher learning institution no sooner than in 1955. In 1995 Poznan University of Technology became the first Polish engineering university that joined the Conference of European Schools for Advanced Engineering Education and Research (CESAER)[2]—an association of leading engineering universities in Europe. PUT participates also in Socrates-Erasmus program which promotes the European dimension of higher education by means of student exchange between universities in the whole Europe.

In Poznan University of Technology there are several student organizations, a few dozens of research clubs, such as e.g. Logistics Club—Simulation and Optimization Center in Logistic and Production Processes (SOCILAPP) in the Faculty of Engineering Management, which is a professional research unit for improving the quality of research and study.

[1] http://www.webometrics.info/en/Europe/Poland, accessed on Jan 5, 2014.

[2] http://www.cesaer.org/en/members/poland/, accessed on Jan 5, 2014.

Specialty of Logistics at the Poznań University of Technology was originally launched during the 2007–2008 academic year. It has a bi-level curriculum—in compliance with the European directives defined by the Bologna Process (2014). The first level (Level 1) is 7 semesters long and upon completion students receive the title of an engineer (equivalent to Bachelor of Engineering, or BEng). After completing 3 more semesters (Level 2) students obtain a Master's of science (MSE—Master of Science in Engineering) degree. Graduates of this program are groomed to become specialists of key activities within any industrial enterprise on the market. They take courses on the design and organization of supply chains, production, transportation and distribution of goods and services. Logistics gains on importance in the context of global enterprises, due to the international trade expansion. This type of knowledge is particularly useful not only in a manufacturing industries, but also in retail and services. Well-rounded background of the graduates opens for them opportunities in positions of leadership, management, system analysis, designers and consultants, project management which can focus on product design, purchasing of goods and services, production, transportation, inventory management, distribution and retail.

The conceptual foundations of developed curriculum were laid out in the paper (Pawlewski and Pasek 2012) presented at ASEE Annual Conference in 2012. This chapter describes the logical "next" step of transition, where student project are being transformed into business projects. It summarizes the experience gained when a student project, which made extensive use of the latest simulation techniques was transformed into a business project. Owing to this idea, most of the students for the first time had an opportunity to be exposed to industrial reality of implementation of specific projects at their host companies. On the other hand, it was also in many cases the first chance for the companies to give the innovative solutions based on simulation techniques a first try. The mutually beneficial approach of conducting these projects seemed to be very attractive to both sides participating in them.

The chapter aims to accomplish the following:

- Point out the gaps in management of logistics-oriented student projects in industry, which rely on use of simulation tools
- Identify clearly evolution phases of student projects transitioning into business projects
- Share the preliminary project transformation experiences, which may serve as practical foundation to build a reference model for such transitions.

The key highlights of presented work consists of the following: consistent portfolio of courses leveraging student group work, concept of a transformation model capturing transition from student project to a business project and use of simulation technologies as an effective means of engagement with industrial partners, in particular when they are neither using nor familiar with simulation tools.

The chapter consists of 6 sections. Section 1 is introduction. Section 2 presents the concept of course Logistics Processes Design based on requirements of the Polish Ministry of Science and Higher Education, which must be met by universities introducing logistics into their study schedule. The syllabus outline of Simulation Laboratory classes and student projects are discussed in detail in Sect. 3. The core of the course, i.e. student projects, is described in detail in Sect. 4. This chapter provides a list of already-implemented projects. Section 5 presents the case study performed in aerospace factory and discusses the experience gained from them. All these lead to conclusions presented in Sect. 6.

2 Concept of Course: Logistics Processes Design

As it was briefly mentioned in the previous section, the concept of field-experience classroom, based on student projects carried out in industry with extensive use of simulation technologies was introduced earlier in the paper presented at ASEE Annual Conference in 2012. It is also worth recalling that the Polish Ministry of Science and Higher Education created the basic framework for the "Logistics" track (Pawlewski and Pasek 2012).[3]

This framework defines qualifications of the graduates and contents of needed courses. First level graduate (engineer) should know principles of modern logistics systems, fundamentals of economics, and management. He/she should have the ability to solve logistical issues using engineering methods and technologies, to design logistics systems and processes, to use computer software for logistics management. The graduate should be prepared to work in an environment of a production factory, logistics company, consulting company or administration. One of the required courses on Level 1 is Process Design.

The graduates of Level 2 should have extended knowledge (in comparison to Level 1) in scope of company logistics (production, commerce, service) and other organizations forming supply chain. They should be prepared to work in positions of leadership to develop and manage logistics strategies. They should use their knowledge and abilities adhering to ethical and legal rules. They should understand the nature of competition in both local and global markets, mission and goals of company logistics, and significance of quality-based competition. They should know how to plan, organize and perform logistics processes, to introduce system solutions to improve company management and find reserves to reduce logistics costs. One of the required courses in this level is Design of Logistics Systems and Processes. This course and Process Design course from level 1 are used as main foundational courses in new concept to integrate knowledge. It is a result of cooperative efforts between Faculty of Engineering Management in Poznań (Poland) and University of Windsor (Canada) (Pawlewski and Pasek 2010). Students form teams (companies) and carry out some projects during two levels in continuous, integral way. Student teams work together throughout the project cycle. The cycle is composed of four main courses (see Fig. 1):

[3] www.nauka.gov.pl, accessed on Jan 5, 2014.

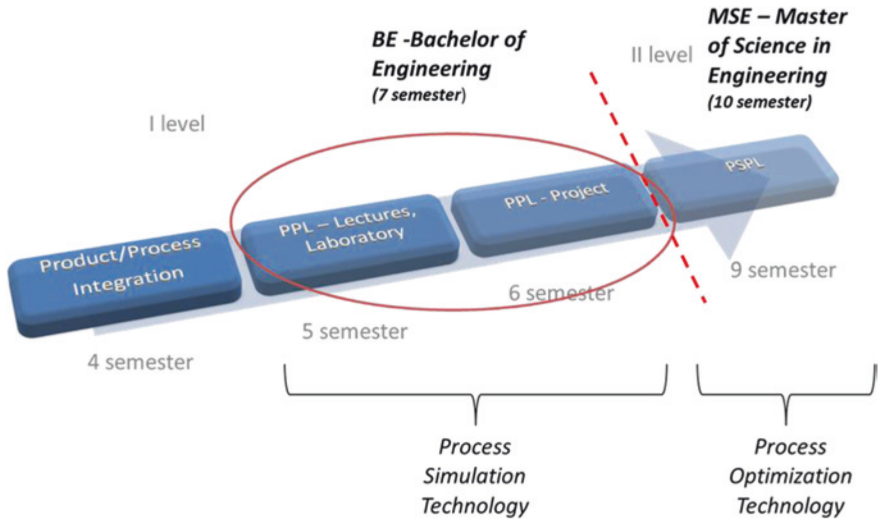

Fig. 1 Cycle skeleton based on process approach (*Source* own study)

1. Product/Process Integration (PPI)
2. Logistic Process Design (PPL)
3. Design of Logistics Systems and Processes (PSPL)—Process Management and Optimization
4. Service Engineering (SE).

Stage 1—PPI Course is introduced to provide students with general overview of product development process (see Table 1). Students form a start-up company and design a new product, develop a (rough) design of processes to manufacture this product, build a corresponding financial model and a business plan.

Stage 2 is divided into two semesters: during the first semester lectures cover Process Design and students are learning hands-on fundamentals of specialized software platform(s) for process modeling and simulation.

Based on the knowledge and experience gained in the PPI class, in the following semester student groups contact local companies, develop project proposals, and carry out projects according to the joint agreement. Student teams offer services to design, model or map real logistics processes.

Stage 3 (still under development) will be performed on Level 2 and will be divided into two specializations with either factory (internal) or supply chain (external) focus. In stage 4 the course on Service Engineering will be introduced.

Students are given an opportunity to expand the completed projects (Fig. 2) into Bachelor of Engineering (BEng) thesis work, which is required for graduation. Afterwards, they can continue their education towards the M.Sc., thesis-based program. Such an opportunity is offered to students who, from the very beginning, study in the same faculty and department.

Table 1 Process-based program curriculum (*Source* own study)

Name	Goal	Outcomes	Semester
PPI—Product process integration	To form a start-up company that produces a new innovative product that fits mass-customization market at global scale	Product design, General process design Manufacturing system Design Financial model Business plan Main process design	Level 1—sem. 4
PPL Process design	Develop practical base for process design using simulation software (lectures and laboratory)	Logistics process design	Level 1—sem. V
PPL Industrial project	Prepare project proposal for industry. Form consulting company (8 students). Project realization in industry	Models, proposal for industry industrial project	Level 1—sem. VI
PSPL Process management and optimization	Base for process management and optimization using specialized software Prepare project proposal for factory and supply chain—optimization	Proposal for factory/supply chain industrial project	Level 2
SE—Service engineering	Base for new service development process Prepare project in service oriented architecture (SOA) and e-service	Assess existing service; develop new service concept	Level 2

The core of the course in Stage 2 is PPL—Logistics Process Design. Effectively, it is a two-semester course, comprising of:

- Semester 5—30 h of lectures and 15 h of labs and tutorials
- Semester 6—30 project classes.

The main goal set for students at stage 2 is to gain competence in designing and managing logistics processes. Such a goal is established by the Polish Ministry of Science and Higher Education, and as such, the subject is treated as mandatory.

In semester 5, students attend laboratory tutorials, where they learn to use process simulation software in a general-purpose version. It is important because students should develop the proper way of thinking and using this kind of software. Neither the kind of company students will work for nor the specific tool they will use in the future are not known at this point. The participating students, as long as they keep registered status, maintain software access both in- and outside of the classroom, as according to the software license and academic network rules. Their accounts expire at the time of their graduation from the university.

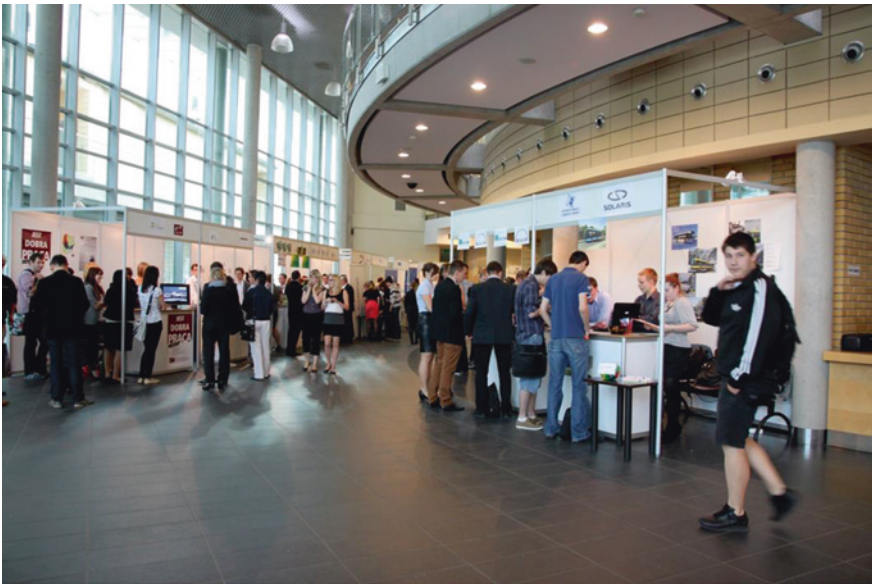

Fig. 2 Student exhibition station in the hallway of lecture center during IV Logistics Gala (*Source* own study)

3 Syllabus Outline of Simulation Laboratory Classes

To support the needs of laboratory classes, a special syllabus was developed. It is based on the content of 48-h Training Programs offered by the distributor of simulation software in Poland. Its full contents, is listed in Tables 2 and 3. Students spend only 16 h in class, so effectively they can learn just the basics. Some student participants, however, in project teams are tasked with building simulation models, so their development is closely watched and guided by the course instructors. That suffices to reach mastery level needed for a student project. Many of such students continue their simulation education when their project work is transformed either into a thesis or an industrial project. The latter path is the focus of the next section.

However, the actual profiles of the students may vary. They are 3rd year students, i.e., semester 5 and 6, usually 21 or 22 years of age. They have no prior exposure to the industry. On the one hand, they are familiar with the way the industry operates and on the other hand, they have already gained certain skills which are considered innovative (e.g. simulation techniques). Therefore, the idea of student projects appeared so as to connect the two aspects; nowadays, in Poland industry is increasingly open to cooperation with academia. Students have already mastered the theoretical foundations of management, logistics, inventory management, operational management and supply chains: they have

Table 2 Training program—the business process simulation modeler (*Source* own study)

No.	Topic	Hours
1	Simulation and discrete events	1
2	Statistical distributions. Capturing variability	1
3	FlexSim terminology and concepts	4
4	FlexSim interface and objects libraries	4
5	Basics of navigations in FlexSim	2
6	Reports and statistics	2
7	Global tables and global variables	2
8	Basic task sequence building	2
9	Pull and push systems	1
10	Building models in FlexSim	4
11	Practice exam	1
Total	24	

Table 3 Training program—the business process simulation consultant (*Source* own study)

No.	Topic	Hours
1	FlexSim functions	4
2	Dashboards. Trace variables	4
3	FlexSim tree	2
4	Reports and statistics, export and import data	2
5	Global tables and global variables	2
6	Task sequence building. Working with task executors	2
7	Basics of kinematics	2
8	Basics of Flexscript	5
9	Practice exam	1
Total	24	

been using them in class and working on class projects. Most of the students have never been in a production plant. As for information technology, students' skills are limited to the use of basic applications such as MS Office and web-based applications; only few can use programs such as Visio and MS Project and hardly any student is familiar with structured programming (object-oriented programming is actually unknown to students). Under such circumstances, certain requirements need to be met both in terms of the applied simulation software and the method of conducting classes.

In semester 6, students work on projects in an industrial environment. They form teams consisting of six to eight students, select their leader and divide the work among themselves, e g., decide who is in charge of collecting data, contacting the representatives of a production plant, creating the simulation model and presenting the results. The project topics are determined by the particular circumstances; however, in most cases the choice of the company and subject depends on students' decision. Students contact the selected company and organize a meeting with the participation of their academic instructor, in which the rules of the cooperation are established:

- the company is asked to prepare a list of few (usually three) suggested subjects, out of which students choose the one to be implemented;
- the subjects must take into consideration the use of simulation techniques;
- the company selects a person (industrial sponsor representative) who, on its behalf, will be responsible for implementing the project; a visit to the company is organized for all students in a team.

4 Student Projects Descriptions

Student projects are organized in companies situated in and around Poznan, which is one of the major industrial centres in Poland. Poznan is considered one of the most interesting cities for investors since it is the centre of industry, commerce, logistics and business tourism. According to data provided by investors, it is estimated that the value of cumulated foreign direct investment in the years 1990–2010 was 6.6 billion USD (Urząd Miasta Poznania 2010).

According to external assessment carried out by Moody's investors Service, Poznan has the second highest investment credibility in Poland, after Warsaw; in March 2013 the city was ranked at the level A3 with a stable outlook. It means that the city has very high capacity to discharge its financial liabilities and in the nearest future the financial credibility should not change. In November 2013 Poznan was ranked at the level A—with a stable outlook by Fitch Ratings which corresponds with the rating of Poland and the A3 rating assigned previously by Moody's (Biuletyn Informacji Publicznej—Ocena ratingowa Poznania Link 2014).

In the list of 500 largest companies in Poland published by Polityka weekly magazine in 2013, there are 54 companies settled in Poznań and Poznań District. Four of them are among 20 largest companies in Poland (based on 2012 sales revenues):

- Jeronimo Martins Dystrybucja S. A. (Kostrzyn Wielkopolski)—28,907 mln PLN
- Enea S. A. (Poznań)—10,096 mln PLN
- Eurocash S. A. (Komorniki)—16,575 mln PLN
- Volkswagen Poznań Sp. z o.o. (Poznan)—9,141 mln PLN.

All listed projects (10) were performed in academic year 2012/2013 with strategic industrial partners:

- Prologistics: Volkswagen Poznań—Simulation of sequential delivery of a new hall for the selected sequence and cargo baskets using various means of transport.
- L-Con: Logzact Logistic Systems—The optimization of completion with the use of the dynamic assortment replacement in the automatic container warehouse.

- EightLog: Bridgestone—Optimalization of products placing in Bridgestone storehouse according to ABC method.
- Logrado: Raben—Optimization of unloading and completion process in Raben's transit warehouse in Gądki.
- DEMDAAX: Solaris Bus—Modification of the mounting positions for the team's S190 and S200 in the new system of assembly stands in terms of organization and logistics.
- AirFlow: Poznań Airport—Simulation of optimal placement of road sings in the parking to the Airport Poznań.
- The Hopelight: Pratt & Whitney Kalisz—Improving the material flow in a logistics stream.
- PLA: Pratt & Whitney Kalisz—Analysis of production sequence of aircraft engine elements.
- Infinity Solutions: Volkswagen Poznań—Flow Simulation of the empty returnable containers inside the plant to the area of sequence and supermarkets and to the external warehouses on the shipment consolidation fields.
- Loft: Nivea Polska (Beiersdorf)—Simulation of routes planning to optimize the use of cars and fulfilment orders on time taking into account interferences in transit.

All successful projects completed on time were entered into a university-wide simulation competition, results of which were presented at 4th Logistic Gala Event at Poznan University of Technology.[4] During the event students present summaries of their projects, and create exhibition stands (see Fig. 2), which are open to the public. The event is well attended by students from other specialties, researchers, and industry representatives.

5 Student Projects Transformation: Case Study

Two projects are performed in aerospace factory. Both are transforming into business projects. This section concerns the project titled "Analysis of production sequence of aircraft engine elements."

The strategy of Project Transformation is introducing simulation technology which is based on FlexSim system simulation to making decision in aerospace factory. This is the base to perform next student, research and business projects.

Pratt & Whitney Kalisz (aerospace factory) was established in 1992. Pratt & Whitney Canada (main aerospace shareholder is a worldwide leader in manufacturing turboprop, turbofan and turboshaft engines for business aircraft, local transportation and helicopters. Currently, the company employs ca 1,500 people. All the time the Company develops dynamically. 97 % of the production is exported. The company manufactures parts for aircraft engines. The primary parts

[4] http://www.flexsim.com/blog/flexsim-represents-at-4th-gala-of-logistics-in-poland/, accessed on Jan 5, 2014.

manufactured are: carries, stators, gears, couplings, main shafts. The current range of manufactured products comprises over 2,000 part numbers and is continuously extended. The above parts are characterized by top engineering and quality requirements and their production requires the state-of-art machinery fleet, modern and innovative processes and exceptional employee skills. The Company is the world leader and a center of excellence in gears and stators for the aviation industry. In the quality area are ISO 9001:2000, AS 9000 certificates. The Company has also implemented the integrated environment and work safety management system in accordance with ISO standards—ISO 14001 and PN-N—18001.

In order to ensure the top workforce so much necessary in the aviation trade, the Company offers its Employees a unique educational program. Each employee is allowed to pursue any course of academic studies at the employer's expense. The Continuous Improvement Program, implemented in 1996 is an everyday tool used to continuously look for improvement in all Company processes in place. The purpose of the program is to improve quality and efficiency in order to achieve maximum Customer satisfaction. The Company also follows Code of Ethics. Trust, respect and honesty are the foundations of our business. The Code not only includes rules governing our actions but also expresses fundamental values and determines the decision making process.

The process approach in a production company and making the right decisions are related with a number of issues concerning results attained by a company, its efficiency, changes within its structure and adjusting resources to the future needs of a company, developing characteristic skills as well as change and knowledge management. The connections within the logistics system of a company and the kinds of flows related with manufacturing are illustrated in Fig. 3.

The assumptions of the project in the aerospace company concern the following areas:

- 25 products—part numbers (gears family) in a production line
- Manufacturing process of 30–40 operations—technological route
- Internal cooperation
- External cooperation
- Loops
- Manufacturing LT (lead time) of 50–60 days
- High quality criteria (Aerospace Standards/AS 9100).

The process orientation of a production company emphasises the quality of work, coordination between particular functions and the significance of teamwork. The mutual interactions of people and decision-making are the essence of management in any organisation. In its course, the interaction plays a crucial role in coordinating actions of people, whose purpose is to achieve goals that are unattainable for an individual. The aim of the project was to optimize a gear production flow including new arrangements concerning changes that might be introduced in the production and technological process. The sequence is complete—starting from a delivery of all the necessary raw materials to the line and ending with a final good ready for a dispatch.

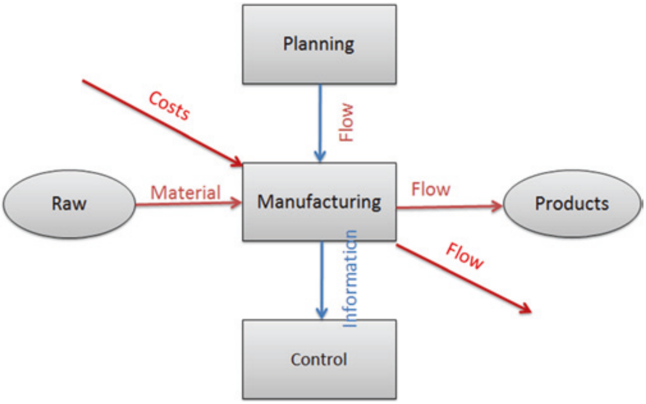

Fig. 3 The kinds of flow related with manufacturing [*Source* (Hitomi 1996)]

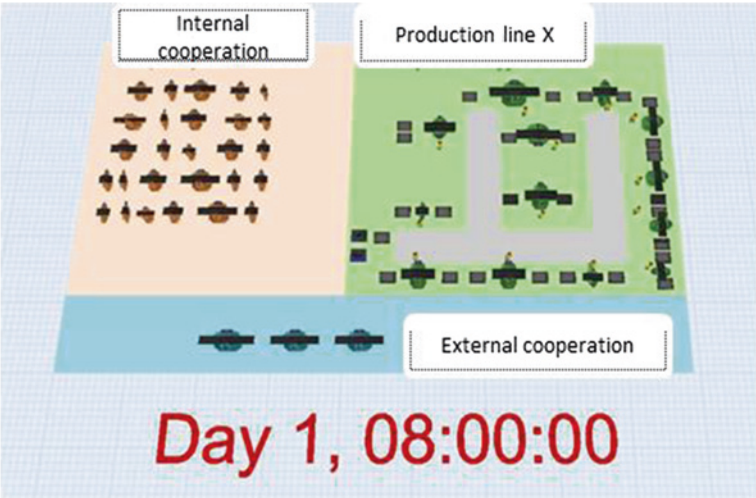

Fig. 4 Student simulation model (*Source* own study)

Student project was limited to 9 products and to presentation method (without validation). The model built by students is presented in Fig. 4.

The main goals of student projects are obtained. The method was showed. Students performed some simulation experiment—they played with the different sequences of products to find the minimal lead times. The results are shown in Table 4.

The model shown in Fig. 4 and comparison of obtained results (Table 4) were successfully presented during the student project competition (4th Gala of Logistics, June 2013).

Table 4 Comparison of results obtained in student project (*Source* own study)

Nr row	Sequence 1	Sequence 2	Sequence 3
1	Product_1	Product_9	Product_3
2	Product_2	Product_8	Product_4
3	Product_3	Product_7	Product_2
4	Product_4	Product_6	Product_1
5	Product_5	Product_5	Product_7
6	Product_6	Product_4	Product_8
7	Product_7	Product_3	Product_6
8	Product_8	Product_2	Product_5
9	Product_9	Product_1	Product_9
	53days 08:56:28	52days 20:15:46	52days 04:15:40

Arrows indicate difference between actual and proposed better solution (1 day 5 hours)

Due to high interest and satisfaction with the results, the industrial partner decided to transform the initial student project in an effort that would be a subject of approval by the executive board of Pratt & Whitney. Original student team consisted of 8 students. Three of them are still engaged in collaboration with the company, actively contributing to the transformation effort and also using that experience as part of their undergraduate theses. The core team has met with two Lean experts, who provided guidelines to further product development. Simulation model created by the students was transformed into a model shown in Fig. 5, where equipment and the employees were placed on an actual production layout provided by the company. The consecutive team meetings were attended by the Production Manager (September 18), and Planning Manager (November 25). At those meetings expectations presented by the management started to grow exponentially, often times visibly exceeding students' level of expertise and available work capacity.

Old and new requirements are compared in Table 5. Analysis of decision making justifies increased requirements. The enterprise decision-making is strictly related to the existing organizational structure of the company.

The interrelations between the decision-making level and the requirements concerning the functioning and effectiveness of a process in terms of anticipated results are growing proportionally to the responsibility level and the position in the hierarchy of an organization (Figs. 6 and 7).

The strategic planning of a production line directs the production activity, as it makes it possible to identify problems before they actually occur, solve them before they become too difficult to deal with and detect risky situations. That is why, with use of the Flexsim simulation tool, the objectives and tasks of a

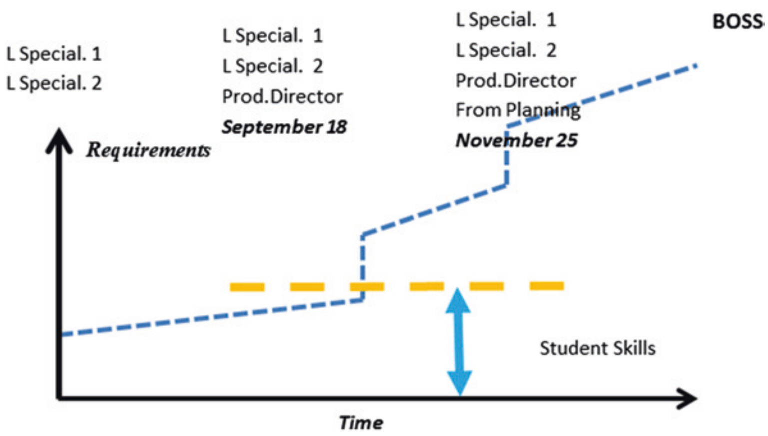

Fig. 5 Project requirements increasing in time (*Source* own study)

Table 5 List of requirements (*Source* own study)

Student project requirements	New requirements
Gears sequence production analysis 9 products	Gears sequence production analysis 15 products (types of gears) + 30 stations in internal cooperation)
Method presentation (without validation and verification of system)	Focus on validation and verification
	Work in progress (WIP) for process (for batch) WIP for station Production cycles

production line are thoroughly analyzed in order to minimize the risk of making mistakes. Then it is possible to assume that in a given company the systemic view is applied to the whole process and configuration of organization processes.

New expectations call for new skills in the FlexSim software, including, for example the following:

- Flow logic in Global Table—(export from excel file)
- User commands
- GUI
- Experimenter and scenario repetition
- Tracked variables.

Figure 8 shows a transformed model in FlexSim, complemented by the list and location of necessary steps and modifications necessary for continuation of project transformation. This was called an “industrial phase” of the project. It requires higher level of skills from the involved project participants, which now includes not only original student team, but also instructor(s) and other technical support personnel and/or researchers. The responsibility for the project has now shifted to

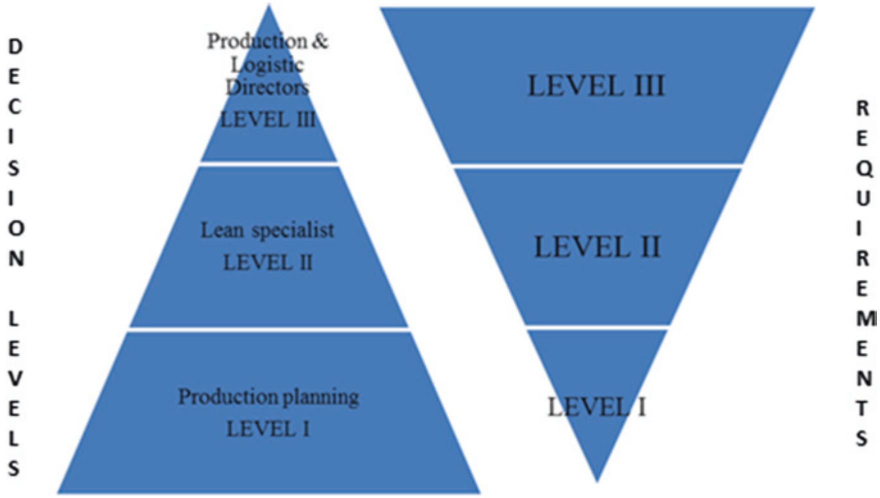

Fig. 6 The interrelations between the decision making level and the requirements (*Source* own study)

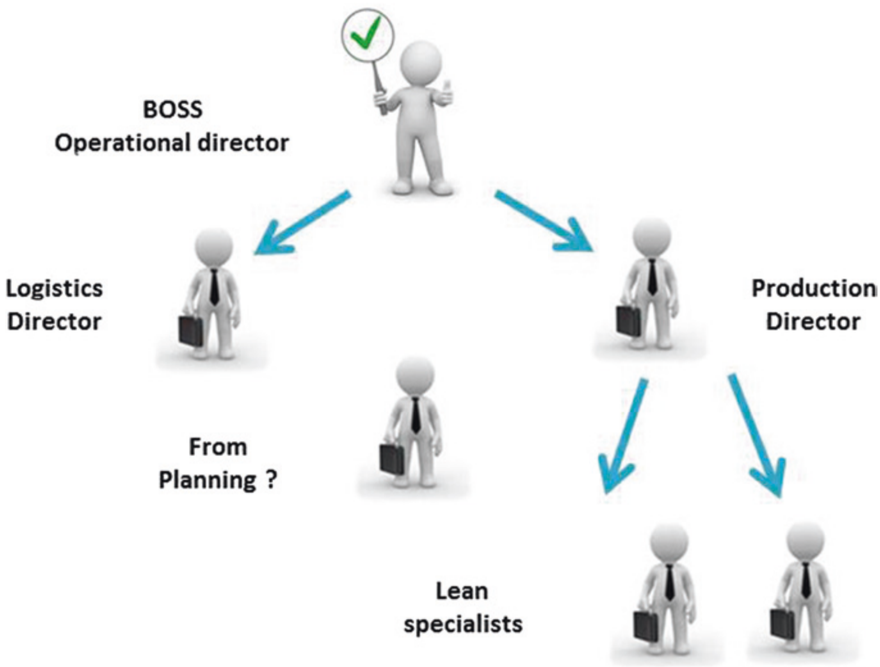

Fig. 7 The decision making structure as tree structure (*Source* own study)

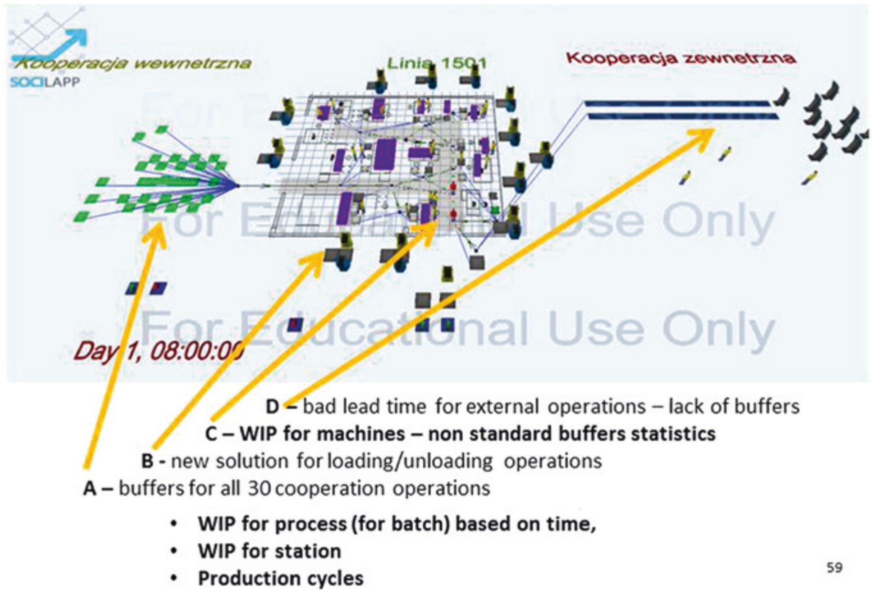

Fig. 8 Necessary steps to continue project in industrial phase (*Source* own study)

the PUT staff. Overall, expansion of the project scale, budget and responsibilities shift warrant calling this phase "industrial pilot." As of January 2014 the project is at that stage, with anticipated completion by March 2014. Further transformation of the "pilot industrial project" into a "business project" may only be considered after company management approves it.

6 Conclusions

The 5th edition of the PPL course is taught in the current academic year (2013/14) and will end with the conclusion of the student project competition in June 2014. It is also interesting to explore to what extent greater engagement of students due to these projects made an impact on continuation of their studies. Table 6 provides a summary number of students who decided to continue with further in-depth simulation studies in their undergraduate thesis, and/or beyond on the graduate level (Master's or Ph.D.).

Two years ago the instructors decided to change the primary simulation software used for course purposes. Initially selected software was a legacy simulation platform, capable of 2D visualization graphics (done only at the post-processor). Currently used software has a modern architecture with 3D capabilities, enabling direct modeling in 3D space, favored by the students. When new training courses in Polish started to be offered recently, the voluntary student enrollment jumped over fivefold.

Table 6 Statistics of courses in 2009–2013 years (*Source* own study)

Year	Total number of students	In-depth simulation study	Ph.D.
2009/2010	73	2	1
2010/2011	77	6	1
2011/2012	106	2	Continuing
2012/2013	110	11	Continuing

There are number of issues that need to be addressed to make transitions from student-to-industrial projects successful. For the time being there is rather scarce literature providing guidelines on how such projects should be conceived and successfully executed. Current approach is definitely more ad-hoc than systematic, which also impacts potential consistency of outcomes. It would be of great help to have resources alerting the instructors to the potential challenges, providing project management tips, etc.

It seems also essential to have not only moral, but also practical support of the college administration. In the presented cases it took form of:

- Organizational support for the Gala of Logistics (public presentation of student projects), e.g., access and permission to use proper venue (large auditorium and hallways for student exhibit booths)
- Legal and contractual services of cooperation agreements, student insurance, etc.
- Marketing and development (fundraising) support.

So far we have not reached yet a point where full transition from a student project into a business project took place. Therefore all college support was requested on as-needed basis, as the effort was treated as an educational experiment. In the future, however, it is foreseeable that planning for access to necessary resources has to take a more formalized shape. It seems that most of the existing programs offered by the Student Career Center are forming sufficient foundation of support.

A contemporary company of the 21st century is a learning organization. Owing to knowledge, the process of changes may be effective and a company may become innovative, capable of prompt changes, competitive and providing satisfaction to both customers and stakeholders. It is necessary to search for original strategies by means of creative thinking and new strategic approaches to the solved problems. It is also crucial to take advantage of the new technologies and the latest IT solutions. Management with use of simulation tool should become the philosophy of managing every modern organization.

Organizations that chose to implement a simulation system assisting process management should make use of the whole variety of possible solutions offered by such a system, as in the particular circumstances varied solutions may turn out to be not only real but optimal. Each organization becomes nowadays a learning one in order to implement its development strategies. A learning organization not only support the learning process of all its members but it transforms, and therefore expands its chances and effectiveness. Increasing the value of human resources is related with higher studies, various forms of training, research clubs and self-education of individuals. Institutions of higher education possess a crucial resource that is necessary for the development and existence of a business organization, i.e. scientific knowledge. On the other hand, business organizations have all the essential practical knowledge that is required for the development and existence of a institution of higher education. In order to attain perfection in every domain, a permanent long-lasting cooperation should be developed between the world of science and the world of business. Only such approach can guarantee strategic development and competitive advantage in the dynamic and aggressive environment.

References

Biuletyn Informacji Publicznej—Ocena ratingowa Poznania Link (2014) http://bip.poznan.pl/bip/ocena-ratingowa-poznania,doc,291/ocena-ratingowa-poznania,1742.html. Accessed on 5 Jan 2014

Bologna Process Official Website (2014) http://www.ehea.info/. Accessed on 5 Jan 2014

Hitomi K (1996) Manufacturing systems engineering. Taylor & Francis, London

Pawlewski P, Pasek ZJ (2010) Logistics engineering curriculum integrated through student projects. In: International conference on engineering education (ICEE 2010), Gliwice, Poland

Pawlewski P, Pasek ZJ (2012) Integrating student projects through the use of simulation tools across logistics engineering curriculum. In: 2012 ASEE annual conference, fttp://www.asee.org/public/conferences/8/papers/4675/view. Accessed on 5 Jan 2014

Urząd Miasta Poznania (2010) (www.poznan.pl), Inwestycje zagraniczne w Poznaniu, 27 listopada, http://www.poznan.pl/mim/public/s8a/news.html?co=print&id=41361&instance=1010&lang=pl&parent=0. Accessed on 5 Jan 2014