Multiple Criteria Decision Making

Constantin Zopounidis
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Applications in Management and Engineering

Springer

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Multiple Criteria Decision Making

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Preface

Introduction to the Theme of the Book

Analytical models for decision making from the field of operations research and management science (OR/MS) often adopt a single-objective optimization perspective using profit or cost-related decision criteria. Such an approach provides a convenient modeling basis because it enables the unambiguous definition of the best solution as one that optimizes the chosen criterion.

Socioeconomic and technological complexities, however, usually require the implementation of more elaborate approaches than the one above, taking into consideration the multiple facets of the problem at hand, the policy judgments and preferences of the stakeholders involved, as well as the uncertainties and risks associated with the implementation of the chosen actions. Such considerations naturally lead to a multidimensional framework described by multiple criteria, goals, and objectives. Clearly, this framework is quite challenging to address, unless a systematic process is adopted, that will allow not only the modeling and resolution of a given problem, but will further act as a learning mechanism that will enable the actors involved to better understand the problem, thus ultimately leading to better decisions through an iterative and constructive approach.

Multiple criteria decision making (MCDM) is the OR/MS field that deals with the above issues. MCDM covers all aspects of the decision process of problems with multiple criteria, including "soft" OR topics (e.g., problem structuring), to analytical/algorithmic procedures, as well as implementations into computerized decision support systems. The success of MCDM over the past decades has been driven by a number of theoretical advances within the field, the establishment of connections with related areas (e.g., decision analysis, artificial intelligence, informatics, etc.), as well as by numerous applications in a wide range of areas.

MCDM is a research field with strong practical orientation, in the sense that the MCDM theory and tools are motivated by actual practical problems met in the private and public sectors. In that regard we consider applied MCDM research as being particularly important for the future development of the field. Real-world applications contribute by strengthening and promoting the connections of MCDM with other areas and disciplines, highlighting new areas of interest, and identifying new challenges for extending the theory of the field and improving existing techniques.

The above observations have been the main motivation for preparing this edited volume, the second in the recently established series "Multiple Criteria Decision Making" of Springer. The objective of the book is to illustrate the contributions of MCDM to a wide range of application areas in management and engineering. The book consists of ten chapters prepared by researchers with extensive research experience on the theory and practice of MCDM. The chapters cover applications in broad range of fields such as the public sector, financial decision making, marketing and e-commerce, transportation, engineering, and energy systems. The unique features of each application domain are discussed together, and the details for implementing established and new MCDM techniques are also presented.

Outline of the Book

The first six chapters of the book involve applications in different areas of management. The book starts with the chapter by Maria Franca Norese, which is devoted to the applications of MCDM to public sector administration. The public sector has several unique characteristics as public policies require the adoption of a strategic and long-term perspective, which poses particular challenges to provide decision support in an efficient and effective manner. The chapter starts with a comprehensive discussion of context of decision support in the public sector and the main issues involved. This leads to the introduction of a framework that underlines the core aspects of the application of MCDM to public administration, which is then discussed in the context of some illustrative applications from the existing literature.

The next three chapters are devoted to applications in financial decision making. In the first chapter of this group, Liern, Pérez-Gladish, and Méndez-Rodríguez consider financial investment decisions in a socially responsible investing (SRI) context. SRI extends the traditional framework of financial investment planning through the introduction of social, environmental, and ethical concerns. The authors first address the problem of assessing social responsibility through techniques based on ordered weighted averaging operators. In the second stage, the portfolio construction problem is also examined to construct SRI portfolios in a risk-return optimization framework.

In the third chapter of the book, Rakotoarivelo and Zarate examine financial investments in a risk management context for banking and microfinance institutions. Such institutions are at the core of the financial sector and play a crucial role for supporting economic activity in other sectors. As the recent turmoils in the global financial markets have shown, financial institutions are exposed to a broad range of different risks. The authors introduce a framework for identifying and measuring these risks using the analytic hierarchy process, which is an established MCDM methodology. Numerical results are presented from an illustrative application of the proposed modeling approach.

Angilella and Mazzù cover a similar subject in the fourth paper. In particular, the authors focus on financing decisions about small and medium-sized enterprises (SMEs). In contrast to standard analytical models for credit granting for large firms (e.g., credit scoring systems), the unique characteristics of SMEs often require the use of different approaches that rely more of qualitative aspects of the SMEs rather than their financial characteristics. This is particularly true for financing new SMEs on innovative sectors, as in the case examined in this chapter. The methodology proposed in the chapter combines the ELECTRE TRI outranking method with simulation techniques and considers both qualitative and quantitative criteria.

The next two chapters are related to applications in marketing and e-commerce. In the first chapter, Martin, Zarate, and Camillieri present the development of a recommender system that provides personalized decision support customized to the profile of the users. Recommender systems have evolved rapidly over the past decade and are widely used in several online applications. The proposed system combines principles and concepts from MCDM with machine learning tools, and its capabilities are tested through its application to case involving movie recommendations.

In the next chapter, Koliouska, Andreopoulou, Zopounidis, and Lemonakis examine the assessment of e-commerce practices, with emphasis on the use of online services for the development of protected areas. Protected areas are cornerstones in national and international nature conservation policies for their biological and environmental values while also having economic prospects. The authors use as a case study a particular area in Greece and use the PROMETHEE multicriteria outranking method to assess the performance and effectiveness of e-commerce websites that promote that area, on the basis of different operating features of the websites.

Chapters 7–10, of the book involve engineering application domains. In the first of these chapters, Sarrazin and De Smet develop a multicriteria methodology to carry out an integrated and preventive assessment of road projects at the design stage by considering both their safety performances and some economic and environmental aspects. The authors consider the road design problem in a multicriteria optimization framework and then use the PROMETHEE method to partition the set of best performing solutions into clusters ordered from the best to the worst. The methodology is illustrated through a real case study involving a project of rural road infrastructure in Belgium.

The next chapter by Stavrou, Ventikos, and Siskos presents an application in shipping. In particular, the authors present a multicriteria approach for facilitating decision related to the selection of ship-to-ship (STS) transfer locations. For this purpose, a case study is used involving four STS locations in the Mediterranean Sea, which are evaluated according to operational, economic, environmental, and safety-security criteria. The analysis is based on the ELECTRE outranking technique, which is combined with a robustness analysis methodology. The latter enables the formulation of robust recommendations taking into account the priorities given to the four performance dimensions.

In Chap. 9, Doan, Milojevic, and De Smet present an application of a multicriteria decision methodology to the microelectronic industry, involving the design of three-dimensional (3D) integrated circuits (IC), which have emerged as an innovative technology to traditional IC design in two dimensions. The design of 3D ICs poses a number of engineering challenges regarding the suitability of the available design options, taking into account issues like the maximization of the performance, minimization of the cost, minimization of the package size, etc. The authors illustrate how a multicriteria approach based on the PROMETHEE method can be applied in this context facilitating engineers and designers in assessing the design options and selecting the most appropriate one.

The book closes with the chapter by Becchio, Bottero, Corgnati, and Dell'Anna, which is devoted to assessment of energy systems for energy-efficient building design. The promotion of actions and policies for improving energy efficiency is an issue of major importance in the global agenda. At the European level, recent directives seek to increase the energy performance of buildings through the introduction of new standards for nearly-zero energy buildings and districts. In this context, the paper uses a multicriteria methodology to support the assessment of construction options for a residential district from the city of Turin. The assessment takes into account technical and economic criteria, and the obtained results are compared against those of cost-benefit analysis.

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Chapter 1
Decision Aid in Public Administration: From Evidence-Based Decision Making to Organizational Learning

Maria Franca Norese

Abstract Multicriteria methods are often used to aid decisions in public administration, where different methodological approaches can be adopted to facilitate interventions for different problem situations. A general framework is here proposed to distinguish and visualize the main kinds of applications as well as to underline the main aspects of these applications, which deal with several complexities and obstacles and produce results that are often underestimated. Some specific applications are described and discussed in relation to the proposed framework.

1.1 Introduction

The use of multicriteria (MC) methods in Public Administration (PA) is becoming more and more frequent, but relatively few real-life applications can be found in the literature because an adequate description, especially when it has to be understood by a larger audience than just a few insiders, requires time and space. Many pages are required to present a decision process for which an analyst's intervention has been requested, to name the involved actors and to explain their roles, the decision aiding process and its orientation towards a specific aim in relation to the decision process, the evaluation model, with the main elements of the modelling process and its validation, the use of the adopted multi-criteria method, the results produced for the decision makers as well as their use of these results.

International journals propose a partial vision of decision aid interventions, which, each time, focuses on different aspects: emphasis on the process of decision making and the involvement of different stakeholder groups, or on the model and method more than on the perceived problem, specific attention to the importance of understanding the problem context and to problem formulation and structuring, or to the evaluation process and its possible solution, and so on.

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The MC applications may be different, not only in literature but also in real life, because they have been developed in relation to different decision problem situations and contexts, and for different aims. Other important differences can be observed on the basis of the country in which an application has been developed, in terms of the cultural frame and past experiences, which induce different kinds of participation of the stakeholders and different attitudes to the decision process (passive vs active, conflictual vs argumentative,. . .). Many Multi-Criteria Decision Analysis (MCDA) approaches and methods exist (see for instance [7, 25]) and an increasing move towards MCDA in the public sector has been observed (see [20]).

The public sector includes government agencies with different problems and decision processes, in relation to a specific sector (military defence, security, public health, social welfare, energy, environment, land use, and above all forestry, agriculture and water management,. . .) and to their institutional level (international, national, regional, or local). Decision aid activities are both oriented towards different specific problems (such as resource allocation or management, infrastructure location, selection of offers or projects, monitoring and control and so on) and towards planning, programming or policy making processes, on the whole.

Some other chapters in this book refer to detailed analysis of MC applications in certain social processes and public sectors. This chapter instead focuses on some elements that characterize decision problems and processes in PA which have a direct impact on decision aid.

Bots and Lootsma [12] have synthesized some of these important elements in their list: decisions are not made but ‘happen’ as a result of a complex interaction between national, regional and local administrators, trade unions, pressure groups and so on; decisions involve many and often divergent interests of a society, and aggregation into ideas such as ‘general welfare’ only hides conflict; the stakeholder network is complex and not so transparent; decision processes have a planning horizon of several decades (e.g. decisions on infrastructure); the variety of interests often implies a wide variety of both quantitative and qualitative evaluation criteria, whose values are difficult to establish (e.g. quality of life, safety) and/or aggregate.

This latter element in particular would seem to favour the adoption of MCDA approaches to facilitate these decision processes. Regulations often explicitly include criteria that will be used in public decision processes, and laws often suggest a formal MC procedure, for use in public announcements (of competition or selection) or invitations to tender, or methods, such as ELECTRE and the Analytic Hierarchy Process, which were proposed for the use and attached to the Italian law known as “Merloni Ter” (Legislative Decree of the President of the Republic [35] and subsequent modifications) to regulate the choice of the “most economically advantageous offer”. In recent years, several manuals and guidelines have appeared, at both a national and a European level, thus extending the use of cost benefit analysis to the European Union or proposing the use of MCDA in public processes.

Public agencies often collect huge quantities of very useful data, but they generally do not know what to do with these data to gain insight and guide decisions

[71], and this constitutes an important context of action for MC analysts, and their ability to structure and use information to facilitate understanding and decision making.

The knowledge of the PA processes is complex and the available information may be incomplete, unreliable or contradictory. MC modeling is often used to integrate knowledge and information from different, technical, natural and social sciences. Scientific and idiosyncratic knowledge, the latter being based on the experience users have acquired with a specific resource in a specific location, could be integrated, and uncertainty and ignorance could explicitly be taken into account.

The aim of this chapter is to distinguish between different Public Administration problem situations and decision contexts in which MC applications are developed, and to facilitate their analysis by means of a common description framework.

The chapter is organized as follows. Section 1.2 introduces and defines some preliminary concepts that will be used in the chapter, and it then proposes a frame to visualize the decision contexts and problem situations in which the applications have been proposed in literature. Section 1.3 presents the framework that is used in this chapter to underline the main aspects of MC applications in Public Administration, and it describes some specific applications, which are distinguished in terms of the framework that is proposed. The conclusion emphasizes possible answers to some open questions that have emerged from the experience and indicates new goals that are necessary for the future, together with their operational validation.

1.2 Complexity Elements and Challenges

A decision process can be characterised by several complexity elements, in relation to a specific problem situation and organisational context. A clear understanding of these elements facilitates the introduction of operational tools into a real decision process, consistently with a multiplicity of elements that limit the operational context in which each technical course of action develops.

A clear understanding of the decision complexity is not so easy to obtain, above all in relation to the processes in Public Administration that are characterized by multiple and different interests and stakeholders as well as long-time horizons, and this implies limited and not so transparent knowledge of a complex situation.

The elements of complexity are related to the specific *decision problem situation*, which can be completely new or the result of a long sequence of past internal or external actions, well-structured or ill or not structured, with specific motivations and critical factors and a role as well as a different "space and importance" in a whole policy making process, and to the *organisational context*, which may be described by means of the nature and stability of the relationship between participants in a problem situation [22]. Participants can play different roles in a decision process. They may be decision makers with an institutional role in PA, or stakeholders who are involved in the decision process and its decision system.

Other participants may be involved in the decision process, as technicians and experts, civil society leaders, citizens, associations, citizen committees, but not in its decision system.

The nature of the *decision system* and the characteristics of its components play a determinant role in the decision aid process. A particular stakeholder (individual, entity or community) can activate a decision aid process and may be called the decision maker, but, in relation to a real-life application, this name may be misleading. This stakeholder is clearly the decision maker in relation to the decision aiding intervention, its development and results, but his/her role in the decision process may be minimal (e.g. a spectator with the aim of acquiring an active role in the process) or marginal, because the process involves several organizations in an intricate way. In practice, at least two actors are involved in a decision aiding process, that is, a client and an analyst, the former describes a "problem", while the latter tries to give him/her advice. Other actors may be involved, each with different concerns and stakes in the process [78].

Some decision aid interventions develop in relation to a decision system that has not yet been activated, because the decision process is in an initial pre-decisional state, in which there is a severe lack of knowledge, or there is a difficulty that should be overcome in order to pass on to a decisional state of the process. In these situations, the client may be an expert in a specific domain or a researcher who only becomes a decision maker as far as the intervention and results are concerned. The client may also be a decision process actor who would like to take on a more active role, or someone who perceives the possibility of activating a new decision process.

A technical action also has to be different in relation to the state of the decision process. Adopting Simon's three-phase framework of Intelligence, Design and Choice [73, 74], a technical action in the Intelligence phase, a pre-decisional state, is mainly oriented towards understanding, analysis and problem structuring. Time limits are not very restricted, because a decision is not imminent. The problem situation should be sufficiently clear and structured in the Design and Choice phases, or it still has to be analysed, but the technical action is defined and may be urgent. In a post-decisional situation, at least one decision has already been made, but the resources may have to be identified and mobilised and the decision implementation may have to be managed. In a post-decisional situation, the decision implementation may require operational support, but also the analysis of the implementation activity and results, in order to improve the decisions of the whole policy making process.

The operational context in which a technical action develops is also characterized by the *information* state and the presence of *knowledge* elements that orient the course of action. Elements of uncertainty are normally present and have to be identified, analysed and controlled in all the phases of the decision aiding processes. Information on a specific problem situation can be completely or partially lacking and may require specific inquiry activities. Knowledge, which includes local or (in some way known) previous experiences and the analysis of their results, but also implicit categories of priority, acceptability, risk, urgency and so on, can be structured in a reference system that facilitates and orients the course of action. The nature and conditions of this reference system can be different. The total absence of a reference system, or a limited and not well structured reference system, characterize an innovative situation.

Innovative situations are often present in Public Administration and its decision processes, with a lack of knowledge/information about previous situations that could be used as references for a decision. A frequent and not simple problem situation in PA is the design and implementation of a new policy, but other situations may be considered innovative: the creation of a participative course of action, or a law that sets aside monetary resources to monitor the law implementation process are innovative and complex situations when there is no previous experience in the specific field.

1.2.1 MCDA in Complex Situations

Decision aiding for a problem situation that is new or not associated to enough clear knowledge elements is not such an unusual request, and it is always challenging. The need to understand the different aspects of an analysed problem and include them in a single decision model can easily be satisfied by MC models. Moreover, MC methods can deal with a high heterogeneity of model components without reducing their richness and can facilitate an easy and direct comprehension of the people who are involved in some way, as decision makers, stakeholders or at least as proponents of specific visions, or of detailed knowledge of some problem elements or domain expertise. However, elaborating a good model becomes more difficult, and sometimes impossible, when the problem is ill or not structured at all. An unstructured problem has been described by Ackoff as an 'unstructured reality' or a 'mess', that is, "a system of constantly changing, highly interconnected problems, none of which is independent of the other problems that constitute the entire mess" [1]. As a result, no problem that is part of a mess can be defined and solved independently of the other problems.

When a problem is at least partially structured, some critical elements may also be present, with heavy consequences on a decision aiding intervention The presence of multiple actors and/or decision makers, with different points of view and objectives, and a very limited attitude to cooperation, is one of these elements, but the difficult identification of stakeholders or the involvement of decision makers that is only marginal, because of cultural reasons, time or economic constraints, or because their roles are not yet clearly defined in relation to a new problem situation, are also critical aspects.

MCDA can help facilitate discussions, structure values, devise creative solutions, and identify the preferred alternatives. Its application implies many challenges, including conciliating differences of opinion and judgment among different parties, structuring a set of criteria and choosing the most appropriate aggregation tools, dealing with uncertainty and incomplete information, tackling difficult feasible solution sets, and communicating conclusions [21]. The application of MC methods in PA is the answer to different demands, not only of performance evaluations to facilitate decisions but also of exploring existing data sets, of acquiring and transferring knowledge, of improving internal communication, of analysing and removing conflict, of clarifying complex and unstructured situations, and so on.

An interesting case was described in [31], in which the results of an MC application in the ambit of Environmental Impact Assessment were used by the decision makers (the Province of South Holland and the Ministry of Transport and Waterways) to select a location and grant an environmental license. However, this decision was challenged by some towns in the Council of State, the highest administrative court in the Netherlands, and the court used MCDA as a means of discussing the assessments of impacts, and as a means of establishing differences in opinion about the importance of impacts. In this situation, MCDA clearly proved its worth as a communication tool.

In some cases, an intervention is activated to facilitate the relationships between public and private sectors, above all when new technologies or new uses of the old ones have to be, or should be, introduced into PA and could lead to changes in the procedures and organization. An MC application in this "frontier" context, often in partnership with enterprises or consulting teams, includes and faces constraints, uncertainties and complexities of both the public and private sectors.

MC applications in PA have been proposed in literature in relation to different possible decision and problem contexts. A structured visualization that distinguishes the main different complexities MC applications have to cope with is proposed in this chapter, by means of a framework whose some components will be used here and the others will be used in the next section, to describe some specific PA applications.

A very simple frame can be used to propose a first distinction of the decision problem situations in: *at least partially structured and new and unstructured ones.* The different decision contexts con be analysed from an organizational point of view that focuses on the decision system (decision makers and decision structure, with rules and formal relationships with other actors in the decision process), and are synthesized in three different situations: *internal PA decision system*, without stakeholders and often with the support of experts; involvement of stakeholders in a *decision system* and a process that both implement *participation*; a *not yet active decision system.*

The six situations that result from the combination of these complexities of problem situation/decision systems are proposed in Table 1.1, and some "classic" decision aid processes have been associated to each situation and are described in this section.

Spronk [76], in a Journal of Multi-Criteria Decision Analysis editorial, invited academics and practitioners to send contributions "to ventilate insights obtained through applying MCDA techniques and studying multiple-criteria decision problems in practice, thus giving mind-teasing, stimulating input to the readers of this Journal". He suggested a presentation of some interesting results of 'practical work' without a full description of the application at hand, but only with a clear description of the problem/application aspects which would capture the attention of the readers.

Table 1.1 Activities of decision aiding in relation to the problem situation/decision system status

Decision system problem situation	Not yet active decision system	Decision system open to participation	Internal PA decision system and process
At least partially structured problem situation	Exploring data sets. Criticism and improvement of the policy making process tools. A new decision system activation. DSS elaboration	MCDA that facilitates exchange, shared vision and modelling. Implementation of environmental laws	Recurring selection or prioritization processes. Implementation of an internal procedure
New and unstructured problem situation	Exploring issues relevant to policy makers. Exploratory workshop in an action research ambit. Knowledge base elaboration	MCDA integration with participatory or structuring methods. Environmental policy analysis. Changes in vision and practice	Improvement of an internal procedure. Definition and activation of a new policy or an internal procedure. Pre-negotiation study for conflict analysis and dissolution

Rauschmayer and Wittmer [63], starting from the analysis of experiences made by combining multi-criteria decision aid and participation methods, realized that the main requirement for the resolution of environmental conflicts is the capability of coping with the main identified complexities, and they proposed aspects/criteria that could express this capability. Their proposal and other criteria taken from the literature (see above all [19, 36, 48, 79, 80]), are here synthesized in a list of aspects that mainly characterize the role of MC applications in PA. These aspects are: *the nature and social dynamics of the organizational context, the main difficulties and the activities adopted to face them, the costs and main results, legitimacy and accountability.*

Some of the MC applications in PA that have been proposed in literature are connected to the six situations that result from combining the complexities of a problem situation/decision system. Some aspects, which mainly characterize the role of MC applications in PA, are outlined here and are discussed in the next section and then used to describe some specific MC applications.

1.2.2 MC Applications Without the Activation of a Decision System

In some situations, MC methods can be applied to problems, even when a decision system has not yet been activated. There may be different reasons for this, and a first distinction has here been made in relation to the presence or absence of a client. A specific client does not exist when MC applications are developed in the ambit of a research project, e.g. sponsored by the European Commission. The application, in relation to a real life problem situation that can be structured or unstructured, may include the involvement of possible actors of a future decision system or actors of the just concluded phase of the process that has produced information for a future phase, with new aims and specific actors (see, for instance, [5, 14, 37]).

The situation is similar when a project is developed as part of a doctoral thesis, in interaction with a real problem situation, experts, stakeholders and possible decision makers, with the aim of elaborating a structured knowledge base that can facilitate future decision processes (see for instance [16, 44, 65]). A different situation is motivated by the criticism of some policy making processes and it has the aim of improving the quality of indices that are used to obtain evidence in order to set specific goals and to measure the progress that has been made towards these goals. An MC application may be developed in relation to an international composite index "to remedy some of the methodological problems where a weighted sum is computed using ordinal data" [39], to evaluate the financial viability of local municipalities (as in the case of Greece, see [15]), to outline how an indicator can be generated to construct measures of poverty and why this indicator is essential in policymaking and monitoring poverty reduction [83], or to underline the limits of the adopted resilience indices and to demonstrate, by means of a new model of resilience and an MC application to a real case study as a pilot case, that MCDA "exists" and can be very useful in decision processes that have the aim of increasing resilience [70].

The situation is similar if a structured approach to decision support has the aim of helping all the involved stakeholders to understand the issues under discussion, to formulate opinions and values, and to identify the most cost effective measures to protect populations, potentially impacted by a major accident, within a land use planning programme [45] or of helping public authorities to understand under which conditions (scenarios of weights and evaluations) an alternative action can become preferable [26]. When a client exists, but a decision system has not yet been activated, the nature of the problem situation and the role of the client, in relation to an actual or possible decision process, can explain why an MC application develops and what its aims are. Two examples are synthetically explained hereafter.

In the first, a methodological proposal has to be tested in practice and only a real/realistic situation would allow a good test to be conducted and understandable results to be obtained. Belton et al. [9] described a study, in the form of a 2 day action research workshop in partnership with the Facilities Directorate of a large U.K. NHS Hospital Trust. The workshop involved managers of the Directorate, of its Department of Supplies and Commercial Services and of the main Department customers (such as Nursing, Pharmacy, Pathology and Hospital Services), to explore the strategic direction of the Department and to develop an action plan that would be consistent with the agreed upon direction. The main aim of the analysts was to learn from the integrated use of two methods, that is, problem structuring and multi-criteria analysis, both of which were put into practice in the workshop. The participants were well aware that the workshop was only exploratory, but a good integration of tools and expertise in their use in complex situations made the application useful for both the analysts and the participants. The group involved in the workshop was enabled to make progress towards the definition of a strategic direction, by means of the identification and evaluation of alternative activities which the Directorate subsequently took into account.

In the second, a situation of conflict between the main actors was blocking any decision being made, because each solution proposed by one actor was rejected by at least one other actor. The development of an urbanization plan for the zone of the city affected by the proposals presented an opportunity to try to dissolve/resolve the conflict. An MC application allowed the impasse to be overcome and a new decision system to be activated. The client was the Municipality and two teams, made up of planners and analysts, collaborated [4]. The analysts were impeded from getting in contact with the involved actors (including the Municipality technicians), because the study was intended as a basis for later negotiations, and any interaction would have reduced the outcome of the negotiations. The other actors' viewpoints were (indirectly) taken into consideration, their proposals were analysed in depth and possible shared solutions were elaborated. At the end of this intervention, a decision system was created, by the National Government, to make the final choice, and the coordinator of the analysts participated as an advisor. A similar situation has been described in [57] and is described synthetically in the next section.

1.2.3 Decision System Open to Participation

Societal complexity calls for stakeholder participation, and in recent years an increasing demand for participation in policy making processes has arisen from opinion groups and citizens. Participation may be described as "forums for exchange that are organised for the purpose of facilitating communication between the government, citizens, stakeholders and interest groups, and businesses regarding a specific decision or problem" [64], but participation has here been analysed in a more restrictive way, as one specific characteristic of some decision processes that are defined as participatory decision processes.

Stakeholders play different roles in PA decision problems and each of them proposes a different way of seeing and interpreting a problem situation on the basis of his/her background, experience, training and values. Sometimes, participation has to be constructed, e.g. when people/organizations that will be affected by the decision are not aware of the situation and have to be identified as possible stakeholders, so as to be involved in the decision process. A participatory decision process presents a complexity that may be different, in terms of attitude and number of the involved stakeholders, their perspectives, objectives and mutual relationships, above all when there is a risk of personal or organizational conflicts. When an organizational context is characterised by a relative stability, time margins may be available to analyse and face a problem. When an organisational context is evolving, the difficulties for the analyst grow.

Qualitative tools offer the possibility of making participatory decision processes more structured and transparent, but the use of transparent tools, such as MC models and methods, also places emphasis on the structuring activity, thus facilitating exchange within the decision group as well as with the institutional or social organizations that are represented in the participatory process and the general public.

Environmental decisions are more frequently facilitated by means of applications that combine multi-criteria and participatory processes than in other domains. Governments and other representative bodies affect environmental decisions by framing the decision situation, giving criteria values and establishing guiding principles, or directly by activating participatory decision processes. MCDA has an important and legitimate role to play in environmental policy analysis [80].

In Europe, MC applications, in relation to participatory processes, are frequent, above all in Finland and Switzerland. Participatory planning approaches and applications of MC methods have been proposed by Finnish scholars in several papers (see for instance [28, 29, 32, 33, 41]) and a new edition of the book by Kangas [34], which places special emphasis on the selection of criteria and the creation of alternatives in practical multi-criteria decision making problems. A Swiss research team has acquired a great deal of experience in aiding participatory decision processes, and the decision aid approach the team has adopted, to elaborate MC models and use MC methods in participatory processes, has been described, with examples and methodological insights, in several books and some papers (see for instance [11, 42, 43, 60, 61, 75]).

Other MC applications in participatory processes, both in Europe and elsewhere, may be distinguished in relation to the nature of the decision problem, which can be at least partially structured (see, for instance, [10, 27, 38, 52, 72, 77, 80]) or new and unstructured [40, 59, 77].

MC applications, in relation to participatory processes, have frequently been proposed in OPDE network meetings (Des Outils Pour Décider Ensemble—Tools to decide together).[1]

In 2002, a workshop, funded by the European Science Foundation, was held at the UFZ-Centre for Environmental Research in Leipzig. The workshop explored the potential of combining multi-criteria and participatory methods to improve processes in which the social dimension is important, stakeholders have to be included, and transparency for the participants and also for the non-participants is essential. Qualitative methods were considered important to facilitate the identification of the

[1] They are available at: http://www.res-opde.org/index.php/opde/index/pages/view/editions

involved organizational system and its participation and, if applied appropriately, to improve legitimacy, reduce the negative impact of some social dynamics and allow the MCDA application to be implemented. A special issue of the Land use policy journal, on the resolution of land use conflicts by means of participation and MC tools, was dedicated to the workshop results [81].

The activities of understanding, formulating and structuring problems are also important in participatory decision processes, and an integration of problem structuring methods (see for instance [49]) and MCDA often improves participatory processes (see for examples [3, 8, 9, 51]).

1.2.4 Internal PA Decision System and Process

MCDA plays an important role in the policy making processes that allocate tangible or intangible public resources. These processes in general only involve a single organization, but its different institutional levels and sometimes different departments are often involved.

In the policy analysis field, the process is characterized by a cycle of design, testing, implementation, evaluation and review of public policies [79]. In the 1990s, the UK Government introduced a definition of policy making as a learning process that should be studied, analysed and monitored in order to obtain new evidence to build future policies. This vision was then included in a new policy making approach, Evidence-Based Policy-Making, that has been criticized for many reasons, above all because it seems that this approach privileges conventional scientific methods and unreliable conclusions when considering, constructing and interpreting knowledge sources and information (see De Marchi et al. [19], for a detailed description of both the interesting aspects and criticisms).

However, the concept of policy making as a learning process is suitable for several MC applications in which MCDA is used at a specific stage of the policy making process, above all to facilitate the implementation and review of public policies. Again in these cases, the distinction between at least partially structured problem situations and unstructured ones should be considered an important aspect.

An example of this distinction was proposed in [47], in which two categories of problems were proposed in relation to the implementation of the Sustainable Development (SD) principle in an Organization in France. The first category of problem is described as “A need to debate and initiate a dialogue between actors about the way to make the SD principle move from philosophical concept to pragmatic and operational tool”. The second is described as “A need to rationalize the implementation of SD actions”, i.e. a problem situation that is at least partially structured, where the involved actors are those of the operational decision level, and information is more quantitative than qualitative. An example of this category is the ranking of operational actions in order to execute a specific SD action, to control the energy consumption of public buildings [47], or to increase the sustainability of a whole community [18], or an MC application in the ambit of an Environment Impact Assessment procedure, to complete the general plan of a municipality (as in the case of a Finnish municipality, which included indications on the order in which the different regions should be developed) [30].

The first category instead describes an unstructured problem situation in which the boundary of the SD principle application, the investment in SD actions that should be made, their impact on both the tactical and the operational level within the Organization have to be analysed, made explicit and formalized, with the involvement of the Organization. An MC method was used to deal with this problem in INERIS, a public institute that works as a technical support organisation for the French Ministry of the Environment (above all in the field of industrial environment risks), and it involved the strategic and tactical levels of decision [46, 47]. More than 48 actions were proposed by the staff, as the result of a long investigation. An important aspect of this MC application is that the Institute was very familiar with the chosen MC method, which they used and continue to use daily for risk management and risk analysis problems. The direct involvement and coordination of the Directors allowed the criteria, weights and parameters to be defined and evaluated. The results of the MC application were debated and some of the suggested actions were implemented. Some aspects that are generally not described in literature were proposed and considered useful for the readers: the process was considered long, hard and expensive, but it reached the objectives of being effective, legitimized and transparent to all the stakeholders.

An intervention in PA, to rationalize a monitoring function associated with the implementation of a law, was described in [53, 54]. The Piedmont Region, in Italy, had requested a team to construct a procedure and set up a system to monitor the implementation of a new law to finance projects in the Tourism sector. The aims of the monitoring and future use of the acquired data were not clearly defined, because of a total lack of previous experience both as far as the team as such and the decision system are concerned. An MC method was used, at the start of the monitoring process, to explain how different data could be dealt with in an MC model and how the acquired information could be synthesized and transferred to the policy making process. A simulation model was created to orient the monitoring process, not only to acquire quantitative data but also to stimulate and memorize different knowledge elements (motivations of project interruptions, answers to a questionnaire, interviews, photographs, judgements of experts and so on) that could have been useful to create a "picture" of the situation that would be clear enough to be understood and collectively analysed by the team and the decision system. At the end of the monitoring process, the same MC method was used to synthesize and use all the acquired knowledge elements and to propose modifications and/or integrations of some activities to the decision system for future law implementations.

An MC application within a PA decision system may involve several institutional levels of the same administration. Bana e Costa [2] described a decision-making body, made up of 18 municipal mayors, that was involved in a problem of public resource allocation in which conflict could have arisen if the environmental, social and economic impacts at the level of the 18 municipalities had been significantly unbalanced. MC concepts, techniques and software tools were used to evaluate both the policy options and conflicts. As a result of the collective analysis of four initial reference options, it was possible to generate two new project packages, which were less conflicting for all the policy units.

This problem can seem partially structured because, at the start, four reference options were available, but the intervention did not have the aim of finding the best option. The analysis of the different reactions to the initial options and of the actual or potential conflicts became the core of this intervention and produced a new and less conflictual decision space.

1.3 A Framework to Underline the Main Aspects of an MC Application in PA

This section proposes a framework to analyse applications in relation to a problem situation and a decision system in a policy making process, and above all to underline how well an adopted approach is suited to deal with a certain aspect.

A list of aspects that mainly characterize the role of MC applications in PA is here synthesized from literature (see Sect. 1.2). They are: *nature and social dynamics of the organizational context, the main difficulties and the activities adopted to face them, the costs and main results, legitimacy and accountability*.

These aspects should be analysed in relation to the specific policy making process cycle in which an application has to be developed (design, testing, implementation, evaluation or review of public policies) and the need for information and knowledge, which can be constructed and interpreted in a decision aid process oriented towards organizational learning, rather than used directly as evidence to build future policies.

The expression *organizational context* has been used in literature to indicate a network of actors that are involved in a decision process and their relationships and attitude to communicate, cooperate or stimulate conflicts. The organizational context includes the decision system, with its rules, resources and relationships. The completeness of a network is not guaranteed if some actors cannot or do not want to be involved, or are only apparently involved. These situations induce an uncertainty that limits the capability of representing interests and points of view, and it should be eliminated or controlled [23]. When the policy making process involves different levels and/or departments of an organization, their a priori relationships (hierarchical and institutional or personal, in relation to previous specific experiences, with a positive or negative meaning result) have a notable impact on the work. The social dynamics are linked to the nature of the specific process, but also to the actors' attitudes to changing perspectives and to learning.

These attitudes should be recognised very quickly, in order to facilitate the choice and implementation of a technical approach in the decision aid process. When an actor network is constructed by experts from the Participation field, their knowledge of each participant's attitude should be passed on to the MC analysts, by means of, for example, a simple simulation of the possible dynamics that could occur during future meetings.

Difficulties may be associated to problems, decision systems and processes, in which psychological, material, organizational, logical and political obstacles can be present [62]. *Activities* adopted to face these difficulties are linked more to communication, knowledge and information management, than to the technical development of solutions and temporary or final results [50]. Uncertainties and complexities are more frequent in the cycles that have the aim of innovating (drafting new policies, defining strategies, changing policies or procedures) than in the cycles that implement already existing policies or procedures.

Each intervention implies *costs*, in the general meaning, and the risk of failure. The decision aid process is often long and expensive for both the organization and the MC analysts. Timing is often a problem, but communication efforts, relationship management and conflict control are also activities that imply specific expertise, and therefore an expensive—not only in financial terms—and not always easy involvement of different experts and/or the acquisition and use of new competences and their integration in MC tools.

Results for decision makers and processes have to be recognized and analysed, even though the long-time horizon often makes this analysis difficult. In a decision-aiding intervention, "it is important to be aware of the myth that such an intervention can provide a so-called 'right' answer, through an 'objective' analysis, which will relieve decision-makers from the responsibility of making difficult or complex judgements". An intervention may instead be aimed "at helping decision-makers and other involved actors learn about the issues and problems they are dealing with, as well as about their values and judgments, which have, of course, a subjective nature" [6].

Another result that should be recognized is the learning process for the MC analysts who should ex-post evaluate the robustness of an approach, and not only of the proposed conclusions, and the capability of coping with the main identified complexities. A failure or poor results may sometimes be more useful than positive ones, if an "action research" approach is adopted and it is considered together with a real world problem. "The experiences will be recorded, analysed and reflected upon in order to extract lessons for future interventions" [77].

Legitimacy is always indicated as an important aspect in methodological studies, but it is often neglected in literature, in relation to MC applications. It refers to the compatibility of the decision aid process (approach, procedure and proposed outcome) with existing legislation and cultural and political frames. *Accountability* and transparency of the procedure and its decision rules are considered essential elements to obtain consensus and legitimation in a decision system and elsewhere. The analysis of several cases that combine MC approaches and participation methods has produced some general observations on legitimacy and accountability [63]: when decision support procedures have officially been mandated in a decision-making system, this does not mean that the results are always taken into account; a process leading to an outcome can take place behind closed doors; all participants are accountable for the outcome; rules and assumptions should be explicitly formulated and presented upfront, and in some cases they need explicit approval by all the participants; the transparency of rules and assumptions is crucial for those who are involved in the procedure, in order to enable participation, but it is important for outsiders to understand the procedure, including such aspects as who participates and in what function, as well as the rules within the process; details on what is debated at what time and how outcomes are reached are less important and in some cases they cannot be made known, because they have to be used in a succeeding phase, for example to facilitate negotiation.

"To support policy makers in a way that is meaningful (in the sense of being relevant and of adding value to the process), operational (in the sense of being practically feasible) and legitimizing (in the sense of ensuring transparency and accountability), analysts need to draw on a wide range of existing data and knowledge (including factual information, scientific knowledge and expert knowledge in its many forms) and to combine this with a constructive approach to surfacing, modelling and understanding the opinions, values and judgements of the relevant stakeholders" [79]. In a constructive approach, actions, criteria, evaluations and preferences are not given elements at the start of the process, but they are elaborated in the decision aiding process [68, 69]. A concept, a model and a procedure are not conceived to reflect a well-defined reality but they are instead constructed by means of an interaction between the analysts and actors. A model cannot exist independently of actors, and certain activities, such as working on the concepts, modelling and activating procedures, constitute a communication and reflection tool that should allow the participant in the decision process to carry forward a process of thinking and to talk about the problem [24]. Tsoukias et al. [79] have used the term Policy Analytics to denote the use of such skills, methodologies, methods and technologies, to support relevant stakeholders engaged at any stage of the policy making process.

The most interesting aspects of some MC applications in PA are described in this section in relation to the proposed framework. Each case has been synthesized in some short statements that describe the problem situation and the MC application. The other elements that are mentioned are the promoter, who is involved in a specific stage of a policy making process, at the start of each case, and the nature and role of the organizational context, and above all of the decision system in relation to the problem situation, the presence of specific complexities, obstacles and difficulties, and the relative actions, costs and results at the end of each case. The first case has been described in detail in the literature and is here proposed to test the framework.

The others, in which I was personally involved, are proposed to underline certain aspects that are not always discussed in the literature and which could stimulate reflection.

1.3.1 Prioritization of Public Investments in Social Infra-Structures Using Multicriteria Value Analysis and Decision Conferencing [6]

The Promoter of the Decision Aid Intervention and the Stage of the Policy Making Process
In a context of scarce financial resources, decision makers of the Portuguese Institute for Social Welfare (ISS) felt the need to change the resource allocation procedure, in the ISS programme, which selects the portfolio of projects that have to be financed annually by the Centre for Social Welfare (CDSS) of the 18 sub-regions, in order to increase transparency and to ensure that the best use was made of a limited budget.

Problem Description
The legal framework that regulated the ISS programme established the aspects on which the priorities should have been based, but it did not specify the meaning of some important aspects, that is, the 'real needs' of the target population or the spatial 'coverage' levels. In order to clarify these two key issues, the multiple perspectives of the ISS decision-makers and CDSS managers had to be applied in the definition of the evaluation criteria. Moreover, the involvement of the 18 sub-regional authorities, the board of the ISS and its central planning department was considered essential to achieve a shared model, that would be common to all the CDSS, thus avoiding an unequal treatment due to the diversity of features of the sub-regions.

MC Application
A socio-technical process was activated within the ISS/CDSS organization, and MCDA was adopted as a tool, in a decision conferencing framework, that was first used to build the value functions and weight the criteria. An MC method was then used to test the model, and a sample of projects was evaluated. An extensive sensitivity and robustness analysis of the MC application was conducted and the results were discussed and used to propose a change in the prioritization order of the procedure.

Nature of the Decision System in Relation to the Problem Situation
MCDA is technically adequate for selecting a portfolio of projects to be financed, but Bana e Costa et al. [6] were involved in the decision problem with a richer and more complex aim. The first formulation of the ISS problem was to clarify some aspects of the Institute's programme and to translate them into criteria, in order to adopt an improved "rationality" in their resource allocations. Only in a second step was the problem reformulated and a decision system activated. The MC analysts,

with the involvement of the 18 sub-regional authorities, the board of the ISS and its central planning department, designed and constructed a new prioritization model.

Difficulties and Results
The large number of actors with different professional roles within the ISS structure (decision-makers, managers, experts, etc.), some representing the central office perspective, others the various regional viewpoints, clearly represented an element of complexity. A decision conferencing framework was required to overcome this problem.

Shared understanding of the key issues emerged in the form of a set of evaluation criteria, common to all the sub-regions. A sense of common purpose emerged throughout the entire organization and it can be considered a clear sign of legitimacy of the entire decision aid process.

An extensive analysis of the model results and the devoting of time to discussing and answering participants' 'what-if' questions generated the proposal of a crucial change in the procedure, which would have had a significant impact on the organisation. From the ISS managers' point of view, the process reached its objectives and a decision was made by the ISS decision-makers to adopt the newly developed model, which is currently gradually being implemented.

1.3.2 An MC Application in the Sustainable Energy Action Plan Ambit [18]

The Promoter of the Decision Aid Intervention and the Stage of the Policy Making Process
The Sustainable Energy Action Plan (SEAP) is a strategic planning tool that can be used by municipalities that have joined the Covenant of Mayors, an initiative promoted by the European Commission [17], to achieve the greenhouse gas reductions required by 2020. Public Administrations and Local Authorities need help in programming SEAP, and an agreement between the Chamber of commerce, the Banking system and Municipalities has led to the application of a new methodology in medium-sized Municipalities in the Lombardy region in Italy.

Problem Description
The new methodology integrates multi-criteria analysis and expertise in the energy saving domain, as a reference method to help Public Administrations and Local Authorities implement SEAP in the already existing building sector. The methodology needed to be tested and generalized and a sequence of applications in medium-sized Municipalities offered the possibility of testing and improving the methodology.

MC Application
A set of actions, or strategies, which combined different energy retrofitting measures, was generated by domain experts, who interacted with a specific medium-sized Municipality. The actions could improve the energetic and environmental quality of the existing building stock and guarantee that the CO2 reduction target indicated by the European Commission is reached. Nine criteria were identified by the team, which included domain experts and MC analysts, in relation to the technological, environmental and socio-economic dimensions and macro-aspects of the problem. The domain experts evaluated the actions, which were compared and ranked by means of an ELECTRE III application [66, 67]. The model parameters for the ELECTRE III application (thresholds and weight scenarios) were defined by the team and used in a first application of the method. Municipality actors were involved in an analysis of the results, and new thresholds and "political" weights were proposed and used in an ELECTRE III application sequence. Changes in some criteria were introduced and tested in a second step. The final conclusions were collectively considered robust enough and acceptable.

Nature of the Decision System in Relation to the Problem Situation
No decision system existed in this problem situation. The Municipality had joined the Covenant of Mayors initiative and was therefore involved in the sustainable energy planning process, but it was above all involved in this application as a beneficiary of an action promoted by others. However, the role of this Municipality in the modelling process and above all in the analysis of the results was active and participative.

Difficulties and Results
A structured, or at least partially structured, formulation of the problem situation characterized the start of this case, and the only complexities and costs were the heavy data acquisition process and the not so easy communication between members of the team, as the domain experts were not inclined to accept a new expression, structuring and documentation logic of their expertise. Moreover, this obstacle had not been foreseen because the promoter of this interdisciplinary team and integrated methodology was one of the domain experts, who had previous experience in a table of experts that had adopted an MC method to synthesize expertise.

The MC model is not exactly simple, but it is transparent enough to be explained to the general public. The only drawback, in my opinion, is that it is not the result of a participative decision process. From the Municipality point of view, the obtained and discussed results were perceived as very interesting and sufficient to demonstrate the validity of such an approach, which is richer than an economic vision alone, takes into account the main objective of the Covenant of Mayors initiative, that is, to increase the sustainability of the whole community, and is compatible with the local cultural and political frames.

1.3.3 An MC Approach for the Concept Design of a Complex Project [57, 58]

The Promoter of the Decision Aid Intervention and the Stage of the Policy Making Process
A Regional Administration wished to propose a public project with the aim of transforming a large area of its territory. The technical, economic and territorial complexities, at a local and at a system level, the numerous uncertainties, the several stakeholders involved in the project implementation and a political context that can be defined at least as 'non-collaborative', all suggested a precautionary approach during the project design phase.

Finpiemonte, the Piedmont Region financial agency, had been designated to develop the concept design of the project, in the form of a feasibility study, and had asked a team of MC analysts from the Politecnico di Torino to be involved in the study.

Problem Description
The MC analysts were asked to be involved in the feasibility study to develop a multicriteria analysis of some alternative actions, in relation to the main decisional problem of the project: the localization of a new structure in the project area.

Finpiemonte proposed the involvement of some territorial actors, at least in the concept phase of the study, to the Region, but the Piedmont Region rejected the proposal because a high level of conflict existed (and exists) in the area, in relation to another ongoing project, and any possibility of new conflict situations had to be avoided. At that point, the Politecnico analysts pointed out a specific difficulty concerning the use of MCDA in the feasibility study. The location alternatives of a new structure could not be evaluated if the specific use of the structure had not yet been identified (as in this case). Therefore, the location of the structure was only one of the interconnected decisional problems that the feasibility study would have had to analyse, above all if the stakeholders were not going to be involved in the study. A new proposal was therefore formulated by Finpiemonte and presented to the Piedmont Region; the proposal was accepted a few months before the end of the feasibility study. A problem structuring methodology, strategic choice approach (SCA) [23] was used in the few available months to anticipate and structure the technical problems and possible impacts of the project. At the same time, an analysis on how the involved parties could interact to reach shared decisions was developed to outline the future phases of the decision process.

MC Application
MCDA was not applied, but the inputs for an MC application were created by means of SCA, a problem structuring method that was used to shape the whole decision problem and to identify specific areas of decision, with their links and uncertainties that could hinder decision making. The uncertainties that could induce difficulties in the implementation of the project were identified, together with their prominence and tractability. The location decision was connected to the other decisions, that is,

the functions that had to be chosen for the new structure, the profiles of the end-users for the transformed and improved area and the location of other structures in the area. Alternative options were identified and combined, and their compatibility was tested. Some values associated to the decision areas and the possible involved actors were identified by means of another SCA component, the comparison areas, and used to eliminate solutions that showed very bad performances. Other solutions were eliminated because they were considered to be affected too much by intractable uncertainties. At the end of the SCA application, the results were a set of interesting solutions, some possible criteria (pointed out from the comparison areas) and an analysis of the uncertainty of each solution. Finpiemonte then completed the evaluation and the feasibility study with its experts.

Nature of the Decision System in Relation to the Problem Situation
This application was developed as part of a feasibility study that involved a restricted group of analysts from Finpiemonte, the Piedmont Region financial agency, and the Politecnico di Torino (with expertise in MCDA, Problem Structuring Methods, Real Estate Appraisal and Urban Planning), but no stakeholder representatives. The feasibility study was developed as a preliminary analysis in order to constitute an important starting point for the Promoting Committee—a decision system that has not yet been established and should include some representatives of the Piedmont Region, the Province of Turin, two mountain communities, local Administrations directly involved in the project and a network of small-medium sized Municipalities involved in correlated projects—and to facilitate its future activities and, in particular, to solve concrete decision problems in a future phase of the policy making process.

Difficulties and Results
The feasibility study was also used to outline the organisational problems that a non-collaborative multi-actor context could generate in relation to the implementation of the project, as a consequence of the limited culture of participation in Italy. Only an incremental logic of organisational learning could change the mentality of certain participants and old practices, and a second part of the SCA application was therefore proposed as a simulation of how a team of actors/experts/analysts could work and be coordinated when an 'important and useful' project implies a risk from an organisational point of view, and as a stimulus and a sort of non-binding guideline for the preliminary step of a real negotiating table [58].

The official and legitimated request for MCDA was rejected by the MC analysts because an MC application in a complex and unstructured situation, without previous analysis and structuring, would not be compatible with the specific technical and political frames.

So far, there are no results of this methodological proposal in the policy making process. However, Finpiemonte considered this approach useful and intends to use it in other situations. Moreover, another MC application that integrates structuring methods is planned.

1.3.4 A Knowledge Base and an ELECTRE Tri Application to Facilitate New Financing Actions in the Public Sector [55]

The Promoter of the Decision Aid Intervention and the Stage of the Policy Making Process
The implementation of a financing law, at a regional level, is a process that is based on operational planning activities, the collection of tenders, evaluation/selection processes, admission and granting of the financing, payment and control. The evaluation/selection activities have the aim of choosing the projects that should be financed and, in a process of organizational learning, they can play an important role in improving the whole implementation process.

In 2003, NUVAL Piemonte, the Evaluation Division of the Piedmont Region, expressed the need to have better knowledge of the competences developed in the Regional Administration offices, regarding the evaluation and selection of projects, and to understand how to intervene in order to fill possible gaps between the requirements and local expertise or between different directorates. The promoter was the president of NUVAL, a new Division that was created in Italy in the 2000s and is present in the Minister of Economics and finance and in the Regional Administrations. A first study was developed, and after it was completed, the elements that indicated the best practices and local gaps were evident. However, the promoter then retired suddenly, and as a result NUVAL did not use the outcomes directly. However, they were published in an internal journal and proposed as guidelines for project evaluation and selection procedures during workshops and training courses for Regional and Provincial Administration executives and officials in the years 2005–2009.

In 2012, the Region reasserted its will to strengthen the skills within the Public Administration in the complex activity of financing action planning and in the activities of project evaluation and selection, in order to simplify the procedures and internalize the activities which had previously been delegated to external organisations.

In this scenario, the knowledge acquired in the first study and during subsequent workshops and training courses encouraged NUVAL to conduct a new analysis, to spread knowledge and competences and to provide support when planning financing actions, either because they are particularly innovative, or to reorganize the activities.

Problem Description
Evaluation/selection is the activity that is aimed at choosing the projects that have to be financed, but it can take on a much broader meaning in a process of continuous improvement. The outcomes of analyses carried out on any previous procedures enable the subsequent ones to be improved and are helpful in defining new calls for tenders, and in some cases in planning the distribution of funds. An MC model that evolves because policy implementation had to change, but also because outcomes

from previous procedures were used to improve the implementation process, is described in [56]. An incremental process of this kind is not always possible, since it is difficult to acquire and transfer knowledge and competences, due to the fact that the figures who cover decisional positions are often changed and the acquired competences are thus dispersed; or, due to the fact that reduced times and budgets do not allow the outcomes to be analysed and therefore the models and procedures to be improved. The lack of funds, time and availability of skilled human resources often result in the externalization of the activities or in a prompt implementation of the procedures that thus end up being not very reliable or effective.

In 2003, the first study was based on the observation of 57 financing actions that concerned all the most important sectorial regulations and instruments adopted by community planning in the 2000–2006 period (professional training, productive activities, education, sports, tourism, culture and entertainment, residential construction and assistance).

The 57 calls for tenders were collected, analysed and synthesized in two schemes; the first indicated the sequence of activities of each action while the second outlined the different processes that had been carried out and indicated both the involved administration levels and their mutual relationships. The latter scheme is very similar to the one used in the Problem Formulation methodology [13] to describe the involved actors and their relationships. The schemes were validated or modified through interviews carried out with those in charge of the procedures activated at a regional level.

Four basic procedural typologies and three typologies of processes that included the procedures were recognized, presented and discussed in workshops and training courses held for executives and officials of the involved Administrations.

In 2012, an MC model was developed and used in a system to support decision and the design of innovative financing actions. It was developed as an operational proposal for the Regional Administration and for other similar decision contexts.

MC Application

A decision support system was created that enabled the level and type of complexity of each innovative financing action to be identified, and which provided connections to procedures with analogous characteristics that had already been implemented and clearly documented.

The knowledge elements, which had been acquired in the 2003 inquiry and tested in organizational learning contexts, were used to identify the aspects that needed to be used to evaluate the complexity of a new financing action. The second analysis step was developed in the ambit of the NUVAL competences, and aspects, such as the limited knowledge of the innovative elements that characterized the new procedure, and the uncertainties of the process in which it would be inserted were synthesized in four criteria: Innovation complexity, Design complexity, Decisional and organizational complexity and Adequacy guarantees for the final user.

The ELECTRE Tri method [69, 82] was used, in order to assign each new financing action to a specific complexity category. A composite index was created for each criterion and used to define an ordinal scale. The evaluation of a new action was structured as a sequence of closed-ended questions that simply and transparently “led” to the evaluation. The model parameters were elaborated with the NUVAL experts, and the knowledge base from the 2003 inquiry on the 57 financing actions was used to test and improve the model, by means of sensitivity analysis procedures followed by a robustness analysis.

Nature of the Decision System in Relation to the Problem Situation
At the beginning, the problem was totally unstructured, but the aim was clear to the promoter/decision maker. He wanted to create a role for the new Division, by improving an important and widespread function in the Regional Administration: the implementation of the Regional laws that allocate public resources to several sectors. His retirement reduced the legitimacy of the research and eliminated the possibility of creating an innovative decision system for the Region coordinated by NUVAL.

An MC model and a decision support system were set up in 2012 in the ambit of the Evaluation Division of the Piedmont Region in order to transfer it to other directorates.

Difficulties and Results
The NUVAL president’s very good knowledge of the organization was an essential element in activating an effective and quick inquiry that involved several Regional Departments. At the same time, his retirement had a negative impact and the use of the research outcomes were limited to a general improvement in the evaluation/selection competences of the involved Administrations.

The results of the inquiry were structured as a rich and easily usable knowledge base that was essential, in 2012, in relation to the new well-structured problem situation. At present, the decision support system needs to be updated but a request of resources for its updating and generalization to other analogous evaluation contexts in Piedmont and in other Regional Administrations, has not yet achieved the expected results.

1.4 Conclusions

The complexity that characterizes a policy making process, or a specific stage of this process, is related to several factors. A single decision process does not exist in a public context; although it may appear as one at the start, it always breaks down into a set of interrelated decision processes, where a decision of the involved stakeholders can reduce the decision space of the others. Actions and policies are interrelated, like their consequences, even when they seem very distant from each other and unconnected. A local change can induce changes in the whole system.

Public policies need a strategic and long-term approach to be effective, but this long-term is in contrast with the short term of legislation. In the last few years, the context has become more complex: participation and “bottom up” actions have become frequent and often mandatory. The citizens who become active in policies do not want to wait for some obscure decisions top-down, but they want to know and to be informed about a government's decisions and actions [19].

These complexities have an important impact on decision aid processes. Many issues often seem ill defined, goals do not seem clear, stakeholders and their roles and resources seem difficult to detect, interactions between administration levels, and between PA and other key actors, seem complex and not transparent, and conflicts can be hidden in apparently effective relationships.

What could the answer be to the general open question: how does one face these huge difficulties? Experience suggests insights and indicates the costs and risks. A clear perception of the long-term horizon, which in general characterizes policy making processes and sometimes also decision aid processes, and the role that organization learning can have in these processes should facilitate a technical action.

The case synthesized in Sect. 1.3.2 is a clear example. The policy making process was at its early stage, that is, the design of a policy, at a local level, consistently with supranational "indications". The methodological proposal consisted of a perspective that was alternatively oriented towards:

- creating and analyzing solutions-strategic actions that were interesting because they were consistent with the legislative frame and which were tailored to a specific local context (existing buildings);
- identifying and transparently formalizing values that were consistent with a political and socio-economic local frame.

MCDA was not used to introduce the procedure as an automatic decision support system, but to demonstrate that both solutions and values/criteria could easily be analysed and discussed, and to show that the results of an MC application were not the "right solution" but, above all, a transparent space of learning and policy making.

Another aim of this application can only be explained by considering a long-term horizon. The domain experts needed an easy and meaningful way of communicating with policy makers. MCDA can supply a structured reference as well as an operational and legitimizing tool to satisfy this aim. A habitual integration of MCDA in this problem context could be an important future result.

In this case, MCDA was applied to a well-structured problem situation, which was only a small part of a long and complex policy making process. The role of this application should be interpreted as being oriented towards facilitating communication and learning. At the same time, the domain experts saw MCDA as a tool to change the perspective from an economic one to another that also included social and environmental aspects, in a logic of sustainability. The MC application was not really innovative, but it facilitated the experts' proposal, which, at that moment, was innovative and original.

MC analysts are often involved in monitoring, evaluation and control activities, in relation to the implementation of a law and to a whole decision system that is not always transparent. A clear distinction between promoter, who has to be engaged in the design of the MC application (approach, model and procedure), and the other components of the decision system, who should at least be involved in the interpretation of the elements of knowledge acquired or elaborated, is an essential requirement for any analyst. However, the presence of these components in the decision system is often not evident and their role in the process may be underestimated. In these cases, attention to the time horizon is also important, but it should be complemented with specific attention to the organizational context and its requirements.

When the problem is new, no reference system for decision and action exists and the situation requires the elaboration of knowledge for the organization, a long and expensive course of action that can be hindered by one of several possible events that can take place in public processes. However, when the problem is not new, the situation is not particularly easy, because the analysis of a long sequence of (often correlated) past actions requires time and tools to facilitate fragmented knowledge acquisition and structuring. These tools should be made compatible and integrated with MCDA.

The time spent on analysing the results of an MC application may represent not only a cost but also a risk. If the general idea and aspiration is that MCDA can provide the "right" solution, a critical analysis that tests the result applicability could demolish the myth and the legitimacy of an analyst. Nevertheless, this kind of analysis is the only correct way of validating and improving both the understanding of the whole problem situation and the model that tries to represent and synthesize several issues and aspects. An analysis that brings the results into question may lead to an important communication space and an occasion of learning, and it only becomes a robustness analysis when knowledge and its formal representation in an MC model are validated and robust conclusions have to be formulated.

The old suggestion of Spronk [76] to propose MC problems in practice, in order to give and obtain stimulating input, should be extended to experiences in which an MC approach has different and interesting roles. Learning from these new roles may be useful because of the need for new achievements to deal with the actual difficulties of MC applications, above all in PA. Their operational validity should be demonstrated, not only in terms of robust conclusions but also in evident outcomes, at the relevant time horizon and in terms of organizational learning.

The described and used framework could be proposed as a tool to facilitate MC applications in PA and to stimulate research papers on MC applications in actual decision problems.

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Chapter 2
Measuring Social Responsibility: A Multicriteria Approach

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Abstract In this chapter we present a portfolio selection model for Socially Responsible Investment. The model, following the spirit of Socially Responsible Investment, consists of two different steps. Firstly, a social screening is applied in order to obtain the feasible set of assets accomplishing the socially responsible investment policy of the assets' manager. In this step, an indicator is obtained for the measurement of the social responsibility degree of an asset. Assets are then ranked using this indicator from the most socially responsible to the less socially responsible. In a second step, once the feasible set is obtained, composed of those socially responsible assets verifying the screens and standards imposed by the assets' manager, a portfolio selection model is proposed based on the classical Markowitz mean-variance model to determine efficient portfolios.

2.1 Introduction

Nowadays, and especially after the 2008 financial crisis, more and more stakeholders are interested in the positive actions of business. Therefore, companies have, now more than ever, to integrate social and environmental concerns into their activities and into their relationships with their stakeholders.

Socially Responsible Investing (SRI) is an investment process that integrates not only financial but also social, environmental, and ethical concerns into investment decision making. The most common socially responsible investment strategy is screening. This investment strategy consists of checking companies for the presence or absence of certain social, environmental, ethical and/or good corporate governance characteristics. Negative screening avoids investing in companies whose products and business practices are harmful to individuals, communities, or the

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environment whereas positive screening implies investing in profitable companies that make positive contributions to society, for example, that have good employer-employee relations, strong environmental practices, products that are safe and useful, and operations that respect human rights around the world [24].

When reviewing the academic literature on Socially Responsible Investing we can observe how it evolves around two main research questions [18]. The first one is concerned with whether a relationship between corporate social performance and corporate financial performance exists or not and its direction, if any exists. On the other hand, the second main research question is concerned with whether social screening has an impact on portfolio performance and its diversification where social screening is implemented through exclusion rules such as operating in a specific sector of industry; for example, gambling [22], through additional constraints; say on the minimum acceptable score on social responsibility as measured, for example, by an index [9], or by using a classification made available by some authority in the field [5].

In this work, we will first address the problem of the measurement of the social responsibility degree of an asset. This is usually done through the screening intensity of the asset defined as the number of applied social screens (see for example, [1–4, 6, 10, 13, 14, 16, 20, 21, 23]). However, measurement of social responsibility requires taking into account other factors. Several rating agencies rate firms based on their social responsibility performance taking into account not only the screening intensity but also questions related with the impact and results of the firms in social terms. Although representing an advance with respect to only taking into account the screening intensity, the measures used by rating agencies still lack of several weaknesses. One of them is the problem of the aggregation of the scores obtained for the different social dimensions into an overall score.

In this chapter we will propose an aggregating method which overcomes the later problem. The method is based on Induced Ordered Weighted Averaging (IOWA) and will allow us to rank firms based on an overall measure of their social responsibility taking into account the specific nature of the data and without the necessity of relying on the manager's preferences.

Once an overall social score is obtained we will address the portfolio selection problem from a multicriteria decision making perspective. The proposed approach will take into account the two main characteristics of Socially Responsible Investment. First, social responsibility is usually approached passively. Assets' managers apply social screens in order to determine the set of possible investments (feasible set). They decide to include or exclude investments from their portfolio based on their socially responsible investment policy and using information from their own research teams or from well-known social rating agencies as EIRIS, Vigeo or KLD. Second, once screens are applied the main objective is to maximize the financial return while minimizing financial risk.

The remaining of this chapter is as follows: in the next section we will present a proposal for the measurement of the social responsibility degree of an asset which overcomes some limitations of the social responsibility scores used in practice. In this section the first step of the model will be addressed, i.e. the application of social screens for the obtaining of the feasible set of socially responsible assets.

In the following section, once assets have been evaluated with regards to their social responsibility and they have been selected and ranked, the second step of the approach will be presented, i.e. a portfolio selection model based on the classical mean-variance model. In this second step the spotlight will be on the financial aspects of the portfolio (return and risk objectives).

All the steps will be illustrated with a real numerical example. Finally, in the last section the main conclusions will be discussed.

2.2 Measuring the Social Responsibility of an Investment

Nowadays, several independent agencies try to supply transparent and credible information about the Environmental, Social and Governance (ESG) performance of companies throughout the world. Some examples are the MSCI ESG STATS (known under the name of KLD Research & Analytics Inc.) database (http://www.msci.com), Ethibel (http://forumethibel.org), Vigeo (http://www.vigeo.com), Oekom Research, SAM (Sustainable Asset Management) or EIRIS (http://www.eiris.org).

In this chapter we will focus on a real example based on data provided by Vigeo. Vigeo is a leading European expert in the assessment of companies and organizations with regards to their practices and performance on ESG issues. Vigeo has developed Equitics®, a model based on internationally recognized standards to assess to which degree companies take into account social responsibility objectives in the definition and deployment of their strategy.

Vigeo offers access to scores in six dimensions, which are commonly used by the rating agencies: Human Rights; Human Resources; Environment; Business Behavior; Corporate Governance and Community Involvement. A description of these dimensions is presented in Table 2.1. Vigeo's database provides scores rated from 0–100, for each firm in each social dimension. It also provides an overall score for each firm calculated as an equally weighted geometric mean. Information about sectors' performance is also provided. Sectors are rated from 0–100 in each dimension.

In order to illustrate our approach we will use a real example with data provided by Vigeo and Morningstar Ltd. Our initial sample is composed of 1081 firms with social scores provided by Vigeo for 2012. We have first ranked companies based on Vigeo's overall scores (see Table 2.2). Then, and in order to take into account performance with respect to the sector of the firms, we have calculated the discrepancy (difference between the overall score and the overall average sector score) and we have ranked companies based on this discrepancy (see Table 2.2).

We have then applied a first filter and we have considered only those companies outperforming their sector, i.e. those with a positive discrepancy. This filter reduced our sample to 492 firms.

Table 2.1 List of Vigeo's evaluation criteria

Goal	Treatment
CG	Corporate Governance: Effectiveness and integrity, guarantee of independence and efficiency of the Board of Directors, effectiveness and efficiency of auditing and control mechanisms, in particular the inclusion of social responsibility risks, respect for the rights of shareholders, particularly minority shareholders
C&S	Business Behaviour: Consideration of the rights and interests of clients, integration of social and environmental standards in the selection of suppliers and in the entire supply chain, effective prevention of corruption and respect for competitive practices
ENV	Environment: Protection, safeguarding, prevention of damage to the environment, implementation of an adequate management strategy, eco-design, protection of biodiversity and coordinated management of environmental impacts on the entire lifecycle of products or services
HR	Human Resources: Continuous improvement of professional relations, labor relations and working conditions
HRts	Human Rights at the Workplace: Respect of freedom of association, the right to collective bargaining, non-discrimination and promotion of equally, elimination of illegal working practices such as child or forced labor, prevention of inhumane or degrading treatment such as sexual harassment, protection of privacy and personal data
CIN	Community Involvement: Effectiveness, managerial commitment to community involvement, contribution to the economic and social development of territories/societies within which the company operates, positive commitment to manage the social impacts linked to products or services and overt contribution and participation in causes of public or general interest

Source: www.vigeo.com

Table 2.2 Ranking based on overall discrepancy with the sector

Rank	Firm	Sector	OSS	OSF	D
F25	Danone	Food	30(6)	60(1)	30
F3	ADIDAS	Specialized Retail	25(9)	54(4)	29
F4	ADP	Transport & Logistics	27(7)	52(5)	25
F19	CGG Veritas	Oil Equipment & Services	26(8)	50(6)	24
F20	Coca-Cola Hellenic	Beverage	30(6)	54(4)	24
F47	L'Oreal	Luxury Goods & Cosmetics	37(3)	60(1)	23
F17	BNP Paribas	Banks	40(2)	60(1)	20
F60	Sanofi-Aventis	Pharmac. & Biotechnology	32(5)	52(5)	20
F62	Schneider Electric	Electric Comp. & Equipment	36(4)	55(3)	19
F52	PSA Peugeot Citroën	Automobiles	44(1)	59(2)	15

A second filter has been applied in the next step. This second filter consisted of selecting only those companies in the Advanced Sustainability Performance Eurozone Index ("ASPI Eurozone®") which is based on Vigeo's sector peers' comparison.

From that comparison companies are classified in four groups: leaders, advanced, average, below average and unconcerned. Our final sample is composed of 73 firms, the leaders and advanced firms in terms of their social responsibility compared with

Fig. 2.1 Steps in the social screening process

their sector. Figure 2.1 summarizes the screening process conducted in the first phase of the portfolio selection model.

Table 2.2 displays firms ranked in the first ten positions taking into account the discrepancy (D) between the overall sector score (OSS) and the overall score of the firm (OSF). In the fifth column (OSF) we have indicated into parenthesis the corresponding position of the firms in terms of Vigeo's overall sector. Comparison with sector scores is a key question, as sectors tend to perform better in certain social responsibility dimensions depending on their type of activities. Observing the ranking of sectors in the fourth column, we can see how best sectors in terms of their overall social responsibility are Automobiles, banks and Luxury Goods & Cosmetics. The worse are Specialized Retails, Oil Equipment & Services, Transport, and Logistics.

We can observe how Danone doubles the overall score obtained in average by its sector, Food. This is the only company ranking in the same position concerning its overall score and taking into account discrepancy with its sector (it is the firm outperforming more its sector). However, its sector, Food, ranks in the sixth position.

If we now pay attention to the performance of the firms in each dimension we can observe how the ranking changes depending on the firms and their sectors. Table 2.3 displays within parenthesis the position of the firm in the ranking considering individually each dimension. As we can observe, position changes depending on the considered dimension. For example, ADIDAS performs the best in Environment and the worst in Human Resources. L'Oreal is the best performer of the sample in Business Behavior and it performs badly in Community Involvement.

We can also observe how there are firms performing worse than the average of their sectors in certain dimensions whereas being classified as leaders when taking into account the overall score aggregating all the dimensions (e.g. ADP, Schneider Electric, PSA Peugeot Citröen and Sanofi Aventis perform worse than they sectors in the Corporate Governance, CG, dimension).

Table 2.3 Ranking based on discrepancies of firms with respect to their sector in each dimension

Firm	*Sector*	*HR*	*ENV*	*C&S*	*CG*	*CIN*	*HRts*
F3	Specialized Retail	24 (6)	**33 (1)**	7 (8)	9 (2)	23 (8)	**8 (10)**
F4	Transport & Logistics	**20 (9)**	27 (4)	12 (7)	**−1 (8)**	29 (4)	**14 (9)**
F17	Banks	24 (5)	20 (8)	15 (5)	19 (1)	25 (6)	22 (5)
F19	Oil Equipment & Services	28 (4)	**11 (10)**	16 (4)	1 (6)	31 (3)	17 (7)
F20	Beverage	24 (7)	27 (5)	5 (10)	5 (4)	13 (10)	23 (4)
F25	Food	**39 (1)**	32 (2)	20 (2)	1 (5)	27 (5)	**38 (1)**
F47	Luxury Goods & Cosmetics	32 (3)	27 (3)	**23 (1)**	5 (3)	**19 (9)**	24 (3)
F52	Automobiles	36 (2)	21 (7)	16 (3)	**−8 (10)**	25 (7)	33 (2)
F60	Pharmaceuticals & Biotechnology	**18 (10)**	24 (6)	13 (6)	**−7 (9)**	34 (2)	21 (6)
F62	Electric Comp. & Equipment	20 (8)	20 (9)	5 (9)	**−1 (7)**	**49 (1)**	15 (8)

Table 2.4 Objectives of our approach for the measurement of the social responsibility of a firm

Goal	Treatment
Take into account the performance of the firm with respect to its sector.	We first calculate the discrepancies of the firms with respect to their sector.
Take into account that certain sectors perform best in certain social dimensions due to the characteristics of their activities.	We then rank the firms based on this discrepancy. We select the best firms with positive discrepancy (ASPI index).
Obtain an aggregated weighted score that takes into account the specific nature of the data overcoming the problems associated with an a priori assignment of weighs, i.e. linear behaviors that are difficult to explain specially in the case of the geometric mean.	We obtain weights for each dimension based on the variability given by the variance of the scores in each social dimension. We apply IOWGA to obtain an aggregated weighted score for each firm.

In sum, and looking at the results displayed in Table 2.3, it seems that the geometric mean with equal weights does not reflect all the information from the firms' scores. Not being a bad choice, other measures can be proposed that based on the Geometric Mean enrich the information provided by Vigeo's overall scores. It seems convenient to take into account the specific nature of each of the social dimensions. Bold values in Table 2.3 reflect peculiar behaviour of the firms in different dimensions. For example, firm F3 behaves the best with respect to the environmental dimension but the worst with respect the Human Rights at the Workplace.

In what follows we will propose an aggregated measure of the social responsibility of the firms based on the scores obtained for each dimension taking into account the variability of these scores in each dimension. Table 2.4 summarizes the main objectives of our proposal.

Ordered weighted averaging (OWA) operators provide a parameterized family of mean type aggregation operators that includes the minimum, the maximum, and the average [29]. As an important feature of these operators, the arguments to be aggregated are ordered according to their value, and the aggregation weights are associated with a particular position in such reordering instead of being associated with a specific argument. In what follows, we will give some basic definitions.

Definition 1 A vector $\mathbf{w} = (w_1, \ldots, w_n)$ is called a weighting vector if the following two conditions are verified:

1. $w_d \in [0, 1], d = 1, \ldots, n,$
2. $w_1 + w_2 + \ldots + w_n = 1.$

OWA operators assign weights that are based on the magnitude of the arguments to be aggregated:

Definition 2 Given a weighting vector **w**, the OWA operator OWAw is defined to aggregate a list of values $\{a_1, \ldots, a_n\}$ according to the following expression:

$$OWA_w(a_1, \ldots, a_n) = \sum_{d=1}^{n} w_d a_{\sigma(d)}$$

where $a_{\sigma(d)}$ is the dth largest element in the collection $\{a_1, \ldots, a_n\}$, i.e., $a_{\sigma(1)} \geq \cdots \geq a_{\sigma(n)}$.

In particular, for $\mathbf{w}_1 = (1, 0, \ldots, 0)$ and $\mathbf{w}_2 = (0, 0, \ldots, 1)$, we obtain, respectively, $OWA_{w_1}(a_1, \ldots, a_n) = \max\{a_1, \ldots, a_n\}$ and $OWA_{w_2}(a_1, \ldots, a_n) = \min\{a_1, \ldots, a_n\}$. In order to measure the similarity of other weighting vectors with the extreme weighting vectors we will introduce the concept of orness as follows:

Definition 3 The level of orness associated with the operator OWA_w is defined as

$$\alpha = \frac{1}{n-1} \sum_{d=1}^{n} (n-d) w_d$$

The level of orness belongs to [0,1] and measures the degree to which the aggregation behaves as the maximum operator or the minimum operator. Thus, degree 1 means that the operator is the maximum, degree 0 means that the operator is the minimum and in between all the other possibilities are allowed.

Yager and Filev [31] proposed a general class of OWA operators in which the ordering of the arguments is induced by another variable called the order-inducing variable. The authors named this class, IOWA operators. Thus, IOWA operators allow us to order the arguments to be aggregated with different criteria, not only that of the order of magnitude used by OWA operators (more details on IOWA operators can be found in [15, 30, 31]).

Researchers searching for operators that allow aggregation of information, soon realized that similar reasoning to the one done with the weighted sums were also valid for products weighted with powers [28]. Therefore, some new induced aggregation operators have also been developed, including the induced ordered weighted geometric (IOWG) operator [12, 27, 28].

The ASPI index based on Vigeo's database uses the geometric mean for the aggregation of the six social dimensions. In this work, and in order to respect as much as possible their aggregation proposal, we will do the final aggregation using the Ordered Weighted Geometric operator.

Definition 4 Given a weighting vector **w**, the OWG operator OWG_w is defined to aggregate a list of values $\{a_1, \ldots, a_n\}$ according to the following expression:

$$OWG_{w,z}(a_1, \ldots, a_n) = \prod_{d=1}^{n} a_{\sigma(d)}^{w_d}$$

where $a_{\sigma(d)}$ is the dth largest element in the collection $\{a_1, \ldots, a_n\}$, i.e., $a_{\sigma(1)} \geq \cdots \geq a_{\sigma(n)}$

In particular, for the weights $w_1 = (1, 0, \ldots, 0)$, $w_2 = (0, 0, \ldots, 1)$ and $w_3 = (1/n, 1/n, \ldots, 1/n)$, we have $OWG_{w_1}(a_1, \ldots, a_n) = \max\{a_1, \ldots, a_n\}$, $OWG_{w_2}(a_1, \ldots, a_n) = \min\{a_1, \ldots, a_n\}$ and $OWG_{w_3}(a_1, \ldots, a_n) = \sqrt[n]{a_1 a_2 \cdots a_n}$.

The operator OGW can be generalized to an Induced Ordered Weighted Geometric (IOWG) operator, in which the arguments are not rearranged according to their magnitude but rather using a function of the arguments, i.e., by using an inducing variable, which is denoted by **z** here (see, for instance, [12, 28]).

Definition 5 Given a weighting vector $\mathbf{w} = (w_1, w_2, \ldots, w_n)$ and a vector of order inducing variables $\mathbf{z} = (z_1, z_2, \ldots, z_n)$, the IOWG operator $IOWG_{w,z}$ is defined to aggregate the second arguments of a list of 2-tuples $\{(z_1, a_1), \ldots, (z_n, a_n)\}$ according to the following expression:

$$IOWG_{w,z}(< z_1, a_1 >, \ldots, < z_n, a_n >) = \prod_{n=1}^{n} a_{\eta(d)}^{w_d}$$

where the arguments $< z_d, a_d >$ are rearranged in such a way that $z_{\eta(d)} \geq z_{\eta(d+1)}$, $d = 1, \ldots, n-1$.

Example Let us consider variables $a_1 = 1.6$, $a_2 = 3.2$, $a_3 = 2.2$, with inducing variables $\mathbf{z} = (z_1, z_2, z_3) = (0.2, 0.9, 0.5)$. Let us calculate the IOWG operators for two different vectors of weights:

(a) With weights $\mathbf{w}_1 = (0.6, 0.1, 0.3)$,
IOWG $(< 0.2, 1.6 >, < 0.9, 3.2 >, < 0.5, 2.2 >) = 3.2^{0.6} \times 2.2^{0.1} \times 1.6^{0.3} = 2.5036$.

(b) With weights $\mathbf{w}_2 = (1/3, 1/3, 1/3)$,
$\text{IOWG}_{\mathbf{w}_2}(< 0.2, 1.6 >, < 0.9, 3.2 >, < 0.5, 2.2 >) = 3.2^{1/3} \times 2.2^{1/3} \times 1.6^{1/3} = \sqrt[3]{3.2 \times 2.2 \times 1.6}$ =Geometric Mean{1.6, 3.2, 2.2} = 2.242.

The use of IOWG allows determining the weights describing the different importance to be attached to the scores in each dimension obtained by a firm and facilitates the aggregation into an overall score.

We will follow the three-step procedure described in León et al. [15]. We will first consider an $n \times n$ matrix **M** composed of the scores of each firm in each dimension. Then, the idea is to use the same IOWG operator n times, once for the aggregation of the scores in each of the columns of **M**.

The inducing order variable is chosen to quantify a certain property of the scores in each dimension; therefore, its definition will be made in terms of the columns of **M**. In our case, we are highly concerned about the variability of the scores within each social dimension. Therefore, our induced variable will be the variance.

Step 1: Rearranging the columns of **M** according to the inducing variable (variance) from the most preferred to the less preferred. In our case, we seek for high variability.

Step 2: Determining the aggregation weights. We cannot only set an order of preference for the scores (and, consequently, for their aggregation weights) but also we can adjust the degree of such preference by means of the orness level [15]. To calculate the weights we use the method proposed by Wang and Parkan [26] in which they solve the so-called minimax disparity problem:

$$
\begin{aligned}
&\min d \\
&\text{s.t.} \quad \frac{1}{(n-1)}\left[(n-1)\, w_1 + (n-2)\, w_2 + \ldots + 2w_{n-2} + 1w_{n-1}\right] = \alpha \\
&\qquad w_1 + w_2 + \ldots + w_n = 1 \\
&\qquad w_k - w_{k+1} - d \leq 0 \quad k = 1, \ldots, n-1 \\
&\qquad w_k - w_{k+1} + d \geq 0 \quad k = 1, \ldots, n-1 \\
&\qquad w_k \geq 0
\end{aligned}
$$

where $\alpha \in [0, 1]$ is the orness degree specified by the assets' manager.

Step 3: Calculating the overall scores for each firm. The overall score for each firm is the result of applying the IOWG operator to each element in a row with the aggregation weights obtained in the previous step.

Table 2.5 displays the rearranging of columns (social responsibility dimensions) according to our inducing variable (variance).

Table 2.5 Rearranging of social dimensions based on their variance

Firm	HR score	ENV score	C&S score	CG score	CIN score	HRts score
F1	29	60	35	36	62	44
F2	42	46	67	57	40	58
F3	49	75	43	63	54	47
F4	47	68	45	43	65	49
...	...	...	...	...	...	...
F73	56	49	40	43	45	56
Variance	128.74	94.83	73.69	102.27	142.69	115.49

Table 2.6 Aggregating weights for different orness levels

Weights	$\alpha = 0$	$\alpha = 0.25$	$\alpha = 0.5$	$\alpha = 0.75$	$\alpha = 1$
w_1	0	0.083333	0.166667	0.350	1
w_2	0	0.083333	0.166667	0.275	0
w_3	0	0.083333	0.166667	0.200	0
w_4	0	0.083333	0.166667	0.125	0
w_5	0	0.083333	0.166667	0.050	0
w_6	1	0.583333	0.166667	0.000	0

Table 2.7 IOWG overall scores

Firm	$\alpha = 0$	$\alpha = 0.25$	$\alpha = 0.5$	$\alpha = 0.75$	$\alpha = 1$
F1	35	38.62	42.61	43.82	62
F2	67	58.32	50.77	45.96	40
F3	43	48.26	54.17	52.99	54
F4	45	48.36	51.97	53.48	65
F5	57	55.44	53.93	50.74	67
F6	50	49.99	49.98	50.88	64
…	…	…	…	…	…
F73	40	43.72	47.78	49.85	45

Table 2.8 Ranks of the firms based on IOWG

Position	$\alpha = 0$	$\alpha = 0.25$	$\alpha = 0.5$	$\alpha = 0.75$	$\alpha = 1$
1	F2	F47	F25	F31	F62
2	F66	F66	F47	F52	F67
3	F47	F54	F17	F25	F70
4	F54	F2	F31	F67	F54
5	F71	F67	F52	F17	F19
6	F67	F17	F67	F62	F77
…	…	…	…	…	…
73	F38	F38	F50	F50	F50
# Coincidences	3	5	73	3	1

Once columns have been rearranged we obtain the aggregation weights for different orness levels, α. Table 2.6 displays the obtained aggregating weights.

Finally, we calculate the overall scores for each firm applying the IOWG operator to each element in a row (obtained scores of the firm in each dimension) with the aggregation weights obtained in the previous step. Results are displayed in Table 2.7 for the different orness levels.

In Table 2.8, we rank firms based on the IOWG overall scores and we compare the number of coincidences on the position of the firms when compared to Vigeo's ranking.

Last row in Table 2.8 shows the number of coincidences in the ranking when comparing to the rank from Vigeo's overall scores obtained using the geometric mean and equal weights for all the social dimensions. As expected, the orness level for which the number of coincidences in the position of the firm is higher is 0.5.

2.3 Portfolio Selection Model for Socially Responsible Investment

Making an investment decision involves solving, explicitly or not, a multiple criteria problem because it intends to balance between the conflicting objectives of minimizing risk and maximizing the financial return of the portfolio. Multiple Criteria Decision Making is a branch of Operational Research which has developed numerous methods for solving such financial multicriteria problems.

Zopounidis et al. [32] present an updated review of the literature on the application of Multiple Criteria Decision Making (MCDM) techniques to financial problems as, for instance, portfolio selection. Most of the portfolio selection models solved by MCDM methods are based on the classical mean-variance model. The classical portfolio analysis assumes that investors are interested only in returns attached to specific levels of risk when selecting their portfolios.

However, despite the wide-spread use of the Markowitz framework [17], there is an increasing acknowledgment among academics and practitioners of the necessity of incorporating social criteria in the portfolio selection decision process, in order to better reflect the individual preferences of investors. Some recent examples can be found in [1, 2, 4, 6–8, 11, 19, 20, 25].

Most of those authors simultaneously proposed the optimization of financial and non-financial objectives. However, SRI is characterized by the passive attitude of the asset managers in terms of social criteria. Managers usually apply negative and/or positive screens to determine the set of possible investments and then optimize financial criteria. In this chapter, once the social screening of the assets is done and their social overall scores are obtained, we propose a classical mean-variance portfolio selection model in order to obtain socially responsible investment portfolios.

2.3.1 Methodology

We use modern portfolio theory and the efficient frontier approach. To be more specific, we use the basic Markowitz's model where the criteria set consists of conventional criteria only, namely, return and risk. The investor's objective is to minimize only risk under the constraint that a specific level of return is required:

$$\begin{aligned}
\text{Minimize} \quad & \sum_{i=1}^{N} \sigma_i^2 x_i^2 + \sum_{i=1}^{N} \sum_{\substack{k=1 \\ k \neq i}}^{N} \sigma_{ik} x_i x_k \\
\text{s.t.} \quad & \sum_{i=1}^{N} \hat{R}_i x_i \geq R_P^{\min} \\
& \sum_{i=1}^{N} x_i = 1 \\
& x_i \geq 0
\end{aligned}$$

where

N = cardinality of opportunity set
$R_{i,t}$ = return on asset i at time t
$\hat{R}_i$ = expected return of asset $i = \frac{1}{T} \sum_{t=1}^{T} R_{i,t}$
σ_i = std. dev. of asset i return = $\sqrt{\frac{1}{T-1} \sum_{t=1}^{T} (R_{i,t} - \hat{R}_i)^2}$
σ_{ij} = covariance of assets i and $j = \frac{1}{T-1} \sum_{t=1}^{T} (R_{i,t} - \hat{R}_i)(R_{j,t} - \hat{R}_j)$
$R_P^{\min}$ = minimum expected return generated by portfolio
x_i = proportion of budget allocated to asset i

Our portfolio selection model does not include among its objectives a social responsibility objective but the sample of firms is composed of the "best" companies in terms of social responsibility (companies outperforming their sectors, i.e. leaders and advanced).

2.3.2 Results

The portfolio selection problem has been solved using LINGO. Table 2.9 shows some examples of the obtained portfolios for different return targets. First column displays the portfolio number; second column shows the composition and weights of each portfolio and finally, in last column we have included the obtained return and risk for each portfolio.

We have also computed the overall social score of the portfolio, OPS, using the overall score obtained with IOWG for $\alpha = 0.5$.

Table 2.9 Some examples of portfolios

	Description of portfolios	
1	*Composition and weights:* **F4**: 0.004137. **F14**: 0.001957. **F15**: 0.046198. **F20**: 0.081607 **F34**: 0.209789. **F64**: 0.028674. **F66**: 0.015262. **F63**: 0.1979 **F67**: 0.054078. **F75:** 0.360397	*Return:* 0.2063 *Risk:* 1.8667 *OPS:* 36.2606
2	*Composition and weights:* **F14**: 0.047373. **F15**: 0.059271. **F20**: 0.072242. **F34**: 0.249584 **F63**: 0.169091. **F64**: 0.017898. **F66**: 0.000610. **F67**: 0.018202 **F75**: 0.365728	*Return:* 0.2501 *Risk:* 1.9053 *OPS:* 44.9700
3	*Composition and weights:* **F14:** 0.0954693. **F15:** 0.0750050. **F20**: 0.0563700. **F34:** 0.2910707. **F63:** 0.1268149. **F75:** 0.3552702	*Return:* 0.3001 *Risk:* 2.0205 *OPS:* 65.9891
4	*Composition and weights:* **F14**: 0.1401843. **F15**: 0.0901143. **F20**: 0.0285395 **F30**: 0.0156617. **F34**: 0.3370393. **F63**: 0.0666574 **F75**: 0.3216319. **F79**: 0.0001716	*Return:* 0.3500 *Risk:* 2.2850 *OPS:* 71.5686
5	*Composition and weights:* **F14**: 0.1763333. **F15**: 0.1017072. **F20**: 0.0013029 **F30**: 0.0414511. **F34**: 0.3778154. **F63**: 0.0100176 **F75**: 0.2873400. **F79**: 0.0040325	*Return:* 0.3999 *Risk:* 2.7016 *OPS:* 35.8386
6	*Composition and weights:* **F14**: 0.234878. **F15**: 0.111753. **F30**: 0.089682 **F34**: 0.410546. **F60**: 0.065551. **F75**: 0.082626 **F79**: 0.004963	*Return:* 0.4499 *Risk:* 3.3782 *OPS:* 77.1147
7	*Composition and weights:* **F14**: 0.168204. **F30**: 0.282336. **F34**: 0.415570 **F60**: 0.091378. **F79**: 0.042512	*Return:* 0.4999 *Risk:* 4.9569 *OPS:* 255.4497
8	*Composition and weights:* **F30**: 0.608525. **F34**: 0.284320. **F60**: 0.000000 **F79**: 0.107155	*Return:* 0.5498 *Risk:* 9.7072 *OPS:* 360.6655

As we can observe in Fig. 2.2, firm F34 (Essilor International, Healthcare equipment) appears in all the portfolios followed in frequency by firms F14 (Beiersdorf, Luxury goods & cosmetics), F15 (BIC, Specialized retail) and F75 (Unilever, Food). These firms rank in positions 71, 60, 45 and 58 respectively, with regards to their overall firm score, OFS, for an orness degree, $\alpha = 0.5$.

It is interesting to observe how the higher the return the higher the risk, as expected. However, when calculating the associated overall IOWA score for each portfolio we find out how portfolio #5 decreases social responsibility with respect to portfolio #4 for a higher return and a higher risk. It is also surprising how the levels of social responsibility of portfolios #7 and #8 are considerably higher when compared to the other portfolios.

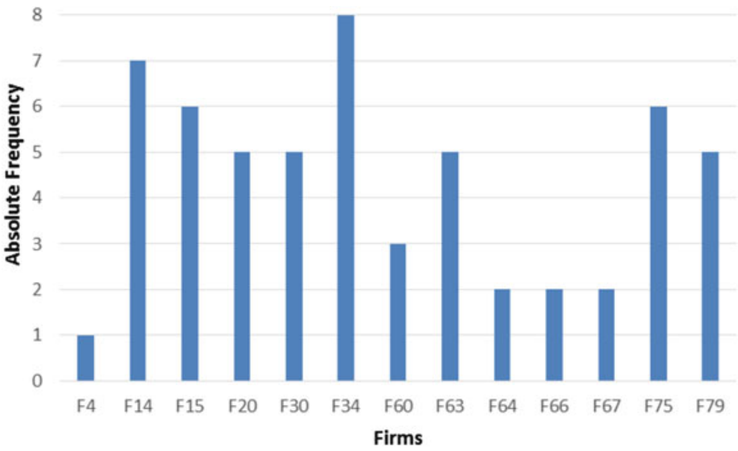

Fig. 2.2 Frequency of firms in portfolios

2.4 Conclusions

In this chapter we have solved a socially responsible portfolio selection problem. The investment strategy of Socially Responsible Investment mainly consists of the application of negative and positive screening. In this chapter we have solved the portfolio selection problem in two main steps. In the first one, we have applied both, negative and positive screenings to the sample of firms rated by a social rating agency, Vigeo. First, we have calculated a measure of the social performance of the firm with respect to its sector. Based on this measure, we have excluded from the sample those firms underperforming their sectors. Then, we have ranked firms outperforming their sectors and we have selected only the leaders and advanced firms.

When analyzing the social scores provided by the rating agency for the firms we have realized that the geometric mean with equal weights used by Vigeo to obtain an overall social score has some important limitations. In order to overcome these limitations we have proposed an aggregating method that allows establishing different objective weights for the different social dimensions based on the nature of the data, in our case, scores in the different dimensions. IOWG has been applied using as inducing variable the variability of the scores in each dimension measured by the sample relative variance. Dimensions have been ordered based on their variance and weights have been determined for each dimension using an objective method. The obtained results are quite different from the results obtained by Vigeo using for the aggregation the geometric mean and using equal unitary weights. This shows how the ranking is sensitive to the weights of the dimensions.

Once a suitable measure has been obtained, a classical portfolio selection model has been solved. Several portfolios have been obtained in this second step with different levels of return-risk and the associated overall social score has been calculated for each of them.

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Chapter 3
Multi-Criteria Decision Analysis for Financial Investments Using AHP

Jean Baptiste Rakotoarivelo and Pascale Zarate

Abstract This article aims to analyse on a risk point of view financial investments. This analysis is possible by first of all defining one the one hand several financial operations, i.e. for customers with respect to funding opportunities, investment or credits reaching, and on the other hand different types of risks associated with this activity. This analysis is conducted through a method of multi-criteria decision support methodology: Analytic hierarchy Process (AHP). We must notice that a financial institution is risky and it is in no case possible to eliminate all sources of risk. Several types of risks, inherent in this activity, are examined. These risks are grouped into four criteria such as operational risk, financial risk, management risk and external risks. Although professionals in risk management are trying to better apprehend complexity of this activity and they use to do this complex models, but many of the risks are still not well understood. Therefore, this article contributes to the risks analysis, and delivers results that will allow the institution to address the factors that may prevent the achievement to better manage financial investment.

3.1 Introduction: Banking and Microfinance Institution

Currently in the era of advanced technology, risk management has become undoubtedly one of the most important issues for financial institutions, to maintain confidence and ensure their sustainability. However credits assignment, generating a multitude of risk, is determined by the quality of the customers or by the changes in the financial markets and the developments in the banking sector. That's why everyone is not solvent for credit; some are so poor that borrowing could plunge them even deeper into debt and poverty instead of helping them, so that credit is the main source of funding for all economic activities. Financial institutions, i.e. commercial banks, microfinance institutions, represent one of the success pillars

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of the recovery and consolidation of economic activities of a country. Indeed, the management of risk is then to identify and control the risks in a financial institution to reduce and seek the best coverage potential financial, considering physical and financial contingencies. This article addresses these risks by the Analytical Hierarchical Process (AHP) methodology (see Saaty [6–8]).

The main contribution of this study consists in the problem definition. The analysis of risks for financial organisms has been defined through a precise literature review. For banking and microfinance institutions, it is essential to collect deposits and distribute credit. This activity must be conceived in relationship with the non-financial sectors that offer the collected deposits and ask the distributed credit. The financial institutions contribute to economy, while the microfinance entities provide access to financial services to those who are excluded from traditional banking system. It concerns the majority of the population in the developing countries, but also the poor persons in developed countries. Their main business is the provision of microcredit that can support and develop small economic activities.

In the second section the AHP methodology is presented as well as the proposed methodology for this analysis. Then, in a third section, the problem of financial institutions is stated and a model of this problem based on criteria, sub-criteria and alternatives, is proposed. The fourth section aims at presenting all results obtained applying the AHP methodology to the stated problem. Finally, in the fifth section conclusions and perspectives are given.

3.2 Presentation of the AHP Method

The AHP method is an analytical approach for supporting decision making following a multi-criteria approach (see Saaty [6–8]). It is fundamentally based on complex calculations utilizing matrix algebra. This method has been used in several areas, such as transport planning, rationing of energy, risk management projects, benchmarking of logistics operations, management of quality of services in hospitals, operations management, allocation resources for product portfolio management, as well as several applications on companies. It was developed by Thomas Saaty in 1970 and allows the decomposition of a complex problem in a hierarchical system. Classifying hierarchically alternatives defined by the decision maker provides the relative priorities of each alternative. Then a synthesis allows decision makers to easily understand what will be the best choice. Classification is performed at several levels which are associated to different criteria. Thus, it is possible to determine the alternative the most appropriated, depending on the priority given to each used criteria.

In this research we develop the decision process using the AHP method (see [2, 5]). This process is decomposed in 20 stages.

1. The purpose of the analysis must be clearly identified. Then the following steps are defined as follows:
2. Develop the hierarchical structure of the project: it implies to define the main criteria used for the analysis

3. Establish pairwise comparisons of criteria defined in the previous step
4. Define the comparison judgment matrix
5. Calculate the priorities vectors
6. Calculate the average value Priority (λ_{max}), which represents the largest eigenvalue
7. Give the value of Random Index (RI), which represents the average of indices calculated at each replication for different sizes of square matrix
8. Calculate the consistency index (CI), which is defined as the ratio between the difference of the eigenvalue λ_{max} minus the number of criteria on the number of criteria
9. Calculate Consistency Ratio (CR), which is the ratio of the index of consistency Calculated on the matrix corresponding to Judgments of the decision maker on the random index.
10. If the CR is higher than 10 % then go back to step 3 otherwise go to the step 11
11. Establish the full table of comparison criteria
12. Establish peer comparison sub-criteria in relation to the studied criteria
13. Establish comprehensive sub-criteria comparison matrix
14. Determine the sub-criteria relative performance relatively to criteria
15. Calculate the global aggregation of sub-criteria
16. Establish the pairwise comparison of the alternatives
17. Establish the comprehensive alternatives comparison table
18. Determine the relative performance of each alternative subject to sub-criteria
19. Calculate the global aggregation of alternatives,
20. Express the best decision.

3.3 Financial Institutions Definition

In this section we present the conducted analysis step by step, following the general algorithm presented in the previous section.

3.3.1 Analysis and Identification of the Project Objective

The main objective of this study is to define what the less risky alternatives for financial institutions like banks and microcredit institutions. The conducted analysis addresses all kinds of financial organisms: banks, credit offering institutions, National Banks etc.... All these organisms are generally faced to decision like for ample: accept a credit for a family, accept credit for companies etc. This analysis aims at ordering all possible alternatives based on several types of risk.

3.3.2 Develop the Hierarchical Structure of the Project: Risk Definition

Risk is caused by random events whose occurrence is likely to cause injury to persons or damages to objects or both. There is an apparent contradiction between the unknown, the uncertain, the risk in one hand, and the need for a method, a discipline, a risk management on the other hand. Risk management leads to the critical examination of the whole project for an identified purpose and aims at evaluating the events that could disrupt the project. Uncertainties may result from events of various kinds. We can distinguish unforeseen hazards, risks and issues. Risk management focuses on identifiable and quantifiable risks.

Our purpose is to define the risk of a financial institution. It can be defined as follows: it is linked to the fact of losing money due to a financial transaction (in an active financial) or an economic transaction with a financial impact (example sale on credit or in foreign currencies).

Risk depends on the economic activity in question and the environment in which the company is situated.

Based on a literature review (see [3, 4]), we have defined different types of risks as for example: risks related to environment, risks related to the political situations, risks based on the client situations etc.

Risk management [1] is defined as a set of activities (financial and operational) that maximizes the value of a company or a portfolio by reducing the costs associated with the volatility of its flow inputs and outflows (cash flows). Risk management and internal control activities stem from the carrier of the risks taken by the bank (especially when granting a loan, or seeks to maximize its cash flow by placing the financial markets) [1].

Integrated Risk Management is a continuous, proactive, and systematic process to understand, manage, and communicate risk from an organizational wide perspective. It is about making strategic decisions that contribute to the achievement of an organization's overall corporate objectives [1].

The management of a bank is a comprehensive and coordinated management, subject to internal and external constraints, profitability and risk in the activities of the establishment [1].

3.4 Financial Institutions Analysis Step by Step

3.4.1 The Hierarchical Structure

The different risks were grouped into four different categories in Table 3.1.

The hierarchy structure reflecting the problem to solve is defined. This hierarchical structure clarifies the problem and allows identifying the contribution of each element to the final decision. The hierarchical structure is detailed in Fig. 3.1. The

Table 3.1 Different types of studied risks

Operational risk	Financial risk management	Counterparty risk	External risk
Risk of fraud	Currency risk	Liquidity risk	Country risk
Risk of hold-up	Credit risk	Interest rate risk	Risk guarantee
Information risk	Risk insider	Market risk	Concentration risk
Generic risk	Legal and regulatory risk	Solvency risk	Risk of recovery
Legal risk	Underwriting risk		Risk of exposure

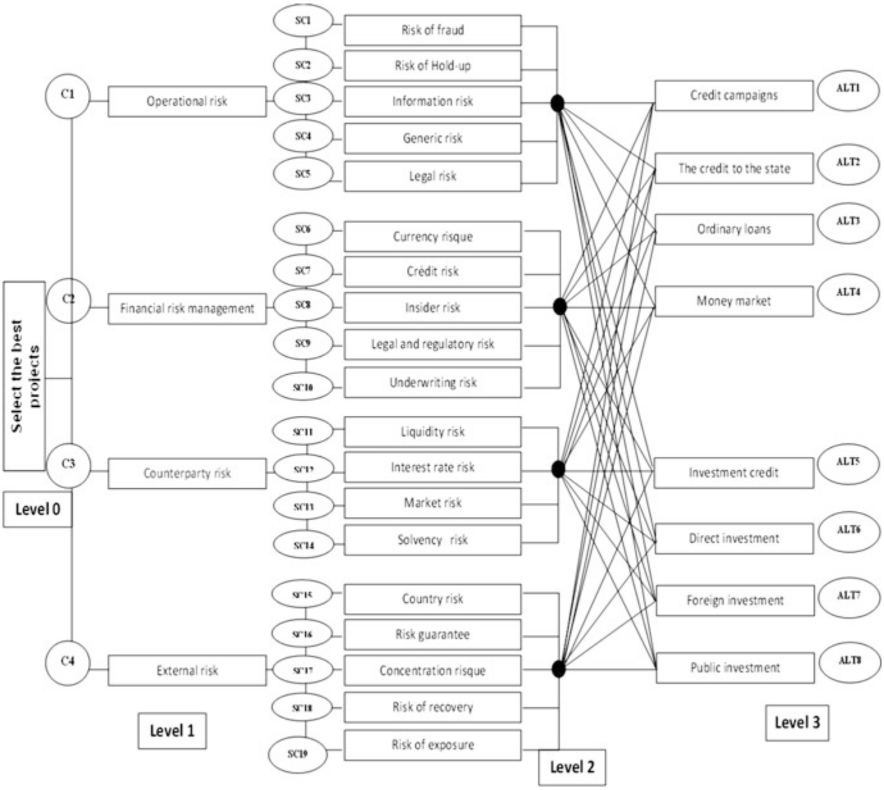

Fig. 3.1 Complete graphical representation

criteria and sub criteria are the elements that influence the final choice. At this step the goal is to found the links among criteria, sub-criteria and alternatives.

In this research we built four hierarchical levels. Level 0 being the global objective, Level 1 compares the criteria in relation to the global objective; level 2 compares the sub criteria subject to criteria, level 3 compares the alternatives subject to sub-criteria. The aim of each analysis is to target the best. Figure 3.1 shows a complete decomposition of the developed hierarchical structure based on four levels.

- C_i = Criteria, SC_i = Subcriteria, ALT_i = Alternatives
- Level 0 represents the aim to select a project among the set of all alternatives.
- Level 1 = C_i, represents the criteria for this analysis that is composed as follows:
- $_1$ = operational risk
- C_2 = financial risk management
- C_3 = counterparty risk
- C_4 = external risks.
- Level 2 includes 19 sub-criteria denoted as SC_i.
- Level 3 includes 8 alternatives denoted as ALT_i.

The lines indicate the links among the four levels. Level 1 is composed of four criteria linked to the level 2 including:

- Level 0: top-level project is connected to the level 1. This link represents the way how the project is structured.
- Level 1: is composed by four criteria C_1, C_2, C_3 and C_4.
- The criterion C_1 is connected to five sub-criteria: SC_1, SC_2, SC_3, SC_4 and SC_5.
- The C_2 criterion is linked to five sub-criteria: SC_6, SC_7, SC_8, SC_9 and SC10.
- The C_3 criterion is connected to four sub-criteria: $SC_{11}, SC_{12}, SC_{13}$ and SC_{14}.
- The C_4 criterion is linked to five sub-criteria: $SC_{15}, SC_{16}, SC_{17}, SC_{18}$ and $SC_1$9.
- All sub-criteria (SC_1 to SC_{19}) are linked with the eight alternatives ($ALT_1, ALT_2, ALT_3, ALT_4, ALT_5, ALT_6, ALT_7, ALT_8$).

3.4.2 Pairwise Comparisons for Criteria

After the presentation of the problem decomposition, pairwise comparisons are carried out for each level. Level 1 (= C_i) and Level 2 (= SC_i) are processed in that order successively. The decision makers judgments are kept thanks to a pairwise comparison among the criteria. The four criteria: operational risk, financial risk management, counterparty risk and external risks are successively compared pair by pair. The comparison can lead to the design of a matrix model called Matrix judgment.

The decision matrix is a representation of the relationship between two elements (pairwise comparison) that share a common parent and assesses the importance relative one element relative to another indicated by the following procedure:

The main objective is to compare the relative importance of all elements belonging to the same level.

For each comparison the most important criterion should be chosen and expressed. For example, one could say that operational risks are greater than financial risks.

Table 3.2 Pairwise comparisons for criteria

Digital or intensity scale	Scale or verbal definition	Commentary
1	Equal importance of elements: **Also important**	Both competitors elements in the same way with the objective
3	An element is slightly larger than the other: **Slightly higher**	The experience and personal judgment slightly in favor of one element over another
5	An element is more important than the other: **Highly signification**	The experience and personal judgment verify in favor of one element to another
7	An element is very more important than the other: **Very highly important**	An element is largely dominant
9	An element is absolutely more important than the other: **Absolutely most important**	The dominance of one element relative to another is demonstrated and absolute
1,2,4,6	Intermediate value between two judgments	Used to refine his judgment
Reciprocity	If the element **i** is assigned on of the above number when compared to the element **j j** will have the opposite value when compared to **i**	

Table 3.3 Matrix judgments

Pairwise comparison criteria	Operational risk	Financial risk management	Counterparty risk	External risk
Operational risk	1	1	7	4
Financial risk management	1	1	3	5
Counterparty risk	1/7	1/3	1	3
External risk	1/4	1/5	1/3	1

The relative importance is expressed on a pre-determined scale from 1 to 9 (see Table 3.2)

The scale is proposed by Saaty [7] and used in our analysis.

3.4.3 *Comparison Judgment Matrix*

Converting the criteria comparison into a matrix called judgment matrix is shown in Table 3.3, by transcribing the feedback values in each cell. The judgment matrix is of course a symmetric matrix and this matrix is defined based on Table 3.3.

This matrix describes the relative importance between criteria. Comparing criteria C_1 and C_2, a value is assigned to this comparison and the inverse value is assigned to the comparison between C_2 and C_1.

$$A = [a_{ij}] = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_4 \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{pmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{pmatrix} \end{array} \tag{3.1}$$

The project is then modeled as a $n \times n$ square matrix as follows:

$$\begin{bmatrix} 1 & 1 & 7 & 4 \\ 1 & 1 & 3 & 5 \\ 1/7 & 1/3 & 1 & 3 \\ 1/4 & 1/5 & 1/3 & 1 \end{bmatrix}$$

3.4.4 Priority Vector Calculation

This step aims at calculating the relative importance of each element of the hierarchy from the evaluations obtained in the previous step. The determination of priorities of each elements of the matrix is calculated using the eigenvector approach. The priorities calculation is done in the following way:

1. Calculate the column totals
2. Dividing each element of the matrix by the total of the column
3. Averaging the elements of each row of the matrix

The result of this calculation is the following:

$$C_1 = 0.434; C_2 = 0.365; C_3 = 0.128; C_4 = 0.072.$$

3.4.5 Calculation of the Value λ_{max}

The matrix A is multiplied by the priority vector elements (x), x is the eigenvalue vector (n) of priority. We calculate the average of the found values. The result is called λ_{max}. a_{ij} is the value in the judgment matrix of the element (i)th line and the component (j)th column.

The normalized value a_{ij} equals to $a_{ij} = W_i/W_j$,and $a_{jj} = 1$ reciprocal $a_{ji} = W_j/W_i = 1/a_{ij}$ Wi represents the contribution to selecting the best choice for each criterion Wj represents the contribution of a specific criterion to the main objective [6] defines that the largest eigenvalue is called λ_{max} **and** is $\lambda_{max} = a_{ij}W_j/W_I$

$$0.434\begin{vmatrix}1\\1\\1/7\\1/4\end{vmatrix}0.365\begin{vmatrix}1\\1\\1/3\\1/5\end{vmatrix}0.128\begin{vmatrix}7\\3\\1\\1/3\end{vmatrix}0.072\begin{vmatrix}4\\5\\3\\1\end{vmatrix}=\begin{vmatrix}\mathbf{1.983}\\\mathbf{1.545}\\\mathbf{0.529}\\\mathbf{0.297}\end{vmatrix} \tag{3.2}$$

Then, we calculate W_j for each criterion by dividing the elements of the vector of the weighted sum with the priority corresponding to each criterion.

Operational risk	1.983 / 0.434 = **4.563**
Risk of Financial Management	1.545 / 0.365 = **4.227**
Counterparty risk	0.529 / 0.128 = **4.145**
External risk	0.297 / 0.072 = **4.096**

The obtained result can be used for determining the mean value λ_{max} with "*n*" number of criteria, in this case $n = 4$.

$$\lambda_{max} = (4.563 + 4.227 + 4.145 + 4.096)/4 =\rightarrow \boldsymbol{\lambda}\mathbf{max = 4.258}$$

3.4.6 Determine the Value of Random Index (RI)

Saaty [7] developed a scale where the Random Index (RI) marks were established by conducting random judgments for a large number of replications. RI represents the average of indices calculated at each replication for different sizes of square matrix (N). Reading the RI value is indicated by a random number given in the following table.

N = number of criteria

In this case, N = 4, the corresponding value is 0.90, RI = 0.90

N	1	2	3	**4**	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	**0.90**	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

3.4.7 Calculation of Consistency Index: CI

In order to be sure of the decision makers judgements, it is possible to calculate a consistency index (CI). This consistency index is defined as the ratio between the difference of the eigenvalue λ_{max} minus the number of criteria on the number of criteria.

$$CI = \frac{\lambda_{max} - n}{n - 1} = 0.086 \tag{3.3}$$

The consistency index is then used to calculate the consistency ratio.

3.4.8 Consistency Ratio Calculation (CR)

The Consistency Ratio (CR) is the ratio of the consistency index calculated on the matrix corresponding to judgments of the decision maker and the random index RI of a matrix of same dimension. If $CR \leq 10\,\%$, the matrix is considered sufficiently coherent, if it exceeds 10 %, the assessments may require certain revisions.

$$RC = \frac{CI}{RI} \tag{3.4}$$

We have CI $=$ 0.086 and RI $=$ 0.90 while RC $=$ CI/RI $=$ 0.086/0.90 $=$ 0.0955 or 9.55

CR $= 9.55\,\%\ \ <= 10\,\%$

CR = 9.55 %, the degree of comparison consistency is acceptable

3.4.9 Establish the Full Table of Criteria Comparison

Table 3.4 called "Table of judging criteria: complete priority" represents the results of calculations.

Matrix judgement

1	1	7	4
1	1	3	5
1/7	1/3	1	3
1/4	1/5	1/3	1

Priority

Priority
0.434
0.365
0.128
0.072

Eigenvalue
Consistency Index
Consistency Ratio

λ_{max} = 4.258

CI = 0.086

RC = 9.55%

The judgment matrix of complete priority, based on eigenvalue λ_{max}, is defined as the index of consistency, and the ratio of consistency.

Table 3.4 Judgment matrix of criteria: complete priority

Comparison of criteria	Operational risk	Financial management	Counterparty risk	External risk	Complete priority
Operational risk	1	1	7	4	0.434
Financial risk management	1	1	3	5	0.366
Counterparty risk	1/7	1/3	1	3	0.128
External risk	1/4	1/5	1/3	1	0.072
λ_{max}= 4.258, CI = 0.086, CR = 9.55 %					

3.4.10 Determine the Relative Importance of Criteria

The same procedure is then applied to all defined sub-criteria presented in the Fig. 3.2 at Level 2 = SC_i. The next step consists of performing pairwise comparisons of the 19 sub-criteria, located on the second level, linked to the four criteria (Fig. 3.3, Table 3.5):

- Operational risk;
- Risk financial management;
- Counterparty risk;
- External risk.

3.4.11 Project Aggregation Calculation

Figure 3.4 shows the numerical value of the weight of four criteria ($C_1-C_2-C_3-C_4$) relatively to the nineteen sub-criteria (SC_1 to SC_{19}). The final matrix obtained by multiplying the weight of each criterion by the weight of each sub-criterion in shown in Fig. 3.5. This principle is called "Project Aggregation".

3.4.12 Establish Comparisons by Pair of Studied Alternatives

This step consists in the pairwise comparisons of the eight (08) alternatives, located on the third level, relatively to each sub-criterion SC_1 to SC_{19}. We will proceed to the calculation of the λ_{max} vector, the consistency of all the judgments, and the ratio of RC consistency. All results are synthesized the Table 3.6.

The judgment matrix of eight (08) alternatives is determined such as: ALT_1: Credits campaigns, ALT_2: The state credits, ALT_3: Ordinary loans, ALT_4: Money Market, ALT_5: Credit Investment, ALT_6: Direct Investment, ALT_7: Foreign Investment, ALT_8: Public Investment.

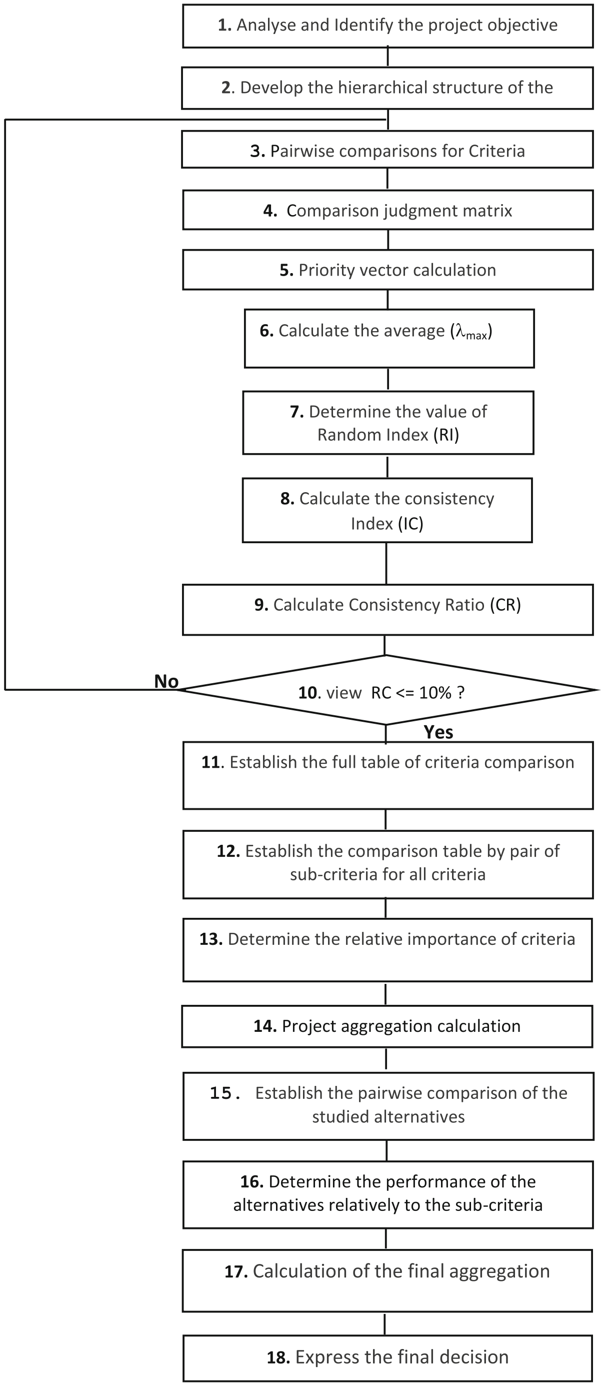

Fig. 3.2 Detailed flow chart of the decision process of using the AHP methodology

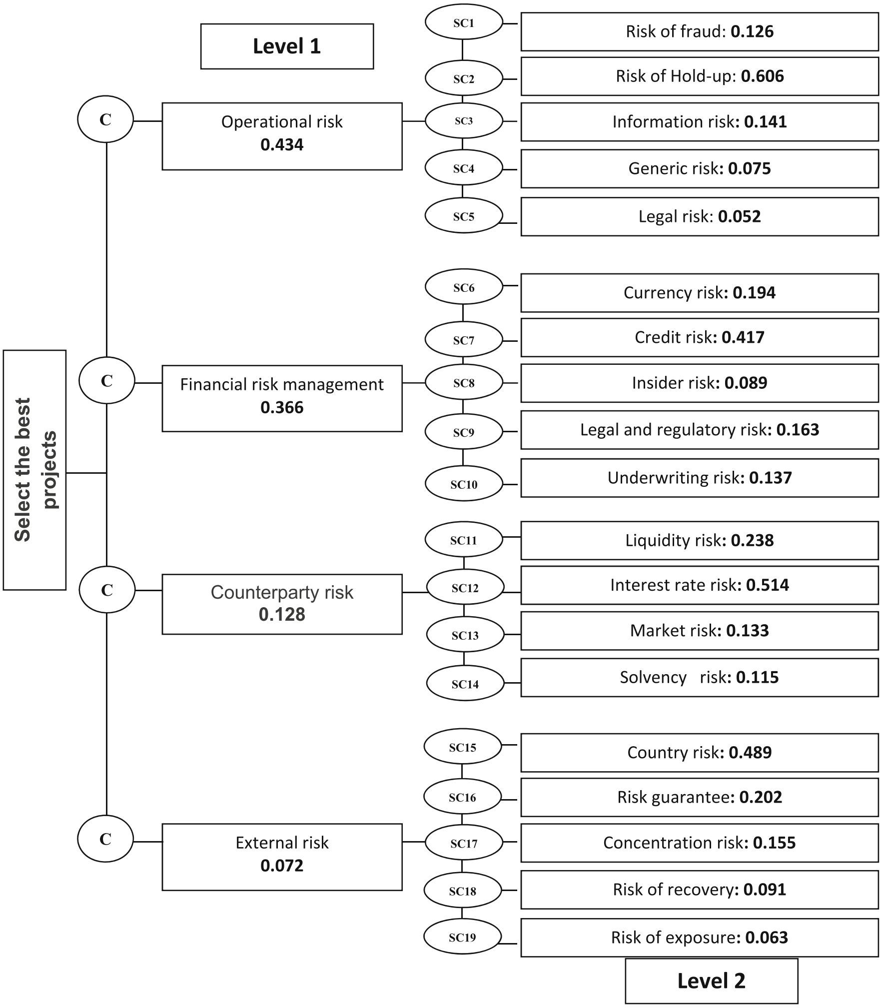

Fig. 3.3 Presentation of performance criteria and sub-criteria

This table of alternatives comparison is the converted in a matrix called Alternatives Judgment Matrix showed in Table 3.6 by transcribing the feedback values in Table 3.7 in each corresponding column.

The obtained results are given in the following table.

Table 3.5 Comparison of performance criteria and sub-criteria

The weight of criteria from the pairwise comparison	Description of weights
$M_1 = \begin{matrix} C_1 \\ C_2 \\ C_3 \\ C_4 \end{matrix} \begin{bmatrix} 0.434 \\ 0.366 \\ 0.128 \\ 0.072 \end{bmatrix}$	M_1: weight of overall risk criteria comparison matrix, priorities for choosing the best alternatives are highly rated in the following manner: M_{11} (C_1) operational risk, M_{12} (C_2) Financial risk management, $M_{13}(C_3)$ counterparty risk $M_{14}(C_4)$ external risk
$M_{11}(C_1) = \begin{matrix} SC_1 \\ SC_2 \\ SC_3 \\ SC_4 \\ SC_5 \end{matrix} \begin{bmatrix} 0.126 \\ 0.606 \\ 0.141 \\ 0.075 \\ 0.052 \end{bmatrix}$	$M_{11}(C_1)$ the criterion weight derived from the comparison of operational risk criteria (C_1) compared to SC_1 sub-criteria: risk of fraud, SC_2: Hold-up risk, SC_3: Information risk, SC_4: generic risk and SC_5: legal risk
$M_{12}(C_2) = \begin{matrix} SC_6 \\ SC_7 \\ SC_8 \\ SC_9 \\ SC_{10} \end{matrix} \begin{bmatrix} 0.194 \\ 0.417 \\ 0.089 \\ 0.163 \\ 0.137 \end{bmatrix}$	$M_12(C_2)$ weight criterion obtained from the comparison criteria risk financial management (C_2) compared to the sub-criteria SC_6: currency risk, SC_7: credit risk, SC_8: insider risk, SC_9: legal and regulatory risk and SC_10: Underwriting risks
$M_{13}(C_3) = \begin{matrix} SC_{11} \\ SC_{12} \\ SC_{13} \\ SC_{14} \end{matrix} \begin{bmatrix} 0.238 \\ 0.514 \\ 0.133 \\ 0.115 \end{bmatrix}$	$M_{13}(C_3)$ the criterion weight derived from the comparison of counterparty risk criteria (C_3) compared with SC_{11} sub-criteria: liquidity risk, SC_{12}: interest rate risk, SC_{13}: market risk, and SC_{14}: solvency risk.
$M_{14}(C_4) = \begin{matrix} SC_{15} \\ SC_{16} \\ SC_{17} \\ SC_{18} \\ SC_{19} \end{matrix} \begin{bmatrix} 0.489 \\ 0.202 \\ 0.155 \\ 0.091 \\ 0.063 \end{bmatrix}$	$M_{14}(C_4)$ the weight criterion obtained from the comparison of external risk criteria (C_4) compared to sub-criteria SC_{15}: country risk, SC_{16}: risk guarantee, SC_{17}: concentration risk, SC_{18}: Risk recovery and SC_{19}: risk exposure

Fig. 3.4 Performance criteria

$M_2 =$

	C_1	C_2	C_3	C_4
	0,434	0,366	0,128	0,072
SC_1	0.126	0	0	0
SC_2	0.606	0	0	0
SC_3	0.141	0	0	0
SC_4	0.075	0	0	0
SC_5	0.052	0	0	0
SC_6	0	0.194	0	0
SC_7	0	0.417	0	0
SC_8	0	0.089	0	0
SC_9	0	0.163	0	0
SC_{10}	0	0.137	0	0
SC_{11}	0	0	0.238	0
SC_{12}	0	0	0.514	0
SC_{13}	0	0	0.133	0
SC_{14}	0	0	0.115	0
SC_{15}	0	0	0	0.489
SC_{16}	0	0	0	0.202
SC_{17}	0	0	0	0.155
SC_{18}	0	0	0	0.091
SC_{19}	0	0	0	0.063

Fig. 3.5 Aggregation project

$M_2 =$

	C_1	C_2	C_3	C_4
SC_1	0.055	0	0	0
SC_2	0.263	0	0	0
SC_3	0.061	0	0	0
SC_4	0.033	0	0	0
SC_5	0.023	0	0	0
SC_6	0	0.071	0	0
SC_7	0	0.153	0	0
SC_8	0	0.033	0	0
SC_9	0	0.060	0	0
SC_{10}	0	0.050	0	0
SC_{11}	0	0	0.030	0
SC_{12}	0	0	0.066	0
SC_{13}	0	0	0.017	0
SC_{14}	0	0	0.015	0
SC_{15}	0	0	0	0.035
SC_{16}	0	0	0	0.015
SC_{17}	0	0	0	0.011
SC_{18}	0	0	0	0.007
SC_{19}	0	0	0	0.005

3.4.13 Determine the Performance of the Alternatives Relatively to the Sub-Criteria

The next step consists in determining the alternatives performances relatively to the sub-criteria located at the second level. Figure 3.6 shows the alternatives weight, as Fig. 3.7 shows the sub-criteria weight.

3.4.14 Calculation of the Final Aggregation

This step consists in calculating the final aggregation, that is to say, we calculate the performance of each alternative relatively to each sub-criterion (SC_1 to SC_{19}). Table 3.8 illustrates the technique of integrating alternatives weight.

Table 3.6 Alternatives judgments matrix

Pairwise comparison of alternatives	Credits campaigns	The state credits	Ordinary loans	Money market	Investment credit t	Direct investment	Foreign investment	Public investment
Credits campaigns	1	3	3	3	4	4	4	1/7
The state credits	1/3	1	3	4	3	4	4	1/3
Ordinary loans	1/3	1/3	1	2	2	2	2	1/3
Money market	1/3	1/4	1/2	1	2	2	2	1/3
Investment credit	1/4	1/3	1/2	1/2	1	2	2	1/4
Direct investment	1/4	1/4	1/2	1/2	1/2	1	3	1/4
Foreign investment	1/4	1/4	1/2	1/2	1/2	1/3	1	1/4
Public investment	7	3	3	3	4	4	4	1

Table 3.7 Global matrix of alternative judgments "complete priority"

Pairwise comparison of alternatives	Credits campaigns	The state credits	Ordinary loans	Money market	Investment credit t	Direct investment	Foreign investment	Public investment	Priority complete
Credits campaigns	1	3	3	3	4	4	4	1/7	0.199
The state credits	1/3	1	3	4	3	4	4	1/3	0.170
Ordinary loans	1/3	1/3	1	2	2	2	2	1/3	0.090
Money market	1/3	1/4	1/2	1	2	2	2	1/3	0.075
Investment credit	1/4	1/3	1/2	1/2	1	2	2	1/4	0.060
Direct investment	1/4	1/4	1/2	1/2	1/2	1	3	1/4	0.054
Foreign investment	1/4	1/4	1/2	1/2	1/2	1/3	1	1/4	0.039
Public investment	7	3	3	3	4	4	4	1	0.313
λ_{max}= 8.92, CI = 0.132, CR = 9.33 %									

Fig. 3.6 Alternatives weight

$$M_{21}(ALT) = \begin{matrix} ALT_1 \\ ALT_2 \\ ALT_3 \\ ALT_4 \\ ALT_5 \\ ALT_6 \\ ALT_7 \\ ALT_8 \end{matrix} \begin{bmatrix} 0.199 \\ 0.170 \\ 0.090 \\ 0.075 \\ 0.060 \\ 0.054 \\ 0.039 \\ 0.313 \end{bmatrix}$$

$\mathbf{M_{22}} =$

Risk of fraud	**SC_1**	**0.055**	0	0	0
Risk of hold-up	**SC_2**	**0.263**	0	0	0
Information risk	**SC_3**	**0.061**	0	0	0
Generic risk	**SC_4**	**0.033**	0	0	0
Legal risk	**SC_5**	**0.023**	0	0	0
Risk of change	**SC_6**	0	**0.071**	0	0
crédit risk	**SC_7**	0	**0.153**	0	0
Risk Insider	**SC_8**	0	**0.033**	0	0
Legal and regulatory risk	**SC_9**	0	**0.060**	0	0
Underwriting risk	**SC_{10}**	0	**0.050**	0	0
Liquidity risk	**SC_{11}**	0	0	**0.030**	0
Risk of in interest rates	**SC_{12}**	0	0	**0.066**	0
Market risk	**SC_{13}**	0	0	**0.017**	0
Solvency risk	**SC_{14}**	0	0	**0.015**	0
Country risk	**SC_{15}**	0	0	0	**0.035**
Risk guarantee	**SC_{16}**	0	0	0	**0.015**
Concentration risk	**SC_{17}**	0	0	0	**0.011**
Risk of recovery	**SC_{18}**	0	0	0	**0.007**
Risk of exposure	**SC_{19}**	0	0	0	**0.005**

Fig. 3.7 Sub-criteria weight

The results, given in the two tables, show that the five Sub-Criteria $SC_1 5$ to $SC_1 9$ are not discriminant. So, a new table of results is built including only the results of the fourteen (14) sub-criteria (Table 3.9):

$$SC_1{-}SC_2{-}SC{-}3{-}SC_4{-}SC_5{-}SC_6{-}SC_7{-}SC_8{-}SC_9{-}SC_{10}{-}SC_{11}{-}SC_{12}{-}SC_{13}{-}SC_{14}$$

C_1 **Result: Operational risk criterion**

Reading the previous table, tt is observed that the three alternative $ALT_8 > ALT_1 > ALT_2$ are superior to (ALT_3, ALT_4, ALT_5) and (ALT_6, ALT_7) are the best alternatives in the C_1 criteria.

C_2 **Result: Financial risk management criteria**

We examine the three alternatives $ALT_8 > ALT_1 > ALT_2 >$ are above $(ALT_3, ALT_4, ALT_5, ALT_6, ALT_7)$, it means they are the best alternatives in the C_2 criteria.

C_3 **Result: Counterparty risk criteria**

The alternative $ALT_8 > (ALT_1, ALT_2 and ALT_3)$ in C_3 criteria, is the best project.

C_4 **Result: External risk criterion**

The three alternatives ALT_1, ALT_2, ALT_8 have equal values; in this case they are reasonably acceptable.

We deduce that the alternative ALT_8 obtains the highest relative weight.

The final result, expressed by the complete vector of alternative priorities presented in Table 3.10 indicates that the alternative ALT_8 proves to be the best choice of getting a result (Sum of all performances = 0.313 or 31.3 %). It is

Table 3.8 Integration of alternative weight on each line

	SC_1	SC_2	SC_3	SC_4	SC_5	SC_6	SC_7	SC_8	SC_9	SC_{10}	SC_{11}	SC_{12}	SC_{13}	SC_{14}	SC_{15}	SC_{16}	SC_{17}	SC_{18}	SC_{19}
	0.055	0.263	0,061	0.033	0.022	0.071	0.152	0.033	0.06	0.05	0.03	0.06	0.017	0.015	0.035	0.015	0.011	0.007	0.005
ALT_1	0.199	0.199	0.199	0.199	0.199	0.199	0.199	0.199	0.199	0,199	0.199	0.199	0.199	0.199	0.199	0.199	0.199	0.199	0.199
ALT_2	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
ALT_3	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
ALT_4	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075
ALT_5	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
ALT_6	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054
ALT_7	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
ALT_8	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313

Table 3.9 Final results

	SC_1	SC_2	SC_3	SC_4	SC_5	SC_6	SC_7	SC_8	SC_9	SC_{10}	SC_{11}	SC_{12}	SC_{13}	SC_{14}	SC_{15}	SC_{16}	SC_{17}	SC_{18}	SC_{19}
ALT_1	0.01	0.05	0.01	0	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0	0	0.01	0	0	0	0	0
ALT_2	0.01	0.04	0.01	0	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0	0	0.01	0	0	0	0	0
ALT_3	0	0.02	0.01	0	0.01	0.01	0	0.01	0	0	0.01	0	0	0	0	0	0	0	0
ALT_4	0	0.02	0	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
ALT_5	0	0.02	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
ALT_6	0	0.01	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
ALT_7	0	0.01	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0
ALT_8	0.02	0.08	0.01	0.01	0.02	0.05	0.01	0.02	0.02	0.01	0.02	0.01	0	0.01	0	0	0	0	0

Table 3.10 Summary of results

Criteria	Operational risk criterion C_1					Criterion financial management C_2					Criterion counterparty risk C_3			Criterion external risk C_4
Sub criteria	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12	SC13	SC14
Alternative	ALT_1	ALT_1	ALT_1	ALT_1		ALT_1	ALT_1	ALT_1	ALT_1	ALT_1	ALT_1	ALT_1		ALT_1
	ALT_2	ALT_2	ALT_2	ALT_2		ALT_2	ALT_2	ALT_2	ALT_2	ALT_2	ALT_2	ALT_2		ALT_2
		ALT_3	ALT_3			ALT_3	ALT_3		ALT_3			ALT_3		
		ALT_4				ALT_4	ALT_4							
		ALT_5					ALT_5							
		ALT_6					ALT_6							
		ALT_7					ALT_7							
	ALT_8	ALT_8	ALT_8	ALT_8	ALT_8	ALT_8	ALT_8	ALT_8	ALT_8	ALT_8	ALT_8	ALT_8	ALT_8	ALT_8
Value	0.01	0.05	0.01	0.01		0.01	0.03	0.01	0.01	0.01	0.01	0.01		0.01
	0.01	0.04	0.01	0.01		0.01	0.03	0.01	0.01	0.01	0.01	0.01		0.01
		0.02	0.01			0.01	0.01		0.01			0.01		
		0.02				0.01	0.01							
		0.02					0.01							
		0.01					0.01							
		0.01					0.01							
	0.02	0.08	0.02	0.01	0.01	0.02	0.05	0.01	0.02	0.02	0.01	0.02	0.01	0.01

followed by alternative ALT_1 (Sum of all performances 0.199 or 19.9 %), and finally the alternative ALT_2 respectively (Sum of all performances 0.170 or 17 %). In this example the result of the analysis suggests to provide, without ambiguity, public investment in alternative ALT_8.

3.5 Conclusions and Perspectives

The results of this study show that $ALT8 > ALT2 > ALT1$. The alternative ALT_8: public investment is the best choice among the proposed alternatives. The results for each risk event depend on choice of comparison maker pairs, the AHP method is an effective tool for decision makers in the field of financial institutions.

Nevertheless, one limit of this work consists in the analysis done in a laboratory. All results must then be discussed by financial organisms.

This study is a first step of a more global study of risks analysis. As perspectives of this work, we envisage a second step of this study that will be to discuss these results with Risks Managers in financial intuitions. Based on this discussion we then aim at analyzing again this problem with another methodology based on Outranking like for example PROMETHEE.

Based on the PROMETHEE analysis, we then aim, in the third step, to compare the two methodologies AHP and PROMETHEE.

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Chapter 4
Financing Innovative SMEs

Silvia Angilella and Sebastiano Mazzù

Abstract Although Small and Medium Sized enterprises (SMEs) are the backbones of all economies, they face many obstacles when they try to access the credit market even more if they are innovative. This chapter focuses on credit risk assessment of innovative SMEs. In this context a multicriteria approach, namely SMAA-TRI is presented. The proposed methodology is illustrated trough an application on a real case study, simulating the financing of four Italian SMEs.

4.1 Introduction

Even if SMEs have been acknowledged as the drivers of innovation and growth of many countries, during the last years they have been characterized by several financing difficulties (see for example, Beck and Demirgüç-Kunt [6]; Berger et al. [7]; and Canales and Nanda [13]). Moreover, a recent research stream is focused on detecting which are the best policy measures targeting SMEs development (see for example Wehinger [24] or the annual Doing Business project of the World Bank Group).

As confirmed by many economies in different countries, the most important policy measures have been undertaken to support SMEs in lending. It is worth noting that the credit crunch increases if SMEs are innovative (see Brown et al. [11]). Innovative SMEs' credit risk evaluation through the use of the existing credit scoring models (see Kumar and Ravi [18] and Crook et al. [12] for a review on this topic) is limited by some SMEs' peculiar features, such as SMEs' lack of sufficient or reliable track records (see Angilella and Mazzù [2] and Mazzù [19]). Due to these characteristics, the most useful approach for evaluating the SME's creditworthiness seems to be a rating based on experts' judgement (judgemental rating). The above statement is also supported by several research papers which highlight the significant role of non-financial criteria for the SME's credit risk evaluation (see, among others, [1], Auken et al. [3], Berger et al. [7], and

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Grunert et al. [17], and specifically for innovative SMEs, see for example Czarnitzki and Hottenrott [14] and Shefer and Frenkel [22]).

This chapter focuses on credit risk assessment of innovative SMEs, building a judgemental credit assessment model. Since the financing of innovative SMEs is an uncertain problem due to several and conflicting aspects, the Multiple Criteria Decision Aid (MCDA) approach (also called the constructive approach Roy [20]) provides a useful tool to deal with the problem.

Several multicriteria approaches have been already adopted to predict business failures, which is a typical sorting problem (see Zopounidis and Doumpos [26]). Most of them rely on a utility function to classify enterprises into two categories: defaulted and non-defaulted (see, among these, the multicriteria hierarchical discrimination approach proposed in Doumpos et al. [16]).

Moreover, some multicriteria approaches relying on a utility function have been proposed, with the aim of helping credit granting decisions: for example the multicriteria methodology MACBETH (introduced in Bana e Costa and Vansnick [4]) has been implemented as a qualitative credit rating model in the banking sector (see Bana e Costa et al. [5]).

Some recent papers have also developed some credit rating models based on an outranking relation; for example, ELECTRE TRI (introduced in Yu [25]) was used for the first time as a quantitative credit rating model in Zopounidis and Doumpos [27] and PROMETHEE II [10] applied for banks' rating evaluation [15].

The rest of this chapter is devoted to the presentation of a multicriteria approach addressed to the innovative SMEs' credit risk evaluation. The proposed methodology is based on SMAA-TRI and it is illustrated trough an application on a real case study, simulating the financing of four Italian SMEs.

4.2 A Brief Reminder of ELECTRE TRI and SMAA-TRI

4.2.1 ELECTRE TRI

The basic set-up of ELECTRE-TRI is:

- A finite set of m alternatives $A = \{a_1, a_2, \ldots, a_i, \ldots, a_m\}$.
- A consistent family of n criteria $G = \{1, 2, \ldots, n\}$,
- p risk ordered categories $C_p > \ldots C_k \ldots > C_1$, where $C_{(k+1)}$ denotes the group of alternatives better than those in the group C_k,
  - The vector $a_i = \{a_{i1}, \ldots, a_{ij}, \ldots, a_{in}\}$ denotes an alternative $a_i \in A$ evaluated on the set of n criteria,
  - A vector of risk profiles $\mathbf{b} = b_{p-1}, \ldots, b_k, \ldots, b_1\}$. Each profile b_k is the upper limit of the group k and the lower limit of the group $k + 1$,
  - The vector of indifference thresholds $\mathbf{q} = \{q_1, \ldots, q_j, \ldots, q_n\}$ with $q_j \geq 0$,
  - The vector of preference thresholds $\mathbf{p} = \{p_1, \ldots, p_j, \ldots, p_n\} \geq \mathbf{q}$,
  - The vector of veto thresholds $\mathbf{v} = \{v_1, \ldots, v_j, \ldots, v_n\} \geq \mathbf{p}$,

– The vector of weights $\mathbf{w} = \{w_1, \ldots, w_j, \ldots, w_n\}$ with $w_j \geq 0$ such that $\sum_{j=1}^{n} w_j = 1$,
– $\lambda \in [0.5, 1]$ a cut-off threshold defined by the Decision Maker (DM).

In ELECTRE TRI, each alternative a_i is assigned to a risk category C_k by comparing it to the risk profiles exploiting two outranking relations $a_i S b_k$, (or $b_k S a_i$) which mean that, respectively, that alternative a_i is at least as good as the profile b_k or vice versa. The outranking relations are exploited trough two phases: the concordance and discordance test. To perform the concordance test the following concordance index is computed:

$$C(a_j, b_k) = \sum_{j=1}^{n} w_j c_j(a_{ij}, b_k),$$

where $c_j(a_{ij}, b_k)$ is calculated as follows:

$$c_j(a_{ij}, b_k) = \begin{cases} 0, & \text{if } a_{ij} \leq b_{kj} - p_j \\ \frac{a_{ij} - b_{kj} + p_j}{p_j - q_j}, & \text{if } b_{kj} - p_j < a_{ij} < b_{kj} - q_j \\ 0 & \text{if } a_{ij} < b_{kj} - q_j \end{cases}$$

The second step of ELECTRE TRI consists in the concordance test that is performed computing the following discordance index

$$d_j(a_{ij}, b_k) = \begin{cases} 0, & \text{if } a_{ij} \geq b_{kj} - p_j \\ \frac{b_{kj} - a_{ij} - p_j}{v_j - q_j}, & \text{if } b_{kj} - v_j < a_{ij} < b_{kj} - p_j \\ 0 & \text{if } a_{ij} < b_{kj} - v_j \end{cases}$$

Finally, the credibility index is computed as follows:

$$\sigma(a_i, b_k) = C(a_i, b_k) \prod_{j \in \bar{T}} \frac{1 - d_j(a_{ij}, b_k)}{1 - C(a_i, b_k)}$$

where $\bar{T}$ is the set of criteria for which $d_j(a_{ij}, b_k) > C(a_i, b_k)$. On the basis of the value λ, the outranking relation $a_i S b_k$ is valid if and only if $\sigma(a_i, b_k) > \lambda$. Similarly, the outranking relation $b_k S a_i$ is valid if, and only if, $\sigma(b_k, a_i) > \lambda$. A value $\lambda \geq 0.5$ means that at least 50 % of the criteria are in favor of the assignment of a_i to class C_k.

In ELECTRE TRI, two assignment procedures can be employed: the pessimistic and optimistic rules. The pessimistic rule consists of comparing each alternative to the profiles $b_{p-1}, b_2, \ldots, b_1$; *if* $a_i S b_k$, then a_i is assigned to the class $C_{(k+1)}$, otherwise a_i is assigned to C_1, the worst class. The optimistic rule consists of comparing each alternative to the profiles $b_1, b_2, \ldots, b_{(p-1)}$; *if* $b_k S a_i$ and $a_i \neg S b_k$, then a_i is assigned to the group C_k and otherwise a_i is assigned to the group C_p, i.e. the best class.

The most used rule is the pessimistic one (Boyssou and Marchant [8]) which, without veto criteria, can be simplified as:

$$\sum_{j=1}^{n} w_j c_j(a_i, b_k) > \lambda \text{ } and \sum_{j=1}^{n} w_j c_j(b_k, a_i) < \lambda,$$

4.2.2 SMAA-TRI

SMAA-TRI is a SMAA (Stochastic Multicriteria Acceptability Analysis) method, that has been introduced for the first time in Tervonen et al. [23]. The principal feature of SMAA-TRI is to consider imprecision and uncertainty on the data and the parameters, inputs of ELECTRE TRI.

By performing Monte Carlo simulations a set of weights on a cutting level λ is generated such that $w_j \geq 0$ and $\sum_{j=1}^{n} w_j = 1$.

In SMAA-TRI a categorization function is introduced to evaluate the class k to which alternative is assigned as follows:

$$k = F(i, \Delta)$$

where Δ is the set of parameters of ELECTRE TRI.

To compute the category acceptability index a category membership function is introduced as follows:

$$m_i^k = \begin{cases} 1, & \text{if } k = F(i, \Delta) \\ 0 & \text{if otherwise} \end{cases}$$

The category acceptability index π_i^k gives an evaluation of the stability of the assignment of an alternative a_i to category C_k. Such index is within the range [0, 1]. If on the basis of all the parameters randomly generated a_i is never assigned to category C_k, then $\pi_i^k = 0$. On the contrary, if during the simulations a_i is always assigned to category C_k, then $\pi_i^k = 1$.

4.3 A Brief Introduction to the Multicriteria Judgemental Rating Model

The principal steps of the multicriteria judgemental rating model proposed are:

- Selection of the evaluation criteria;
- Definition of the risk classes;
- Assessment of weights of criteria.

4.3.1 Selection of the Evaluation Criteria

In every multicriteria model the criteria under which every alternative is evaluated are selected on the basis of the multicriteria problem at hand (see Bouyssou et al. [9]).

In evaluating the SME's creditworthiness, as pointed out in the introduction, the criteria that have been detected beyond the financial ones are in particular the non-financial (qualitative) ones, since track records are not sufficient or not reliable.

In this chapter, the criteria evaluation selected are the ones presented for the first time in Angilella and Mazzù [2].

In the following we provide a brief reminder of this set of criteria (for a comprehensive discussion on the justification and description of such set of criteria, see Angilella and Mazzù [2]).

The set of criteria considered have an hierarchical structure; at the first level the criteria considered are concerned to the development (G^1), technological (G^2), market (G^3), and production risk (G^4), innovation indicators (G^5) and financial criteria (G^6).

The elementary criteria relative to the development risk are: awards ($g^1_{(1)}$) and scientific skills ($g^1_{(2)}$) (both on a five ordinal scale); the one concerning the technological risk is: pros of technique ($g^2_{(3)}$) on a five ordinal scale); the ones on the market risk are: the key competitors ($g^3_{(4)}$) and the potential market ($g^3_{(5)}$) (both on a five ordinal scale), the ones on the production risk are: availability of testing and pilot units ($g^4_{(6)}$) and patent ownership ($g^4_{(7)}$) (on a binary code), the ones relative to the innovation (in percentage) indicators are: intangible assets/fixed assets ($g^5_{(8)}$), R& D/sale ($g^5_{(9)}$); the financial criteria (in percentage) are: ROA ($g^6_{(10)}$), short debt/equity ($g^6_{(11)}$) and cash/total asset ($g^6_{(12)}$). The qualitative and quantitative criteria are, respectively, shown in Tables 4.1 and 4.2.

4.3.2 Definition of the Risk Classes

While with respect to the qualitative criteria the DMs (the loan officers) have determined four limit profiles equal for all the firms under consideration, on the contrary with respect to the financial criteria the DMs built a different set of four limit profiles on the basis of the enterprise's sector under consideration.

4.3.3 Assessment of the Criteria Weights

Among several MCDA techniques to elicit the weights of criteria, in this chapter we adopt the revised Simos' method [21].

Table 4.1 Family of qualitative criteria

Qualitative criteria	Codes
G^1: *development risk*	
$g^1_{(1)}$: awards	No awards (1)
	Municipal (2)
	Regional (3)
	National (4)
	International (5)
$g^1_{(2)}$: scientific skills	No skills (1)
	Degree (2)
	Master (3)
	Ph.D.(4)
	Ph.D. + Work experiences (5)
G^2: *technological risk*	
$g^2_{(3)}$: pros of the technique	Irrelevant (1)
	Weakly significant (2)
	Significant (3)
	Strongly significant (4)
	Very significant (5)
G^3: *market risk*	
$g^3_{(4)}$: key competitors	Monopolist (1)
	Numerous competitors (2)
	Few competitors (3)
	One competitor (4)
	Pioneer (5)
$g^3_{(5)}$: potential market	Reducing (1)
	Static (2)
	Weakly rising (3)
	Rising (4)
	Booming (5)
G^4: *production risk*	
$g^4_{(6)}$: availability of testing and pilot units	No (0), yes (1)
$g^4_{(7)}$: patent ownership	No (0), yes (1)

Table 4.2 Family of quantitative criteria

Qualitative criteria	Unit
G^5: *innovation indicators*	
$g^5_{(8)}$: intangible assets/fixed assets	Percentage
$g^5_{(9)}$: R&D/sales	Percentage
G^6: *financial criteria*	
$g^6_{(10)}$: ROA	Percentage
$g^6_{(11)}$: short term debt/equity	Percentage
$g^6_{(12)}$: cash/total asset	Percentage

The DM ranks the criteria from the least to the most important by using a set of cards (one for each criterion). The DM can also insert some blank cards to separate the relative importance between criteria. If the DM inserts no white cards between criteria, this means that these criteria do not have the same weights and their relative difference can be taken as a unit measure u for weights.

Similarly, if the DM inserts one white card, two white cards, etc, this means respectively a difference of weights of two times u, three times u, etc.

4.4 Case Study

Here we present a case study of credit risk evaluation of four Italian innovative SMEs. The case study has been based on data collected from their business plans and questionnaires recording some information on the company, distribution and customer networks, demand forecasting, supply chain information, the founders' CVs and eventual awards received by the company.

Then five loan officers of one of the main Italian banks have simulated the decision process of credit risk evaluation of the SMEs under analysis. After we provide a short description of the SMEs considered in the case study. Company A is a biotechnological start-up operating in the field of the green economy. It has developed some biological systems based on plants and micro-organisms forming some eco-friendly barriers, to prevent soil from hydrological destruction and environmental pollution.

Company B is a technological company with an expertise in digital communications. The innovative idea of the company is to develop a "Water-MeMo" that is a wireless sensor network to detect water leakages, based on energy harvesting. In particular, its technology can be applied not only in the water distribution field, but also in other energy applications, such as heating and gas, or environmental monitoring.

Company C is a high-technological start-up, a R&D mechanical design and service provider company with a focus on material recovery systems applied to thin-film deposition processes. Its mission is to provide breakthrough technology in order to increase the efficiency of PVD (Physical Vapour Deposition) processes used nowadays to produce microchips, MEMS (Micro Electro-Mechanical Systems), solar cells and other hi-tech devices.

Company D is a high-technological start-up that aims at producing and marketing graphene and carbon nanotubes for industrial use and research. The company is mainly focused on producing nano-engineered epoxy resins used in the manufacture of sports equipment, for example sailing boats or kite boards.

The evaluation matrix relative to the four companies is presented in Table 4.3. The limit profiles relative to the qualitative criteria are elaborated by four loan officers (see Table 4.4), while the limit profiles relative to the financial criteria have been determined by assessing from the AIDA dataset the 20-% quantiles of each financial ratio for the companies in the same sector of each SME (see Table 4.5).

Table 4.3 Evaluation matrix

Company	$g^1_{(1)}$	$g^1_{(2)}$	$g^2_{(3)}$	$g^3_{(4)}$	$g^3_{(5)}$	$g^4_{(6)}$	$g^4_{(7)}$	$g^5_{(8)}$	$g^5_{(9)}$	$g^6_{(10)}$	$g^6_{(11)}$	$g^6_{(12)}$
A	4	3	3	4	3	0	0	0.55	0.06	0.24	0.18	0.37
B	4	5	5	5	1	0	1	0.72	0.17	0.03	0.12	0.26
C	5	3	5	2	5	1	1	0.18	0.05	0.94	0.3	0.28
D	4	3	3	2	5	1	0	0.06	0.14	0.52	0.11	0.26

Table 4.4 Limit profiles with respect to the qualitative criteria

$g^1_{(1)}$	$g^1_{(2)}$	$g^2_{(3)}$	$g^3_{(4)}$	$g^3_{(5)}$	$g^4_{(6)}$	$g^4_{(7)}$	
b1	1	1	1	1	1	0	0
b2	2	2	2	2	2	0	0
b3	3	3	3	3	3	0	1
b4	4	4	4	4	4	1	1

Table 4.5 Limit profiles with respect to the financial criteria

	$g^5_{(8)}$	$g^5_{(9)}$	$g^6_{(10)}$	$g^6_{(11)}$	$g^6_{(12)}$
(a) Company A					
b1	0.00	0.03	−0.05	8.00	0.01
b2	0.01	0.05	0.00	2.46	0.04
b3	0.03	0.07	0.02	0.80	0.11
b4	0.29	0.10	0.07	0.03	0.22
(b) Company B					
b1	0.00	0.03	−0.03	4.87	0.01
b2	0.06	0.05	0.01	1.89	0.05
b3	0.39	0.07	0.05	0.77	0.11
b4	2.16	0.10	0.11	0.19	0.21
(c) Company C					
b1	0.00	−0.03	−0.02	4.47	0.01
b2	0.04	0.05	0.02	1.76	0.04
b3	0.18	0.07	0.05	0.66	0.09
b4	0.63	0.10	0.11	0.18	0.19
(d) Company D					
b1	0.00	0.03	−0.06	3.65	0.02
b2	0.01	0.05	−0.01	1.04	0.06
b3	0.22	0.07	0.01	0.41	0.13
b4	1.65	0.10	0.05	0.08	0.24

Then on the basis of the loan officers' preference information on the importance of criteria, the weights of criteria were assessed by considering the Simos' method (see Table 4.6 for the results).

Then, the category acceptability indices SMAA-TRI method have been computed considering 10,000 simulations. The highest category acceptability indices for each DM are shown in Table 4.7, where the final category has been evaluated by the majority rule. From Table 4.7 one can notice some conflicting situations

Table 4.6 Weights for each DM

	$g^1_{(1)}$	$g^1_{(2)}$	$g^2_{(3)}$	$g^3_{(4)}$	$g^3_{(5)}$	$g^4_{(6)}$	$g^4_{(7)}$	$g^5_{(8)}$	$g^5_{(9)}$	$g^6_{(10)}$	$g^6_{(11)}$	$g^6_{(12)}$
DM1	0.025	0.025	0.1650	0.056	0.056	0.196	0.181	0.040	0.040	0.0720	0.0720	0.0720
DM2	0.053	0.053	0.0934	0.174	0.184	0.164	0.023	0.033	0.033	0.0632	0.0632	0.0632
DM3	0.112	0.112	0.1390	0.019	0.019	0.072	0.060	0.046	0.046	0.1250	0.1250	0.1250
DM4	0.033	0.033	0.1490	0.054	0.160	0.064	0.170	0.023	0.023	0.0970	0.0970	0.0970
DM5	0.022	0.022	0.1000	0.061	0.074	0.035	0.087	0.112	0.112	0.1250	0.1250	0.1250

Table 4.7 Results of SMAA-TRI for each DM with λ varying in the range [0.65, 0.85]

Company	DM 1 (%)	DM 2 (%)	DM 3 (%)	DM 4 (%)	DM 5 (%)	Category result
A	C_4 (65)	C_4 (100)	C_4 (100)	C_4(79)	C_4 (76)	C_4
B	C_4 (74)	C_4 (83)	C_5 (100)	C_5 (47)	C_5 (60)	C_5
C	C_5 (90)	C_4 (47)	C_5 (56)	C_5 (100)	C_3 (68)	C_5
D	C_3 (63)	C_4 (60)	C_4 (100)	C_4 (51)	C_3 (55)	C_4

Table 4.8 Criteria Interval weights

Criteria	[min,max]
$g^1_{(1)}$	[0.0175, 0.1165]
$g^1_{(2)}$	[0.0175, 0.1165]
$g^2_{(3)}$	[0.08982, 0.16858]
$g^3_{(4)}$	[0.01125, 0.18175]
$g^3_{(5)}$	[0.01075, 0.19225]
$g^4_{(6)}$	[0.02695, 0.20405]
$g^4_{(7)}$	[0.01855, 0.11645]
$g^5_{(8)}$	[0.01855, 0.11645]
$g^5_{(9)}$	[0.06011, 0.1289]
$g^6_{(10)}$	[0.06011, 0.1289]
$g^6_{(11)}$	[0.06011, 0.1289]
$g^6_{(12)}$	[0.01855, 0.11645]

Table 4.9 Results of SMAA-TRI by considering interval weights

Company	Class 1 (%)	Class 2 (%)	Class 3 (%)	Class 4 (%)	Class 5 (%)	Category result
A	0	0	9	91	0	C_4
B	0	1	0	48	51	C_5
C	0	0	9	54	37	C_5
D	0	0	41	57	2	C_4

among loan officers. To reach an agreement among the DMs, SMAA-TRI has been implemented by considering a set of interval weights of criteria with the range from the minimum ($\min_j$) to the maximum weight ($\max_j$) of each criterion for all the DMs (see the results shown in Tables 4.8 and 4.9).

Since within SMAA-TRI the weights are distributed uniformly, during the simulations it is impossible to pick a weight exactly equal to the lower bound and/or the upper bound. This could lead to some contradictory situations, i.e. some acceptability indices may be zero at the group level, when for some DMs the corresponding indices are positive.

For this reason, we extend the interval $[min_j, max_j]$ by subtracting/adding a small positive quantity equal to 5 % $[min_j, max_j]$.

Moreover, to have more insights from a decisional point of view some useful indices have been evaluated, namely the downward and upward cumulative category acceptability indices (presented for the first time in Angilella and Mazzù [2]).

The downward cumulative category acceptability index is defined as follows:

$$\pi_{\downarrow}^{k}(a_i) = \sum_{j=1}^{k} \pi_i^j$$

expressing the frequency of classification of a_i to a risk class less or equal to k.

The upward cumulative category acceptability index is defined as follows:

$$\pi_{\uparrow}^{k}(a_i) = \sum_{j=k}^{p} \pi_i^j$$

evaluating the frequency of classification of a_i to a risk class more or equal to k.

Roughly speaking, the downward cumulative acceptability index expresses the frequency of classification of a company as a high risk company, while the upward cumulative acceptability index expresses the frequency of classification of a company as a low risk company.

The downward and upward cumulative indices of the companies under analysis are reported in Tables 4.10 and 4.11.

Table 4.10 Downward cumulative category acceptability indices

Company	$\pi_{\downarrow}^{1}$	$\pi_{\downarrow}^{2}$	$\pi_{\downarrow}^{3}$	$\pi_{\downarrow}^{4}$	$\pi_{\downarrow}^{5}$
A	0	0	9	100	100
B	0	1	1	49	100
C	0	0	9	63	100
D	0	0	41	98	100

Table 4.11 Upward cumulative category acceptability indices

Company	$\pi_{\uparrow}^{1}$	$\pi_{\uparrow}^{2}$	$\pi_{\uparrow}^{3}$	$\pi_{\uparrow}^{4}$	$\pi_{\uparrow}^{5}$
A	100	100	100	91	0
B	100	100	99	99	51
C	100	100	100	91	37
D	100	100	100	59	2

Since in innovative projects the risks are mostly due to the uncertainties in the data, we extend our analysis by considering the criteria expressed in terms of intervals. In the case study, since the evaluation criteria of the development risk and the ones expressed in a binary codes are not related to a human judgement its scores were considered precise.

For the other qualitative data, the evaluations of the alternatives under consideration on each criterion are integer numbers within an interval. For example, the evaluation of Company B on criterion ($g^3_{(5)}$) can be 1, 2 or 3 (see Table 4.12). For the innovation indicators and financial criteria, to be prudential we reduce their evaluations by 20 % (see Table 4.12). The category acceptability indices obtained are presented in Table 4.13.

Table 4.12 Evaluation matrix with the criteria expressed in terms of intervals

Criteria	Companies			
	A	B	C	D
$g^1_{(1)}$	4	4	5	4
$g^1_{(2)}$	3	5	3	3
$g^2_{(3)}$	[3, 5]	[4, 5]	[4, 5]	[3, 5]
$g^3_{(4)}$	[4, 5]	[4, 5]	[2, 4]	[2, 3]
$g^3_{(5)}$	[3, 4]	[1, 3]	[4, 5]	[4, 5]
$g^4_{(6)}$	0	0	1	1
$g^4_{(7)}$	0	1	1	0
$g^5_{(8)}$	[0.44, 0.55]	[0.58, 0.72]	[0.14, 0.18]	[0.05, 0.06]
$g^5_{(9)}$	[0.05, 0.06]	[0.14, 0.17]	[0.04, 0.05]	[0.11, 0.14]
$g^6_{(10)}$	[0.19, 0.24]	[0.02, 0.03]	[0.75, 0.94]	[0.42, 0.52]
$g^6_{(11)}$	[0.18, 0.22]	[0.12, 0.14]	[0.3, 0.36]	[0.11, 0.13]
$g^6_{(12)}$	[0.03, 0.37]	[0.21, 0.26]	[0.22, 0.28]	[0.21, 0.26]

Table 4.13 Category acceptability indices with the evaluation criteria in terms of intervals

Company	Class 1 (%)	Class 2 (%)	Class 3 (%)	Class 4 (%)	Class 5 (%)	Category result
A	0	0	10	89	2	C_4
B	0	1	1	57	41	C_4
C	0	0	16	48	36	C_4
D	0	0	40	44	16	C_4

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Chapter 5
A Multi-Criteria Recommender System Based on Users' Profile Management

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Abstract The work consists in developing a recommender system in order to support decision makers in their activities. This support is possible through the management of users' profiles that will evolve following their answers or actions. This evolution is possible using automated techniques, especially reinforcement learning. The developed recommender system is based on a Multi-Criteria approach.

5.1 Introduction

Considering user profiles and their evolutions, is considered in the Decision Support Systems (DSS) community as an important issue [8]. Indeed, the inclusion of context in the decision is currently emerging for DSS. The purpose of a DSS is to support a decision maker giving him solutions or parts of solutions to his problem. A natural evolution of DSS was to offer advices to users based on their profile. These profiles generally represent decision makers' preferences. Several approaches are possible to define these profiles. One of them consists to determine a list of valued criteria. The criteria are defined according the decision making problem to solve. It is called Multi-criteria Recommender System. The main challenge for Recommender Systems comes from the fact that the system needs to continuously bring relevant information. It therefore requires changing user profiles thanks to their actions. So, the system must not only "understand" what the user likes, but also why. The users' assistance will evolve over the time and therefore with the user. Thus the user has at his disposal a kind of personal assistant.

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The objective of this work is to provide assistance to decision makers' activities according to their profiles. The objective is to develop an algorithm based on automatic learning techniques, in order to allow the profile evolution. Then, the provided support will dynamically change with the user's profile changes. In order to achieve this objective, a refining is performed through scalable scheduling solutions presented to the user depending on his/her profile. Nevertheless, the users' inputs must be considered at two levels: in one hand items chosen by the users and in another hand, actions done by users. As an output, the system provides a ranked list of items.

In the Sect. 5.2, we define the recommender systems. Then in the following section, Sect. 5.3 Multi-Criteria DSS are described. The next section, Sect. 5.4, is devoted to machine learning description. The Sect. 5.5 gives a general view of the developed system. The next section, Sect. 5.6, proposes a detailed description of the system operating. The Sect. 5.7 allows us to show how the implemented system is correctly working through several tests and results. In this section frameworks have been developed to evaluate the system and compare it to other systems. Finally, several conclusions are given and some perspectives are drawn.

5.2 Recommenders Systems

> Users have no longer time to look at all available information, that's why the recommender systems can be extremely useful to direct and filter information that users have to access. [28]

These systems rely on user profiles representing their preferences, and to filter, order information and select the best information fitting to users' preferences. The general process of recommender systems is decomposed in three steps:

1. The user provides a list of examples of his tastes, which can be explicit, such as notes on specific elements, or implicit, as visited URLs, or selecting an object from a list.
2. These data are used by the system to create a representation of the user's profile, what he likes or does not likes, and how much.
3. The system computes recommendations according to the user's profile.

The proposed solutions are actually the following:

- Synchronous solution: adaptive factors (criteria's score) are derived from the filtered items accumulated over-time [15].
- Asynchronous or deferred solution: factors are derived from existing collections of objects. These collections also provide examples of relevant elements for each profile.

The synchronous solution offers the possibility of having a system that evolves in real time. Thus the user has a direct feedback of his actions. However, this solution requires the use of appropriate computations in their complexity, implying their cost/time computation, compared to the expected reactivity of the desired system. This is major constraint for DSS as it has been proved that in order to facilitate the cognitive following of the problem solving the answering time must be as little as possible (no more than 3–4 s).

The asynchronous solution eliminates the problems of cost computation, but the user's experience is reduced in quality. Indeed, these systems update user's profile and perform various other computations in a deferred way.

Several methods, taking into account the user's past, have emerged to recommend items to users:

- Social recommendation (collaborative filtering): make recommendations based on past behavior of similar users [3, 7]. Users are here categorized in classes and recommendations are made following the categories.
- Recommendation Object (content based): recommend things based on the intrinsic qualities of the object itself [18, 30]
- Hybrid recommendation: a combination of the two approaches described above [1, 26]

Many systems use collaborative filtering; these systems can satisfy a lot of people who do not have very different tastes. But they cannot satisfy users with precise tastes which are not very popular, and they do not work properly with few users [9]. Moreover with these systems, new items or not yet rated items may be discarded in the process of recommendation and the new objects are not recommended.

In another hand, content based systems can rank all items without taking into account other users. But the main problem remains to have a sufficiently precise description of these items, and to be able to handle all these data.

A multi-criteria approach including a database describing precisely items allows us to define an efficient recommender system.

5.3 Multi-Criteria Decision Support

The practice of using multiple criteria decision often leads to build recommendations more varied than just choosing one and only one action [23]. That's why, in order to better take into account user preferences, we propose to use multicriteria/multiattribute systems. This allows us to better manage and use of user preferences.

To properly do the difference between an attribute and a criterion, we need to introduce the following definitions:

- Attribute: Characteristic describing each objects (age, qualifications, aptitude test results, claims).
- Criterion: Expresses preferences of the decision maker with respect to a point of view (eg powerful car). This concept incorporates the preferences of the decision

maker on this criterion (maximizing power, maximum speed). A criterion may refer to one or more attributes. For example, the criterion of “skill” refers to attributes such as qualifications, past experiences, etc.

When some subjective characters related to the decision maker preferences are introduced into the description of an object, the word “criterion” is gladly more used. However, we often can define a criterion by a single attribute and generally the following approximation is done: ***attribute*** $\leftrightarrows$ ***criterion***. To resume the criterion of “skill”, it can be defined, for example, as a single attribute corresponding to a skill level, computed from other attributes.

That’s why, generally, and for the rest of this work, we use the following approximation ***attribute*** $\leftrightarrows$ ***criterion***. Two “schools” exist in Multi Criteria Decision Aiding (MCDA) and follow quite different basic principles [16]. The first approach is the “American School”, which most often uses an additive utility function that combines the utility values in an overall score for the action. The simplest aggregation method of this category is the weighted sum, where the overall rating is the weighted sum of scores for each selected criterion multiplied by its weight. Other methods of this type are MAUT, Multi Attribute Utility Theory MHM, multicriteria ranking method or AHP Analytical Hierarchy Process [25].

The “European school” promotes methods based on comparisons between potential actions. The methods set which are the best known, are the ELECTRE (Elimination Et Choix Traduisant la Ralit) methods [21, 22, 24] and the PROMETHEE method, Preference Ranking Organization Method for Enrichment Evaluations [6]. [5]

There are still many other methods that do not belong to one or other of the two “schools” as Qualiflex [17] and methods using the principles of cost and benefit [19]. All these methods require obtaining an a priori weight and other parameters.

It is generally accepted that “a priori” preference of the decision maker is very difficult to obtain, which explains the development of the interactive methods aiming to progressively obtain preferences [10]. An interactive method consists in alternating steps of computations and steps of dialogue with the decision maker. The first stage of computations provides a first solution. It is presented to the decision maker, and he (or she) reacts by providing information about its preferences (dialog step). This information is injected into the model and allows building a new solution [29].

Interactivity also allows the decision maker to better understand their preferences regarding the addressed problem, and change them based on a gradually improved understanding. In the same time this approach facilitates accepting the recommendations of the system, since the decision maker can continue the dialogue until he (or she) is satisfied [10]. This kind of methods can be easily coupled with machine learning technics in order to satisfy the users as much as possible.

5.4 Machine Learning

The machine learning refers to the development, analysis and implementation of methods that allow a machine, with a large meaning, to evolve through a learning process. These technics allow fulfilling tasks which are difficult or impossible to perform in ways of more conventional algorithms.

Several methods exist but the most interesting method for our work is the so-called reinforcement, because it is particularly suitable for profiles updating. The method of reinforcement learning applied to user profiles has been presented and most experienced in [28] and [4].

This method was used in a system that was performing information retrieval as well as information filtering. It is described as follows: "Learning profiles that we use is based on the principle of reinforcement [27]. To this end, we consider $wo_{ik}^{(t)}$ corresponding to the weight of attribute k of the selected object $o_i^{(t)}$ and considered relevant. We must find a representation of the profile $p_x^{(t)}$ at the time t which retrieves this object with a "strong" score λ. Then use these data in order to update the overall profile of the user. We must find $wc_j^{(t)}$ as weight of the attribute a_j in the profile $p_x^{(t)}$, which satisfies the following equation":

$$\sum_{k \in o_i^{(t)}, aj \in p_x^{(t)}} wo_{ik}^{(t)}.wc_j^{(t)} = \lambda$$

For integration into the user profile, the formula for distribution of the gradient is used as follows:

$$w_i^{t-1} = w_i^t + 0.1 * \log(1 + wc_i^{(t)})$$

- w_i^{t-1} is the weight of criterion i at time $t-1$
- w_i^t is the weight of criterion i at time $t-1$
- $wc_i^{(t)}$ is the weight of criterion i at the current object

This method is very suitable for our work thanks to the introduction of several criteria in the profile definition. However, there are many limitations for this method, in particular the way how the intermediate weights are computed. Indeed, the system proposed by Boughanem et al. [4] aims to provide an information filtering system, and use it only for textual data. Thus the way how the $wc_j^{(t)}$ are obtained cannot be used because it refers only for text types data. In our case, the types of used data are diverse, and vary depending on objects and their description. We provide an adjustment in order to adapt these formulas to our goal and our data types.

5.5 System Description

Our aim is to develop a system able to recommend on several kinds of items or objects. Our system focus on a content based approach.

We firstly define, build and allow the evolution of a user profile (evolutionary profiling) based on explicit and implicit user's actions. This evolutionary profiling is implemented within a recommender system usable without learning base, i.e. initialization, synchronously and completely incremental. The system is open for inconsistencies because this work is based on Bounded Rationality that is one hypothesis of the decision making domain. This system, which complements an Information System Research, aims to establish a total order on a list of items proposed to the user in accordance with his preferences. The development of such a system implies the following challenges:

- The disaggregation of criteria
- The inclusion of a variable number of criteria.

We firstly define a coherent family of criteria on which the decision is based. This family of criteria is the total set of criteria necessary to evaluation an item. All the criteria are not necessarily valued at each step of the solving process.

The built system complements retrieval system information. Indeed, as described in [2], information filtering (and recommender systems) is a dual process to the information retrieval. So the goal of our system is to order the available solutions for the user by taking into account the user's profile.

The user's profile is composed by a vector of weight criteria representing the user's preferences. We want to learn the user's profile which implies to obtain these weights. In addition, we want those weights without asking directly them.

Several constraints for designing the system have been defined. Thus, the system will be used by various users, for who we don't know anything. Indeed, for the initialization phase, we do not have basic information about the user and therefore we cannot use algorithms using a learning base.

In addition, users have the ability to change preferences even if they are not rational (bounded rationality).

Another constraint is to retrieved information about selected items or rated items by the users in a sequential manner. So we need to update the user profile, each time data are collected. We have to learn continuously (there is no learning delay), in synchronous way and with an acceptable response time.

The system must have the ability to be used for any type of items (items such as books, telephones, houses, etc ...). We cannot use the approaches already developed, for example related to the recurrence of a word in a text [20].

We propose a purely incremental method of profile learning, which requires no knowledge to start the recommendation process.

This method begins first to build a temporary vector of valued criteria based on a set of criteria describing a rated or selected element by the user. This temporary profile is then integrated into the overall profile of the user.

We provide to the user recommendation based on a ranking of proposed items, using a scoring method to obtain an overall score for an item. This score is calculated for the evaluated item from its characteristics and the user's profile.

5.6 System Operating

5.6.1 Introduction

The first step is an initialization step for new user, i.e. for who we don't have any information. In this case, we provide a random list of item to him, and all criteria weight in his profile are set to 0. Otherwise, the system begins by present a list of item to the users, this list is ranked by his profile and his preferences, better items first, if we already have information about the user. In a second step, these are two possible actions for the use: select an item or rate an item.

The system uses is described in the following Fig. 5.1.

1. User begins by doing an action on a presented item. Indeed, if he already knows an item in the list, he rates this item (explicit data). Otherwise, if he does not know any item in the list, he looks the characteristics of items and selects the one he prefers (implicit information).
2. Depending of his choice, a Rate computation, i.e. explicit data, or a Pairwise computation, i.e. implicit data, is launched in order to disaggregate the item score.

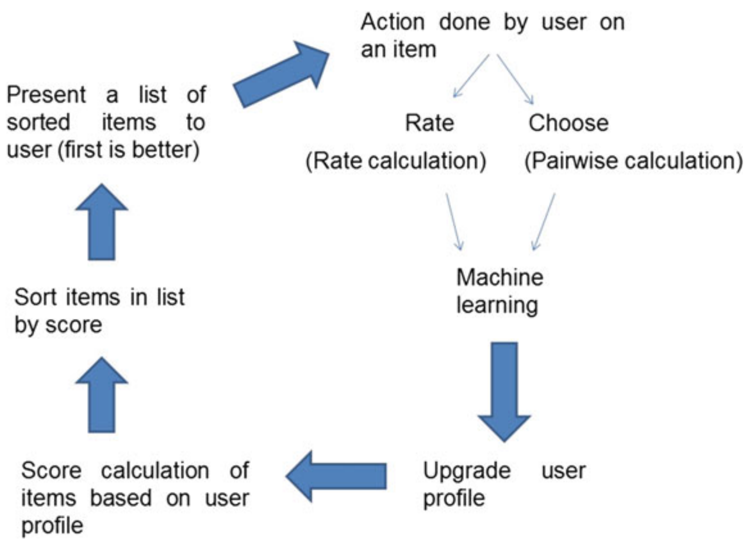

Fig. 5.1 System operation schema

3. With these data the system computes a machine learning algorithm and updates the user profile.
4. The system makes a score computation of available items, for the global database or a selection obtained through a request, based on user profile.
5. The system sorts items with these new scores.
6. The new list is presented to the user (this list is reduced to the top ten items).

5.6.2 Scoring

For each element we compute a score (Item Score) which represents the satisfying value of an item for the user. This score is used to rank the list of presented items to the user (descending order). As used in the reinforcement learning, we use a sum-type function which is based on the utility principle.

We calculate the item score as follows:

$$\text{Item Score} = \frac{\sum_{i=1}^{N} s(t)_i}{N}$$

- N corresponds to the number of criteria in item
- $s(t)_i$ corresponds to the score of criterion i at time t in user profile

This sum corresponds to the scores contained in the user profile corresponding to the criteria contained in the element i at time t. We than are faced to two cases: if the criteria is not present in the user profile then add 0 to the score; if the criterion is present then add his score to the overall score. Example: An object defined by the following criteria: Brand, Age, Speed, Color A corresponding item can be: Ford, Modern, Fast, Red A user profile can be: (Ford, 9), (Fast, 3), (Red, 6)

The item score is then computes as follows: Item Score= $\frac{9+3+6}{3} = 6$

We then defined two methods to compute the score sc_i for the criterion i for the current item. This sc_i represents the user interest for this criterion i. These two methods are defined depending on the user action. The first method is based on the explicit rate and the second on the implicit information.

5.6.3 Rate Computation

In this case for which the user provides a rate on an item, scaled from 0 to 5, we got explicit data.

We calculate the distribution of scores for each criterion, and we integrate the resulting criteria vector in the user profile.

This is the way how we disaggregate the global value:

$$sc_i = \frac{\text{rate of item}}{N}$$

- sc_i corresponds to the score of criterion i at time t in user profile

One hypothesis of our work is that we consider that no criterion is more important than another. All the criteria of one item get an equivalent score.

Then, with these scored criteria, we are able to update the user profile.

In order to do this, we use the following formula:

$$s(t+1)_i = s(t)_i + 0.1 * \log(1 + sc_i)$$

- $s(t+1)_i$ is the score of criterion i at time $t+1$ in the user profile
- $s(t)_i$ is the score of criterion i at time t in the user profile. That is to say that $s(t+1)_i$ is the new score of criterion i and $s(t)_i$ is the former score criterion i in the user profile.
- sc_i is the computed score of the current element

We use a logarithm function in order to reduce the impact of high values. A coefficient of 0.1 is used to control the impact of new data on the system, and adding a parameter, i.e. 1, to the logarithm function in order to prevent the addition of negative values.

The second method to calculate the score sc_i for the criterion i for the current item based on implicit information is called pairwise computation and is described in the following section.

5.6.4 Pairwise Computation

We are here faced to the case where the user chooses an item. We launch a machine learning algorithm using a Pairwise computation. Several advantages to this type of methods are described in [12]. We use the following procedure: we construct a weight vector and we use it to update the user's profile.

We performed several intermediate computations, which are used to upgrade a temporary vector for each pair of items. These pairs of items consist in each case of a displayed item selected by the user and an item displayed above the selected one. Above corresponds, in this work, to the position of an element with a lower index in the list presented to the user than the selected one by the user. Indeed, more the item is located down in the list and greater the index is and more the Item Score is low.

We perform the computations by using the preferred object and alternately the above items, which make several pairs. This principle reflects the idea that for a sorted list, when the user selects an item that is not in first position, this corresponds to the fact that the user considers the selected item favorite to previous.

The temporary vector is used in order to storage the current calculation for the selected item.

The main process of the Pairwise Computation is described as follows:

1. Initialize temporary valued vector using a disaggregation rate for the selected item and an average rate, i.e. $Average(maxscale = 5) = 2.5$
2. Removing non-discriminating, i.e. criteria in common with the two items, criteria between the selected item and one above.
3. Do a sc_i computation, described here after, and upgrade the temporary vector with obtained data.
4. Repeat task 1 to 3, with another item above the selected one, until there is no other item above.
5. Upgrade user profile using the temporary vector.

In order to do the sc_i computation, we use the following method: The k item is considered as the one selected by the user, and the item j as an item above the selected one. We then have the following equation because item j is higher in the list presented to the user than item k:

$$\frac{\sum_{i=1}^{N} s(t)_{ij}}{N} > \frac{\sum_{i=1}^{N} s(t)_{ik}}{N}$$

- $s(t)_{ij}$ being the score of criterion i at time t for item j
- $s(t)_{ik}$ being the score of criterion i at time t for item k

But we want, because the user selected the item k that must be preferred to j:

$$\frac{\sum_{i=1}^{N} s(t)_{ij}}{N} < \frac{\sum_{i=1}^{N} s(t)_{ik}}{N}$$

This would imply that the built user's profile is correct. We then have to correct the user's profile. In order to correct it, we must determine which criteria and their related scores will update their profile. We then calculate the score difference between the two objects.

$$\Delta = \frac{\sum_{i=1}^{N} s(t)_{ij}}{N} - \frac{\sum_{i=1}^{N} s(t)_{ik}}{N}$$

Indeed, we have two items with their computed scores. We want that the selected item score higher than the score of the above item. The score difference (Δ) is then used for upgrading user's profile. We have used here an additive decomposition nontransitive by difference. We use Δ to get the score of each criterion included in our temporary vector.

$$SC_i = \frac{\Delta}{N}$$

Thus we can deduce that greater the score difference is, more the system is not properly adjusted. We also see that greater the difference is and more we need to correct the user's profile.

This correction is done by using Δ, because greater the difference is, greater Δ is, and more sc_i get an important value.

This allows us to adjust the system quickly. Indeed when Δ (and sc_i) have an important value, our updating have a large impact on the user's profile. With this computation we get a fast adaptive system which can handle users changing often their taste and therefore the weighting of criteria inside their profile.

Thanks to the sc_i we can update the user profile. We use almost the same formula that the one used in the rate computation for the upgrading. We add a variable who will allow us to have a fair impact on the system. Indeed, in order to maintain an effective system we want a fair impact on the system and that need to take into account the number of pair computation that we have done.

To do this, we use this formula:

$$s(t+1)_i = s(t)_i + 0.1 * \log(1 + \alpha * sc_i)$$

With: $\alpha = \frac{1}{\text{number of element above the one selected}}$

- $s(t+1)_i$ is the score of criterion i at time $t+1$ in the user profile
- $s(t)_i$ is the score of criterion i at time t in the user profile. That is to say that $s(t+1)_i$ is the new score of criterion i in the user profile and $s(t)_i$ is the former score criterion i in the user profile.
- sc_i is the computed score with the current element

Upgrading user's profile is then possible with explicit (rate) and implicit (selection by user) information. The implemented system must be tested and validated through several experiments described in the following section.

5.7 Experiments and Results

The developed system is implemented in order to validate the proposed calculation methods. For this purpose we need to compare it with existing systems. This comparison will be done through a free data set. We then searched a database with some constraints; indeed we wanted a multi-criteria database with rate from users and for each of them as much as possible marks.

We finally used the MovieLens dataset, which is a free service provided by GroupLens Research at the University of Minnesota (grouplens.org). It is used sometimes in order to study how members use MovieLens for learning how to build better recommendation systems. This dataset contain ten millions marks and 100,000 tags for 10,681 movies given by 71,567 users. Marks are based on an integer scale of 1 to 5.

We also recovered the database of IMDB (Internet Movie DataBase) which allows us to get all available information about one movie. We use it in order to add information's about the movie. We used criteria defined by these databases.

To achieve the test, we use a K-Cross fold validation [14]. One round of cross-validation involves partitioning a sample of data into complementary subsets, performing the analysis on one subset (called the training set), and validating the analysis on the other subset (called the validation set or testing set). To reduce variability, multiple rounds of cross-validation are performed using different partitions, and the validation results are averaged over the rounds.

In order to compare our results we look for a metric. We do not make prediction, so we cannot use metrics like MAE.

When items are tied in the ranking (got the same score or rate) it means that the user is indifferent between the two items. Thus, the system should not rank one item higher than the other. In such cases, rank correlation measures such as Kendall's τ can be used.

In statistics, the Kendall rank correlation coefficient, commonly referred to as Kendall's τ coefficient, is a statistic used to measure the association between two measured quantities. A τ test is a non-parametric hypothesis test which uses the coefficient to test for statistical dependence. Its value varies between -1 and $+1$, where 1 corresponds to a perfect ranking of item, -1 corresponds to the inverse order, and 0 to no correlation. In a general manner, if the value is higher than 0.4 we can say that we got a good ranking.

We use the Kendall's τ_B measure which takes into account tied values.

$$\tau_B = \frac{n_c - n_d}{\sqrt{(n_0 - n_1)(n_0 - n_1)}}$$

With:

$n_0 = \frac{n(n-1)}{2}$
$n_1 = \sum_i t_i(t_i - 1)/2$
$n_2 = \sum_j u_j(u_j - 1)/2$
t_i =Number of tied values in the ith group of ties for the first quantity
u_j =Number of tied values in the jth group of ties for the second quantity

Moreover, we use the associated p-value, which indicates if quantities are statistically independent, that is if p-value is very low, we can assume that data are not independent.

In order to test our system, we take a sample of 100 people and we launch our two algorithms. We take into account only the marks for the following criteria: title,

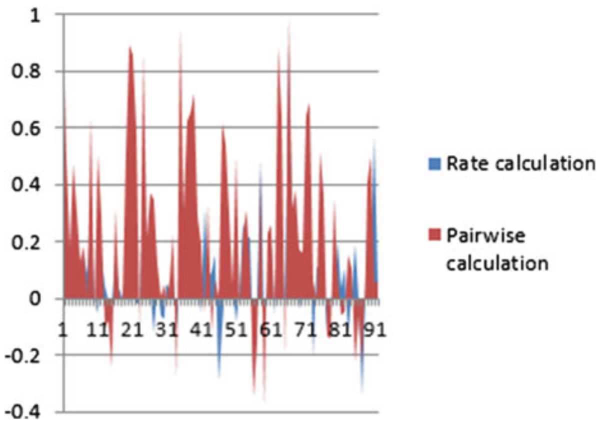

Fig. 5.2 Rate computation and pairwise computation Kendall's τ_B value for 100 users

year of the movie distribution, many styles (no limit), duration. We do no limit the number of marked movies. With the K-Cross fold method, K was equal to 6. We use an average of computed Kendall's Tau-b of each part.

We can deduce from Fig. 5.2, than our Pairwise algorithm (average 0.443 of Kendall's τ_B value) is far better than the Rate computation (average of 0.09). Moreover we can say that our system made quite good recommendation for the Pairwise algorithm because the average is higher than 0.4. This result can be explained by the ability of our system to very quickly correct erroneous weight criteria. Then, we can assume that the impact of the correction depends of the error level.

In order to produce more results, we wanted to see if our system is efficient with a large amount data. We launch our Pairwise computation on the same set of data, but we change the amount of criteria taken into account.

For this test, the used marks criteria were all the available data, up to 21 different criteria. The number is considered users stays the same: 100 users (Fig. 5.3).

We got an average of 0.233 for all available criteria taken into account. From this results we can deduce than, having more criteria didn't help. Worse, the results are poor in comparison with the situation when we use only few criteria (0.443 of Kendall's τ_B value). We can explain this bad result by the fact than our system considers more data as more noise than having more useful information. This result constitutes on the perspective that we want to work on.

Finally, a comparison between our system and some other recommender systems is made. In The results from [13] are used for this purpose.

The evaluation method uses a correlation coefficient of Spearman Rho. This factor tends to be very similar to Kendall's τ_B in practice [11]. It allowed us to directly compare the values of the coefficient of Kendall's τ_B obtained with our system (Table 5.1).

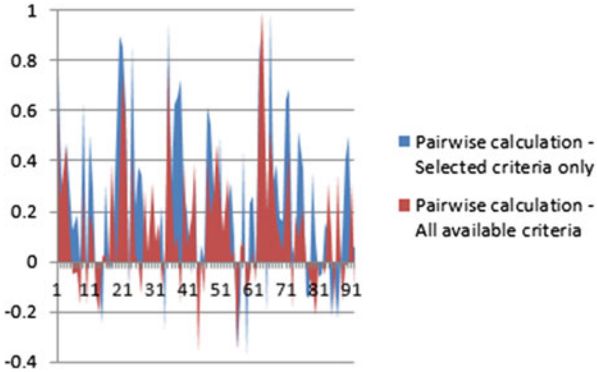

Fig. 5.3 All available criteria Kendall's τ_B value with pairwise computation for 100 users

Table 5.1 Spearman Rho coefficient for other recommender system

Method	Coefficient of Spearman Rho
Hybrid	0.3523
Content based	0.3235
Collaborative filtering	0.3214
Random	0.0104

As we can see our Rate computation (average 0.09) is very poor, but our Pairwise method (average 0.0443) gives better result than the ones got from these other recommender systems.

5.8 Conclusions and Perspectives

First of all we can assume that the implemented system satisfies the constraints and objectives which have been defined in the system requirements.

The experimentations demonstrate that our system give good recommendations, some improvements can be done. Indeed, we demonstrate that our system help users, but we do not get good performance when many criteria are used. We believe that it is possible to improve its performance in this particular case.

In order to obtain a more accurate system, we would try to use more complex computations of disaggregation and a scoring method using the Choquet integral. Indeed, it would be a major improvement for the system. For the moment, we consider that criteria are independent, but most of the time, it is not the case.

The weighted sum and, more generally, the quasi-linear medium have some weaknesses. None of these functions are capable of modeling any interaction among the attributes. Indeed, it is well known in the Utility Function theory (MAUT) that these functions lead to mutual preferential independence among the attributes, which expresses, in a sense, the independence of attributes. As these functions are not appropriate in the presence of dependent attributes, the trend has been to build the attributes supposed to be independent, which often caused errors in the assessments.

In order to obtain a flexible representation of complex phenomena of interactions among attributes or criteria (eg positive or negative synergy between certain criteria), it has proved useful to replace the weight vector by a set of non-additive functions, thus defining not only a weight for each criterion, but also on each subset of criteria [5]. Another major improvement of our system would be to introduce a set of non-additive functions as criteria.

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Chapter 6
E-commerce in the Context of Protected Areas Development: A Managerial Perspective Under a Multi-Criteria Approach

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Abstract Protected areas are under national and international environment laws because their recognized biological and environmental values provide economic prospects. The Prespa Lake Ecosystem, shared by three countries, Greece, FYROM and Albania, constitutes a dynamic model of local economic growth, environmental protection, joint management and international cooperation. Internet has become an alternative channel on business standard and especially, e-commerce constitutes an imperative within the viability of an enterprise. The concept of e-commerce is all about using the Internet to incorporate previous business models and economic strategies. This paper studies the e-commerce adoption in the Prespa Park Basin, a Greek protected area, member of NATURA2000 network, for regional development. E-commerce websites are ranked respecting their content and characteristics, as attributed to 30 variables. Following, the multicriteria method of PROMETHEE II is applied in order to perform evaluation and ranking tasks. Furthermore, the optimum e-commerce units are identified aiming to benchmark further e-commerce adoption in local enterprises. Finally, necessary recommendations for e-commerce website optimization is presented.

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6.1 Introduction

Protected areas are cornerstones in national and international nature conservation policies for their biological and environmental values, which also provide economic prospects. The continuous degradation of the natural environment due to the impact of human activities, particularly in recent centuries, resulted in the establishment of protected areas at the end of the nineteenth century [6]. It is not easy to establish a general rule to explain the impact of protected areas on socioeconomic features of local human settlements (and buffer areas surrounding protected areas), partly because of the multifaceted local impact that can be exerted under any circumstance [8, 28]. Protected areas regulation constitutes an extremely important measure for the protection and preservation of our natural heritage. Natura 2000 is the centrepiece of EU nature & biodiversity policy [16]. NATURA 2000 is an EU wide network of protecting natural areas aiming to provide long-term viability of Europe's most valuable and threatened species and habitats. The Prespa Park Basin in Greece (Fig. 6.1) constitutes a member of NATURA2000 network and it is shared by three countries, Greece, FYROM and Albania. The ecosystem of Prespa constitutes a model of local growth, environmental conservation, joint management and international cooperation.

Effective and successful management of this protected area relies on a complete understanding of the goods and services which they provide to the society [19]. Implementation of technology into social and economic developments has provided key strengths in improving competitiveness and meeting the demands of modern society for life and the economy [3]. Internet constitutes a tool for cultural and socio-economic development. It provides various advantages and benefits by offering a rich, dynamic environment for the exchange of information and resources [5]. Internet offers huge opportunities for all to progress and benefit and new prospects exist for economic growth, better service delivery, social and cultural advances [1, 4, 37]. With the broad commercialization of the Internet (mid-1990s), the focus on exploitation of new internet technologies reached new heights [17, 26]. Internet services are well appreciated by the society and e-commerce is an imperative within the viability of an enterprise.

E-commerce is a new business concept that incorporates all previous business management and economic concepts. E-commerce refers "to the process of buying, selling, or exchanging products, services and information via computer networks, including the Internet" [23]. Enterprises are more and more required to incorporate new internet technologies into business practices to improve competitiveness and bridge the gap between the production site and the final users of the products [29]. The enterprises aim at their participation in the internet society since the benefits are high and electronic systems are ready to serve customers all over the world 24 h per day and 7 days a week [20]. Internet connection is considered a particularly powerful instrument, especially for SMEs, because it offers this type of firm an efficient and permanent connectivity to the global market at a price that many SMEs could not previously afford [13]. By conducting e-commerce, manufacturers can eliminate

Fig. 6.1 Prespa Park Basin

distributors and wholesalers; optimize internal processes; reduce the production period, inventory and circulation [12] and thus obtain higher margins [14, 24]. Many enterprises have already created their web presence [2].

The aim of the chapter is to study the employ of e-commerce in the context of protected areas development and rank the e-commerce websites respectively. Internet presences of the Prespa Park Basin, member of NATURA2000 network are evaluated qualitatively and quantitatively according to their content and features, as attributed to 30 variables. Following, the multicriteria method of PROMETHEE II is applied in order to perform evaluation and ranking tasks. Moreover, the optimum e-commerce units are identified aiming to benchmark further e-commerce adoption in local enterprises.

In Sect. 6.2, the data collection and the multicriteria method that was applied is described. In Sect. 6.3, the results are presented. Finally, in Sect. 6.4, some conclusions are presented.

6.2 Data and Methodology

6.2.1 *Data*

The e-commerce websites that contribute to the Prespa Park Basin development are retrieved from the Internet through large-scale hypertextual search engines, such as “Yahoo”, “MSN Search”, “Pathfinder” and “Google” which provide satisfying results. Thematic search engines were also used to improve the standard search results. Yellow pages for local enterprises websites were also used. The research in the internet was made from September 2012 until February 2013, so the accomplishment or not of the characteristics are referred to that period of time. The characteristics that were selected are the most common features of functional websites. For this reason, some of them can be highly correlated with each other.

Various keywords and combinations were used such as ‘Prespa National Park’, ‘Prespa Park Basin’, ‘Prespa Lakes’, ‘Management Body of Prespa National Park’, ‘Prespes’, ‘Florina’, etc.

6.2.2 *Methodology*

Many criteria were introduced in these e-commerce websites, aiming to promote local development in the Prespa Park Basin. The criteria were used to describe variables $x_1, x_2, \ldots, x_n$. These criteria are presented in Table 6.1. The first step was

Table 6.1 List of Vigeo’s evaluation criteria

Variable	Criterion	Variable	Criterion
x_1	More than one language	x_{16}	Links to other companies etc
x_2	Information about products, services or activities	x_{17}	Topics with information on different categories
x_3	Contact information	x_{18}	Downloadable files
x_4	Local information	x_{19}	Calendar application
x_5	Digital map	x_{20}	Event calendar application
x_6	Audiovisual material	x_{21}	Celebration calendar application
x_7	Live web camera	x_{22}	Social media sharing
x_8	Search engine	x_{23}	Social media profile
x_9	Sitemap	x_{24}	Forum
x_{10}	Updated enterprise information	x_{25}	Related sources of information
x_{11}	Online survey	x_{26}	Third person advertisement
x_{12}	Online communication form	x_{27}	Newsletter
x_{13}	Weather forecast	x_{28}	RSS
x_{14}	Website visitor tracker	x_{29}	Code access
x_{15}	Frequently Asked Questions (FAQ)	x_{30}	Personalization of the page, trace, safety

to implement qualitative analysis in order to examine the type of common criteria, representing e-commerce technologies, found in the Prespa Park Basin websites. Then, a quantitative analysis through a 2-dimensional table was carried out in order to examine the presence or absence of these criteria. The value of 0 and the value 1 were attributed to the variables $x_1, x_2, \ldots, x_n$, for the non-existence and the existence of each criterion respectively.

Variable x_1 refers to the ability to view the content of the website in more than two languages (Greek and English). Variable x_2 refers to the provision of further information about the products or services of the enterprise while variable x_3 refers to the provision of information about the enterprise (ownership, mailing address, telephone number and email address) that simplifies the communication between the customers and the enterprises. As for variable x_4, it refers to the provision of detailed information about the local area.

Variable x_5 is associated with the provision of an interactive digital map for the better orientation of website visitors—customers. Variable x_6 refers to the provision of any kind of audiovisual material, such as photographs, videos and virtual tours. Variable x_7 refers to the existence of live web camera application. Variable x_8 represents the provision of web search engine. Variable x_9 refers to the provision of a sitemap for an overview of the website content. Variable x_{10} is associated with the continuous updating of the website regarding the enterprise activities. As for variable x_{11}, it refers to the online surveys and polling applications to identify the users' trends. Variable x_{12} refers to the provision of online communication form.

Variable x_{13} is associated with the provision of application for weather forecasting and variable x_{14} refers to the website visitor tracker. Variable x_{15} refers to the FAQ (Frequently Asked Questions) tab and variable x_{16} is associated with the provision of useful links to other relevant organizations or enterprises. Variable x_{17} refers to the provision of information on various topics, while variable x_{18} refers to the ability to download some useful files from the website. Variable x_{19} is associated with the clock and calendar application, variable x_{20} is associated with the local events calendar and variable x_{21} with the celebration calendar application integration.

Variable x_{22} refers to the provision of sharing the website through users' account in social networks such as Facebook and Twitter, while variable x_{23} refers to the participation of the enterprise in social media. Variable x_{24} is associated with the provision of an online interactive community through the website and variable x_{25} is associated with the available information on related topics. Variable x_{26} refers to the third person advertisement. Variable x_{27} refers to the use of newsletter service. Variable x_{29} refers to the ability to create a user account. Variable x_{30} refers to the ability to be personalized the website by the registered users, while variable x_{28} refers to the RSS service, which distributes information through the Internet. The subscription to a website RSS removes the need of manually checking the website for new content because the users' browser regularly monitors the website and informs the users of any updates.

The PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) belongs to the class of Multi-Criteria Decision Aid (MCDA) instruments. Several MCDA techniques have been developed over the years that deal with the ranking of numerous alternatives based on a variety of criteria. In other words, the MCDA allows for the selection of the best from the analyzed alternatives. Their development was actually the result of the practitioner's motivation to provide academics and researchers with improved decision making processes suitable for real-life multiple criteria decision situations by taking advantage of the recent evolutions in computer technology and the mathematical techniques involved [32]. For the purposes of our analysis, following Kosmidou and Zopounidis [21, 22], we were based on one of the most recent MCDA techniques, the PROMETHEE II method.

PROMETHEE II method is an outranking multi-criteria decision aid approach developed and presented for the first time by Brans [9] at the University Laval, Quebec, Canada, during an organized conference on multi-criteria decision aid instruments by Nadeau and Landry. This method has attracted the increased attention of the researchers for practically complex problems and the growing records of conference presentations and academic papers can easily illustrate this. As the time passed, a number of extensions have been suggested with the aim of assisting researchers in dealing with more complex problems. Indeed, PROMETHEE methodology has effectively been applied in a variety of areas such as Banking, Business and Financial Management, Chemistry, Energy resources, Health, Investments, Industrial Location, and other fields. As Brans and Mareschal [10] have pointed out, the above technique owes its success mainly to its particular friendliness of use and to its' mathematical properties.

Addressing a classification problem requires the development of a classification model that aggregates the characteristics of the alternatives to provide recommendations on the assignment of the alternatives to the predefined classes. The significance of classification problems has motivated the development of a plethora of techniques for constructing classification models. Statistical techniques have been dominating the field for many years, but during the last two decades other approaches have become popular mainly from the field of machine learning.

Also, the contributions of MCDA are mainly focused on the study of multicriteria classification problems (MCPs). MCPs can be distinguished from traditional classification problems studied within the statistical and machine learning framework in two aspects [36]. The first aspect involves the nature of the characteristics describing the alternatives, which are assumed to have the form of decision criteria providing not only a description of the alternatives but also some additional preferential information. The second aspect involves the nature of the predefined classification which is defined in ordinal rather than nominal terms. Classification models developed through statistical and machine learning techniques often fail to address this issues focusing solely on the accuracy of the results obtained from the model.

Within the MCDA several criteria aggregation forms have been proposed for developing decision models. These include relational forms, value functions, and rule-based models. Relational models are based on the construction of an outranking relation that is used to compare the alternatives with some reference profiles characterizing each class. The reference profiles are either typical examples (alternatives) of each class or examples that define the upper/lower bounds of the classes. Some typical examples of this approach include methods such as ELECTRE TRI [30], PROAFTN [7], and PAIRCLAS [15]. The main advantage of this approach is that it enables the decision maker (DM) to take into account the non-compensatory character of the decision process and to identify alternatives with special characteristics through the incorporation of the incomparability relation in the analysis. On other hand, the construction of the outranking relation requires the specification of a considerable amount of information which is not always easy to obtain.

Value functions have also been quite popular as a criteria aggregation model in classification problems. This approach provides a straightforward methodology to perform the classification of the alternatives. Each alternative is evaluated according to the constructed value function and its global evaluation is compared to some value cut-off points in order to perform the assignment to one of the predefined classes. Due to their simplicity linear or additive value functions are usually considered [18, 25, 34, 35]. These provide a simple evaluation mechanism which is generally easy to understand and implement. However, there has been criticism on the assumptions underlying the use of such simple models and their ability to capture the interactions between the criteria.

The PROMETHEE methodology gives the ability to solve a decision problem where a finite set of comparable alternatives is to be evaluated according to several and often opposing criteria. The implementation of the PROMETHEE method involves the construction of an evaluation table (Table 6.2), in which the alternatives are estimated on the preferred criteria and ranked from the best to the worst. The PROMETHEE methods are considered to provide solutions for multicriteria problems of the form (6.1) and their associated evaluation table.

$$\max\{g_1(a), g_2(a), g_3(a), \ldots, g_j(a), \ldots, g_k(a) | a \in A\} \tag{6.1}$$

where: A is a finite set of possible alternatives $\{a_1, a_2, \ldots, a_i, \ldots, a_n\}$ and $\{g_1(\cdot), g_2(\cdot), \ldots, g_j(\cdot), \ldots, g_k(\cdot)\}$ is a set of evaluation criteria.

Additional requirements for the application of PROMETHEE are the consideration of the relative significance of the selected criteria (i.e., the weights) and the information on the individually defined preference function of the decision-maker, regarding the comparison of the alternatives in terms of each single criterion.

Table 6.2 Evaluation table

A	$g_1(\cdot)$	$g_2(\cdot)$	$\ldots$	$g_j(\cdot)$	$\ldots$	$g_k(\cdot)$
a_1	$g_1(a_1)$	$g_2(a_1)$	$\ldots$	$g_j(a_1)$	$\ldots$	$g_k(a_1)$
a_2	$g_1(a_2)$	$g_2(a_2)$	$\ldots$	$g_j(a_2)$	$\ldots$	$g_k(a_2)$
$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$
a_i	$g_1(a_i)$	$g_2(a_i)$	$\ldots$	$g_j(a_i)$	$\ldots$	$g_k(a_i)$
$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$	$\ldots$
a_n	$g_1(a_n)$	$g_2(a_n)$	$\ldots$	$g_j(a_n)$	$\ldots$	$g_k(a_n)$

Source: Brans and Mareschal [10]

The weights are typically arbitrary positive numbers, determined independently from the measurement units of the criteria. According to Macharis et al. [27], the selection of the weights is of high importance in the case of multicriteria decision analysis, since it reflects the decision-makers' insights and priorities.

The preference structure of PROMETHEE is based on pair wise comparisons. This means that a separate preference function for each criterion must be defined for all pairs of alternatives, reflecting the degree of preference for an alternative a over b. Vincke and Brans [31] suggested six specific types of preference functions, provided in the appendix section, from which the researcher can easily define its preference structure. No matter, which is the preference function, the decision maker has to define the values of q, p and σ parameters. In contrast to q which is an indifference threshold that corresponds to the largest deviation, p is a strict preference threshold with the smallest deviation, capable of generating a full preference sufficiently for the decision maker. As far as the σ parameter is concerned it represents an intermediate value between q and p.

According to Brans et al. [11], this preference degree for all couples of actions, can be represented by the preferred index of the following form:

$$\Pi(a, b) = \frac{\sum_{i=1}^{n} w_j P_j(a, b)}{\sum_{j=1}^{n} w_j}$$

where w_j is the weight for each criterion, and $P_j(a, b)$ expresses the degree at which action a is preferred to action b, when all the criteria are considered at once. Its value varies between 0 and 1.

As for the ranking of alternative actions, two flows should be defined, the leaving and the entering flow, briefly described below:

$$\phi^{+}(a) = \sum_{b \in A} \pi(a, b)$$

$$\phi^{-}(a) = \sum_{b \in A} \pi(b, a)$$

The leaving flow $\phi^{+}(a)$ expresses how an alternative a dominates all the other alternatives of A (the outranking character of a). On the other hand, the entering flow $\phi^{-}(a)$ measures how an alternative a is surpassed by all the other alternatives of A (the outranked character of a). According to PROMETHEE I partial ranking an action a is favoured over an action b, $(a\,P\,b)$ if the leaving and entering flows of action a are greater and smaller respectively than those of action b:

$$\begin{aligned} a\,P\,b \text{ if :} &\phi^{+}(a) > \phi^{+}(b) \text{ and } \phi^{-}(a) < \phi^{-}(b) \text{ or} \\ &\phi^{+}(a) > \phi^{+}(b) \text{ and } \phi^{-}(a) = \phi^{-}(b) \text{ or} \\ &\phi^{+}(a) = \phi^{+}(b) \text{ and } \phi^{-}(a) < \phi^{-}(b) \text{ or} \end{aligned}$$

In the case that the leaving and entering flows of two actions a and b are the same, the indifference situation can be written with the following expression ($a\,I\,b$):

$$a\,I\,b \text{ if } : \phi^{+}(a) = \phi^{+}(b) \text{ and } \phi^{-}(a) = \phi - (b)$$

There is also the possibility for two alternative actions to be incomparable, ($a\,R\,b$), if the entering flow of action a is worse than the corresponding flow of action b, while the opposite is implied by the leaving flow:

$$a\,R\,b \text{ if} : \phi^{+}(a) > \phi^{+}(b) \text{ and } \phi^{-}(a) > \phi^{-}(b) \text{ or } \phi^{+}(a) < \phi^{+}(b) \text{ and } \phi^{-}(a) < \phi^{-}(b)$$

In this paper we utilized only the PROMETHEE II method which provides a complete ranking of the comparable alternatives from the best to the worst. The net flow implied by $\phi(a)$,which is the difference between the two flows, corresponds to a value function for which the higher the value the higher the attractiveness of alternative a. For each action $a \in A$ the net flow can be described as follows:

$$\phi(a) = \phi^{+}(a) = \phi^{-}(a)$$

The outranking relations in PROMETHEE II method are such that:

$$a\,P_{II}\,b \text{ if } \phi(a) > \phi(b) \text{ (preference for } a \text{ over } b\text{)},$$

$$a\,I_{II}\,b \text{ if } \phi(a) = \phi(b) \text{ (indifference between } a \text{ and } b\text{)}$$

To sum up, the PROMETHEE II methodology was selected in order to perform evaluation and ranking tasks, for the following reasons [33]: (a) because the estimated relation of superiority (of one internet presence over another) is less sensitive in small changes and that offers an easier analysis and discussion of the results, (b) the use of the superiority relation in the PROMETHEE method is applied when the alternative solutions (internet presences) have to be ranked from the best to the worst, and (c) the procedure of assessing and ranking complicated cases of internet presences is proper for the application of the above methodology in the sense that it is closer to reality.

6.3 Results and Discussion

Internet provides a variety of e-commerce technologies and tools to boost the local economic development and especially the protected areas development. The research in the Greek Internet retrieved 15 e-commerce websites that promote the Prespa Park Basin in Greece. Aiming to study the e-commerce adoption for economic perspectives, the retrieved websites were studied through 30 different characteristics.

Table 6.3 Total ranking of Prespa Park Basin e-commerce websites and total net flows

Total ranking	Website	Type of enterprise	Total net flow
1	http://www.viologikafasolia.gr/	Local food enterprise	0.757
2	http://www.fasolia.gr/	Local food enterprise	0.629
3	http://www.kingbeans.gr/	Local food enterprise	0.619
4	http://www.villaplatythea.gr/	Resort	0.381
5	http://prespes-hotelprespaspa.clickhere.gr/	Resort	0.381
6	http://www.varnous-hotel-prespa.com/	Resort	0.248
7	http://www.prespesfasolia.gr/ http://prespes-fasolia.nextnet.gr	Local food enterprise	0.105
8	http://www.ariadni-prespes.gr/	Resort	−0.010
9	http://mimallones.gr/	Resort	−0.129
10	http://fasoliaprespas.weebly.com	Local food enterprise	−0.276
11	http://www.syntrofia-prespes.gr	Resort	−0.424
12	http://www.sourino.gr/	Resort	−0.452
13	http://www.hotel-philippos.gr/	Resort	−0.486
14	http://www.fasolia.eu/ http://www.e-ospria.gr/	Local food enterprise	−0.581
15	http://www.prespabeans.gr/	Local food enterprise	−0.762

Based on the application of the PROMETHEE II method, the first and the last ten cases of the total ranking of Prespa Park Basin internet presences are presented in Table 6.3. In the same table it is also presented the total net flow that is estimated for each internet presence and it is used for the comparison between the internet presences in order to obtain the total ranking, as each internet presence with a higher net flow is considered superior in ranking.

According to these findings, the values estimated for total net flows ϕ present a spectrum of values between $+0.75$ to -0.76 and that indicates a great difference concerning "superiority" between the first and the last case in the ranking of the enterprises' website. The e-commerce websites with high "superiority" and at the same time with high "lag" belong to enterprises that commerce local products (e.g. beans, etc.). Regarding the hotels websites, the range of the estimated values for total net flows seems to be smaller and that reveals that hotels implement websites that operate at the same level of e-commerce.

The e-commerce websites with high "superiority" are the ones which provide downloadable files (x_{18}), event and celebration calendar applications (x_{20}, x_{21}), forum and related sources of information (x_{24}, x_{25}), RSS, code access and personalization of the web pages, traces and safety (x_{28}, x_{29}, x_{30}). Some other features that improve the total net flow of a website are the Calendar application (x_{19}), the Newsletters (x_{27}) and sitemap (x_9). The web visitors of these commercial websites are mainly interested in the protected areas development as a whole and not so much for the updates especially in enterprise information (x_{10}). Furthermore, social media sharing and profile (x_{22}, x_{23}), seem not to be critical to users.

6.4 Conclusions

The findings of this study are useful in improving e-commerce adoption through the improved design and implementation of a website to accomplish certain features and to generally optimize the e-commerce activities in the protected areas in Greece. The results could be helpful for policy makers and managers while planning activities and implementing innovative technological advances, such as the dynamic and efficient websites aiming to lead to radical and structural changes.

The existence of e-commerce websites constitutes the first significant step for the promotion of this protected area with the high natural, ecological and cultural values. Findings confirm that e-commerce adoption in protected areas in Greece is still in initial level. However, raising the environmental public awareness for the protected areas, the e-commerce websites that promote the protected areas should evolve in further internet adoption for local development. Internet is a dynamic sector and is constantly evolving. Hundreds of companies create their own e-commerce website every day. Since this study was made from September 2012 until February 2013, more e-commerce websites that are not included in this study will probably provide the Prespa Park Basin development.

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Chapter 7
Solving a Multicriteria Road Design Problem: A Practical Example

Renaud Sarrazin and Yves De Smet

Abstract Improving the safety performances of road infrastructures had been a major issue in recent transport policies in Europe. Simultaneously the concept of sustainable development has become a key element in many strategic and operational policies—including the road sector ones. However, few methodologies have been developed to support actively the road sector in the design of safer and greener roads: road design remains mainly a single-criterion decision problem based on the global costs. This study seeks to develop a multicriteria methodology to carry out an integrated and preventive assessment of road projects at the design stage by considering both their safety performances and some economic and environmental aspects. It would support design engineers in the analysis of their projects and the identification of innovative, consistent and performing solutions. For this purpose, we consider road design as a combinatorial optimisation problem to be solved in a multicriteria context. For a given road project, we use an evolutionary algorithm to identify efficient solutions. Then, we apply a multicriteria clustering technique based on PROMETHEE to detect groups of similar alternatives that support a partially ordered structure. We illustrate the methodology on a real design project of a rural road infrastructure in Belgium.

7.1 Introduction

Designing a road project is not an easy task. It requires a strong technical expertise to develop efficient and performing solutions that would respect the design standards. Simultaneously, many external aspects should be taken into consideration in order to develop the most appropriate solutions according to the characteristics of the project and the demands of the specification. Among these aspects, we may cite

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the economic performances and the social values of the project, the environmental impacts of the road infrastructure, the travel safety and comfort, the preservation of the landscape, or even some societal and political aspects.

Over the past few decades, designing safer and greener roads has became a major concerns of mobility and transport policies in Europe. Since 2001, several reports and directives were published by the European Commission (EC) about the improvement of the safety level on the European road network. In the European White Paper on Transport Policy [16], an objective of halving the overall number of road deaths in the European Union by 2010 had been targeted. Then, this challenging objective has been updated and reinforced in the Road Safety Programme 2011–2020. It has been completed with several strategic objectives and principles such as the development of an integrated approach to road safety [18]. In 2003, the European Road Safety Charter had been published and submitted to several actors of the road sector, as a commitment to take concrete actions in order to reduce road accident fatalities. Additionally, in 2008, the European Commission had published the Greening Transport Package about strategies to apply in order to strive for a transport system more respectful of the environment [17].

In Belgium, the Federal Commission for the Road Safety had been formed in 2002 with the intent to fulfill the EC objectives. In 2011, the initiative "Go For Zero" has been launched by the State Secretary for Mobility and the Belgian Institute for Road Safety. It conducts several actions to make the road users sensitive to road safety issues (e.g., speed, seatbelt, alcohol and driving, etc.) [25]. In Wallonia, the government reaffirmed its willingness to promote sustainable mobility for every road user in its declaration of regional policy for the period 2009–2014 [44].

However, this increasing political support is not followed by practical and effective actions while they would be essential to meet the objectives of the EC. In particular, an effort should be made to develop preventive and innovative tools which may be used during the design stage to assess the technical and sustainable performances of a road project. In the long run, these tools would allow us to design innovative road infrastructure projects and to promote solutions that are more consistent with sustainable transport policies.

To date, the assessment of the road safety performances of an infrastructure is essentially based on reactive approaches such as the evaluation of databases containing accident statistics. These offer the administration a support in the identification of the areas or routes with high accident concentration—also called black spots. These methods consist of curative analysis and handling of the high accident concentration areas. Moreover, the selection of project alternatives at the design stage is still mainly motivated by the economic aspect while the environmental and the social aspects are often neglected. Based on these observations, we have initiated the development of a preventive analysis of the sustainable and safety performances of a road project at the design stage.

In the field of operational research, only a few studies were conducted to address the problems of infrastructure management, road design and road safety assessment from a multicriteria perspective. Concerning the evaluation of road safety, we could cite studies that were related to the development of safety performance indicators

[8] or aggregated indices based on ex-post evaluation of road projects or features [2]. Recently, multicriteria decision making techniques were applied to specific safety assessment problems such as prioritizing the accident hot spots based on geometric characteristics of the road infrastructure and traffic conditions of the road network [36] or evaluating the safety performances of pedestrian crosswalks [47]. In 2002, the research project ROSEBUD was conducted on the assessment of the performance of several safety measures from benefit-cost and cost-effectiveness analysis [37]. However, this project focused more on the evaluation of standardized safety techniques than on the preventive assessment of road designs in their direct environment.

Moreover, a recent review paper pointed out that approximately 300 published papers were concerned by the application of multicriteria decision techniques in the field of infrastructure management during 1980–2012 [28]. This result suggests a growing interest of the road sector in the use of multicriteria decision techniques. Nevertheless, it is still restricted to infrastructure management applications. In the field of transportation planning and road design, we could cite the work of Dumont and Tille about the interest of using a multicriteria decision making approach to design more sustainable road infrastructures [15]. In 2014, de Luca published a paper about the application of the Analytic Hierarchy Process to support the public engagement during the whole transportation planning process [10]. The evaluation of the alternatives was based on several criteria such as the accessibility of the road, the travel safety and comfort, the impact on the environment and the preservation of the landscape. However, the assessment of the safety performances was highly qualitative. In 2008, Brauers developed a multiobjective optimization approach to support decision makers in the selection of road design alternatives but the evaluation process was restricted to the longevity of the infrastructure, the construction price and duration, the environment protection and the economic validity [7]. Road safety performances were not considered.

Based on these observations, this study was initiated with the aim of developing a multicriteria analysis method to assess the performances of road project alternatives at the design stage. This assessment both consider the road safety performances from a preventive perspective and some environmental and economic concerns related to the sustainable character of road infrastructures. In practice, our approach is composed of two main models. At first, we use a multiobjective evolutionary approach that allow us to consider road design as a combinatorial optimisation problem and to extend the analysis to all feasible solutions of a given road project. The approximated set of the best solutions is then identified. Secondly, we use an multicriteria ordered clustering technique that regroup the solutions according to their similarity and separate those that are not. The groups of solutions finally obtained support an ordered structure so that it is possible to rank them from the best to the worst one (while allowing incomparability between some pairs).

The structure of this paper is as follows. First we provide a description of the research motivation where we briefly discuss the evaluation of road safety and the integration of sustainability assessment in the design process. Next, the methodology is presented. We introduce briefly the state of the art of our approach and we describe the multiobjective evolutionary approach and the multicriteria clustering technique. Thereafter, the method is applied on a practical case study to underline the results that could be obtained. Finally, some conclusions are provided.

7.2 Research Motivation

During the design process of a road infrastructure project, a limited set of alternatives is defined. Different design choices are made by varying parameters that represent the main characteristics of the project, such as the number of lanes, their width, the nature of the pavement materials, the type of intersections, etc. At the end of this modeling stage, an alternative is selected among the limited set of proposed solutions. But even if this selection is not exclusively motivated by the economic criterion, there is to date no integrated tool that could help the design engineers to analyze the performances of each alternative on multiple criteria. As a consequence, the selected solution might not be the most appropriate regarding all the characteristics, challenges and constraints of the project.

In this paper, we propose an approach that aims to support design engineers in the evaluation of their project alternatives on the one hand, and the identification of the best possible solutions on the other hand. This assessment is done in a multicriteria context so that it would be possible to select the best solution according to the characteristics of the project or the demands of the specification. Each alternative is evaluated on a set of criteria which is composed of road safety performances and some sustainable aspects related to environmental, social and economic issues. In the long run, we assume that the use of integrated assessment during the design stage of a road project may promote the development of innovative and sustainable solutions. In addition, the preventive evaluation of the road safety performances may support engineers in designing safer projects in accordance with the EC policies.

7.2.1 An Innovative Approach of Road Design

7.2.1.1 For a Preventive Assessment of Road Safety

In 2013, the level of safety on the Belgian road network had slightly improved with a global decrease of road deaths by 5.8 %. This reduction corresponds to a total of 720 road deaths and it is in accordance with the objectives of the EC of decreasing to 620 road deaths in 2015 and 420 in 2020. However, when comparing with the situation in France (−11 %) and Germany (−10 %), the decrease is slower in Belgium [26]. Therefore, to reinforce the improvement of road safety in Belgium and to maintain this orientation in the long run, it would be relevant to assess the safety performances of a road project during the design stage. We assume that this preventive evaluation of road projects would allow design engineers to identify and avoid potential safety issues.

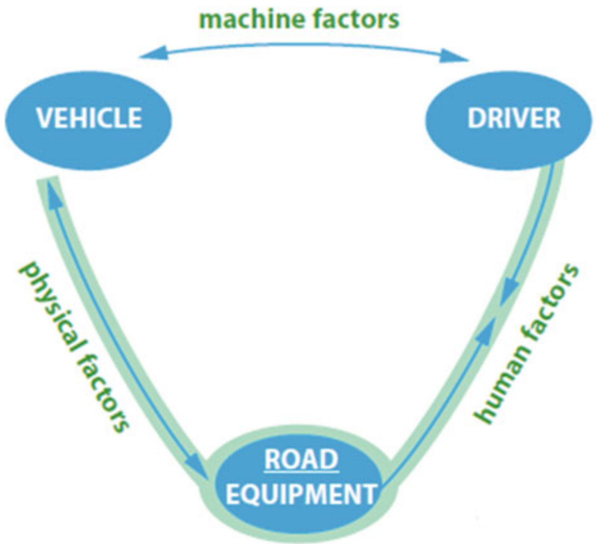

Fig. 7.1 Elementary triangle of road safety composed of the dimensions vehicle, driver and road equipment

From a theoretical point of view, we may define road safety as a complex concept resulting from the association of the dimensions vehicle, driver and road equipment. On the basis of this so-called *triangle of road safety*, we are able to classify all the causes of an accident in at least one dimension of the triangle, or even a combination of them (cf. Fig. 7.1). To improve the global level of safety of a road infrastructure, it is then relevant to take an interest in the dimensions of this triangle. According to different studies, from 18 to 28 % of the accidents are due to an unsafe road environment or infrastructure [34]. These safety issues might occur either due to the misapplication of the guidelines or because of the local characteristics of the project. In our approach, we focus on the analysis of safety issues related both to the road equipment dimension and the interactions road-driver and road-vehicle. Regarding the nature of the roads concerned by our analysis, we concentrate specifically on the evaluation of secondary rural roads. Indeed, the Belgian road network is composed of roads with different functions[1] and roadside environment[2] so that their characteristics may differ significantly with regard to traffic volume and composition, density of the road network, travel patterns, roadside obstacles, etc. Then, the safety issues that may occur on these different roads are related to different causes. Consequently, the methodology that we would use to assess the performances of these roads should also differ in order to consider their distinctive features.

[1] Highway, primary, secondary or local.

[2] Urban, peri-urban or rural.

A large literature review was conducted on the topic of road safety [23, 34]. In particular, we analyzed the safety issues or characteristics related to the legibility of the road infrastructure [20, 34, 35], the protection of vulnerable road users [21, 31, 34], the quality of road pavement materials [8, 9], the impact of road layout and equipment [46], the design of intersections [20] and the safety on road works [45]. The seven following criteria were identified and sorted in the categories Infrastructure (INF) and Services (SRV).

INF1—Visibility of the infrastructure
INF2—Road design and road safety equipment
INF3—Quality of the road pavement materials
INF4—Protection of the vulnerable roads users (VRU)
INF5—Intersections
INF6—Safety on road works
SRV1—Information and intervention services

They constitute the first part of the set of criteria that is used in the proposed multicriteria analysis methodology. They will allow us to quantify the performance of road infrastructure projects in relation to safety. As mentioned previously, our approach is based on a preventive assessment of road project at the design stage. Consequently, we need to develop criteria exclusively from design parameters and data that are available at this stage (e.g. operational traffic volumes either from predictive models or preliminary collect sessions in case of an existing road infrastructure). Due to this constraint, the definition of the criteria was a strong methodological challenge that required an important stage of modelling and creation of data. Additionally, a few meetings were organized with experts from the road sector to review critically and validate the selected criteria.

7.2.1.2 A Support to Sustainable Road Projects

Considering the major environmental, economic and social crisis that the world has experienced, and due to the collective nature of a road infrastructure, it has become crucial to integrate the road sector policies into a more sustainable approach. Indeed, road infrastructures have close links with some sustainable topics such as energy consumption [19], preservation of environment, economic performance, noise disturbance [14, 33] or even social impact [40]. In practice, it both implies to reconsider current policies by taking into account more precisely sustainable development concerns and to develop some new evaluation processes and decision aiding tools to offer the road sector a common definition about sustainability. As mentioned previously, several reports have been published during the past years by national and European organizations in order to promote sustainable roads. However, there is still a lack of tools and processes that could assist the actors of the road sector in the practical and integrated evaluation of the sustainable performances of their projects.

In this study, we aim to enrich the evaluation of the safety performances of road projects with some fundamental concerns related to the environmental, social and economic dimensions of sustainable development. By doing so, we define a more complete and integrated assessment model which would meet the needs of the transport and mobility policies in Europe. Over the past few years, several studies have been conducted on the topics of sustainable roads [3, 24, 32] and sustainable safety (e.g., Vision Zero [42], Sustainable Safety [1]). But regarding the sustainable safety concept, these studies exclusively focused on the social dimension of the sustainable development. As part of our approach, we broadened the sustainability notion to the three pillars of sustainable development—economic (ECO), social (SOC) and environmental (ENVI). The five following criteria were selected.

ENVI1—Reduction of greenhouse gases emissions
ENVI2—Limitation of noise pollution
SOC1—Ensure mobility of all
ECO1—Limitation of the construction costs
ECO2—Limitation of the maintenance costs

The association of these criteria with the ones introduced in the previous section represents, to our point of view, the concept of sustainable road safety. They constitute the set of criteria of our multicriteria decision aiding problem. The exhaustive definition of the full set of criteria goes beyond the scope of this paper but we refer to [38] for further information. Obviously, the importance of each criterion might vary depending on the characteristics of the road project, the specifications or the preferences of the decision maker. For instance, we may consider a rural road project in a non-developed area that would exclusively support motorized traffic. In that case, the criteria about noise pollution (ENVI2), mobility (SOC1), or even protection of the VRU (INF2) would be of low importance.

7.2.2 Towards a Multicriteria Analysis of the Design Process

Once a complete set of criteria has been developed, we could imagine to evaluate the alternatives that were defined at the design stage on every criteria. By doing so, it would be possible to identify which would be the set of best solutions among the ones defined by the design engineers. However, the actual design process only consider a limited set of alternatives (generally from 5 to 15 alternatives) while it would be very interesting to consider the exhaustive set of all the feasible solutions. It would allow the decision maker to analyse more precisely his problem and to finally select the most performing and consistent solution considering his own preferences and the characteristics of the project.

In this study, we assume that the design process of a road infrastructure could be considered as a combinatorial optimisation problem. Each alternative of a road project is composed of a list of variables, such as the number of lanes, their width, the type of road surface materials, the nature of the road signs, lighting equipments or vehicle restraint systems, the nature of the pedestrians and cyclists facilities, the speed limit on the roadway or even the type of intersections. Each of these variables could take a finite number of values so that a complete set of alternatives could be generated by simply combining them. As an example, if we consider a simple combinatorial optimisation problem with ten parameters that can take four different values each, the number of feasible alternatives that could be generated is already quite important (about 10^6 possible combinations). In Sect. 7.4, we will see that even for a design problem that involves 12 variables ranging from 2 to 5 values, the size of the problem is significantly large. Efficient solutions are then identified by using a metaheuristic approach. Finally, a multicriteria clustering model is used to structure the multicriteria problem and identify groups of similar solutions that are partially ordered.

7.3 Methodology

The methodology we present in this paper is composed of two successive approaches. First, we use a multiobjective evolutionary approach to identify a set of performing solutions. Then, a multicriteria ordered clustering approach is applied to group similar solutions, rank them according to their performances and solve the multicriteria problem by selecting the best ones. In the following section, we briefly define the proposed model by introducing the main theoretical concepts that are related to the proposed method.

7.3.1 *Multiobjective Evolutionary Algorithm*

Optimization techniques are applied with the aim to find a global optimal solution (or a set of global optimal solutions). When a model is always able to identify the global optimal solution of a problem in a reasonable amount of time, it is classified in the family of exact optimization algorithms. However, computing optimal solutions could be sometimes difficult, or even impossible, when dealing with very large and complex decision problems. In many situations, decision makers are then satisfied with a set of performing and acceptable solutions, so called a *good approximated set of solutions* that can be computed quickly. To obtain this approximated set, we may use approximate algorithms such as metaheuristics. Due to their efficiency and applicability, metaheuristics are then used in many real-world optimization problems in the fields of engineering, system modeling or data mining [22].

When solving multiobjective optimization problem with a metaheuristic, a good approximated set is obtained when the solutions are both well-performing and diversified. It corresponds to an approximation of the Pareto front that is as close as possible to the optimal Pareto front and with solutions that are well-spread. These characteristics refer respectively to the exploitation of the best solutions that are found (i.e. intensification) and to the examination of nonexplored areas of the search space (i.e. diversification) [41]. In this paper, we use the popular non-dominated sorting-based genetic algorithm called NSGA-II[3] [13].

The main steps of the multiobjective evolutionary algorithm NSGA-II can be described as follows. From the complete set of alternatives, we randomly select a limited subset that constitutes the initial population. Next, we generate the evaluation table of this initial population and then, we identify the non-dominated solutions. Afterwards, we start the genetic process and we improve the quality of the initial solutions by applying crossover and mutation operations on each successive set of solutions. At the end, the set of solutions has converged and the set of non-dominated solutions of our problem are identified.

During the genetic process, we select two parents in the current population by using binary tournament selection based on the non-dominated rank of the alternatives and the crowding distance. When comparing two individuals, we select the one with the smaller rank (i.e. the *most performing*) or with the greater crowding distance (i.e. the *most diversified*). Then, we allow the parents to make a crossover with a probability P_c of 90 %. We use *Simulated Binary Crossover* to generate new individuals [12] :

$$\begin{aligned} c_{1,k} &= 0.5 \times [(1-\beta_k)\, p_{1,k} + (1+\beta_k)\, p_{2,k}] \\ c_{2,k} &= 0.5 \times [(1+\beta_k)\, p_{1,k} + (1-\beta_k)\, p_{2,k}] \end{aligned} \tag{7.1}$$

where β_k (≥ 0) is a spread factor, $c_{i,k}$ (resp. $p_{i,k}$) is the evaluation of the ith child (resp. parent) on the kth objective.

Then, we allow the individuals of the child population to mutate with a probability P_m of 30 %. We use a polynomial mutation to generate the offspring c_i'.

$$c_i' = c_i + \left(c_i^u - c_i^l\right) \delta_i \tag{7.2}$$

where c_i^u (resp. c_i^l) is the upper (resp. lower) bound of the individuals c_i and δ_i is a parameter computed from a polynomial probability distribution [41]. In the following equation, η_m is the distribution index and r_i is a random number between 0 and 1:

$$\begin{aligned} P(\delta) &= 0.5 \times (\eta_m + 1)\left(1 - |\delta|^{\eta_m}\right) \\ \delta_i &= \begin{cases} (2r_i)^{\frac{1}{\eta_m+1}} - 1 & \text{if } r_i < 0.5 \\ 1 - (2\,(1-r_i))^{\frac{1}{\eta_m+1}} & \text{otherwise} \end{cases} \end{aligned} \tag{7.3}$$

[3] Nondominated Sorting Genetic Algorithm II.

7.3.2 Multicriteria Ordered Clustering Model

After applying the multiobjective evolutionary algorithm to the combinatorial road design problem, we obtain an approximated set of good solutions. However, the size of this set of solutions may remain quite important so that it may not be trivial to make decisions. To this end, we propose to use a multicriteria clustering approach to simplify the multicriteria problem. Multicriteria clustering refers to the detection of groups of alternatives in a multicriteria context. It relies on the explicit consideration of preference relations between alternatives in order to build clusters. The resulting groups can be (partially or completely) ordered or considered as being incomparable. Instead of considering all Pareto optimal solutions, we can focus ourselves on representative elements of the different class in order to guide the DM.

In this study, we apply the PCLUST model which is an extension of the outranking method PROMETHEE I for interval (or partially ordered) clustering [39]. The aim of this model is to structure a multicriteria clustering problem by defining a set of categories that supports a partially ordered structure. In other words, it groups the alternatives that are similar and separate those that are not. As a consequence, it partitions the decision space (i.e. the alternatives of the approximated set) into a set of partially ordered clusters. Then, we consider two different types of clusters in the PCLUST model: the principal clusters that are completely ordered from the best one to the worst one, and the interval clusters that are located *between* two principal clusters and then induce a partial order. We assume that the use of principal and interval clusters allows the decision maker to generate a clustering structure that reflects better the preferential information in a complex multicriteria problem.

In the following, we briefly introduce the PROMETHEE and FlowSort methods. Then, we describe our PCLUST model.

7.3.2.1 The PROMETHEE Methods

The PROMETHEE outranking methods were initiated in the early 1980s by J.P. Brans [4–6, 43]. They offer the decision maker a support to solve multicriteria problems by using a valued outranking relation. This relation is based on pairwise comparisons between alternatives and it defines the preference structure of the PROMETHEE method.

Let us consider a set of alternatives $A = \{a_1 \dots a_n\}$ and a set of criteria $F = \{g_1 \dots g_q\}$. We suppose in the following that these q criteria have to be maximized. For each criterion g_k, the DM evaluates the preference of an alternative a_i over an alternative a_j by measuring the difference of their evaluation on g_k.

$$d_k(a_i, a_j) = g_k(a_i) - g_k(a_j) \tag{7.4}$$

This pairwise comparison allows the DM to quantify how alternative a_i performs on g_k compared to alternative a_j. Then, we use a preference function P_k to transform this value into a preference degree. Depending on the shape of the preference function, the DM could define the indifference threshold q_k and the preference threshold p_k for each criterion.

$$P_k(a_i, a_j) = P_k[d_k(a_i, a_j)] \tag{7.5}$$

$$0 \leq P_k(a_i, a_j) \leq 1 \tag{7.6}$$

To quantify the global preference of a_i over a_j, we define the notion of preference index $\pi(a_i, a_j)$. It allows us to aggregate all the unicriterion preference $P_k(a_i, a_j)$ by considering the weights ω_k associated to each criterion.

$$\pi(a_i, a_j) = \sum_{k=1}^{q} P_k[d_k(a_i, a_j)] \cdot \omega_k \tag{7.7}$$

$$\omega_k \geq 0 \quad \text{and} \quad \sum_{k=1}^{q} \omega_k = 1 \tag{7.8}$$

The last step of the PROMETHEE methods relies on the calculation of the outranking flow scores of each action. It allows the DM to quantify on average how an action a_i is preferred to all the remaining actions x of the set A and how these actions x are preferred to a_i. These two notions are respectively represented by the positive flow score ϕ^+ and the negative flow score ϕ^- in PROMETHEE I.

$$\phi^+(a_i) = \frac{1}{n-1} \sum_{x \in A} \pi(a_i, x) \tag{7.9}$$

$$\phi^-(a_i) = \frac{1}{n-1} \sum_{x \in A} \pi(x, a_i) \tag{7.10}$$

The positive and negative flow scores could be combined into the outranking net flow score ϕ which is used in PROMETHEE II.

$$\phi(a_i) = \phi^+(a_i) - \phi^-(a_i) \tag{7.11}$$

Based on the positive and negative flow scores, the PROMETHEE I method generates a partial ranking of the alternatives. In PROMETHEE II, a complete order is generated from the net flow scores of the alternatives.

7.3.2.2 The FlowSort Method

The FlowSort method was developed by Nemery and Lamboray [30] for solving multicriteria sorting problems. This method allows the DM to sort the alternatives into categories based on their positive and negative flows. The categories are assumed to be defined a priori and to remain unchanged during the sorting process.

Let us consider a set of categories (or clusters) to which the actions will be assigned $\kappa = \{C_1, C_2 \ldots C_K\}$. We assume that the K categories are completely ordered such that C_j is preferred to C_{j+1}. In the FlowSort method, the categories could be defined either by one central profile or two limiting profiles. In the following, we will focus on the categories characterized by central profiles [29]. Let us denote them by $R = \{r_1, r_2 \ldots r_K\}$. These reference profiles are representative elements of the category which they belong to. In order to be consistent with the categories definition, they should respect the dominance principle as mentioned in Definition 1.

Definition 1 $\forall r_h, r_l \in R$ such that $h < l : \forall g_k \in F,\ g_k(r_h) \geq g_k(r_l)$ and $\exists g_x \in F \mid g_x(r_h) > g_x(r_l)$

The fundamental principle of the FlowSort method relies in the association of an alternative $a_i \in A$ to a given category using either the net flow scores of PROMETHEE II or the positive and negative flows of PROMETHEE I. Later, the net flow scores will be used to generate a complete clustering while the positive and negative flows are appropriate in the context of an interval clustering. In practice, we generate for each alternative $a_i \in A$ the combined set $R_i = R \cup \{a_i\}$. Then, the assignment of a given alternative to a category is done in two steps. First, we compare its score to the scores of central profiles. And then, we assign the alternative to the category whose the profile has the closest flow score. With net flow scores, this is formalized by the following condition [29].

Definition 2 $C_\phi(a_i) = C_h$ if: $|\phi_{R_i}(r_h) - \phi_{R_i}(a_i)| = \min\limits_{\forall j} |\phi_{R_i}(r_j) - \phi_{R_i}(a_i)|$

We denote $\delta(A, \kappa)$ the final distribution of the alternatives $a_i \in A$ in the set of categories κ. When the final clustering is of good quality, it produces compact but well-separated categories.

7.3.2.3 The PCLUST Model

Based on the principles of FlowSort and PROMETHEE methods, we have developed the PCLUST model which is an extension of PROMETHEE I for interval clustering [39]. The aim of this model is to solve a multicriteria clustering problem by defining a set of categories κ^* that could be divided in two groups: the principal categories C_i and the interval categories $C_{i,j}$, $\forall i,j \in \{1 \ldots K\}$ and $i \neq j$. The principal categories are ordered and respect the dominance principle. While the interval categories $C_{i,j}$ are located "between" the principal categories C_i and C_j.

Considering the preference relation of PROMETHEE, it means that the profile $r_{i,j}$ is incomparable with r_i and r_j. In this paper, we assume that the number of categories is defined a priori by the DM. The clustering procedure of the PCLUST method is composed of the following steps:

1. Initialization of the central profiles
2. Assignment of the alternatives to the categories
3. Update of the central profiles
4. Repeat the procedure from step 2 until stop condition

In the following, we describe each step of the clustering procedure. The reader who is familiar with the k-means procedure directly see that the proposed approach works similarly. Nevertheless, two distinctive features have to be highlighted. At first, the allocation is based on a multicriteria sorting method. Secondly, the update of the reference profiles has to respect the multicriteria nature of the problem (i.e. the dominance condition).

Initialization of the Central Profiles

At first, we determine the central profiles either randomly (*Rdm*) or by equidistributing (*Eqd*) the evaluations on every criterion. When initializing the reference profiles randomly, we need to sort the evaluations on every criterion in order to respect the dominance principle between clusters.

Assignment of the Alternatives to the Categories

Let us consider an alternative $a_i \in A$ and the set of reference profiles $R = \{r_1 \ldots r_K\}$. As in FlowSort, we define the set $R_i = R \cup \{a_i\}$. We compute the preference degrees between the actions of R_i and we calculate the positive and negative flows. Finally, we assign an alternative to a category by referring to these two definitions:

Definition 3 $C_{\phi^+}(a_i) = C_h$ if: $|\phi^+_{R_i}(r_h) - \phi^+_{R_i}(a_i)| = \min_{\forall j} |\phi^+_{R_i}(r_j) - \phi^+_{R_i}(a_i)|$

Definition 4 $C_{\phi^-}(a_i) = C_l$ if: $|\phi^-_{R_i}(r_l) - \phi^-_{R_i}(a_i)| = \min_{\forall j} |\phi^-_{R_i}(r_j) - \phi^-_{R_i}(a_i)|$

Based on these conditions, two different categories C_h and C_l could be obtained. In order to assign each alternative to one category, we apply the following assignment rule:

Definition 5 $\forall a_i \in A, \forall h, l \in \{1 \ldots K\} \begin{cases} \text{if } C_{\phi^+}(a_i) = C_{\phi^-}(a_i) = C_h : \; a_i \in C_h \\ \text{else} : \; a_i \in C_{h,l} \end{cases}$

We denote the categories C_h as the principal categories while $C_{h,l}$ are the interval categories ($h < l$).

Update of the Central Profiles

At the end of each iteration, all the alternatives of the set A are assigned to categories. So, we need to update the reference profile of each category in order to take into consideration this new distribution. In completely ordered clustering, the updated value of the reference profile r_h corresponds to the average value of the evaluations of the alternatives in C_h. However, in interval clustering, the alternatives of the problem could be assigned either in principal or interval categories. So, we could imagine that the updated value of the reference profile r_h would also consider the alternatives in the interval categories $C_{h,j}$ which are related to C_h, $\forall j = \{1 \ldots K\}, j \neq h$.

The description of the update procedure goes beyond the scope of this contribution but we refer to [39] for further information.

Repetition of the Procedure Until Convergence of the Model

Given that the clustering procedure is iterative, we have to specify stopping conditions. At first, we define a convergence condition that stops the clustering procedure when the distribution $\delta(A, \kappa)$ remains unchanged during ten successive iterations. This value was measured experimentally from tests specifically modelled to provoke a situation of local convergence (e.g. 10 alternatives to cluster in 10 categories). In addition, we define a stopping condition that interrupts the model after 100 iterations without converging.

7.4 Case Study: A Rural Road Project in Belgium

In order to illustrate the interest of using multicriteria decision aiding tools during the design process of a road project, we propose to apply the proposed approach to a real case study. It concerns the reconstruction of the national road N243a in the rural area of Walhain in Belgium. This road section connects the highway E411/A4[4] and the national road N243,[5] so that important motorized traffic volumes are observed including numerous commuters and a local heavy traffic of trucks and agricultural vehicles.

The N243a is 2 km long and it presents 4 at-grade intersections with rural roads. It was previously a small rural road with a speed limit of 50 km/h and some strong horizontal and vertical curves. Due to the growing traffic it supports, the N243a was under standard (i.e. narrow width, lack of marking and safety equipments, etc.)

[4] 2×3 lanes motorway section between Namur and Brussels.

[5] 2×1 lanes carriageway connecting the city of Wavre with the village of Perwez (and numerous local connections with smaller villages).

and the pavement was deteriorating on some sections of the road. On the basis of these observation, a reconstruction project was initiated to improve both the level of safety and the mobility on the infrastructure. In particular, the installation of safety equipments and the creation of a cycling facility were identified as priorities.

7.4.1 Definition of the Problem

At first, we structure the road design problem of the N243a in our model by defining the local parameters of the project and the considered variables of the road. The local parameters refer to the characteristics and the constraints of the project such as the geometrical parameters (e.g. maximum road width, road length, etc.), the environmental parameters (e.g. roadside environment, presence of eventual obstacles along the roadway, number of intersections, number of retails, industrial or residential entrances, etc.) and operational parameters (e.g. function of the road, traffic volume, fraction to traffic congestion, proportion of heavy vehicles, etc.). These local parameters are available in the Table 7.1. Note that the maximum road width is also used as the feasible constraint of the combinatorial design problem.

The variables of the combinatorial optimisation problem refer to the parameters that are used to build the different alternatives of the problem. Each alternative may be defined as a vector of variables (see the Table 7.2). Depending on the value of

Table 7.1 Local parameters of the N243a rural road

Parameter	Values	Description (unit)
w_{max}	14	Maximum width of the road reserve (m)
L_{tot}	2400	Total length of the road (m)
rdfct	Secondary	Function of the road
AADT	3246	Annual average daily traffic (veh/day)
AADThv	13.7	Proportion of heavy vehicles in the AADT (%)
FS	5.0	Fraction of the traffic congestion (%)
typeroad	1	Roadside environment coefficient[a]
typespeed	2	Roadway average speed type[a]
d_{obs}	6	Average distance obstacles—road (m)
obs_{1m}	10	Obstacles at less than 1 m of the road lanes (%)
entr	0	Number of entrances per kilometer[b]
cr	3	Number of crossroads along the road
$n_{l,cr}$	{1;2;2;2}	Number of lanes of each crossing road
$rdfct_{cr}$	local	Function of each crossing road
$AADT_{cr}$	{20;120;450;250}	AADT on each crossing road (veh/day)

AADT annual average daily traffic

[a] These parameters are defined in the CAR model [27]

[b] Residential, retail and industrial entrances are considered

Table 7.2 Variables of the design combinatorial optimisation problem of the road N243a

Variable	Values	Description (unit)
w_l	{2.5;3;3.5}	Width of the roadway lane (m)
n_l	{2;3;4}	Number of lanes
w_{sh}	{0;1;2;3}	Width of the shoulder (m)
b_{sh}	{Y;N}	Physical separation with the shoulders
cp_nat	{1–17}	Type of cycling facility
w_{med}	{Y;N}	Physical separation between flow and contraflow
mat_nat	{1;2;3;4;5}	Type of road surface material
rsign	{1;2}	Nature of the signalization equipment
marking	{1;2}	Nature of the marking equipment
lighting	{0;1;2;3}	Nature of the lighting equipment
intertype	{1;2;3;4}	Type of intersection
v	{50;70;90}	Operational speed limit (km/h)

the feasible constraint and the range of values that can be taken by the variables, the size of the problem varies. For the case study of the N243a, we must handle about 2×10^6 alternatives. Obviously, this practical example is used as a proof of concept so that 10^6 solutions constitutes a lower bound. It is clear that bigger problems would involve many more alternatives. Consequently, given that computing the exhaustive multicriteria analysis would be intractable regarding the calculation time, we use the multiobjective evolutionary algorithm NSGA-II to identify an approximated set of performing solutions.

7.4.2 *Identifying the Approximated Set of Performing Solutions*

The application of the NSGA-II to the studied problem allows us to identify an approximated set of performing solutions. The initial population was composed of 50 alternatives randomly selected and 50 generations have been conducted in NSGA-II. A limited set of eight criteria has been considered for methodological reasons.[6] At the end of the process, 169 non-dominated (or Pareto) solutions have been identified as illustrated in Table 7.3. Concerning the computational time, the Pareto frontier is computed in 25.8 s on MATLAB R2014b with Intel Core i5 CPU 2.40 GHz and 400 GB of memory. This value is determined on an average basis after 30 runs of the NSGA-II algorithm.

These interesting results illustrate the utility of using a multiobjective evolutionary algorithm to describe the problem, given that it proceeds to an efficient and extensive design space exploration. Moreover, it allows us to consider several

[6]The criteria INF6, SRV1, SOC1 and ECO2 were not considered.

Table 7.3 Parameters and results of the NSGA-II algorithm applied to our problem

Data	Value	Description (unit)
alt	2,350,080	Total amount of feasible alternatives
initial_pop	50	Size of the initial population for NSGA-II
gen	50	Number of generations in NSGA-II
time	25.8	Average time to compute the Pareto front (s)
pareto_sol	*169*	*Size of the approximated Pareto front*

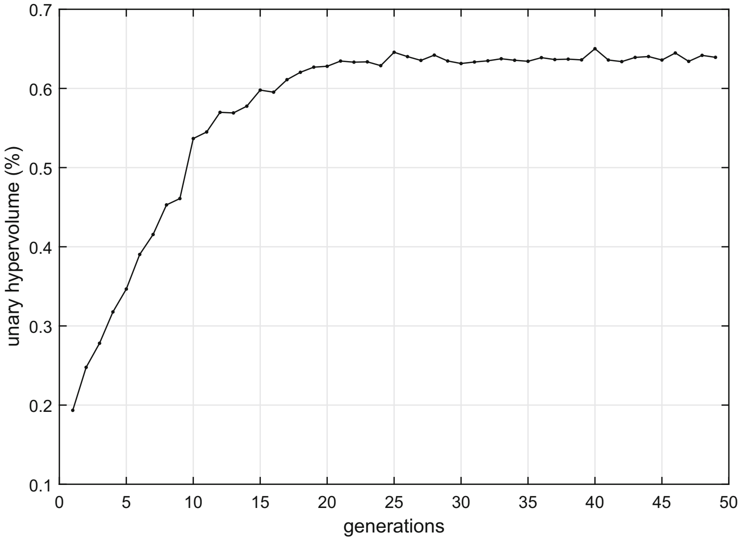

Fig. 7.2 Evolution of the unary hypervolume indicator during the genetic process (N243a)

criteria at the same time and then to give a relevant information to the DM. However, it is crucial to analyse the quality of the approximated set at the end of the genetic process. In particular, we must verify that the convergence of the model and the diversity of the final solutions on the Pareto front. To this end, we use the unary hypervolume indicator.

According to Zitzler et al. [48, 49] and Deb [11], when considering a reference point Z_{ref}, the unary hypervolume metric quantifies the volume of the multiobjective space portion which is weakly dominated by the approximation set A. The more the value of the hypervolume metric is close to 1, the more the quality of the approximation set A increases. We set the reference point Z_{ref} as the nadir point of the problem, being the vector of the worst objective function values. Figure 7.2 shows the evolution of the unary hypervolume indicator during the genetic process. We clearly observe the convergence of the model after 20–25 generations. It indicates that the approximation set A is good and well distributed. The methodological interest of applying the NSGA-II algorithm to our design combinatorial optimisation problem is also underlined.

From a decision perspective, using such a metaheuristic allows the decision maker to reduce significantly the size of his problem—from 2.35×10^6 to 169 solutions, while preserving the quality of the final solutions. However, the selection of the most preferred solution from the approximated set remains a non-trivial task. In order to structure the set of efficient solutions, we decide to apply the PCLUST algorithm. This allows to identify the set of best solutions but also to point out different groups of profiles within road projects. To our point of view, this qualitative information will help the DM in the selection of the most interesting solution.

7.4.3 Solving the Multicriteria Decision Problem

In the design problem of the N243a rural road, the decision maker must select the best compromise alternative from a set of 169 non-dominated solutions. To support him in the identification of the solutions that would be the most performing and adapted to the design problem of the N243a rural road, we propose to use the PCLUST model. We set the number of clusters to $k = 10$. We use the equidistributed strategy to initialize the reference profiles.

Concerning the PROMETHEE parameters instantiation, we consider usual preference functions for the criteria ENVI1 and ENVI5 because of their few evaluation levels. We select the linear preference function for the remaining criteria while this shape is well suited for quantitative evaluations. We set the preference threshold p_k to the third quartile of the difference between all the evaluations on each criterion. Besides, equal weights are considered given that the preferences of the DM were not defined a priori. This allows to study the problem neutrally by considering that each criterion has the same importance.

Table 7.4 shows the distribution of the 169 solutions of the approximated set among the principal and interval categories of the clustering structure. For the

Table 7.4 Clustering distribution for the N243a design problem (169 alternatives, $k = 10$)

		$\delta_{\phi+}$									
		$\|C_1\|$	$\|C_2\|$	$\|C_3\|$	$\|C_4\|$	$\|C_5\|$	$\|C_6\|$	$\|C_7\|$	$\|C_8\|$	$\|C_9\|$	$\|C_{10}\|$
	$\|C_1\|$	0	0	0	0	0	0	0	0	0	0
	$\|C_2\|$	–	1	4	0	0	0	0	0	0	0
	$\|C_3\|$	–	–	5	9	0	0	0	0	0	0
	$\|C_4\|$	–	–	–	26	11	5	0	1	0	0
$\delta_{\phi-}$	$\|C_5\|$	–	–	–	–	19	29	3	1	0	0
	$\|C_6\|$	–	–	–	–	–	12	11	6	0	0
	$\|C_7\|$	–	–	–	–	–	–	4	13	0	0
	$\|C_8\|$	–	–	–	–	–	–	–	8	1	0
	$\|C_9\|$	–	–	–	–	–	–	–	–	0	0
	$\|C_{10}\|$	–	–	–	–	–	–	–	–	–	0

Table 7.5 Objective functions values of the references profiles r_i ($k = 10$)

	INF1	INF2	INF3	INF4	INF5	ENVI1	ENVI2	ECO1
r_1	1.000	0.162	1.852	5.627	1.000	4.2552	2.6957	7.14×10^4
r_2	1.000	0.173	1.852	5.671	1.000	4.2582	2.6957	9.99×10^4
r_3	1.000	0.176	1.852	7.000	1.000	4.2653	2.6957	1.36×10^5
r_4	1.109	0.211	1.852	11.000	1.066	4.2659	2.6957	1.67×10^5
r_5	1.205	0.256	1.852	23.538	1.154	4.2670	2.6957	1.99×10^5
r_6	1.421	0.282	1.852	28.667	1.316	4.2685	2.6957	2.17×10^5
r_7	1.556	0.341	1.852	33.579	1.833	4.2696	2.6957	3.25×10^5
r_8	1.667	0.343	1.859	40.125	2.000	4.2697	2.6957	4.62×10^5
r_9	2.000	0.388	1.880	40.750	2.000	4.2703	2.6998	4.91×10^5
r_{10}	2.152	0.491	2.083	45.112	2.000	4.2710	2.7098	1.27×10^6

purposes of clarity, Table 7.4 is a double-entry table with the clustering distributions $\delta_{\phi^+}(A, \kappa)$ and $\delta_{\phi^-}(A, \kappa)$ respectively obtained with the positive and negative flows of PROMETHEE I. The distribution $\delta_{\phi^+}(A, \kappa)$ is readable vertically while the distribution $\delta_{\phi^-}(A, \kappa)$ is readable horizontally. The final distribution corresponds to the combination of the assignment in the rows and columns. For instance, the alternatives that are assigned to C_4 in the both direction are in the principal cluster C_4, while the alternatives that are assigned to C_4 horizontally and C_6 vertically belong to the interval category C_{4-6}. Table 7.5 shows the objective functions values of the reference profiles of each principal category of the clustering structure.

On the basis of these two tables, we clearly observe that the distribution of the solutions within the different clusters is quite well-spread. However, the best and worst clusters are empty. It may indicate that the two extreme reference profiles are too exclusive or that any alternatives of the set maximise (resp. minimize) their evaluations on every criteria. In addition, we see that 1 alternative is assigned to the best non-empty principal category C_2 while four alternatives belong to the interval category C_{2-3} and five alternatives are assigned to C_3. To select the best alternative of the multicriteria problem, the DM should then focus on these solutions. In order to define the composition of each category, we may analyse the values of the decision variables of each representative solution.

The analysis of the Table 7.6 indicates that several design options are represented. For simplification reasons, we only considered the non-empty principal categories and the best non-empty interval category C_{2-3}. At first, when focusing on the roadway lanes (width and number), many configurations are represented : 2×2.5, 2×3.0, 2×3.5. In addition, four different solutions for the cycling equipment are also represented and correspond to a mixed traffic on the roadway ($cp\_nat = 1$), a marked lane on the roadway ($cp\_nat = 2$) and a cycle lane separated from the roadway without physical separation ($cp\_nat = 6$) or delineators ($cp\_nat = 7$). Similarly, the nature of the equipments for the road signs and the marking differs from a category to another. However, the maximum speed limit is set to 50 km/h for

Table 7.6 Decision variables values of a the non-dominated solutions that are the closest to the reference profiles of each category of the clustering structure

C_i	id	w_l	n_l	w_{sh}	b_{sh}	*cp_nat*	w_{med}	*mat_nat*	*r*	*m*	*l*	*it*	*v*
C_2	130	2.5	2	3	0	7	0	6	2	2	3	3	50
C_{2-3}	131	2.5	2	3	0	6	0	6	2	2	3	3	50
C_3	19	3.5	2	3	0	6	0	6	2	2	3	3	50
C_4	67	2.5	2	3	0	7	0	6	2	1	3	3	50
C_5	158	2.5	2	3	0	6	0	6	1	2	3	1	50
C_6	114	3.0	2	3	0	7	0	6	2	1	3	1	50
C_7	107	2.5	2	1	0	1	0	6	2	1	3	1	50
C_8	163	3.5	2	1	0	2	0	6	1	1	3	1	50

r rsign, *m* marking, *l* lighting, *it* intertype

each representative solution, essentially because we did not considered the mobility criterion (SOC1).

Consequently, based on the results of the multicriteria clustering problem, a performing solution for the reconstruction of the N243a should consider an efficient and safe cycling facility (with a physical separation from the roadway). In addition, the better are the road signs, marking and lighting equipments, the better is the global performance of the designed solution. These two observations constitutes an interesting output while they were the main requirements in the specifications for the reconstruction of the N243a. Moreover, we observe that the construction of wide shoulders is strongly recommended. However, it seems that increasing the operational speed limit is not necessary. These first conclusions provide the basis for a strategic discussion between the DM and the others actors of the project at the end of the pre-design stage. In particular, they convey preliminary information and guidelines to refine the search of a performing and consistent solution (e.g. by eliciting the weights associated to each criterion more precisely). The design of a road project may then be considered as an iterative process that would involve the different actors of the project at the end of each stage. This would support the development of performing compromise solutions.

7.5 Conclusions

Considering the objectives of the EU to reduce the number of fatalities on the road network by 2020, it is crucial to take practical and effective actions in favor of road safety. In this study, the development of an innovative model to assess both the road safety and the sustainable performance of a project at the design stage had led to interesting results. In addition, we underlined the interest of applying successively a multiobjective optimisation approach and a multicriteria clustering technique to assist the engineers during the design process of an infrastructure. Moreover, we do think that the proposed methodology is scalable to more complex problems.

About the use of a multiobjective evolutionary approach to characterize the design problem, the main added-value lies in the consideration of the design process as a combinatorial optimisation problem. By doing so, we enrich the preliminary stage of the road design process by considering all the feasible solutions of a specific project. Then, it may support the engineers in the identification of new challenging solutions and the comparison of several design options. From a methodological point of view, performance indicators illustrate the quality of the solutions generated by the algorithm in terms of convergence and diversity. In particular, the results obtained from the computation of the unary hypervolume indicator show the quality of the approximation set given by our model. Let us point out that a quantified study of this approach has been provided in [38].

To structure the multicriteria decision problem, the use of a multicriteria clustering approach seems also interesting and appropriate. Especially, it may assist the decision maker in the identification of the representative alternatives of the Pareto frontier. The comparison of these alternatives and the selection of a final solution would then be facilitated. In order to consider the multicriteria nature of the problem and to guarantee the relevancy of the clustering, the development of a clustering model based on the preferential information between alternatives is particularly interesting. This approach allows the decision maker to partition the set of performing solutions by taking into account the preferential relations between them. In the end, the definition of a partially ordered clustering structure constitutes a strong information in a decision aiding context, while it indicates which are the best and worst categories or even the categories of alternatives with singular profiles (i.e. interval categories).

Additionally, some improvements could be done in the proposed approach to give an even more relevant, precise and useful output to the decision maker. In particular, the improvement of the set of criteria may help to have a better understanding of the road project safety issues and their quantification. Concerning the methodology, it may be interesting to integrate the weights elicitation procedure in the multiobjective evolutionary algorithm in order to identify efficient solutions that illustrate the preferences of the DM. To help structuring the multicriteria decision problem, we may also imagine to consider the number of categories as a variable of the multicriteria clustering model. By doing so, we may suggest to the DM the clustering structure that partitions the set of alternatives by maximising the quality of the distribution.

In the long run, the use of this model may lead to the definition of innovative and integrated solutions. It may also help design engineers in the promotion of their solutions by the others actors of the project and to set off constructive discussions.

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Chapter 8
Locating Ship-to-Ship (STS) Transfer Operations via Multi-Criteria Decision Analysis (MCDA): A Case Study

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Abstract Nowadays Ship-to-Ship (STS) transfer has become common practice. However, it remains a complex and difficult procedure, with risk assessment essential for both vessels and location selection. A variety of risk assessment techniques are thus commonly applied in order to evaluate the factors affecting STS transfers. This paper proposes a novel approach to the risk assessment of different locations for STS transfer operations, using the ELECTRE methodology borrowed from the Multi Criteria Decision Aid (MCDA) discipline. The proposed MCDA methodology is properly developed and thoroughly analysed with the aim of supporting operators in choosing the best alternative STS location. To this end, a case study is presented with which to testify the effectiveness and verify the strength of the suggested approach. In particular, four different locations within the Mediterranean Sea, which represent the set of alternative actions, are evaluated according to four different groups of criteria, with a view to selecting the most appropriate location at which to conduct the transfer operations. Different operational, economic, environmental and safety-security criteria regarding each location are assessed and evaluated by a team of three experts designated by the stakeholders (decision makers) of a shipping company. In addition, a robustness analysis is performed in order to control the stability of the model results. The objective is to develop an MCDA model with which to select the most appropriate location according to its operational eligibility.

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8.1 Introduction

Ship-to-Ship (STS) transfers originated in the 1960s in the Gulf of Mexico as a result of the limitations of oil terminals and refineries in accommodating ships (VLCCs and ULCCs) with increasing draft dimensions [20]. Although the initial use of such procedures was for oil transfer, STS operations have now been extended to the transfer of other cargoes such as liquefied gases (LPG, LNG) and even bulk or dry materials.

As oil currently accounts for 33.1 % and liquefied natural gas (LNG) 23.9 % of global energy consumption [6], transshipment at sea forms an essential link in the global movement of energy, providing valuable help for the optimization of the distribution plan from producer to final consumer [34]. During a common transfer procedure, both ships move at low speed in order to bring their manifolds in line to conduct the cargo transfer. Such operations can be conducted either stationary or underway, depending on different factors such as the selected area for the transfer (shallow or deep waters, sufficient room for maneuvers etc.) or weather and sea conditions [22]. The addition of the Chapter 8 to MARPOL (Annex I of the Protocol of 1978 for the Prevention of Pollution from ships), was the first significant action aimed at establishing common rules for STS transfer operations [16]. Generally, an STS transfer procedure comprises four different phases: preparation, mooring, the transfer procedure and unmooring. Each phase of these STS operations includes different procedures and checklists which must be completed. Figure 8.1 shows the most common STS transfer areas on a global scale.

The success of any STS transfer operation depends on many different factors, particularly the effective cooperation and communication between the masters of each ship and the personnel directly involved in the different phases of the operation,

Fig. 8.1 Global locations of STS transfer operations

as well as those remaining on board. Further factors include the coordination of the STS provider in terms of person overall advisory control (POAC), STS superintendents and the relevant personnel involved in the procedure; local authorities in whose waters the operation takes place also participate as an independent observer.

A very significant factor of special importance is the selection of the location at which to conduct the cargo transfer. This decision must take account of the prevailing environmental conditions (currents, weather, etc) and other characteristics of the area, such as traffic density, logistical support and even potential security threats [34]. Thus, the success of an STS transfer operation primarily depends on correct location selection. The choice of an inadequate area may lead to the suspension of the operation, with adverse economic consequences for stakeholders. Moreover, a wrong location decision in combination with inappropriate environmental conditions may lead to an accident, with adverse consequences for human life, the environment and property. In light of the above, the proper choice for STS transfer location should be considered a strategic decision that should be taken only after careful and detailed examination of the alternatives with regard to the criteria that affect the operation [2]. One feasible way in which to tackle the uncertainty associated with insufficient or imprecise data is through the use of Multi Criteria Decision Aid (MCDA) methodologies. MCDA techniques [10, 11, 35] have become a popular and effective tool for dealing with complex problems with multiple alternative solutions.

Generally, MCDA methods can be divided in two main categories: ordinal regression approaches, which employ methodologies based on additive value models [13–15], and preference modeling approaches that are based on binary relations of the alternatives under the outranking relation law [25, 27]. Alternatively, preference modeling can also be based on the aggregation of individual judgments or priorities [1]. ELECTRE methods, which form part of such preference modeling approaches, have been successfully applied in solving various types of problem. For example, Buchanan and Vanderpooten [7] employed ELECTRE methodologies to rank and evaluate different investment projects; Ozcan et al. [23] implemented the methodology for warehouse location selection; Augusto et al. [3] applied the methodology for firms benchmarking and Merad et al. [19] for organization sustainability; Siskos and Houridis [28] employed the methodology to solve the problem of choosing the right investment in the photovoltaic energy market; and finally Aytaç et al. [4] developed a fuzzy ELECTRE I model to evaluate catering firm alternatives. Lastly Bottero et al. [5] applied the ELECTRE III method with interaction between pairs of criteria in order to rank order five alternative projects, compared on the basis of six different criteria, for the re-qualification of an abandoned quarry located in Northern Italy. The authors proposed robust conclusions based on different sets of weights and coefficients. For a plethora of further examples, see [29].

In the present study, the development of an MCDA framework applying the ELECTRE I methodology to choose the most suitable area for a STS transfer operation is outlined. During this process, a set of four different STS locations within the Mediterranean Sea was identified, followed by the structuring of a consistent family of four criteria based on economic, operational and environmental factors. A team of three experts with experience in such operations then assisted the analyst in evaluating the locations according to the predetermined criteria, simultaneously determining the weight of these criteria by answering a series of questions set by the analyst. Finally, the most appropriate location was selected for the STS transfer operation.

The paper is organized as follows: Sect. 8.2 presents the general background for the STS transfer operation locations; Sect. 8.3 consolidates the theoretical background of the ELECTRE methodology; Sect. 8.4 outlines the implementation of the proposed methodology by applying a practical example of how to identify the most appropriate STS transfer location among a range of alternative areas; Sect. 8.5 presents the model results, which are then discussed in Sect. 8.6; and Sect. 8.7 concludes the paper. Finally, an algorithmic development of ELECTRE I is given in Appendix 1, while a short description of the proposed STS alternatives is presented in Appendix 2.

8.2 The Role of STS Transfer Areas

Currently, there are over 50 areas worldwide in which STS transfers are conducted systematically (Fig. 8.1). One of the major factors responsible for a successful STS transfer is the selection of the most appropriate area in which to conduct the operation. Certain conditions and requirements regarding the characteristics of the proposed area should be met so as to avoid unfortunate situations that could compromise the entire operation.

The OCIMF [21] guidance and the IMO manual on Oil Pollution [17] highlight the most important factors with respect to STS transfer area selection. As mentioned above, an STS transfer can be conducted either stationary or underway. For operations carried out during anchorage, adequate water depth is necessary. Shallow waters may thus pose a serious problem for large vessels, with deep waters setting limitations for anchorage. In contrast, for operations taking place underway, sufficient room and water depth are needed for the "run-in" procedure, in which the two vessels come alongside each other for the transfer of cargo. The total room required is analogous to the size of the vessels involved as well as to the total amount of transferred cargo. Moreover, the traffic density in the area of interest should also be taken into account, especially in case of underway operations; the vessels involved should be able to carry out all necessary maneuvers without any disturbance from passing vessels that could adversely affect the transfer procedure. In addition, geological irregularities that demand special vessel maneuvers, for instance to avoid obstacles, can compromise the entire operation. The selected area should preferably be sheltered from the open sea in order to mitigate the effect of adverse weather conditions. The quality of the sea floor is another factor that should be examined if the operation is to be conducted at anchorage, as vessels must able to maintain their positions at all times. The presence of underwater pipelines and/or submarine cables can also affect anchorage safety and may lead to the suspension of the transfer operation.

In addition, the suitability of the transfer area is strongly correlated with the prevailing environmental conditions. The presence of sea currents, tides and low visibility can all adversely affect operations. Prevailing and forecasted weather, including both wind and sea conditions, are of considerable importance during all phases of the transfer, particularly for those operations conducted in darkness. The most common limits regarding STS transfer operations according to FCM information are:

- Mooring: 25-knot wind, equal to approximately 13 m/s,
- Transfer: 35-knot wind equal to 18 m/s and swells/seas reaching 2 or 3 m.

Accident statistics [8] for period 2011–2013 indicate that wave height has an adverse effect on operation success. Another factor affecting STS transfer area selection is the distance of the area from onshore logistical support. As STS providers typically provide all the necessary equipment, including fenders, hoses and supporting vessels/tugs, onshore facilities should be located in a relatively short distance from the selected transfer area. Moreover, in case of an emergency such as oil leakage, the rapid arrival of appropriate equipment is of utmost importance. In addition, the selected STS transfer area must be checked for security threats due to vessels' vulnerability during the operation. Environmentally sensitive areas should also be carefully examined in order to avoid irreversible damage to the marine ecosystem. Finally, other factors that should be taken into account are related to the control of the area by the responsible body, such as port or harbor authorities.

8.3 The ELECTRE Methodology

Multi-criteria decision aid (MCDA) is a discipline that aims to support decision makers facing multiple and conflicting criteria in their efforts to make satisfactory decisions [32]. The ELECTRE methodology assists decision makers in identifying the most appropriate solution among a set of alternatives with regard to true measurable and/or ordinal criteria. ELECTRE methods are partially non-compensatory, allowing for pairwise comparison of actions in terms of outranking, which is based on criteria concordance and the veto effect of each criterion (discordance) [28]. ELECTRE I, as part of the ELECTRE family of methods, was initially introduced by Roy [24] as the first decision-aid technique to use the concept of the outranking relation [26].

A flowchart diagram of the implemented methodology is shown in Fig. 8.2, whereas an analytical description of the ELECTRE I method is presented in Appendix 1. According to the method's results the best alternative should be cheeked among the alternatives belonging to the kernel of the outranking graph (see the results' Sect. 8.5).

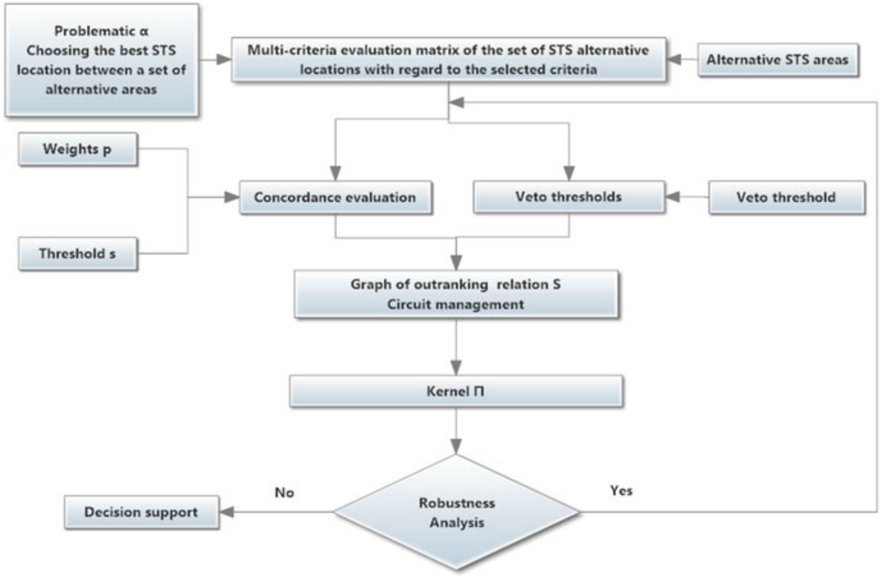

Fig. 8.2 Flowchart diagram of the ELECTRE I methodology

8.4 STS Location Problem Definition

8.4.1 Introduction to the Transfer Areas

Thousands of oil tankers cross the Mediterranean Sea each year, transporting crude oil from the Middle East to ports in Europe and North America via the Suez Canal [18].

According to recent estimates, in 2012 about 112 million tons of oil were transferred from the Middle East to Northern Europe via this route, with 108 million tons of oil sent to North-East America through the Suez canal and the Strait of Gibraltar [6]. Figure 8.3 shows the major routes for oil transport within the Mediterranean Sea. The dimensional limitations of the vessels passing through the Suez Canal, together with the profit gained from the transfer of oil in large vessels (VLCC and ULCC class), has led to the coordination of several STS transfer operations within the Mediterranean, all with the aim of optimizing the distribution plan from source to final consumers. As a result, such Mediterranean-based STS transfers play an important role in the global energy trade. In the frame of the decision problem addressed through this paper, let us assume that a vessel of Suezmax classification will sail from the Persian Gulf, pass through the Suez Canal and deliver her oil cargo to a VLCC class vessel via an STS transfer operation. The final destination of the transferred cargo is somewhere in Northern Europe. The alternative areas identified in which to conduct the transfer, which in the present

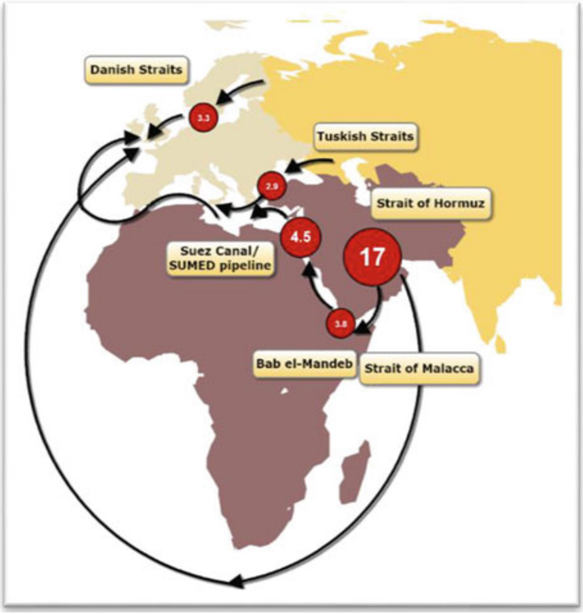

Fig. 8.3 Estimates in million barrels per day of global oil shipping crosses the Mediterranean (*Source*: U.S. Energy Information Administration analysis based on Lloyd's List Intelligence)

study form the set of actions in the developed methodology, are located in Cyprus, Crete, Malta and the Strait of Gibraltar. Based on a study of several sources [8, 12] regarding the suggested STS transfer areas, a general description of each location is presented in Appendix 2.

The stakeholders, i.e. the decision makers, must select the most appropriate location at which to make the STS transfer according to four different criteria related to economic, operational and environmental factors.

8.4.2 Addressing a Consistent Family of Criteria

The criteria employed in the implemented methodology, as summarized in Fig. 8.4, can be categorized into four main groups:

- **Operational criteria**, O_{tot}: These are related to the operational factors that may affect the STS transfer, such as the ability to conduct the procedure stationary or underway, the previous experience of local authorities in conducting such operations, the existence of alternative STS providers for assistance and the latter's corresponding experience in performing STS operations safely and without unnecessary delays. To evaluate the operational criteria, the following process was adhered to: It is assumed that each operational sub-criterion corresponds to a hypothetical scenario; stationary or underway, O_1, thus refers to the scenario that the STS transfer can be conducted using either method, although ideally

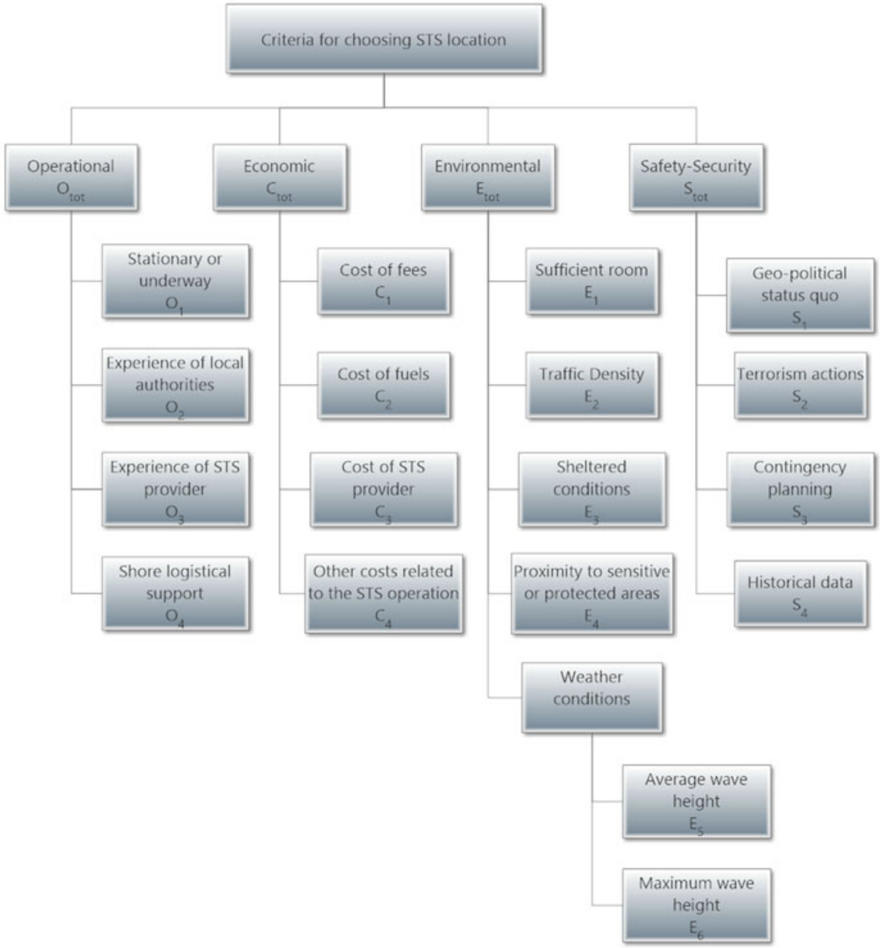

Fig. 8.4 The evaluation criteria employed for choosing STS transfer location

both ways could be employed depending on operator planning. The experience of local authorities, O_2, depends on the waters in which the STS transfer takes place, as well as the rate of the STS operations conducted in the area. In the case of Cyprus for example, when STS operations are conducted within international waters the local authorities have minimum involvement in the process. In contrast, the experience of the STS provider, O_3, may be limited or of a high level, depending on the operations previously completed by the provider in the area of interest. After a thorough review, six major STS providers were found to operate within the Mediterranean Sea. All operate in Malta, four in Cyprus, three in Gibraltar and finally only one in Crete. Finally, onshore logistical support, O_4, may be located in close proximity to or a large distance from the

Table 8.1 Ordinal scale for the operational criteria

Criterion level	Assumptions
0	All factors (O1,O2,O3,O4) are inadequate according to operator planning
1	At least 3 out of 4 factors are unsatisfactory according to operator planning
2	At least 2 out of 4 factors are unsatisfactory according to operator planning
3	At least 1 out of 4 factors is unsatisfactory according to operator planning
4	All factors (O1,O2,O3,O4) are satisfactory according to operator planning

Table 8.2 Expert evaluation of the operational criteria

	Cyprus	Crete	Malta	Gibraltar
O_1	x		x	
O_2			x	x
O_3	x		x	x
O_4			x	x
O_{tot}	2	0	4	3

operation location. To this end, different combinations of O_1, O_2, O_3, O_4 may lead to five different levels of the corresponding criterion. The sub-criteria are assumed to be of equal importance. The preference sense of the operational criterion has a positive meaning, which means that the higher the value the more suitable is the location for the transfer. A relative ordinal scale criteria classification scheme is shown in Table 8.1 and an expert evaluation for each location in Table 8.2.

- **Economic criteria**, C_{tot}: These refer to the additional costs facing the stakeholders for the completion of the STS operation, including fees asked for by local authorities for cases in which the transfer is conducted in territorial waters, the cost of fuel needed by the delivering vessel to reach the STS transfer location, total losses due to the time spent in carrying out the operation, the cost of any assistance given by the STS transfer provider, and finally any other cost related to the operation either directly or indirectly. The preference sense of the economic criterion has a negative meaning, which means that the lower the value the more suitable is the location for the transfer. In order to evaluate the economic criteria, it is assumed that each economic sub-criterion makes a weighted contribution to the total cost of the STS transfer. The corresponding values of the weights were elicited from experts after a short consultation period. Thus, experts determined the weight w_1 of the cost of fees C_1, the weight w_2 of the cost of additional fuels C_2, the weight w_3 of the cost for the assistance of the STS provider C_3 and finally the weight w_4 for other related costs C_4. The total cost is a linear combination of the above weights and costs:

$$C_{tot} = c_1w_1 + c_2w_2 + c_3w_3 + c_4w_4$$

$$w_1 + w_2 + w_3 + w_4 = 1$$

Table 8.3 Evaluation of economic criteria. Hypothetical assumption for the cost of crude oil: 400$/ton

	Cyprus	Crete	Malta	Gibraltar
Distance to area (miles)	210	80	30	10
Time to detour from main route (h)	13.50	5.01	1.90	0.65
Fuel consumption (tons)	31.89	12.05	4.49	1.51
C_1	0	0	3284$	3284$
C_2	12,756$	4820$	1796$	604$
C_3	13,333$	18,333$	10,000$	15,000$
C_4	5625$	2125$	791$	270$
C_{tot}	31,714$	25,278$	15,871$	19,158$

Table 8.3 shows the results of expert evaluation of the economic criteria. To calculate C_1 it was assumed that both vessels involved in the operation belong to the same stakeholder. The Suezmax vessel's characteristics are presented in detail in Appendix 3. The estimation of C_4 assumes a crew of 32 persons and a total operational cost per day of 5000$. To determine C_3 it was assumed that the more numerous the available providers for a location, the lower the operation costs. For a hypothetical price of 10,000$ in Malta and given the provider numbers discussed earlier, the price increases at a proportional rate at the remaining three locations with decreasing provider availability. To calculate the value of C_1 it was assumed (based on a literature review) that Cyprus and Greece have no additional associated costs. Gibraltar's fee was taken based on GPA [12], with the value for Malta assumed as equal to that of Gibraltar due to a lack of specific information. Finally, for reasons of simplicity, the sub criteria are assumed of equal importance meaning $w_1 = w_2 = w_3 = w_4$.

- **Environmental criteria**, E_{tot}. These are related to the prevailing weather or sea conditions that may affect the success of the operation, including the existence of sufficient room in which to conduct the transfer (especially those carried out underway), the traffic density of the proposed transfer area (too high a density may lead to early transfer suspension), the proximity of sensitive or protected areas, and finally the presence of a sheltered environment able to protect vessels from the forces of nature. The preference sense of the environmental criterion has a negative meaning; thus, the lower the value the more suitable is the location for the transfer. To evaluate the environmental criteria, it is assumed that each environmental sub-criterion makes a weighted contribution to the total cost of the STS transfer. The sub-criteria sufficient room, E_1, and traffic density, E_2, are variables evaluated by experts with a weight of $w_1 = w_2 = w = 0.1$. The sub-criterion of sufficient room, receives a value of zero for existence or one for absence. Accordingly, the traffic density sub-criterion, E_2 is also assigned a value of one if there is traffic in the area or zero if there is not. Sheltered conditions, E_3, is an independent variable, which is as equally important ($w_3 = 0.2$) as the previous two. For sheltered conditions a value of zero is assigned, otherwise a value of one is selected. The proximity of the transfer location to environmentally sensitive or protected areas, E_4, is evaluated using a weight of $w_4 = 0.1$, with a criterion value of one assigned for true and zero for false. Due to the significance of weather conditions, two relevant factors are evaluated. Thus, the average significant wave height, E_5, and the maximum recorded value, E_6, are calculated for each location. Data for the latter two criteria were here taken from the Poseidon Live Access Server (LAS), with a weight of equal importance assumed for the calculations: $w_5 = w_6 = w' = 0.5$. In summary, the empirical expression of the environmental criteria is as follows:

$$E_{tot} = 0.1(E_1 + E_2) + 0.2E_3 + 0.1E_4 + \frac{1}{2(E_5 + E_6)}$$

It should be noted that:

– The aggregation of the weights is equal to one.
– The above equation is valid for $E_5 + E_6 \geq 1$. When $E_5 + E_6 < 1$ the value 0.5 is applied.

Table 8.4 shows the values assigned after expert evaluation of the environmental criteria for the presented case study.

- **Safety-security criterion**, S_{tot}. This refers to the geo-political status of the proposed transfer area, including the potential for unpredictable situations due to unstable geo-political relations between nearby nations. This criterion also accounts for the possibility of terrorist activity that may endanger crew, vessel and cargo safety. A further factor is historical data regarding incidents or accidents within the area under consideration. The preference sense of this criterion has a positive meaning, which means that the higher the value the more suitable is the location for the transfer. The corresponding ordinal classification scale for this criterion is shown in Table 8.5 and the expert evaluation in Table 8.6.

Table 8.4 Expert evaluation of the environmental criteria

	Cyprus	Crete	Malta	Gibraltar
E_1	0.00	1.00	1.00	1.00
E_2	0.00	0.00	1.00	1.00
E_3	1.00	1.00	1.00	0.00
E_4	1.00	1.00	1.00	0.00
E_5	0.80	0.90	1.07	0.42
E_6	2.90	5.57	4.68	2.43
E_{tot}	0.44	0.48	0.59	0.38

Table 8.5 Ordinal scale for the safety-security criterion

Level	Description
1	Location with a high level of geo-political inconsistency and high risk of piracy. Historical data indicate a high rate of accidents regarding STS transfers
2	Location with a low level of geo-political inconsistency and low piracy risk. Historical data indicate a medium rate of accidents regarding STS transfers
3	Location with no geo-political inconsistency and no piracy risk. Historical data indicate a low rate of accidents regarding STS transfers

Table 8.6 Evaluation of the safety-security criterion

	Cyprus	Crete	Malta	Gibraltar
S_{tot}	2	3	3	3

8.5 Results

In order to implement the ELECTRE I method the next step is to calculate the weights of the selected criteria. These data are then combined to construct an outranking relation among the alternative locations, thereby enabling the determination of the kernel of this relation/graph.

8.5.1 Weight Determination

The criteria weights play an important role in the successful implementation of the ELECTRE I methodology, determining the relative importance of each criterion and taking into account the relative experience of the experts as well as the needs and priorities of the stakeholders. It is assumed that the operational, environmental, economic and safety criteria have the vector of weights $(p_{op}, p_{en}, p_{ec}, p_{sf})$. For the determination of the weights, pairwise comparison of the criteria in terms of importance must be carried out. For other methods see [9, 30, 31, 33] and the recent survey conducted by Siskos and Tsotsolas [29]. To this end, a series of questions composed by the present authors were answered by a panel of selected experts, whose responses can be summarized as follows:

(a) The operational criteria are the most important of all.
(b) The safety criteria are the least important of all.
(c) The environmental criteria are more important than the economic criteria by at least 10 %.
(d) The safety criteria cannot be valued at less than 15 % of the final evaluation.

Interpretation of the expert answers led to the development of the system of equations (a)–(d) shown below. The following equations (e) and (f) were derived from the limits of the problem:

(a) $p_{op} \geq p_{en} + \varepsilon$
(b) $p_{op} \geq p_{ec} + \varepsilon$
(c) $p_{op} \geq p_{sf} + \varepsilon$
(d) $p_{op} \geq p_{sf} + \varepsilon$
(e) $p_{en} \geq p_{sf} + \varepsilon$
(f) $p_{ec} \geq p_{sf} + \varepsilon$
(g) $p_{en} - p_{ec} \geq 0.10$
(h) $p_{sf} \geq 0.15$
(i) $p_{op} + p_{en} + p_{ec} + p_{sf} = 1$
(j) $p_{op}, p_{en}, p_{ec}, p_{sf} \geq 0$

To solve the relative consistency of the above system, a goal programming technique was applied using a threshold of $\varepsilon = 0.01$. Thus, the system was transformed accordingly:

$$
\begin{aligned}
[\min]z = \sigma_{op}^{-} + \sigma_{op2}^{-} + \sigma_{op3}^{-} + \sigma_{en}^{-} + \sigma_{ec}^{-} + \sigma_{en2}^{-} \\
& p_{op} - p_{en} + \sigma_{op}^{-} \geq 0.01 \\
& p_{op} - p_{ec} + \sigma_{op2}^{-} \geq 0.01 \\
& p_{op} - p_{sf} + \sigma_{op3}^{-} \geq 0.01 \\
& p_{en} - p_{sf} + \sigma_{en}^{-} \geq 0.01 \\
& p_{ec} - p_{sf} + \sigma_{ec}^{-} \geq 0.01 \\
& p_{en} - p_{ec} + \sigma_{en2}^{-} \geq 0.10 \\
& p_{sf} - \sigma_{sf}^{-} \geq 0.15 \\
& p_{op} + p_{en} + p_{ec} + p_{sf} = 1 \\
& p_{op}, p_{en}, p_{ec}, p_{sf} \geq 0 \\
& \sigma_{op}^{-}, \sigma_{op2}^{-}, \sigma_{op3}^{-}, \sigma_{en}^{-}, \sigma_{ec}^{-}\sigma_{en2}^{-} \geq 0
\end{aligned}
$$

Goal programming for the above system of equations was performed in Microsoft Excel, assuming a linear relation between the criteria weights. The objective of this linear programming formulation is to safeguard the consistency of the criteria importance weights with the DM's judgements ($z = 0$). In case of inconsistency errors ($z > 0$), a DM-Analyst should be engaged for the removal of these inconsistencies. In our case, there is no any inconsistency ($z = 0$) and the feasible weighting solutions satisfying the conditions from (a) to (j) belong to a polyhedron determined from the min and max possible values of each individual criterion (see Fig. 8.5 and Table 8.7). In order to manage the set of multiple weighting solutions a robustness analysis was performed. In this context, Siskos and Tsotsolas [29] suggested the determination of eight extreme weighting solutions, by solving eight linear programs that minimize and maximize separately each individual weight over the polyhedron (a)–(j). Then they propose to consider as a representative weighting solution the average weighting vector of the eight extreme solutions.

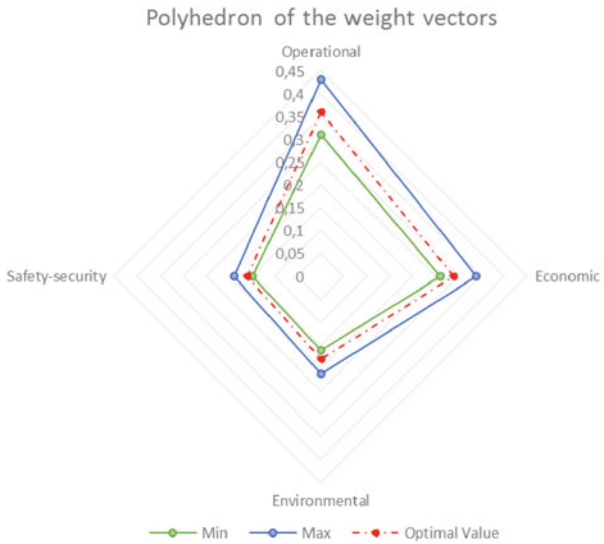

Fig. 8.5 Min-max range polyhedron of the criteria weight vector

Table 8.7 Relative importance weights of the four criteria (eight extreme solutions and mean weighting)

Weighting vector	p_{op}	p_{en}	p_{ec}	p_{sf}
(1) min p_{op}	0.31	0.30	0.20	0.19
(2) max p_{op}	0.43	0.26	0.16	0.15
(3) min p_{en}	0.43	0.26	0.16	0.15
(4) max p_{en}	0.35	0.34	0.16	0.15
(5) min p_{ec}	0.35	0.34	0.16	0.15
(6) max p_{ec}	0.32	0.31	0.21	0.15
(7) min p_{sf}	0.35	0.34	0.16	0.15
(8) max p_{sf}	0.31	0.30	0.20	0.19
Mean weighting	0.36	0.29	0.18	0.16

The range of each criterion weight was thus determined using the above described min-max technique, with the corresponding results shown in Table 8.7 and Fig. 8.5. As the obtained criteria weights are judged by the analyst as sufficiently robust the mean weighting solution is firstly used to run the ELECTRE I method. A robustness analysis is then performed in Sect. 8.6.1 to study the kernel's variation due to the weights' variation.

Finally, the summarised data for the selected criteria at each location are shown together with the most representative weights in Table 8.8.

Table 8.8 Multi-criteria evaluation of the proposed STS locations

Criterion Scale	Operational (0–4)	Environmental (0–1)	Economic ($)	Safety-security (1–3)
Sense	Positive	Negative	Negative	Positive
Cyprus	2	0.37 (0.44)	31.714	2
Crete	0	0.45 (0.48)	25.278	3
Malta	4	0.27 (0.59)	15.871	3
Gibraltar	3	0.55 (0.38)	19.158	3
Importance weight	0.36	0.29	0.18	0.16

Table 8.9 Veto threshold values for the selected criteria

Criterion	Veto threshold
O_{tot}	$(O^i_{tot} - O^j_{tot}) \geq 2, \forall i, j = 0, \ldots, 4$
E_{tot}	0.30
C_{tot}	5.000$
S_{tot}	(1,3)

8.5.2 *Veto Threshold Determination*

The veto threshold of a criterion refers to the maximum tolerable difference of the values of the criterion, which is able to overcome the outranking of an action against an alternative due to the superiority of the second alternative on a big majority of criteria. To determine the veto threshold value for each criterion, we assume the existence of two fictitious STS locations named Loc_a and Loc_b. Under the condition that location Loc_a outranks location Loc_b in 3 of the 4 selected criteria, the analyst uses the criterion that Loc_a comes short of Loc_b to discover the value of this criterion. The aforementioned process was applied iteratively for the four selected criteria, the results of which are shown in Table 8.9. In order to make more comprehensive the veto threshold of the operational criterion O_{tot}, we assume that a location a outranks location b on the environmental, the economic and the safety criteria. Location b on the other hand outranks location a only on the operational criterion. A veto threshold of a value at least two means that location a outranks location b if and only if the difference between the values of the operational criterion of the two locations is lower that two. If the difference is equal or bigger than two then the two locations are incomparable.

8.5.3 *Concordance Analysis*

To perform the concordance analysis, step 1 of the method discussed in Sect. 8.3 is employed. The outranking relation between all pairs of the STS locations, $Concord(Loc_i, Loc_j)$, is presented in Table 8.10. For example, as Malta outranks

Table 8.10 Concordance indices

		Loc_1	Loc_2	Loc_3	Loc_4
Cyprus	Loc_1	1.00	0.36	0.29	0.00
Crete	Loc_2	0.65	1.00	0.29	0.00
Malta	Loc_3	0.70	0.54	1.00	0.54
Gibraltar	Loc_4	1.00	0.84	0.29	1.00

Table 8.11 Validation of the discordance condition

	O_{tot}	C_{tot}	E_{tot}	S_{tot}	Outranking
(Loc_2, Loc_1)	2				No
(Loc_3, Loc_1)			0.15		Yes
(Loc_3, Loc_2)			0.11	(3,3)	Yes
(Loc_3, Loc_4)			0.21	(3,3)	Yes
(Loc_4, Loc_1)					Yes
(Loc_4, Loc_2)				(3,3)	Yes
Veto threshold	≥ 2	5000$	0.30	(1,3)	

Cyprus in terms of O_{tot}, E_{tot} and S_{tot}, the concordance value is:

$$Concord(Malta, Cyprus) = Concord(Loc_3, Loc_2) = 0.36 + 0.18 + 0.16 = 0.70$$

The concordance threshold can be assigned values ranging from 0.5 to 1 [25, 27]; hence, in the above example the concordance threshold is given a value of 0.54 ($s = 0.54$). To this end the results shown in Table 8.10 identify the (Loc_i, Loc_j) pairs for which $Concord(Loc_i, Loc_j)$ meets the concordance condition, i.e. for a value greater or equal to the concordance threshold. The pairs of interest are marked in bold italics in Table 8.11.

8.5.4 Discordance Analysis

For those pairs shown in Table 8.10 for which the concordance condition ($s = 0.54$) was satisfied, the discordance condition was also checked for agreement or disagreement regarding threshold veto values. Thus, the pairs under consideration were (Loc_2, Loc_1), (Loc_3, Loc_1), (Loc_4, Loc_1), (Loc_4, Loc_2), (Loc_3, Loc_2), (Loc_3, Loc_4).

The results of pairwise comparison for those criteria not meeting the outranking relation of the others is shown in Table 8.11. The values for pair (Loc_4, Loc_1) indicate the complete dominance of the former over the latter, with Loc_4 outranking Loc_1 for all criteria.

Table 8.12 displays the final determined outranking relation between the STS transfer locations. A zero value is assigned to those that satisfy only one of the two required conditions (concordance and discordance), while a value of one signals that both conditions are met.

Table 8.12 Outranking relations for the four selected STS locations

		Loc_1	Loc_2	Loc_3	Loc_4
Cyprus	Loc_1	1			
Crete	Loc_2	0	1		
Malta	Loc_3	1	1	1	1
Gibraltar	Loc_4	1	1		1

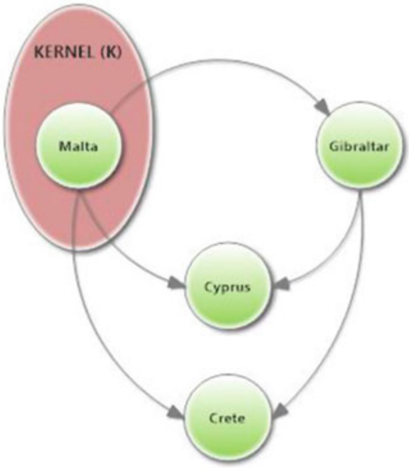

Fig. 8.6 The kernel of the outranking graph

8.5.5 The Kernel of the Outranking Graph

Figure 8.6 graphically illustrates the outranking relation values found in Table 8.12, with the arrows indicating the outranking direction. According to this result, Malta is the best STS location choice.

8.6 Discussion

8.6.1 Robustness Analysis of Criteria Weights

An important issue arises from the determination of relative criterion importance, with criterion weight a prevailing factor affecting the final results. The direct method of weight determination cannot express the difference between criteria effectively, because the analyst cannot know exactly what the expert had in mind when ranking the criteria numerically. As a result the "question and answer" method was employed here to elicit the relative importance the experts assigned to each of the criteria. This method is very effective as it allows the analyst to verify the preferences of the experts via the use of relatively similar questions (same meaning, different approach). In this way, the experts' answers contain

Table 8.13 Robustness analysis for the selected areas under different weight combinations and concordance threshold values

Weight vector	$s = 0.54$	$s = 0.60–0.80$	$s = 0.90$
1	Malta	Malta or Gibraltar	Crete or Malta or Gibraltar
2	Malta	Malta or Gibraltar	Crete or Malta or Gibraltar
3	Malta	Malta or Gibraltar	Crete or Malta or Gibraltar
4	Malta	Malta or Gibraltar	Crete or Malta or Gibraltar
5	Malta	Malta or Gibraltar	Crete or Malta or Gibraltar
6	Malta	Malta or Gibraltar	Crete or Malta or Gibraltar
7	Malta	Malta or Gibraltar	Crete or Malta or Gibraltar

all the information necessary with which to determine the relative importance of the selected criteria; the only thing the analyst then has to do is conduct the goal programming process carefully and precisely. However, the equation system employed during the programming procedure may have no solution which satisfies the conditions, or it may even give more than one solution satisfying system limits. In cases of no adequate solution, the analyst must compose and obtain expert answers to additional questions in order to correct the equations. Due to the fact that this is not always feasible, the analyst must therefore be very experienced and take great care in the setting of these new questions. In the case of finite feasible solutions, sensitivity analysis should be performed in order to find the ideal solution.

In the light of the above and with objective to validate the results and control the stability of the model, a robustness analysis was performed for the different weight combinations of Table 8.7.

The results presented in Table 8.13 reveal that final location ranking depends on both the limited values of the criteria and the value of the concordance threshold. These results, thus, demonstrate the robustness of the model against fluctuations in both weight values and the concordance threshold.

8.6.2 Interpretation of the Results

The kernel-outranking graph indicates that Malta is the STS location that the operators should select for the transfer operation. Furthermore, the graph also indicates that Malta and Gibraltar outrank both Cyprus and Crete. Thus, the objective of selecting the most suitable STS location at which to conduct the operation was achieved.

An important observation regarding the presented example is that Cyprus and Crete cannot be compared to each other due to the ambiguity associated with the comparison of the selected criteria. A concordance value of 0.5 provides the analyst with the ability to gain a clearer idea of the comparison of the proposed areas. If the concordance value is increased to 0.6, Malta and Gibraltar cannot be compared and both would be included in the graph kernel. A concordance threshold above 0.71 would make the results even more ambiguous due to the inability to compare Malta with any of the alternative locations. This fact represents a weakness of the proposed methodology in cases where decision makers wish to make a strict and direct decision, with the lower the concordance threshold the more flexible and lax the resulting decision. It is therefore preferable to set the concordance threshold after the construction of the concordance matrix, thereby providing the analyst with time to take into account all the parameters that may affect the final result.

Furthermore, the discordance threshold veto may also affect the results of the implemented methodology. For instance, expert disagreement regarding the veto may lead to the production of different solutions according to the set values. In the presented case study for example, if one expert had chosen to set the environmental criterion to 0.2 instead of the selected 0.3, Malta and Gibraltar could not be selected one over the other and both would be found in the graph kernel. Moreover, if the threshold veto of the operational criterion was set to one instead of two, Cyprus would outrank Crete and thus provide additional information for decision makers to process. Such fluctuation of the results with regard to the veto threshold may become problematic for inexperienced analysts due to the fact that appropriate questions must be composed in order to obtain useful expert information.

8.7 Conclusion

When in the hands of experts, MCDA techniques are an efficient tool with which to help operators make correct decisions regarding the safety and operability of STS transfers and thereby protect against potential threats that may compromise their success. The choice of an appropriate area in which to conduct an STS transfer operation is a strategic decision which should be made only after careful and thorough examination of the selected criteria. Criteria selection is itself an important issue given the impact of any suspension of the operation, not to mention the potential for accidents. To this end, the ELECTRE I technique is presented here as an effective method with which to select an STS transfer area. The paper's case study shows that this technique can be successfully applied in evaluating alternative locations based on the selected criteria. The effectiveness of the implemented MCDA methodology in combination with the ability of the stochastic MCDA methodologies to deal with uncertainty, forms a challenging way to cope with similar STS transfer operation problems, such as, those where the experts' evaluations is expressed from a probability distribution or the need to select the most suitable STS transfer equipment is perquisite for the success of the operation.

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Appendix 1: Analytical Description of the ELECTRE I Methodology

In MCDA modeling, a set of actions $A = a_1, a_2, \ldots, a_m$ is evaluated based on a consistent family of criteria $F = g_1, g_2, \ldots, g_n$ under the assumptions that

$$g_j(a) > g_j(b) \Leftrightarrow a \text{ is preferred to } b \tag{8.1}$$

$$g_j(a) = g_j(b) \Leftrightarrow a \text{ is indifferent to } b \tag{8.2}$$

To implement the ELECTRE I methodology for the aforementioned problem, three different types of data must be addressed:

- **Weights of the criteria** $p_1, p_2, \ldots, p_n$: These refer to the relative importance of each criterion (see the recent survey [29]) and can be calculated via direct or indirect methods. In direct assessment, users assign a value to each criterion, with these values then normalized accordingly. A more effective and complex indirect approach involves the use of pairwise comparisons between the selected criteria, applying goal-programming methodologies. The sum of the weights in both cases is equal to 1.

$$\sum_{i=1}^{n} p_i = 1 \tag{8.3}$$

- **Concordance threshold** s: An absolute number selected by the analyst which can range from 0.5 to 1, the concordance threshold is applied in order to determine the pairs subject to discordance evaluation, and thus examine the outranking relation for the actions to which the pair members refer.
- **Veto thresholds** $v_1, v_2, \ldots, v_n$: Veto thresholds are employed to control large differences between the values of specific criteria for the corresponding actions.

In particular, for a pair of actions or alternatives (a, b) the outranking relation is determined via the equation

$$a\,S\,b \Leftrightarrow (a, b) \text{ satisfy the concordance and veto conditions} \tag{8.4}$$

Assuming that the criteria weights have been calculated and the concordance and veto thresholds determined, the implementation of the ELECTRE I methodology comprises the following general steps:

Step 1. Concordance validation: To validate an outranking relation between a pair of actions (a, b), the concordance indicator is introduced via the function $C(a, b)$ as follows:

$$C(a, b) : A \times A \rightarrow [0, 1] \tag{8.5}$$

$$C(a, b) = \sum_{i^*} p_i, \quad \text{for } i^* \in \{i | g_i(a) \geq g_i(b)\} \tag{8.6}$$

Relations (8.5) and (8.6) show that $C(a, b)$ is the aggregation of the criteria weights where action a is preferred or the user is apathetic regarding action b. Due to Eq. (8.3), the aggregation of the weights cannot exceed a value of 1. The pair (a, b) satisfies the concordance condition when

$$C(a, b) \geq s, \quad \text{where } s \text{ is the concordance threshold} \tag{8.7}$$

Step 2. Discordance validation: A pair of actions (a, b) satisfies the discordance condition

$$g_{j*}(b) - g_{j*}(a) \leq v_{j*}, \quad \forall j^* \in \{i | g_i(a) \geq g_i(b)\} \tag{8.8}$$

Indicator j^* belongs to the consistent family of the criteria for which action b is preferred over action a, and v_{j*} is the veto threshold for criterion j^*. In case that action b has a difference in values that exceeds the veto threshold of a particular criterion, the latter criterion opposes the veto regarding the outranking relation of action a over action b.

In summary, the outranking relation employed in the ELECTRE I methodology is determined as follows:

$$aSb \Leftrightarrow \begin{cases} C(a, b) = \sum\limits_{i_* \in \{i | g_i(a) \geq g_i(b)\}} p_i \geq s, \quad 0.5 \leq s \leq 1 - \min\limits_{j \in F} p_j \\ \qquad\qquad\qquad\qquad\qquad\qquad \text{(concordance validation)} \\ g_j(b) - g_j(a) \leq v_j, \quad \forall j \in F \text{ (discordance validation)} \end{cases} \tag{8.9}$$

The discordance validation is conducted under the condition that the concordance validation has a positive result. Following the outranking relation determination, results are presented in the form of the kernel of the outranking graph, after the elimination of any circuits.

Step 3. Kernel construction: We can define the kernel of the outranking relation as a set of actions Π, which is itself a subset of a set of actions A, for which the following attributes must be satisfied:

$$(1)\ \forall b \in A - \Pi,\ \exists a \in \Pi : aSb \text{ (external condition)} \quad (8.10)$$

$$(2)\ \forall a_1 \in \Pi \text{ and } a_2 \in \Pi,\ \ a_1 \$ a_2 \text{ and } a_2 \$ a_1 \text{ (internal condition)} \quad (8.11)$$

By definition, the kernel consists of the most important actions in set A that the decision maker must take into account before making a final decision. Therefore, the efforts of the analyst should be concentrated on the minimization of kernel-included actions. The optimization of kernel actions can be achieved via sensitivity or robustness analysis, both of which provide the ability to modify the variables p, s and v accordingly.

Appendix 2: Short Introduction to the Proposed STS Transfer Locations

Malta: The island of Malta is strategically located (35°50'N 14°50'E) at the center of the Mediterranean Sea and is the common point of sea lanes linking Europe, North Africa and the Middle East (Fig. 8.7). Malta also offers a comprehensive suite of inspection, testing and surveying facilities for disparate cargoes ranging from heavy to light. Many STS providers are available to assist with transfers. However, the transfer area itself is not adequately sheltered and environmental conditions may have an adverse effect on operations. The area on Hurd Bank has been used for many years to conduct such operations and thus the local authorities are familiar with procedures. STS operations can be undertaken both within and outside territorial

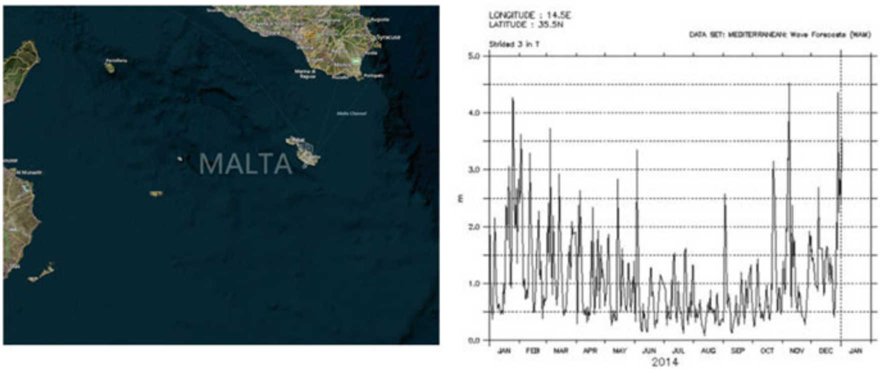

Fig. 8.7 *Left*: topological map of Malta. *Right*: statistical data retrieved from the Poseidon Live Access Server (LAS) regarding significant wave height for the Malta STS area for the year 2014

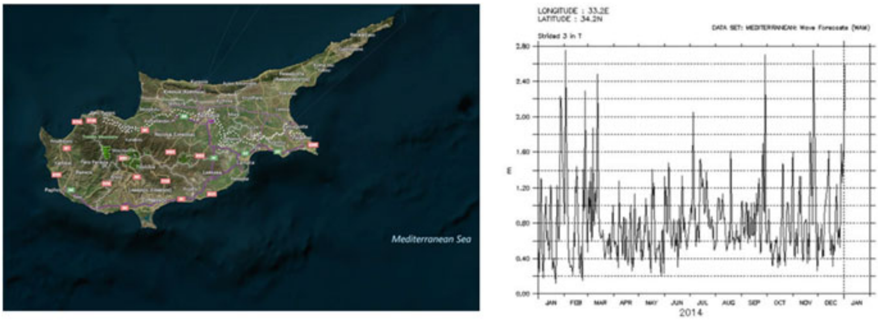

Fig. 8.8 *Left*: topological map of Cyprus. *Right*: statistical data retrieved from the Poseidon Live Access Server (LAS) regarding significant wave height for the Cyprus STS area for the year 2014

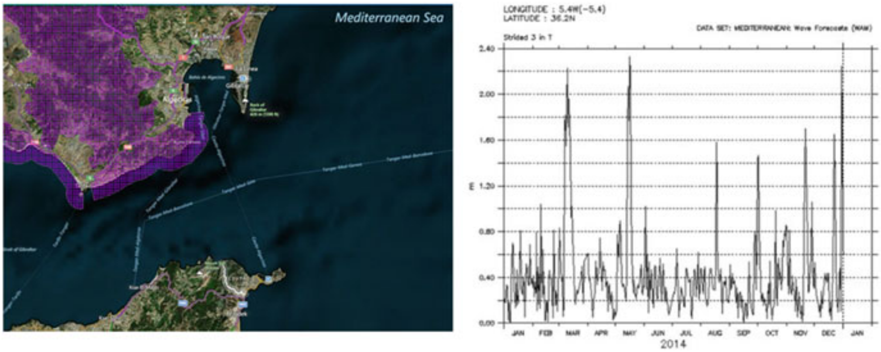

Fig. 8.9 *Left*: topological map of the Strait of Gibraltar. The areas shown in *light* represent protected landscape/seascape areas according to Natura2000. *Right*: statistical data retrieved from the Poseidon Live Access Server (LAS) regarding significant wave height for the Gibraltar STS area for the year 2014

waters. The average height of waves is approximately 1.07 m, with maximum wave height reaching 4.68 m. Malta is classified by the World Lightering Organisation as a level one response area.

Cyprus: (34°20’ N 33°20’ E) Located in Limassol, the Cypriot site (Fig. 8.8) is one of the most important and strategic STS areas in the north eastern Mediterranean. As operations are conducted in international waters there are no port fees. Approximately 200 miles from the Suez Canal, Cyprus provides clients with the option to both deliver to eastern Mediterranean markets and to tranship larger parcels of cargo east, avoiding the inherent delays facing larger vessels transiting the Turkish Straits. STS transfers can be conducted either stationary or underway. Average wave height is 0.8 m and maximum wave height 2.9 m.

Gibraltar: (36°20’ N 5°40’ W (−5.4)) The STS transfer area is located close to the Strait (Fig. 8.9). Strict regulations must be followed regarding emissions, with zero impact to the environment. Additional fees must also be paid to ensure permission

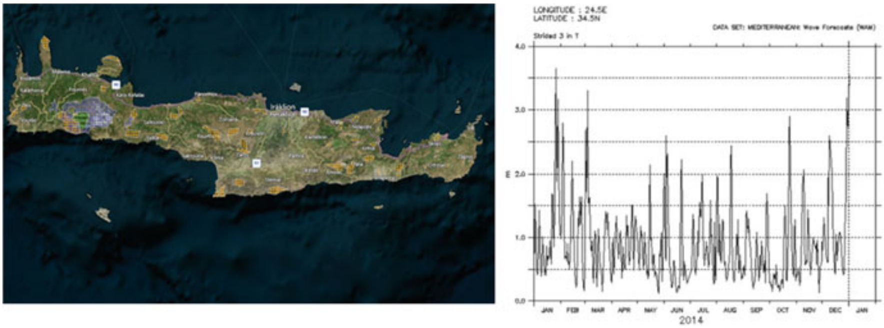

Fig. 8.10 *Left*: topological map of Crete. *Right*: statistical data retrieved from the Poseidon Live Access Server (LAS) regarding significant wave height for the Crete STS area for the year 2014

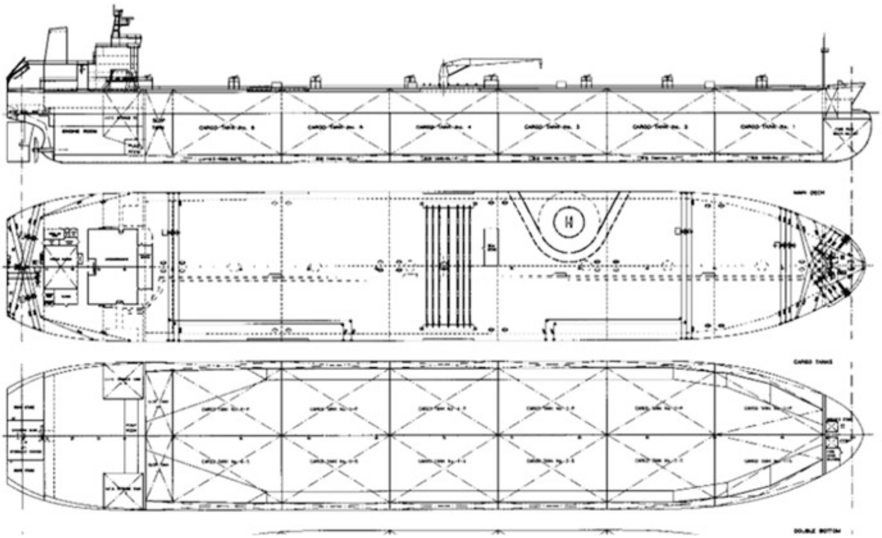

Fig. 8.11 General arrangement of the vessel used in the practical example

from the Gibraltar port authorities for the transfer of crude oil and/or other by-products. Operations can be conducted at anchorage only. Average wave height is 0.42 m and maximum wave height 2.43 m.

Crete: (34°50’ N 24°50’ E) The area of Kaloi Limenes (Fig. 8.10) in southern Crete has recently been designated by local authorities as an STS transfer operation location. As a result, local staff have limited experience and no records of previous STS operations exist. Average wave height is 0.90 m and maximum wave height 5.57 m (Fig. 8.11).

Appendix 3: Main Characteristics of the Vessel Used in the Practical Example

Main dimensions	Capacities (100 %)
Total length 281.20 m	Cargo and slop tanks 185,447 m^3
Length between perpendiculars 270.00 m	Ballast tanks 52,313 m^3
Breadth moulded 48.20 m	Heavy fuel oil 4025 m^3
Depth moulded 23.00 m	Diesel 130 m^3
Design draught 16.00 m	Fresh and feed water 410 m^3
Scantling draught 17.10 m	Cargo equipment
Deadweight at design draught 152,852 t	Cargo pumps $3 \times 3500\,m^3/h$
Deadweight at scantling draught 166,447 t	Cargo stripping $1 \times 250\,m^3/h$, $2 \times 406\,m^3/h$
Main engine Split-MAN-B&W 6S70MC-C	Cargo manifolds 3×500 mm
Selected max continuous rating 16,780 kW/82 rpm	Auxiliary engine plant
Trial speed at design draught and 85 % SMCR 15.5 kn	Main diesel-generator sets 3×912 kW
Main engine daily fuel oil cons. 56.7 t/day	Emergency diesel-generator set 1×248 kW
Cruising range 23,000 nm	
Crew complement 32	

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Chapter 9
MCDM Applied to the Partitioning Problem of 3D-Stacked Integrated Circuits

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Abstract In the past decades, the microelectronic industry has been following the Moore's law to improve the performance of integrated circuits (IC). However, it will probably be impossible to follow this law in the future due to physical limitations appearing with the miniaturization of the transistors below a certain threshold without innovation. In order to overcome this problem, new technologies have emerged, and among them the 3D-Stacked Integrated Circuits (3D-SIC) have been proposed. 3D-SICs can bring numerous advantages in the design of future ICs but at the cost of additional design complexity due to their highly combinatorial nature, and the optimization of several conflicting criteria. Currently, most decisions about the production of a circuit are based on subjective considerations. In order to help designers facing choices when developing 3D chips, we present in this study an application of multi-criteria decision making (MCDM) tools, and more precisely the PROMETHEE methods, to the partitioning problem of 3D-SICs. Our work addresses two different production scenarios for the design of an OpenSPARC-T2 System-on-Chip. With this study, one can observe that multi-criteria analyzes can give to designers insights into the trade-off possibilities for the optimization of a circuit. In addition, the PROMETHEE methodology can help a designer facing choices and provide a transparent process when selecting a valid chip to develop. This shows that applying MCDM tools such as PROMETHEE to design 3D-SICs can indeed help designers to make a better use of this technology.

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9.1 Introduction

In order to continuously improve the performances of integrated circuits (IC), technologists have compelled themselves to follow the well-known Moore's Law (see Fig. 9.1). This empirical law predicts a doubling of the transistors' density each 18 months and therefore increasing logic capacity of the circuit per unit area.

The improvements of 2D architectures are primarily driven by the reduction of the transistor size. However, as the transistor size is decreasing, the observed improvement is also getting smaller, as shown in Fig. 9.1. Indeed, a smaller transistor allows higher device density but will slightly increase the total delay (sum of gate and interconnection delays) at the level of the complete circuit. Besides, with the miniaturization, quantum effects such as quantum tunnelling will significantly affect how a transistor behave. Indeed, even if a transistor is blocking, current can flow through due to quantum tunnelling such that it will be difficult to control its state and thus the basic working principle of a transistor [24]. In addition to these physical aspects, economical considerations that will hinder the IC evolution beyond 10 nm have to be taken into account [4, 17]. Indeed, the wafer cost is expected to increase and the cost per transistor will eventually stop decreasing [2, 15], as shown in Fig. 9.2.

In order to overcome these limitations, new technologies have been introduced such as the carbon nanotubes [21], the nanowire transistors [7], the single-electron transistors [10], and also the 3D-Stacked Integrated Circuits (3D-SIC) proposed by the academic and industrial communities. The latter has often been cited as the most prominent one as it is based on the current technologies and still uses silicon as basis

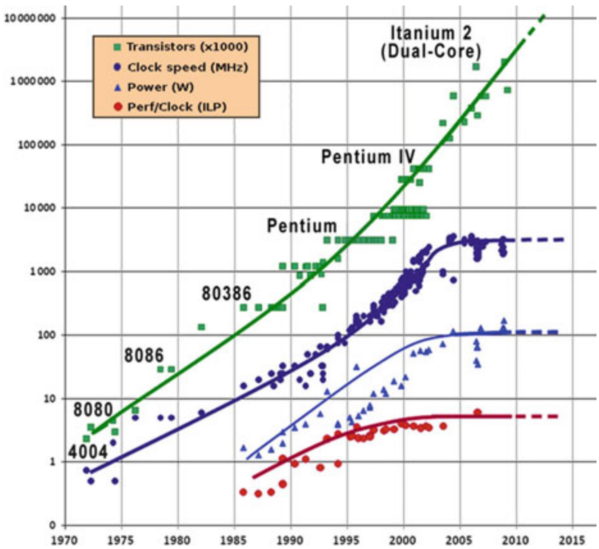

Fig. 9.1 Moore's law [6]

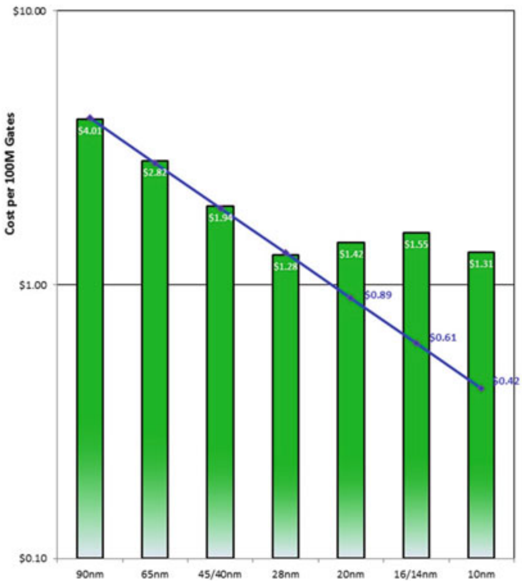

Fig. 9.2 Cost per transistor evolution [18]

material; 3D-SICs can also allow shorter interconnection lengths, smaller footprint, larger bandwidth, heterogeneous circuits among their main advantages [1, 3, 8, 19].

Fast evolution of IC manufacturing technologies makes the design of 2D-ICs a complex and tedious task with the growing number of design choices at the system level (e.g. number and type of functional units and memories, type and topology of the interconnection system, etc.) and physical level (respecting area/timing/power constraints). Using 3D-SICs introduces more degrees of freedom: number of tiers, choices for manufacturing technology (e.g. full 3D integration, silicon interposer, face-to-face, back-to-face, etc.), 3D partitioning and placement strategies, etc. These new degrees of freedom contribute to the combinatorial explosion of already huge design spaces. Moreover, practice and 2D design experience cannot be fully exploited with 3D technology, since 3D-SICs change considerably the way ICs are implemented. Indeed, physical implementation of ICs involves solving several complex problems and hence work only with approximated solutions.

Current design flows can produce workable solutions after manual definition of the physical constraints as there is no preconceived method that can provide good solutions. Also, they are sequential in nature as certain parameters are fixed at certain stages in the flow, which can lead to local optimal solutions that might be far from global optima so this requires time consuming (hence, costly) iterative processes to adjust these parameters. Since the 3D technology is more complex than the 2D, it is necessary to improve the current design flows by developing design exploration [17].

One of the solutions to address this problem is to develop high-level tools which can quickly explore design spaces and give early and reasonably accurate performance estimations based on physical prototyping of the 3D circuits [17]. In addition, performance estimation/optimization and the selection of the most-suitable solutions usually implies to take several objectives into account (e.g. maximization of the performance, minimization of the cost, minimization of the package size, etc.).

Currently, these high-level design tools can be considered to follow a uni-criterion paradigm. Indeed, they have sequential development steps and each criterion is optimized without considering the impact on other criteria. This can lead to several rollbacks in the design flow since the achievement of the requirements can be time consuming (typical design iterations are measured in weeks). For instance, current tools will only minimize the area of a circuit to reach the timing constraints by solving a 2D place-and-route problem and this will be more complex with 3D-SICs because the system has also to be partitioned.

On the other hand, multi-criteria approaches have been developed to consider all the criteria simultaneously. Designing 3D-SICs inherently implies a huge design space and numerous degrees of freedom and criteria, hence many possible choices when it comes to decide upon the IC to produce. With these reasons, we propose to apply a multi-criteria paradigm based on the PROMETHEE methods [5] for the design of 3D-SICs.

9.2 Multi-Criteria Decision Making Tools: The PROMETHEE Methods

In this subsection we recall the basics of the PROMETHEE and GAIA methods. Of course, a detailed description of these approaches goes beyond the scope of this contribution. Therefore we refer the interested reader to [9] for a detailed analysis.

Let $\mathscr{A} = \{a_1, a_2, \ldots, a_n\}$ be a set of n alternatives and $\mathscr{F} = \{f_1, f_2, \ldots, f_m\}$ be a set of m criteria. Without loss of generality, we assume that all criteria have to be maximized. The PROMETHEE methods are based on pairwise comparisons. At first, each pair of alternatives $a_i, a_j \in \mathscr{A}$ is compared on every criterion f_k:

$$d_k(a_i, a_j) = f_k(a_i) - f_k(a_j)$$

The quantity $d_k(a_i, a_j)$ represents the *advantage* of a_i over a_j for criterion f_k. On the one hand, when $d_k(a_i, a_j)$ is small enough, there is no good reason to say that a_i is better than a_j regarding criterion f_k. On the other hand, when $d_k(a_i, a_j)$ exceeds a certain limit, the decision maker may express that a_i is strictly preferred to a_j for f_k. In order to model these statements, the difference $d_k(a_i, a_j)$ is transformed into a unicriterion preference degree, denoted $P_k(a_i, a_j)$, by using a non-decreasing function H_k;

$$P_k(a_i, a_j) = H_k(d_k(a_i, a_j)), \quad \forall\, a_i, a_j \in \mathscr{A}$$

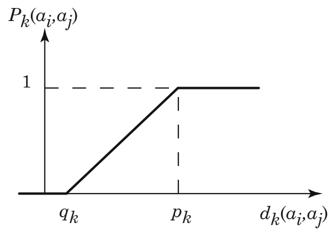

Fig. 9.3 Generalized criterion of type 5

The quantity $P_k(a_i, a_j) \in [0, 1]$ and $P_k(a_i, a_j) = 0$ when $d_k(a_i, a_j) < 0$. There are plenty of functions that can be considered to compute the unicriterion preference degrees. In most software implementing the PROMETHEE method, six main functions are considered [12]. Figure 9.3 represents the so-called linear preference function. Two thresholds characterize it:

- q_k expresses an *indifference* threshold. When the difference $d_k(a_i, a_j) \leq q_k$, it is considered to be so small that the unicriterion preference is equal to zero;
- p_k expresses of a *preference* threshold. When the difference $d_k(a_i, a_j) \geq p_k$, it is considered to be important enough to state that a_i is strongly preferred to a_j for this criterion.

Once the unicriterion preference degrees between two actions a_i and a_j have been computed for every criterion, one has to aggregate these marginal contributions to obtain $P(a_i, a_j)$ i.e. a global measure of the preference of a_i over a_j:

$$P(a_i, a_j) = \sum_{k=1}^{m} \omega_k \cdot P_k(a_i, a_j)$$

where ω_k represents the relative importance of criterion f_k. These weights are assumed to be positive and normalized. Obviously, we have $P(a_i, a_j) \geq 0$ and $P(a_i, a_j) + P(a_j, a_i) \leq 1$.

The PROMETHEE I and II rankings are based on the exploitation of the P matrix. Therefore, three flow scores are built.; the positive flow score ϕ^+, the negative flow score ϕ^- and the net flow score ϕ:

$$\phi^+(a_i) = \frac{1}{n-1} \sum_{a_j \in \mathscr{A}, i \neq j} P(a_i, a_j)$$

$$\phi^-(a_i) = \frac{1}{n-1} \sum_{a_j \in \mathscr{A}, i \neq j} P(a_j, a_i)$$

$$\phi(a_i) = \phi^+(a_i) - \phi^-(a_j)$$

The PROMETHEE I ranking is obtained as the intersection of the rankings induced by ϕ^+ and ϕ^-. The PROMETHEE II ranking is given by the ranking given by ϕ.

Finally, it is worth noting that:

$$\phi(a_i) = \frac{1}{n-1} \sum_{k=1}^{m} \sum_{a_j \in \mathscr{A}} [P_k(a_i, a_j) - P_k(a_j, a_i)] \cdot \omega_k = \sum_{k=1}^{m} \phi_k(a_i) \cdot \omega_k$$

where $\phi_k(a_i)$ is called the k^{th} unicriterion net flow score assigned to action a_i.

The PROMETHEE I and II rankings provide prescriptive tools for decision making. The GAIA [16] tool complements them with a descriptive approach. The idea is to represent each alternative by its evaluations in the unicriterion net flow score space:

$$\Phi(a_i) = [\phi_1(a_i), \phi_2(a_i), \ldots, \phi_m(a_i)]$$

GAIA is the result of a principal component analysis applied to this dataset. Therefore, the decision maker is able to visualize the decision problem on a plane and compare:

- the relative positions of alternatives (in order to identify groups of similar or distinct alternatives profiles);
- the relative positions of criteria (in order to identify conflicts or synergies);
- the relative positions of alternatives with respect to a given criterion (in order to identify the best and worst alternatives for the different points of view);
- the relative positions of alternatives with respect to the so-called *decision stick* (in order the identify the best compromise solutions).

9.3 3D Integration Technology

3D integration technology is considered to be one of the most promising paths to enable further scaling of Integrated Circuits (ICs). Over the past years different 3D integration technology types have been proposed in both academia and industry. Depending on the integration granularity, a very coarse grain 3D technology classification differentiates between 3D-Stacked Integrated Circuits (3D-SICs) and 3D Monolithic integration [14]. Each of these technology options has its own merits and drawbacks and as of today there is no clear preference for one or the other. The right choice is very much design dependent and is strongly affected by our ability to perform optimal design implementations.

3D-SICs are built using 2 (or more) fully processed integrated circuits (wafers) that are integrated vertically one on the top of each other (i.e. dies are stacked). Different 3D structures that enable this particular type of 3D integration have been proposed over the past years and they typically include: wire bonding, Through Silicon Vias (TSV), micro-bumps and copper pads [13, 22]. Even if the wire bonding technique is well known, practical usage remains limited because of the connection pitch that is quite high (∼100 μm range). Also, wire bonds have high resistance and capacitance that will strongly affect delay and power of a 3D wire. Further, as wire bonds appear at the periphery of the IC, the signals connected to them need to be routed throughout the whole circuit. For all these reasons it is generally considered that the wire bonding is not well suited for efficient 3D integration.

On the other hand TSVs, micro-bumps and copper pads are much more promising technology features since they can be manufactured at very low pitch, the diameter depends on the structure but is generally in the μm range allowing dense 3D integration (many inter-die nets). These 3D structures also have good resistance and capacitance values, allowing small delay and power overheads of 3D nets compared to wire bonding and even 2D as long as we enable some wire length savings for 3D.

With these structures 3D circuits can be stacked in different ways depending on the orientation of the circuit *face*, i.e. the side of the IC where we find the active layer (transistors i.e. gates). Not all of the options are interesting from the integration perspective, Face-to-Face (F2F) and Face-to-Back (F2B) integration schemes are the ones that are used most of the time [20, 23]. Cross-sections of F2F and F2B 3D integration schemes is shown on Fig. 9.4.

In F2F 3D-SIC, the face of both dies are oriented towards each other and they are interconnected directly. Input/output TSVs are used to connect the active layer of one of the dies to the package ensuring the system communication with the external world. F2F is in principal limited to stacking of two dies only (although it would be possible to stack yet another die on the top of the stack using F2B approach). In case of F2B 3D-SIC, face of one die is oriented towards the back of the other die. The active layers of the dies are connected using TSVs, a vertical connection that goes through the substrate of the die. Active layer of one of the dies is exposed to the package used for communication of the system with the external world. F2B can be used to stack more than two dies and is used for manufacturing of highly dense SRAM and DRAM circuits.

The assembly of the dies can be carried out at die or at the wafer level, hence we distinguish: (a) Die-to-Die, (b) Die-to-Wafer, or (c) Wafer-to-Wafer 3D integration. Each assembly method has its advantages (and disadvantages) and the choice

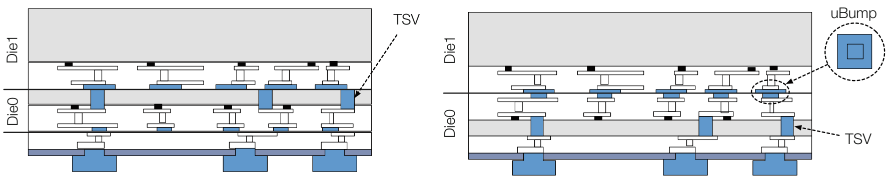

Fig. 9.4 Cross section of Face-to-Back and Face to Face 3D-Stacked Integrated Circuit

depends on the application needs to realize the cost benefits of the 3D integration (trade-off between the wafer processing speed, yield and die area). From the design perspective, there is no significant difference in the choice of the assembly approach. We can thus safely assume any of the proposed assembly methods. 3D stacking technology is mature today and is already used in production lines (e.g. DRAM/FLASH memories).

In 3D monolithic integration multiple transistor or logic gate layers are formed sequentially starting from the bottom-most layer. Minimal interconnect structures are used in between these layers: Monolithic Inter-Layer vias (MIVs) for vertical connections and very limited metal layers for horizontal connectivity. The dimension and parasitics of MIVs are of the order of a local via (in the range of nm). As a result, ultra fine-grained vertical integration of devices is possible. The integration grain is finer from the one of the 3D-SICs, since we can stack at lower level (transistor and gate).

If the stacking is happening at the gate-level, the appropriate EDA tools should perform system partitioning at gate-level, and they should be able to place&route the design in 3D. Note that current EDA tools are not ready for this, since the IC design was a 2D problem until today. If stacking happens at transistor level, the existing EDA, 2D, tools can be used because the problem is now moved to the one of the 3D standard cell design.

While 3D monolithic integration is very promising, there are lot of issues that remain associated with the efficient wafer manufacturing. 3D monolithic process requires high-temperature operations that heavily impact the device performance. Thus, it is known that two consecutive layers will not have the same performance; the top layer having worse performance than the bottom layer, since it is processed afterwards. This will have important consequences on the system design and will lower the benefits of such integration.

In the context of this work we focus on the 3D-SIC circuits approach.

9.3.1 Implementation

In order to assess the multiple physical parameters of an Integrated Circuit (IC) we need to create an IC layout model. In traditional IC design this model is typically generated after gate-level synthesis and place&route (P&R). Both steps are performed using Electronic Design Automation (EDA) tools, in a sequence of different applications. The whole process typically requires many man and CPU cycles before the final model is built. This is due to the system complexity; the accuracy of the models at different abstraction levels that we need to build; and the lack of completely automated methods and algorithms (most of the problems that any design flow is solving are NP-hard problems). To deal with 3D design we have extended the commercially available tools suite from Atrenta (now Synopsis).

The flow is depicted on Fig. 9.5, and we do provide additional explanations of each flow step.

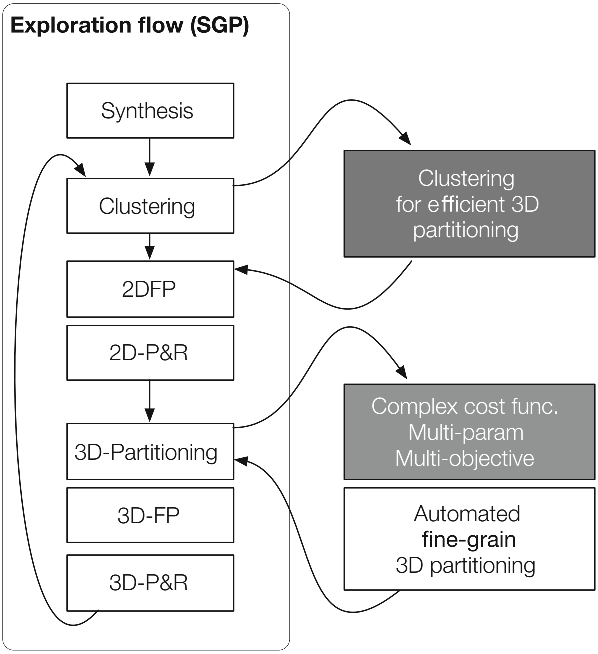

Fig. 9.5 Sequence of steps required to enable 3D-SIC design (3D Design Flow)

Step 1: RTL Synthesis—The input of the proposed flow, as in any IC design flow, consists of several elements. First we need to provide the description of the circuit itself. This is done using any of the standard Hardware Description Languages (VHDL, Verilog). Also, if present, abstracted high-level models of certain blocks can be supplied with multiple criteria such as interface definition, area, power, timing, etc. (i.e. black-boxes). Finally, typical system constraints (timing) are supplied through standardized file format (.sdc files).

Once the design database is ready, the RTL is synthesized to gate-level netlist using standard technology files (.lib and .lef files) provided by the technology vendor. Note that if the design is intended for 2.5D/3D integration, the technology files will have to capture both electrical and geometrical information not only for standard cells, but also for 3D specific features such as TSVs, micro-bumps, Cu-pads, RDLs, etc. that will be instantiated depending on the chosen stack configuration (F2F or F2B).

Synthesized gate-level netlist is analyzed for different criteria (area, timing, logical congestion and other properties). The constraints and synthesis tool guides are adapted to reach realistic goals. Once the synthesis flow is stable i.e. the process produces the netlist in line with timing constraints, generated netlist can be used as input for both 2D and 3D physical design flows.

Step 2: Standard cells (gates) grouping—Prior to floorplanning, the gate-level netlist is partitioned into a number of "reasonably" sized physical groups of standard cells. The grouping is done so that the floorplan engine works on a reduced number of placeable instances. The size of groups (the meaning of "reasonable") will depend on the total circuit size. In general it is chosen in such a way that the total number of groups is in order of few dozens to few hundreds of physical (thus placeable) entities. This is the optimal number of instances (tool run-time vs. quality of the solution) for the floorplan engine.

The purpose of this step is twofold. First, the system is viewed as an assembly of blocks, rather then a collection of logic gates (it could be few dozen of millions) in the design to enable floorplanning (i.e. block level placement) as explained. But secondly, such system view will help in establishing what should go where in the stack.

Standard cell grouping can be performed using different methods. Note that this is a very important step since the quality of the physical design will depend on the grouping scheme adopted. In the current design flow we can use either top-down approach (from top-level of the design, way to the standard cell level) or bottom-up (from the standard cell level and up). Different objectives could be achieved during grouping: keeping and following the logical hierarchy, creating groups of the similar size, hierarchical min-cut across the groups, etc. Note that in the case of the 3D integration, the grouped netlist is further partitioned into a number of gate-level entities (that will remain grouped), equal to the number of dies in the system (see next step, 3D-Partitioning).

Step 3: 3D-Partitioning—This step is only performed in a 3D flow. The stack structure includes numerous parameters to choose among: the number of dies, technology node on per die basis (this is to support heterogeneous integration), stacking orientation (face-up or face-down), 3D structure properties (TSV/micro-bump/CuPad) and RDL net properties (width/pitch), etc. Currently, these are specified in a manually generated XML file, given as an input to the tool. The actual 3D partitioning of the gate level netlist is carried out in an automated way, using the stack configuration file, synthesized gate-level netlist.

For 2.5 and 3D designs, the synthesized gate-level netlist is partitioned into so many gate-level entities as there are dies in the system. Depending on the 3D integration scheme appropriate inter-die interconnect models are applied. To enable the partitioning, the designer first needs to specify the initial stack structure. This is done with a manually created XML file. The stack is divided into tiers, each tier can contain multiple dies (all dies in the same tier have the same z coordinate). XML also specifies the orientation of each die in the stack (face-up or face-down). Each die container can also define its own TSV, micro-bumps, RDL properties that will override those specified in the technology file. This is to ensure that during design exploration phase we can easily replace one basic technology parameter and understand the impact on the system performance (e.g. TSV size, form factor/pitch).

In the case of user specified partitioning directives, the information on which block should go where is provided manually in the form of explicit block-to-die assignment directives using a dedicated tool command. However in fine pitch 3D interconnects we could perform fine grain partitioning, i.e. system blocks are smaller and smaller. Thus their number, as well as their interconnectivity view, will increase considerably making manual partitioning process impossible.

In order to automate the partitioning we use graph theory, which is already extensively used in the field of the VLSI design. Graph structure, with vertex and edge mimic perfectly well a logic circuit, no matter the level of hierarchy we are looking at (although it might become very complex as we go down in the logical hierarchy). Graph vertex represents a logic gate or a group of standard cells (whatever the size of that group in terms of gates might be). The edge models the connection(s) between the gates (or groups).

One of the particular problems that have been extensively covered in the graph theory literature concerns graph partitioning problem. For this problem the algorithm tries to automatically produce two, or eventually more graph partitions that have specific properties. Most of the time these properties aim certain cut objective: like min-cut, in which the sum of the weights of the cut edges is minimal. This can be eventually combined with the objective on vertexes that could be equally balanced between the partitions.

Graph partitioning is illustrated in Fig. 9.12 where we show a simple graph with both edges and vertexes being weighted (the numbers between the square brackets). The initial graph, shown on the left is partitioned into two partitions, providing a min-cut on the edges (cut cost of 5) and balanced vertex weights (respectively the cost of 12 and 11 for Die0 and Die1) (Fig. 9.6).

Once the partitioning information is generated (manually or automatically) the design is effectively partitioned. The tool performs module assignment for a given tier. During this process all inter-die nets will be automatically extracted and corresponding physical inter-die net models applied depending on the die orientations (choice between F2F and F2B) and specified technology options. With the internally partitioned netlist, we can now proceed with the floorplanning of the

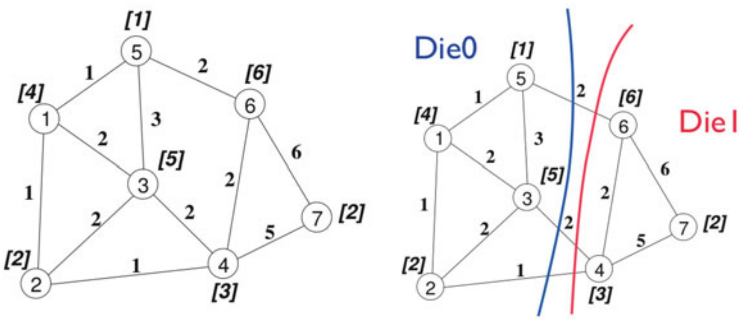

Fig. 9.6 Simple graph with annotated vertices (system blocks and their area) and edges

design, and this is then followed by standard cell placement and routing. At this stage the approximated layout of the circuit is generated and it can be characterized to assess the different system parameters. Typically we extract area, congestion and timing analysis, power dissipation per component, etc.

Step 4: Floorplanning—The grouping and 3D partitioning steps are followed by the floorplanning step. In case of 2D, the floorplanning is carried out automatically, with physical constraints that are manually generated based on connectivity analysis and whatever knowledge/constraints we might have on the design (e.g. hard-macro pre-placements, etc.). In case of 3D, additional physical constraints related to 3D net placement are generated (TSV/micro-bump grouping and placement). Floorplanning is carried out for each die separately.

Step 5: Standard cell Placement and Routing (PNR)—Standard cell placement and routing are carried out after floorplanning. In case of 3D, it is performed separately for each die, in a sequential way.

9.4 Case Study

9.4.1 Experimental Set-up: Design and Implementation

We have carried out experiments using three different sub-blocks of the OpenSPARC-T2 SoC design: the core (SPC) that is gate dominated; the crossbar circuit (CCX) that is wire dominated; and the Ethernet module (RTX), an example of "typical" circuit. For graph formation of hyper-edges we use 10 different cost functions: Min-cut based (number of wires per C2C connection, average wire length of all nets for each C2C connection, total WL of all nets in each C2C connection, product of 1 and 2, product of 1 and 3) and the inverse of the above. For standard cells grouping, we have considered logical (four different hierarchical levels), top-down (two sizes) and newly developed bottom-up grouping methods (two sizes). For graph vertices weights we have been considering area.

9.4.2 Multi-Criteria Analysis

Each design results in 70 alternatives (7 standard cells (gates) grouping schemes $\times$ 10 cost functions per hyper-edge = 70 runs) that we will analyze for key distribution criteria: number of 3D nets (to be either maximized or minimized), total wire length (to be minimized) and maximum wire length (to be minimized). The number of 3D nets represents a measure of the performance of a circuit (and to a certain extent also its cost), the total wire length its economical aspects and power while the maximum wire length will reflect the performances. The evaluation table of these 70 alternatives is shown in Appendix.

Let us note that the number of 3D nets has to be either maximized or minimized, depending on the production case, respectively for a high performance circuit of for a low cost chip. In consequence, we will analyze this study as two separate problems. In the following we will use and analyze the PROMETHEE methods, with the D-Sight Web platform [11, 12], that will allow us to rank all the alternatives and ease the decision process. We will consider two production scenarios given by an expert in the IC design field. The first one will consider a case where performances are more important than the economical aspects (goal for the high performance community) while the second one will put more emphasis on the cost, allowing concession on the performances (goal for the mobile computing community).

9.4.2.1 High Performance Production Scenario

In this case, we want to maximize the number of 3D nets, minimize the total wire length and minimize the maximum wire length.

Preliminary Analysis

From the 70 alternatives, we will take into account the Pareto optimal set which is composed of the five alternatives shown in Table 9.1. As a first analysis, we will consider the three best unicriterion alternatives as the designers can be interested to know how the circuits are performing on each parameter: RandomL3 5 (for the number of 3D nets), Hier L3 4 (for the total wire length) and RandomL3 8 (for the maximum wire length) (in bold in Table 9.1).

By analyzing the evaluations, we can observe that the Hier L3 4 alternative, while being the best on the total wire length criterion (by a difference of 1.9 % compared to the RandomL3 5 alternative), is really bad on the two other criteria: only 45 compared to 3421 (1.3 %) for the number of 3D nets, and 599.8 compared to 324.92 (54.2 %) for the maximum wire length. Given these poor evaluations this alternative may not represent a good compromise solutions and it would be necessary to make concession in order to achieve a better overall circuits.

With these preliminary analyzes, we can already provide valuable multi-criteria information to a designer so that trade-off decisions would be eased. However, until

Table 9.1 High performance production scenario: Pareto optimal set

Standard cells grouping name	3D nets	Total WL	Max L
Hier L3 2	50	773,884.54	596.94
Hier L3 4	45	**769,255.55**	599.8
Auto1000 3	3301	800,223.427	353.625
RandomL3 5	**3421**	784,257.1375	355.1875
RandomL3 8	2991	836,486.01	**324.92**

Table 9.2 High performance production scenario: indifference and preference thresholds

Thresholds	3D nets	Total WL	Max L
Indifference (q_k)	340	15,242.76	29.1
Preference (p_k)	3254.75	48,237.30	245.78

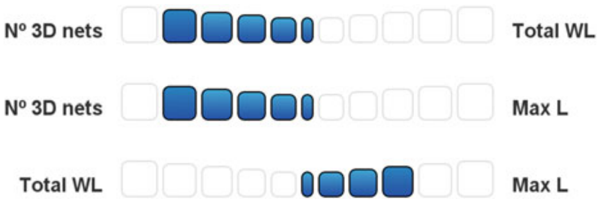

Fig. 9.7 High performance production scenario: weights elicitation

now we have only considered alternatives that are optimal on one of the criteria. These are therefore not necessarily suitable as compromise solutions as we have observed previously.

Preference Modeling

The first step of the PROMETHEE methods is to model the decision maker's preferences. To simplify the questions asked to a designer who is not familiar with preference modeling, we will make the assumption that the preference functions are linear since the evaluations are all quantitative (based on a cardinal scale). The indifference and preference thresholds will be set respectively as the first and third quartile of all the evaluation differences (see Table 9.2). We will also elicit the weight of the criteria following a procedure similar to what is used in AHP.

The weights elicitation for this case is represented in Fig. 9.7. The designer expresses the preference for a high performance circuit by putting more importance to the number of 3D nets and maximum wire length criteria than on the total wire length criterion. The resulting weights are given as follows: 59.36 % for the number of 3D nets, 15.71 % for the total wire length, and 24.93 % for the maximum wire length.

The PROMETHEE II ranking with this preference model is shown in Fig. 9.8, with the associated GAIA plane in Fig. 9.9. We remark that the three first-ranked alternatives are RandomL3 5, Auto1000 3 and RandomL3 8. Without great surprise, the best unicriterion alternative on the number of 3D nets criterion is ranked first since the higher weight on this criterion. On the GAIA plane, we can observe that the number of 3D nets axis and the total wire length axis are orthogonal while the maximum wire length axis is in between (but closer to the number of 3D nets). This indeed reflects that performance (number of 3D nets) are in conflict with economical aspects (total wire length) while the maximum wire length criterion considers both.

An analysis of the evaluation of the RandomL3 5 alternative shows that, while it is not the best on the criterion with the highest weight (number of 3D nets), its

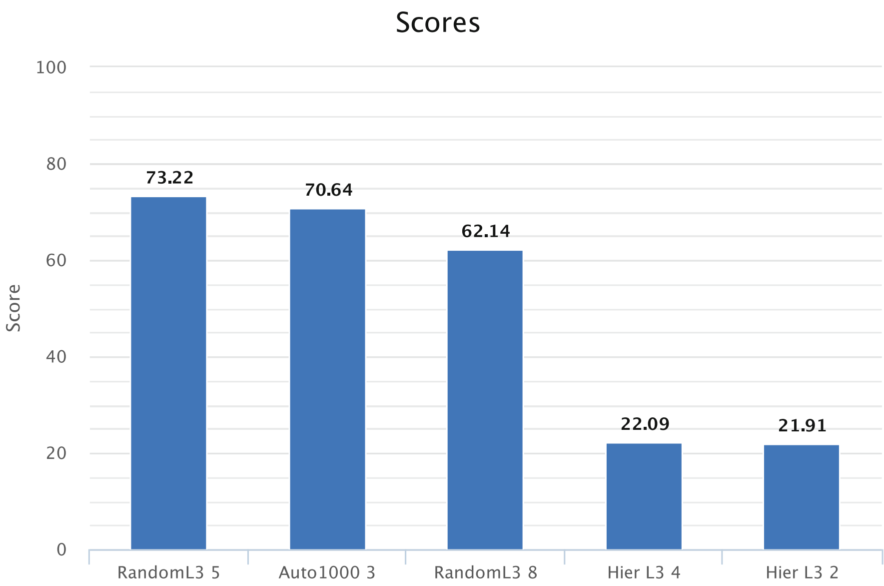

Fig. 9.8 High performance production scenario: PROMETHEE II ranking

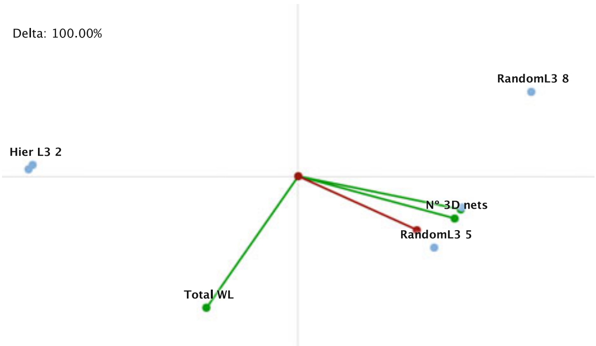

Fig. 9.9 High performance production scenario: GAIA plane

evaluations on the other criteria are more balanced which justify its ranking as first (Table 9.3).

Stability Analysis

Since the weights have been elicited through a procedure similar to what is used in AHP, the real values may be subject to approximations so it is necessary to analyze whether a slight change in the weights will affect the ranking. The stability intervals

Table 9.3 High performance production scenario: top 3

Rank	Standard cells grouping name	3D nets	Total WL	Max L
1	RandomL3 5	3421	784,257.1375	355.1875
2	Auto1000 3	3301	800,223.427	353.625
3	RandomL3 8	2991	836,486.01	324.92

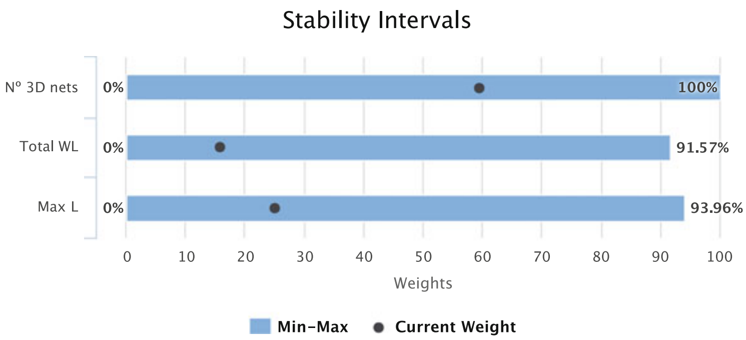

Fig. 9.10 High performance production scenario: weights stability intervals

for each criterion is shown in Fig. 9.14. As we can observe, the possibilities of weight modification are also large for this case, which means that the RandomL3 5 alternative is a stable compromise solution for this high performance production scenario and small modifications will not affect the ranking of the first alternative (Fig. 9.10).

9.4.2.2 Low Cost Production Scenario

In this case, we want to minimize the number of 3D nets, minimize the total wire length and minimize the maximum wire length.

Preliminary Analysis

The Pareto optimal set for this scenario is composed of 19 alternatives shown in Table 9.4. The problem is therefore more complex since more alternatives have to be taken into account. The best unicriterion alternatives in this scenario are: Hier L3 4 (for the number of 3D nets and the total wire length) and RandomL3 8 (for the maximum wire length) (in bold in Table 9.4).

The observations are similar to the ones for the high performance production scenario, except that there are only two best unicriterion alternatives, as the Hier L3 4 is at the same time the best for the number of 3D net and the total wire length criteria.

Table 9.4 Low cost production scenario: Pareto optimal set

Standard cells grouping name	3D nets	Total WL	Max L
Hier L1 3	3219	815,036.54	394.12
Hier L1 10	1551	1,173,632.4	520.6
Hier L2 2	3217	828,529.875	378.24
Hier L3 2	50	773,884.54	596.94
Hier L3 4	**45**	**769,255.55**	599.8
Auto0500 6	74	1,961,277.892	591.19
Auto1000 1	130	1,795,247.45	591.345
Auto1000 3	3301	800,223.427	353.625
Auto1000 10	1551	1,211,404.99	518.43
RandomL2 2	2853	871,314.057	355.012
RandomL2 4	2780	881,218.65	470.167
RandomL2 5	2766	941,690.592	483.63
RandomL2 7	3351	799,765.04	384.1
RandomL2 9	2949	846,481.907	357.465
RandomL3 3	2974	875,502.4425	326.9675
RandomL3 4	2609	957,730.9975	549.7075
RandomL3 5	3421	784,257.1375	355.1875
RandomL3 7	2840	854,184.0025	390.09
RandomL3 8	2991	836,486.01	**324.92**

Table 9.5 Low cost production scenario: indifference and preference thresholds

Thresholds	3D nets	Total WL	Max L
Indifference (q_k)	237	44,502.68875	35.7715
Preference (p_k)	2713	386,125.1888	195.88125

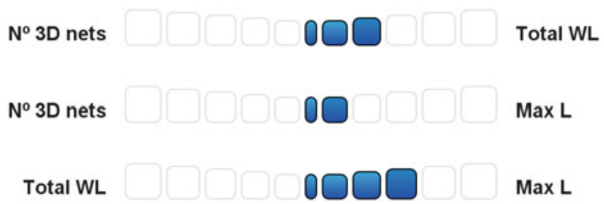

Fig. 9.11 Low cost production scenario: weights elicitation

Preference Modeling

For this case, the indifference and preference thresholds for the linear preference function are computed as previously and shown in Table 9.5. The weights elicitation for this case is represented in Fig. 9.11. The designer expresses the preference for a low cost circuit by putting more importance to the maximum wire length criterion than on the total wire length and number of 3D nets criteria since it has more impact

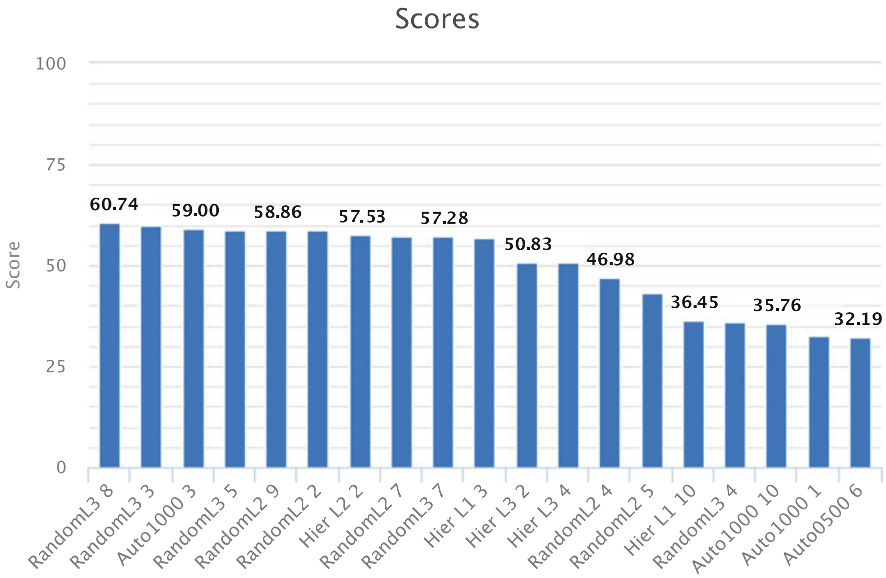

Fig. 9.12 Low cost production scenario: PROMETHEE II ranking

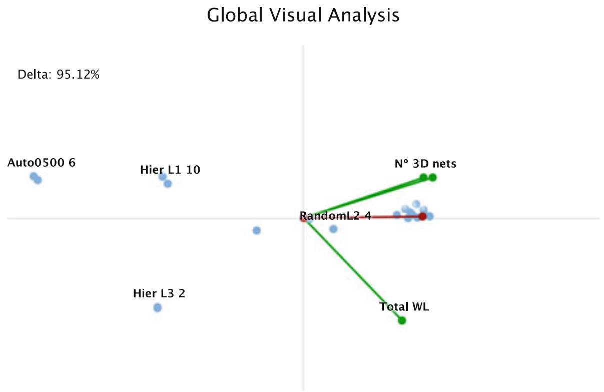

Fig. 9.13 Low cost production scenario: GAIA plane

on the cost. The resulting weights are given as follows: 26.78 % for the number of 3D nets, 29.6 % for the total wire length, and 43.62 % for the maximum wire length.

The PROMETHEE II ranking with this preference model is shown in Fig. 9.12, with the associated GAIA plane in Fig. 9.13. We remark that the three first-ranked alternatives are RandomL3 8, RandomL3 3, and Auto1000 3. Without great surprise, the best unicriterion alternatives on the total wire length is ranked first due to its higher weights. As for the GAIA plane, it is similar to the one for the high performance production scenario, except that the maximum wire length axis is closer the number of 3D nets axis since both criteria reflect the cost of a circuit.

Table 9.6 Low cost production scenario: top 3

Rank	Standard cells grouping name	3D nets	Total WL	Max L
1	RandomL3 8	2991	836,486.01	324.92
2	RandomL3 3	2974	875,502.4425	326.9675
3	Auto1000 3	3301	800,223.427	353.625

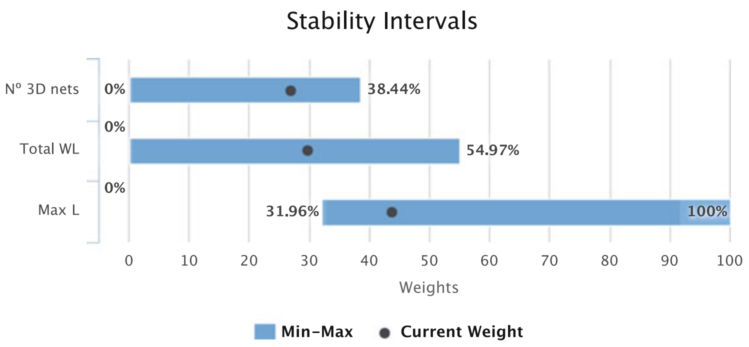

Fig. 9.14 Low cost production scenario: weights stability intervals

Let us now analyze the RandomL3 8 alternative compared to the second and third ones with their evaluations, as shown in Table 9.6. We observe that, while it is the best on the criterion with the highest weight (maximum wire length) and its evaluations on the other criteria are well-balanced, which justify its ranking as first.

Stability Analysis

The stability intervals for each criterion is shown in Fig. 9.14. As we can observe, the possibilities of weight modification are rather large, which means that the RandomL3 8 alternative is a stable compromise solution for this low cost production scenario and small uncertainties will not affect the ranking of the first alternative.

9.4.2.3 Results Interpretation for an IC Designer

Based on a given preference modeling, a designer will be able to know which design can be the best compromise solution, while following a transparent decision process. This can constitutes a great help since the design of 3D-SIC requires to make numerous choices. Currently, most decisions are based on subjective considerations so integrating a transparent process such as the PROMETHEE will ease the developments. Furthermore, even if the model can contain approximate evaluations (e.g. for the weights), stability studies can be performed to analyze the robustness of the ranking (for the first alternatives). Finally, multi-criteria analyzes can also help a designer to understand how a concession on one criterion will help in optimizing another. Applying an MCDM-based method can therefore help for the numerous choices a designer have to face when developing 3D-SICs.

9.5 Conclusion and Future Works

This work mainly aimed at showing an insight into the use of multi-criteria analysis, and more precisely the PROMETHEE methodology for designing 3D-SICs. Given the growing complexity of designing conventional 2D-ICs, current design flows can already exhibit their limits and we have shown that with the complexity of 3D-SICs, making right system level and physical design choices has become more difficult.

To the best of our knowledge, the application of the proposed methodology, using multi-criteria decision making tools, to this particular application domain has never been done.

As we have observed, multi-criteria analyzes can give to designers insights into the trade-off possibilities for the optimization of a circuit. In addition, the PROMETHEE methodology can help a designer facing choices and provide a transparent process when selecting a valid chip to develop. Indeed, having a ranking can help to easily choose the best compromise solution and it is also possible to analyze its robustness if the preference model contains approximations. While the tools have been developed in order to be simple to use and analyze, the main difficulty is to model the preferences accordingly with a designer's needs. As the specifications required for a design cannot translate easily into preference information, establishing a preference model is not a trivial task. In this work, we have simplified the preference modeling by using only linear preference functions with arbitrary thresholds (first and third quartiles) to minimize the number of questions asked to a designer. Therefore, in order to improve the model further, this will need investigations to adapt the methodology to designers so that they can easily develop suitable preference models.

Nonetheless, we believe that with these results, using MCDM tools such as PROMETHEE to design 3D-SICs will help designers to make a better use of this technology, help them to analyze their optimization possibilities with trade-off information and ease their choices in a transparent process.

Appendix

OpenSPARC-T2 SoC Design Alternatives: Evaluation Table

Standard cells grouping name	3D nets	Total WL	Max L
Hier L1 1	1551	1,253,781.34	580.74
Hier L1 2	3217	842,376.29	381.98
Hier L1 3	3219	815,036.54	394.12
Hier L1 4	1551	1,260,965.38	552.54
Hier L1 5	1551	1,206,637.52	532.56
Hier L1 6	1551	1,260,965.38	552.54
Hier L1 7	3219	854,282.92	427.11
Hier L1 8	3217	832,211.6	389.58
Hier L1 9	1551	1,250,498.59	590.52
Hier L1 10	1551	1,173,632.4	520.6
Hier L2 1	1551	1,264,331.707	545.572
Hier L2 2	3217	828,529.875	378.24
Hier L2 3	3219	859,517.265	451.59
Hier L2 4	1551	1,250,566.685	544.65
Hier L2 5	1551	1,256,812.31	586.145
Hier L2 6	1551	1,250,566.682	544.65
Hier L2 7	3219	862,537.155	417.615
Hier L2 8	3217	843,293.522	380.585
Hier L2 9	1551	1,263,855.49	541.1
Hier L2 10	1551	1,206,165.9	534.14
Hier L3 1	45	995,023.46	606.1
Hier L3 2	50	773,884.54	596.94
Hier L3 3	45	992,746.45	608.71
Hier L3 4	45	769,255.55	599.8
Hier L3 5	45	992,746.45	608.71
Hier L3 6	45	994,874.62	604.39
Hier L3 7	45	992,746.45	608.71
Hier L3 8	50	988,884.17	596.94
Hier L3 9	50	995,832.51	605.74
Hier L3 10	45	995,023.4	606.1
Auto0500 1	74	2,008,363.082	614.52
Auto0500 2	892	1,842,296.135	603.315
Auto0500 3	74	2,120,039.087	592.335
Auto0500 4	892	1,911,618.982	606.46
Auto0500 5	892	1,842,296.135	603.315

(continued)

Standard cells grouping name	3D nets	Total WL	Max L
Auto0500 6	74	1,961,277.892	591.19
Auto0500 7	74	2,120,039.085	592.33
Auto0500 8	892	1,842,296.142	603.31
Auto0500 9	892	1,842,296.142	603.31
Auto0500 10	892	1,842,296.13	603.3
Auto1000 1	130	1,795,247.45	591.345
Auto1000 2	130	1,795,247.45	591.345
Auto1000 3	3301	800,223.427	353.625
Auto1000 4	1551	1,250,566.682	544.65
Auto1000 5	1551	1,256,812.31	586.14
Auto1000 6	1551	1,250,566.682	544.65
Auto1000 7	130	1,795,247.45	591.345
Auto1000 8	3217	843,293.522	380.58
Auto1000 9	1551	1,197,233.495	541.69
Auto1000 10	1551	1,211,404.99	518.43
RandomL2 1	3327	845,356.947	400.27
RandomL2 2	2853	871,314.057	355.012
RandomL2 3	3227	836,782.54	451.262
RandomL2 4	2780	881,218.65	470.167
RandomL2 5	2766	941,690.592	483.63
RandomL2 6	3246	863,068.172	428.25
RandomL2 7	3351	799,765.04	384.1
RandomL2 8	2853	986,269.035	563.042
RandomL2 9	2949	846,481.907	357.465
RandomL2 10	3030	866,805.157	426.855
RandomL3 1	3270	862,183.1175	487.8075
RandomL3 2	3123	864,232.175	456.695
RandomL3 3	2974	875,502.4425	326.9675
RandomL3 4	2609	957,730.9975	549.7075
RandomL3 5	3421	784,257.1375	355.1875
RandomL3 6	3007	836,500.6825	363.0275
RandomL3 7	2840	854,184.0025	390.09
RandomL3 8	2991	836,486.01	324.92
RandomL3 9	2976	865,025.065	545.9425
RandomL3 10	3157	877,046.3125	463.3975

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Chapter 10
A MCDA-Based Approach for Evaluating Alternative Requalification Strategies for a Net-Zero Energy District (NZED)

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Abstract In Europe the building sector is responsible for more than 40 % of the total energy consumption and for 36 % of the CO_2 emissions. To avoid a further increase of these values, the European Union decided to issue several Directives in order to encourage the reduction of energy consumptions and to promote the use of renewable energy sources. In particular, the recast of the European Energy Performance of Buildings (Directive 2010/31/EU) promotes the improvement of buildings energy performance within the European Union, and introduces a new standard, the nearly-Zero Energy Building (nZEB). More recently, the European Commission is shifting the matter with steady increase from the single level of the building to the district one in order to hit the target of post-carbon cities and the concept of Net-Zero Energy District (NZED) is emerging. The evaluation of alternative strategies for the construction of NZED constitutes a multidimensional problem, where different aspects and impacts have to be considered, from the reduction of pollutant emissions to the investment cost, from the increase in indoor comfort to the creation of benefits in term of real estate assets value. The objective of the present study concerns an investigation of Multicriteria Decision Analysis for supporting decision problems in the context of NZED. In particular, starting from a real case study in the city of Turin (Italy), the multicriteria PROMETHEE method is employed for comparing four alternative strategies for the construction of a new NZED and to select the best solution from a socio-economic and environmental point of view.

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10.1 Introduction

The residential building sector is one of the biggest consumers of energy in the European Union (EU) with one of the largest cost-effective energy saving potentials [7, 14]. In this context, there is an increasing interest in environmental issues. In fact, reducing energy consumption in the building sector and using renewable sources play an important policy target. The recast of the European Energy Performance of Buildings Directive (2010/31/EU EPBD, [23]) encourages the improvement of the buildings energy performance within the EU, and promotes a new standard, the nearly-Zero Energy Building (nZEB).

In particular, nZEB is introduced as a target to achieve the reduction of greenhouse gas (GHG) emissions produced by the building sector, that represent today around 36 % of the total CO_2 emission in EU. The concept of nearly-Zero Energy Building has gained an increasing recognition in the literature as it is characterized by very low energy consumption; nZEB design features should be defined at individual building level in order to capture the specific features of each contest and to guarantee really high energy performance and indoor comfort conditions. In addition, the nZEB target suggests that a "significant extent of energy by renewable sources produced on-site or nearby" (2010/31/EU—EPBD, [23], article 2) should cover the need of the buildings, in order to reduce emissions through cleaner sources and decrease the dependence from the grid.

Moreover, the European Commission is shifting the matter with steady increase from the single level of the building to the district one in order to hit the target of post-carbon cities. The change of scale is translated in a cluster of private and public units where the energy demand is partly met by renewable energy self-produced within the neighbourhood, so called Net-Zero Energy District (NZED) [36]. On a large-scale, better performances could be reached in energy, reducing primary energy consumption, and in economic terms, achieving cost-optimality with current market prices of refurbishment measures [30]. To develop an evaluation of a district project, it is necessary to extend the analysis to a macroeconomic scale, including several points of view and incorporating the project co-impacts into decision-making framework, in order to determine the net social benefit for the community involved and select among alternative programs in preliminary energy design phases [27].

When speaking about energy planning and energy district projects, many objectives have to be considered in the decision making process: factors that range from the reduction of pollutant emissions to the investment cost, from the increase in indoor comfort to the creation of benefits in terms of real estate assets value. Multicriteria Decision Analysis (MCDA) is an approach that can deal with such multidimensional issues at both micro and macro study levels and the use of an MCDA framework is a very useful tool to implement such an inter-disciplinary approach [3, 41]. The paper investigates the role of MCDA in supporting decision problems in the domain of energy planning. In particular, the objective of the present study concerns an experimentation of the method PROMETHEE for supporting the construction of new NZEDs. The employed methodology was validated through its application to a case study; a selected district in Turin (Northern Italy) was hypothetically transformed into a Net-Zero Energy District and four different retrofit strategies were compared in order to identify the best solution from a socio-economic and environmental point of view.

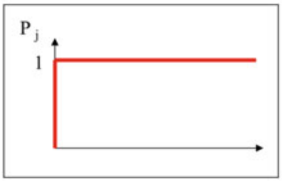
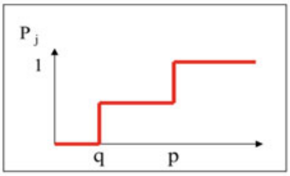
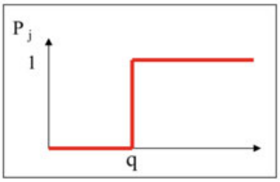
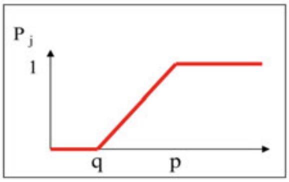
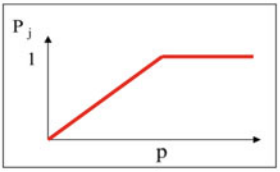
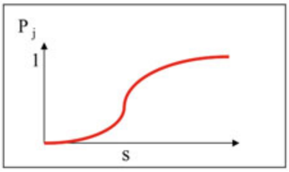
After the introduction, the rest of the chapter is organized as follows: Sect. 10.2 illustrates the methodology of the study, describing the MCDA framework and the PROMETHEE technique; Sect. 10.3 presents the application of the PROMETHEE method to the real case study and Sect. 10.4 discusses the results. Finally, Sect. 10.4 contains reflections on the work done in this study, and different areas of future developments.

10.2 Methodological Framework

Energy efficiency projects require new methods and tools to improve decision-making effectiveness, to take into account not only energy savings, but also other effects, as the decrease of environmental impacts or the changes in investment and operation costs. The assessment of alternative strategies of retrofit measures is therefore a complex decision problem where different aspects need to be considered simultaneously. In this context, a very useful aid is provided by the techniques that are part of the Multiple Criteria Decision Analysis (MCDA) family, which are used to make a comparative assessment of alternative projects or heterogeneous measures [9, 25, 35].

In recent years, the MCDA approach assists decision-makers to learn about the problem and the possible alternative courses of actions addressed from different views. The PROMETHEE method (Preference Ranking Organization Method for Enrichment Evaluations) belongs to the family of MCDA methods and it was drawn up by Brans [15] and subsequently extended by Brans et al. [16, 17] and Vincke and Brans [40]. PROMETHEE is a non-parametric outranking method for a finite set of alternative actions to be ranked. Several alternatives are evaluated according to different criteria, which are often conflicting. Each alternative is valued by a positive or negative preference flow through a value outranking relation, in order to determine how much an alternative is outranked compared to the others. Two types of information must characterize the evaluation model. The first important information regards the preference weight assumed by the decision-maker about a specific criterion, to determine the relative importance of one over another. The second information concerns the preference function for each criterion, that allows to establish how much an alternative is preferred over another. The preference function ranges between 0 and 1. In the case of indifference the preference is equal to 0, while in the case of strict preference the value is 1. Six choices for preference functions are available [40]: usual criterion, quasi-criterion (U-shape), criterion with linear preference (V-shape), level criterion, criterion with linear preference and

Table 10.1 List of preference functions

Preference function	Shape	Preference function	Shape
Usual function		Level function	
U-shape function		Linear function	
V-shape function		Gaussian function	

indifference area (linear), and Gaussian criterion. The preference functions include also different type of threshold, namely indifference, preference and Gaussian thresholds. Indifference threshold (notation q) is the largest deviation between two alternatives which is considered negligible by the decision maker (DM); preference threshold (notation p) is the smallest deviation between two alternatives which is considered by the DM sufficient to generate a full preference; Gaussian threshold (notation s) corresponds to the inflection point of the Gaussian curve (Table 10.1).

In summary, the stepwise of the PROMETHEE procedure is:

- To establish an impact matrix for the selected criteria, using cardinal (quantitative) and ordinal (qualitative) data.
- To apply the preference function $P(a, b)$, for each criterion, in order to decide how much the outcome a is preferred to b.
- To calculate the global preference index $\Pi(a, b)$, which represents the preference strength of a over b.

$$\Pi(a, b) = \sum_{j=1}^{k} w_j P_j(a, b)$$

where $\Pi(a, b)$ is the preference degree of a over b, k represents the number of criteria, w_j is the weight of criterion j and $P_j(a, b)$ is the preference function of a over b with reference to criterion j.

- To calculate the outranking flows. In PROMETHEE method for each $a \in A$, where A is a finite set of possible alternatives, there is a leaving flow (outranking) Φ^+:

$$\Phi^+(a) = \frac{1}{n-1}\sum_{b \in A} \Pi(a, b)$$

and entering flow (being outranked) Φ^-:

$$\Phi^-(a) = \frac{1}{n-1}\sum_{b \in A} \Pi(b, a)$$

where n is the total number of alternatives.

- To compare the outranking flows and to define the complete ranking of the alternatives, PROMETHEE provides a complete ranking of the alternatives by calculating the net flow Φ:

$$\Phi(a) = \Phi^+(a) - \Phi^-(a)$$

The result of the PROMETHEE method is the net outranking flow for each alternative and the complete ranking.

A recent paper by Behzadiana et al. [8] highlights that many applications of the PROMETHEE methods exist in the different fields, including environmental management, water management, business, chemistry, logistics, transportation, manufacturing, energy management and social. It has to be noticed that in the context of energy management, the PROMETHEE applications were concentrated on selecting and evaluating energy generation or exploitation alternatives [2, 37, 42]. Mention has to be made to the fact that no application exists in the context of building energy assessment and management.

10.3 Application

10.3.1 Description of the Case Study

The neighbourhood chosen for the methodology validation is a residential district in the municipality of Turin (Northern Italy), characterized by high-rise apartment buildings different for typology and use. There are two main reasons that support this choice. Firstly, this district was selected because of buildings low thermal properties, since they were built before 1980. Secondly, as this neighbourhood is not

Fig. 10.1 Case study relative to Turin (*Source*: Google Maps)

connected to district heating (buildings are heated with individual boilers), and there are no provisions for it, this case study represents a good opportunity to experiment the application of an evaluation methodology for the design of a new NZED.

The neighbourhood (Fig. 10.1) extends on an area of approximately 8 ha and accommodates about 1950 inhabitants. The number of residents is estimated based on the assumption that the overall occupancy rate for flat is three persons. The total number of dwellings is 635, and the total area of buildings is equal to 74,115 m^2.

After having chosen the case study and done its characterization, it was necessary to proceed with the estimation of its current energy consumption. To simplify the calculation, the buildings were grouped in few typologies, hypothesizing that the constructions with the same features could be characterized by comparable consumptions. Consequently, the district buildings were clustered in five typologies, according to their geometrical and thermo-physical features and their construction period using the TABULA database [4], as shown in Fig. 10.2. Once typified the neighbourhood, it was possible to proceed to the estimation of the annual energy consumption for the different typologies, extrapolating the energy needs for space heating and domestic hot water production by the TABULA database and, then, assessing the related energy uses according with national Standards [39]. From these values the whole district energy consumption could be evaluated.

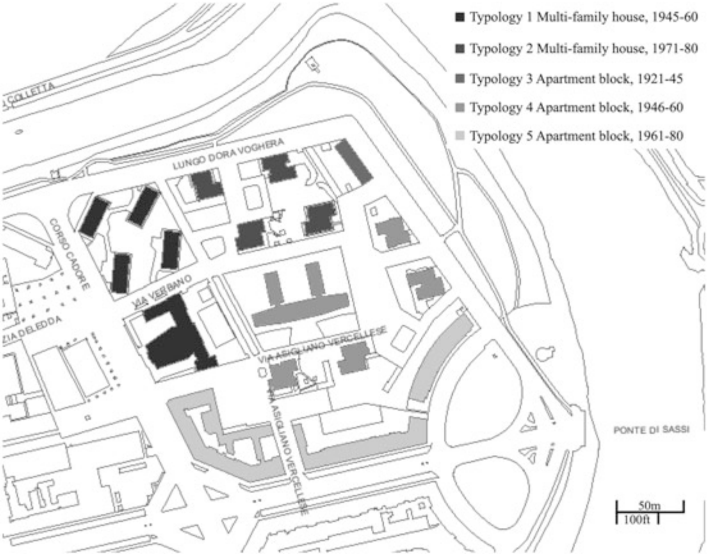


Fig. 10.2 Characterization of the building stock of the case study according to the TABULA database (*Source*: Geoportal of Turin City)

10.3.2 *Presentation of the Alternative Strategies for Energy Requalification*

The energy district retrofit project was launched with the purpose of increasing the quality of life of the residents in the present and future, reducing the cost of energy, improving the thermal, acoustic and indoor comfort of the buildings, promoting a sustainable development of the neighbourhood, and turning the inhabitants proud of living in the district.

The building envelope improvements proposed for reducing energy needs for space heating are measures that decrease the thermal transmittance values and/or increase solar gains through the transparent components during the winter period. As thermal insulation for the opaque walls it was opted for an external composite system; this choice was considered to be the best option for pre-existent buildings refurbishment since it reduces the thermal bridges. While for transparent components, replacement of glasses or windows with better thermal transmittance values was proposed. Two levels of building envelope retrofit were considered (according to the limits prescribed by D.G.R. n.46-11968 of the Piedmont Region [26]): a "standard" retrofit, applying measures that are commonly used on the market; an "advanced" refurbishment, applying measures that reflect the best available technologies.

The energy needs for space heating related to these two retrofit levels were extrapolated from TABULA database (Tables 10.2 and 10.3), as the need for

Table 10.2 Energy need for space heating of reference typologies and of the buildings with envelope "standard" measures and relative energy savings

	Existing building typologies					Standard retrofit typologies				
	1	2	3	4	5	1	2	3	4	5
$Q_{H,nd}$ [kWh/m^{2}y]	170	153	162	157	134	36.3	35.7	35	33	33.4
Saving						78.6 %	76.7 %	78.4 %	78.9 %	75.1 %

Table 10.3 Energy need for space heating of reference typologies and of the buildings with envelope "advanced" measures and relative energy savings

	Existing building typologies					Advanced retrofit typologies				
	1	2	3	4	5	1	2	3	4	5
$Q_{H,nd}$ [kWh/m^{2}y]	170	153	162	157	134	29.3	27.5	27.9	26.2	25.8
Saving						82.8 %	81.9 %	82.8 %	83.3 %	80.7 %

Table 10.4 Definition of the energy retrofit alternative strategies for the NZED

		Envelope EEMs	
		Standard	Advanced
Generation EEMs	District Heating and DHW—Biomass Oil Circuit Recloser cogeneration system—Biomass thermal system—Photovoltaic system	Strategy 1	Strategy 2
	District Heating and DHW—Gas turbine cogeneration system—Gas thermal system—Photovoltaic system	Strategy 3	Strategy 4

domestic hot water (DHW) production (16.9÷ 18.2 kWh/m^2). As regards to Energy Efficiency Measures (EEMs) related to system components, all the considered strategies assume district heating as solution coupled to the cogeneration, in order to cover a large part of the electrical needs, but with different energy carrier (biomass and natural gas) and with different generation efficiencies. Moreover, photovoltaic panels were installed on the building roof for all retrofit configurations; in detail, for strategies 1 and 2 the system is characterized by 290 kW$_{peak}$ and for strategies 3 and 4 by 348 kW$_{peak}$.

The combination of these two criteria (referred to the envelope and to the system) allowed the creation of four different strategies, as shown in Table 10.4.

10.3.3 Definition and Evaluation of the Criteria

For the definition of the family of criteria to be included in the analysis, requirements coming from the legislative framework in the context of energy performance of buildings (first of all, the European Directive 31/2010) were considered. Moreover, the International Energy Agency [27] helps to understand the multiple relationships that exist between a project of energy efficiency and not only the traditional measures for reduced energy demand and GHG emissions considered in cost-optimal approach [23], but also other aspects. Other selected impacts were identified and evaluated in quantitative or qualitative terms through a literature review about nZEB and NZED projects.

The different criteria included in the present application are described in the following subsections.

10.3.3.1 Energy Performance

Energy savings represent a direct benefit resulting from increased energy efficiency. The energy performances of the retrofit strategies for the district were quantified in terms of consumption data. Thanks to primary conversion factors, different for each energy carrier, the energy uses could be split up into non-renewable (fossil) and renewable primary energy. To assess energy performances, it was decided to compare the annual non-renewable primary energy (expressed in kWh), for each strategy, calculated according to the quasi-steady state method described in the Italian Standard UNI/TS 11300 [38, 39]. It is a simplified monthly method based on a balance of all thermal losses and gains determined in quasi-steady conditions. The dynamic effects that directly influence the building performance are taken into account: the external climatic variability is the first among these parameters (e.g., air temperature and solar radiation), by average monthly value; secondly, the indoor environment variables (e.g., occupation, internal heat sources). Moreover, in the calculation of the overall thermal balance, this method includes the heat storage effect of the building mass through a utilization factor.

10.3.3.2 CO_2 Emissions

Energy efficiency has an important role, acknowledged at national and European level, with regard to the reduction of GHG emissions, in line with international commitments to tackle climate change. For the environmental impact, CO_2 equivalent emissions were quantified from the consumption data (non-renewable primary energy) throughout the life-cycle. Thanks to CO_2 emission factors given by the Italian Standard UNI/TS 11300 [38] for each energy carrier, the produced CO_2 ($kgCO_2$/kWh) was calculated by the following formula:

$$M_{del,lCO_2} = Q_{del,l} \times k_{em,l}$$

where M_{del,lCO_2} is the CO_2 amount of energy carrier, $Q_{del,l}$ is the specific production of energy carrier, $k_{em,l}$ is the corresponding CO_2 emission factor (Table 10.5). This value was calculated for each energy carrier and retrofit strategy.

Table 10.5 CO_2 emission factors (UNI/TS 11300)

Energy carrier	$k_{em,l}$ [kgCO_2/kWh]
Natural gas	0.1998
Biomass	0.0000
Electricity	0.4330

10.3.3.3 Global Cost

The variation in economic costs was calculated comparing the existing district with the alternative strategies, with the methodology of global cost according to the European Standard EN 15459-2007 [5]. It permits to consider the sum of several costs which arise during the whole life-cycle of the building:

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) \times R_d(i) \right) - V_f, \tau(j) \right]$$

where $C_g(\tau)$ represents the global cost referred to starting year τ_0, C_I is the initial investment cost, $C_{a,i}(j)$ is the annual cost for component j at the year i (including running costs and periodic or replacement costs), $R_d(i)$ is the discount factor for year i, $V_{f,\tau}(j)$ is the final value of component j at the end of the calculation period (referred to the starting year τ_0).

The first step was the calculation of the initial investment costs of each measure, thank to an analytic estimation. Operating in specific local context, the price-list of the Piedmont Region [34] for envelope measure of buildings was chosen as reference. Instead, for energy measures at district scale and for urban infrastructure (as the distribution network) the Department of Energy of Politecnico di Milano [32] price-list and Moras [31] research were taken into account.

The second step was the calculation of running costs that permit to evaluate the energy consumption costs (electricity and natural gas) during the life-cycle of the buildings. The energy prices refer to the actual values defined by the AEEG [1] (Italian Authority for electricity and gas) for electricity and natural gas, and by Politecnico di Milano [32] for biomass.

For strategies 1 and 2 which include biomass as energy carrier, it was necessary to take into account also the disposal cost. The production of ash was set equal to 1 % of the mass of wood chips consumed. According to literature data, costs due to business disposal amount to 100€/t_{ash}.

Finally, the maintenance costs, including repair and service costs, were calculated as a percentage of the initial investment cost of every building component, according to EN 15459:2007 [18]. For the district system the reference was made to the price-list developed by Politecnico di Milano, which proposed the maintenance cost for cogeneration (€/each) and photovoltaic system (€/$kW_{peak\ installed}$).

As soon as every single cost incidence was established, the global cost calculation was estimated for every design strategy.

10.3.3.4 Indoor Comfort

Energy efficiency measures aim to improve the energy performances of buildings that could also determine an increase of indoor comfort, and so an improvement of physical conditions and air quality, raising occupants' satisfaction level. For this case study, it was assumed that all envelope (opaque and transparent components) retrofit strategies guarantee an increment of indoor comfort. In particular, it was considered a different comfort level linked to the two levels of building envelope retrofit. Indeed, using a less efficient designed building envelope causes higher consumption besides relinquishing thermal comfort, in different climate conditions. Bearing in mind this assumption, an ordinal scale was introduced for the evaluation of the alternative strategies with reference to this criterion, presuming a "good" comfort level for a "standard" retrofit, and a "very good" level for an "advanced" retrofit.

10.3.3.5 Energy Surplus Production

A sufficient integration of renewable sources plays a strategic role for homeowners. The electricity self-production could reduce annual electricity bills of owners, achieving energy self-sufficiency and selling to the grid the surplus energy generated that is beyond the immediate needs. To measure this benefit, the renewable electric energy produced in surplus by cogeneration and photovoltaic was calculated for each strategy. To register the surplus energy delivered to the utility, it was necessary to compare the consumed kWh to energy produced amount, in order to obtain the electrical output that is not being used.

10.3.3.6 Green Jobs

Creating new jobs and fighting unemployment are nowadays increasingly considered as a positive externality. EEMs investments have positive macroeconomic impacts in terms of additional economic growth and employment creation and offer the opportunity of goods and services production according to the green economy market. The new jobs created by building retrofit were estimated by the research developed by Janssen and Staniaszek [28]. Taking into consideration 35 case studies in EU and USA, this study quantifies the net new jobs referring to 1 Mln invested for different energy efficiency measures, considering the amount of lost jobs in other sectors in a given period (Table 10.6).

Table 10.6 New jobs created by EMMs

Energy efficiency measure	New jobs created jobs/1Mln€ invested
Envelope system	19
Biomass system	11.90
Natural gas system	11.24
Photovoltaic system	8.11

The net new jobs number was calculated considering the investment and management costs of envelope and system energy efficiency measures, in order to take into account the new jobs created in all life-cycle of every building in the district.

10.3.3.7 Real Estate Market Value

The EEMs have positive effects in terms of real estate valorisation and respond to the current green economy demands [19, 33]. This benefit was calculated by the hedonic price approach, as proposed by [12], in order to consider the immediate added value by energy efficiency measures. According to this method, the real estate price can be considered as a set of attributes, able to influence its value. Therefore, it is possible to value the individual characteristics of an estate by looking at how people are willing to pay for it when the characteristics change. The hedonic pricing method is most often used to value environmental amenities that affect the price of residential properties. In the present application, a simplified version of the hedonic pricing model was applied for estimating the benefits of energy requalification operations in terms of increase in real estate market value. At first a market analysis was carried out on around 160 real estate listing sites located in the microzone considered in this case study, and the prices and features of the properties were tabulated. Some important buildings features (e.g., surface, floor, apartment condition, location and Energy Performance Certificate [EPC]) were selected and inserted into multiple regression function. Thanks to it, it was possible to assess the relationship between the dependent variable (price) and one or more independent variables (building attributes) and to estimate the willingness to pay for different EPC levels, isolating its coefficient. From the calculations done for the case under examination, the EPC value is equal to €9,600 per considered apartment. The benefit general value was calculated multiplying the EPC coefficient value for the number of buildings energy class changes multiplied for the estimated number of apartments in the area under investigation.

Table 10.7 Input parameters of impact matrix

Criteria	Non-renewable energy	CO_2 emissions	Global cost	Indoor comfort	Energy surplus production	Green Jobs	Asset value
Minimum/maximum	Minimise	Minimise	Minimise	Maximise	Maximise	Maximise	Maximise
Preference Function	Linear	Linear	V-Shape	Level	V-shape	U-Shape	V-shape
Indifference threshold	10	5	n/a	0.5	n/a	1	n/a
Preference threshold	50	10	€50	1.5	20	n/a	€2,000
Unit	MWh/y	t/y	€/m^2	5-point	MWh/y	No.	€
Strategy 1	96	183	997	Average	447	221	18,325,967
Strategy 2	99	184	1199	Very good	287	277	19,885,341
Strategy 3	9058	1962	834	Average	123	196	18,325,967
Strategy 4	7852	1749	1040	Very good	96	260	18,864,184

10.3.3.8 Construction of the Performance Matrix

According to the PROMETHEE methodology, once the impacts are estimated, it is necessary to assign a set of parameters for them, selecting the maximising or minimising ranking sense, and a preference function with related thresholds of the criteria (Table 10.7). With specific reference to the definition of the preference functions, for the qualitative criterion "Indoor comfort" the "Level function" was used, which allows to modulate the preference degree according to the deviation between evaluation levels. In this case, the indifference threshold (noted q) was assumed equal to 0.5 and the preference function (p) equal to 1.5. For the quantitative criteria "Non renewable energy" and "CO_2 emissions", the "Linear function" was identified, which permits to introduce preference and indifference thresholds. In this case, the chosen thresholds were $q = 10$ MWh/y and $p = 50$ MWh/y for "Non renewable energy" and $q = 5$ t/y and $p = 10$ t/y for "CO_2 emissions". For the "Green jobs" criterion, the "usual function" was used; this function corresponds to a standard optimization where the larger the value the better the situation. Finally, for the criteria "Global cost", "Energy surplus production" and "Asset value" we used a "V-shape function" that is suitable for dealing with quantitative criteria for which small deviations have to be taken into account. For this function the indifference threshold is zero while the preference threshold is 50€, 20 MWh/y and 2,000€, respectively. Mention has to be made to the fact that the typology of preference function and the levels of the thresholds have been decides by an experts panel led by the project team.

10.3.4 Weighting

Since the selected criteria do not have the same importance, the weight evaluation for each criterion also influences the result. The application of the methodology included personal interviews with experts in different fields. For the assessment of the criteria weight four scientists were selected as experts, according to their competence and working experience in the energetic, economic and socio-environmental fields, in order to capture different points of view about energy retrofit projects. According to the revised Simos procedure [24], the interviews were carried out through the set of cards methodology that allows setting the criteria weights and determining their priority, according to experts' preferences. The technique used to collect data consists of the following four steps:

- A set of cards was given to each expert; one card for each considered criterion. The name of each criterion is written on each card together with other descriptive details. These cards should exhibit no number what-so-ever in order not to induce the answers. A set of white cards with the same size was also given to the experts. The number of the latter will depend on the user's needs.
- Each expert was asked to rank these cards from the least important to the most important. According to the user's point of view, if some criteria have the same weight, he should build a subset of cards holding them together with a clip or a rubber band. This provided to obtain a complete pre-order on the whole of the n criteria.
- The next step is to ask the user to think about the fact that the importance of two successive criteria in the ranking can be more or less close. So, he could introduce white cards between two successive cards to determine different weights.
- The last step of the revised Simos procedure consists in collecting information from the user with reference to the ratio between the most important criterion and the least most important one in the ranking ("z" value).

The software SRF[1] [24] was used to determine the normalized criterion weight for each expert. The weights value obtained for different specialists are shown on the axes of radar charts displayed in Fig. 10.3. As it is possible to see from the figure, the expert in energy efficiency emphasised energy criteria giving the highest weights to reduce energy consumption and ecological impacts. The expert in occupants' behaviour highlighted the importance of indoor comfort and the energy savings. The expert in built environment gave importance to ecological criteria, such as the emissions and energy reduction. The last expert is the economic evaluator, which gave preference to economic criterion as the increase of asset value.

[1]The software SRF, developed at the LAMSADE (University Paris Dauphine), was used to determine the weights of criteria.

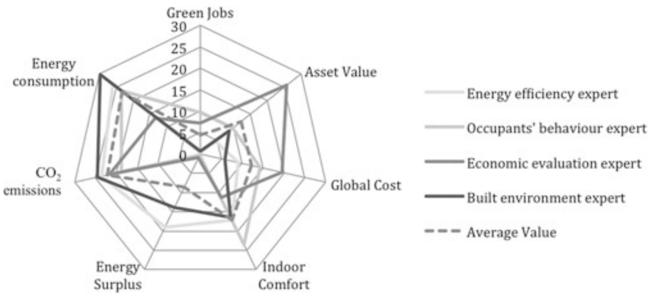


Fig. 10.3 Sets of weights resulting from the different experts (*Source*: SRF data reworked in Microsoft Office Excel)

Fig. 10.4 Global ranking resulting from the PROMETHEE application

10.3.5 Aggregation

The PROMETHEE results aggregation[2] (Fig. 10.4) indicated that strategy 1 and strategy 2, characterized by biomass energy carrier, were generally preferred over the alternatives with fossil fuel carrier by all experts, highlighting the interest for

[2]The Visual PROMETHEE 1.4 software was used for aggregating the various criteria and various experts' evaluations.

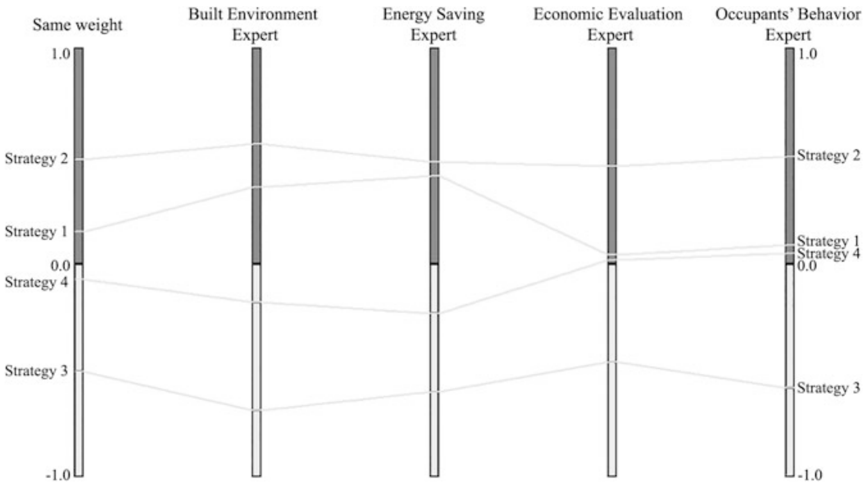


Fig. 10.5 Ranking comparison for the different expert

environmental impacts. Strategy 2, thanks to its higher comfort level, achieves a higher satisfaction compare to strategy 1. Moreover, an advanced level of envelope retrofit resulted in a consuming fewer energy sources and then in greater money savings.

On the other hand, strategy 3 turned out to be the one with the worse performance according to all experts.

Figure 10.5 shows the final ranking of the alternative strategies with reference to the sets of weights of the different experts. As it is possible to see, the ranking is preserved in all the cases and strategy 2 is confirmed as the best performing option for the NZED.

10.4 Discussion of the Results

Another tool used in this research is GAIA[3] (Geometrical Analysis for Interactive Aid) that provides valuable information in addition to the PROMETHEE ranking. The GAIA method offers a two-dimensions representation of the multidimensional

[3]GAIA plan is a complementary tool of Visual PROMETHEE 1.4 software to visualize the multicriteria problem.

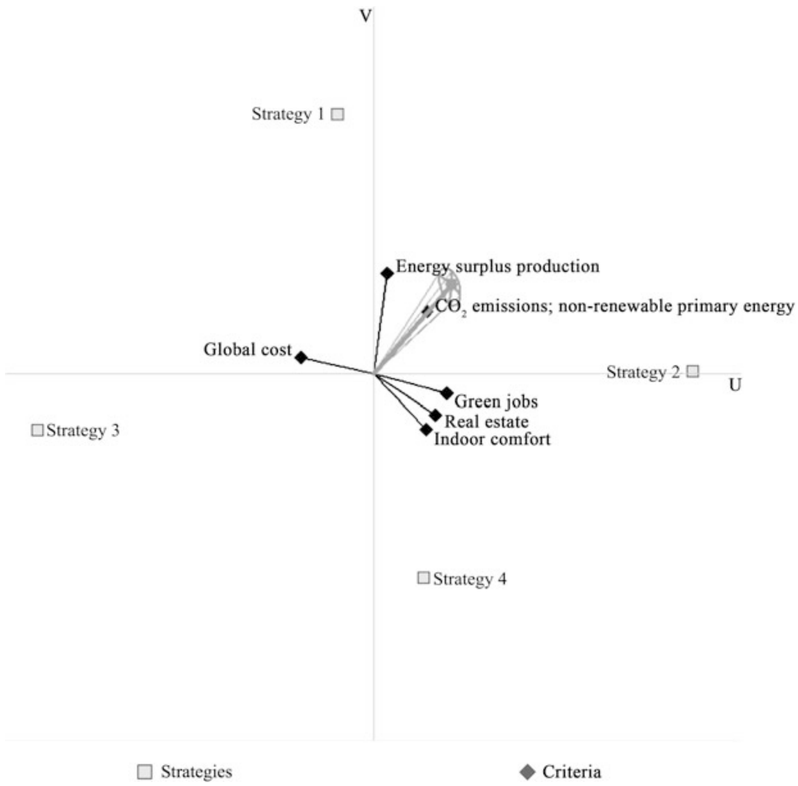


Fig. 10.6 GAIA plane for energy efficiency expert

problem, allowing a deeper understanding of the issues under examination. In the GAIA plane, each criterion is represented by an axis drawn from the center of the plane. The orientation of the axes indicates how closely the criteria are related to each other. Alternatives are represented by points on the same plane.

As an example, Figs. 10.6 and 10.7 illustrate the GAIA planes according to the preferences expressed by the experts in energy efficiency and built environment, respectively. From Figs. 10.6 and 10.7 it is possible to notice that the axes related to energy consumption and CO_2 emissions are oriented in the same direction. In addition, the figures highlight that indoor comfort is divergent compared to the global cost, according to a proportionately relationship among the criteria. This

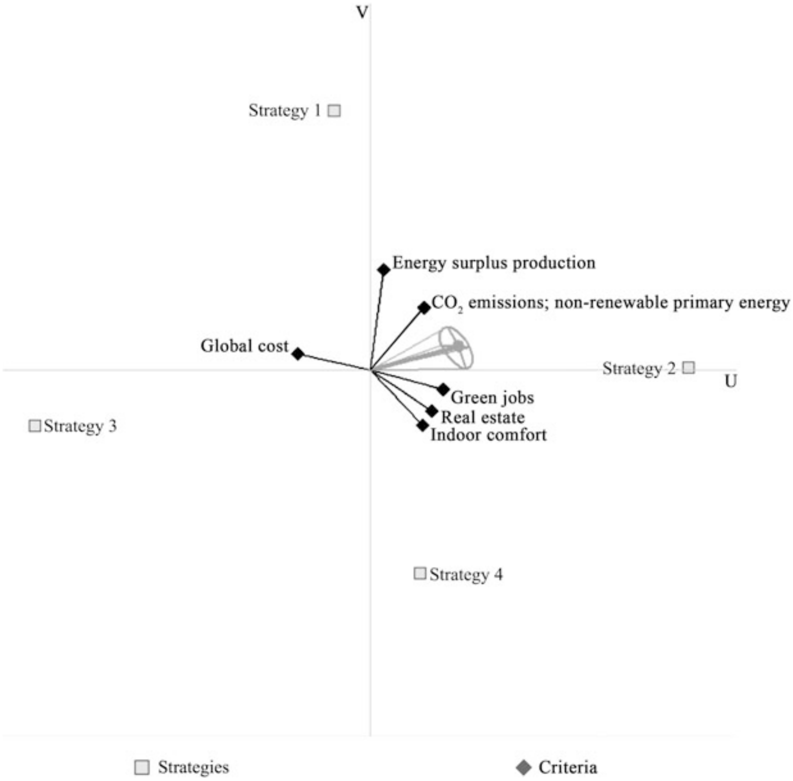


Fig. 10.7 GAIA plane for built environment expert

means that a greater global cost is reflected in a higher comfort level, guaranteed by high investment cost due to envelope efficiency measures. The grey axis is the decision one, which represents the aggregation of the alternatives performances according to the set of weights of the different experts. The decision axis directions indicate which criteria are in agreement with the PROMETHEE rankings and which are not for each expert point of view.

Moreover, through the GAIA plane it is possible to observe the results of the model with reference to the different points of view of experts (i.e. decision scenarios, where are displayed the different preferences). As shown in Fig. 10.8, the experts focused their attention on criteria in two different ways. Occupants' behaviour and economic evaluation experts are very close to each other and prefer strategy 2. On the other hand, energy efficiency and built environment experts prefer strategy 1. In general, there is no very strong divergence as all the preference axes are oriented to the right.

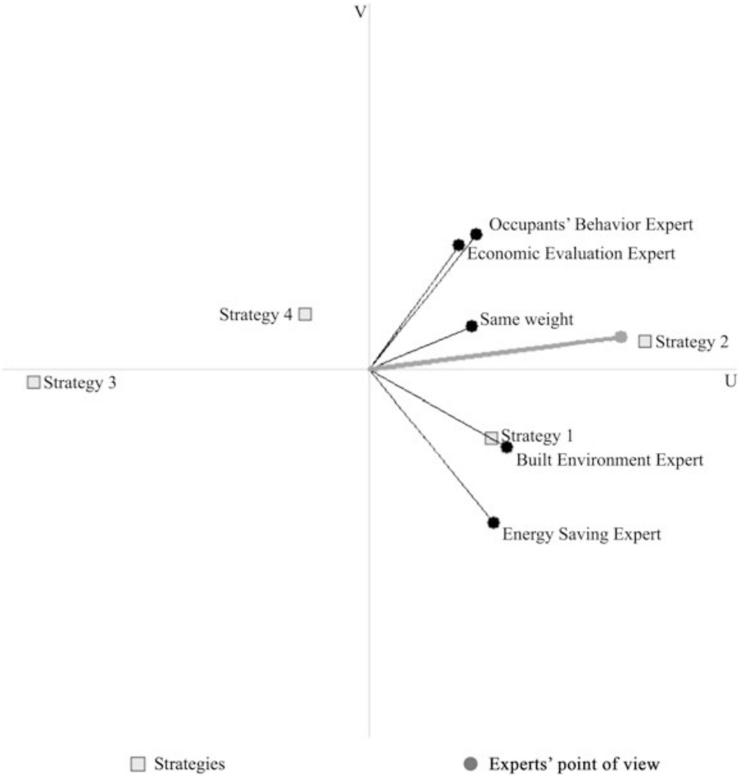


Fig. 10.8 GAIA plan for the considered decision scenarios

10.5 Conclusions

Many studies recognized co-impacts from projects related to green energy different from the effects that commonly are considered. The main challenge of this research was to provide methodological guidance for the identification and valuation of co-impacts, and their analysis through a multi criteria approach to support decision-making, in order to identify the best alternative. In particular, the multicriteria PROMETHEE method was applied to a district energy retrofit case study, located in Turin. The MCDA results showed that the most convenient strategy in socio-economic and environmental terms is the second one, characterized by an advanced level of envelope retrofit, and by EMM system fuelled by biomass. From this study it is possible to highlight that, despite a higher investment cost, these design choices can greatly reduce the impact on environment and CO_2 emission, thanks to the use of renewable sources to meet the heating and electricity demand, in line with the European decarbonisation objective. Another reason that favoured this strategy is the benefit of new jobs created by retrofit interventions, a major number of workers employed compared to strategies with fossil fuels and a high comfort level thanks to advanced envelope retrofit.

The results show the advantages of using the PROMETHEE method for this particular problem. In particular the PROMETHEE II complete ranking allows to overcome the problem of the incomparability between actions. This is a very important strength of the method because it provides the DM with a clear ranking that is useful to base the final decision. In addition, GAIA plane allows a global view of the problem, which can lead to constructive discussions between the specialists and the decision-maker.

It is worth noting that another emerging approach in decision problems in the context of energy requalification operations is the theory of the Cost Benefit Analysis (CBA) [22]. As it is well known, CBA is an evaluation technique for assessing infrastructural investments and it is based on monetisation and inter-temporal discount. Money is the common measure used as unit to reduce all costs and benefits associated to an investment. For the specific case under investigation, the retrofit strategies were also valued through CBA [6]. While the monetization of direct costs, as the cost of energy, is trivial, the non-market goods are difficult to be quantified. The first ones are translated into the common numeracy through the willingness to pay or by deriving prices from substitute markets (hedonic prices method). The second ones are translated into their opportunity cost and by looking at the direct effect only (for example shadow price of labour cost) [10]. Therefore, CBA is more complex to apply compared to MCDA, due to the difficulties in identifying and quantifying the main costs and benefits and translating them into monetary value. Referring to this case study, the results of CBA are aligned with those coming from the MCDA application, although CBA highlighted that the strategy most suitable was the first one, with the same system EMMs of the second strategy, but characterized by a standard envelope retrofit. It is interesting to notice that originating from a different methodological background, both approaches succeed in broadening the evaluation perspective and aggregate in a single indicator the overall performance of each alternative strategy [21].

As a future development of the present study, it would be interesting to investigate the problem from the point of view of the private real estate operators that could be involved in the energy requalification operations. In this sense, particular attention should be devoted to the use of multicriteria decision systems for financial problems [43] that could provide information about the viability of the operation for individual or institutional investors.

Extra work could also be devoted to the exploration of other MCDA methods in combination with the cost-optimal analysis, with specific attention to the examination of the interactions between evaluation criteria [11, 13] and to the use of multiple criteria hierarchy models [20].

Finally, given the spatial nature of the decision problem under consideration, further improvements of the work will refer to the integration of the PROMETHEE model with Geographic Information Systems in order to develop a Multicriteria Spatial Decision Support System [29].

To this end, it is possible to conclude that the use of PROMETHEE seems to be a very promising line of research for supporting decision-making processes in the context of energy retrofit operations and urban transformation projects.

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