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Decision Support System for Project Monitoring Portfolio

Diploma Thesis for the degree computer engineering

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Preface

This thesis is the result of a diploma project at the Decision Support Systems laboratory at the National and Technical University of Athens (NTUA). The work has been carried out from March 2010 to July 2010.

The topic of this thesis is *decision support system* for *project monitoring portfolio*. The two concepts were italicised to emphasise some essential delimitations of the thesis.

- *'Decision support system'* means a system which is developed in order to provide a satisfactory solution in a decision problem. Usually, like occurs in the problem that this thesis is focused on, decision problems are characterized by multiple conflicting criteria that must be taken into consideration. These specific decision problems are called multi-criteria decision problems.

- *'Project monitoring portfolio'* means that the focus of this thesis will be on the planning of a large number of projects, funded by the European Commission, in order to decide which ones of the whole set of projects are the most appropriate to monitor.

The thesis is focused on supporting the Decision Support Systems laboratory in order to solve the multi-criteria decision problem provided to them by the European Commission. As the Commission provides to the DSS's laboratory a set of projects in order to monitor the most appropriate ones, the goal of this thesis is to support the DSS's laboratory by selecting those projects that are considered the most important ones to be monitored.

When reading the thesis, it is important to realize that this work and the accompanying modellisation of a multi-criteria decision analysis (MCDA) have been carried out by a student of computer engineering, and not by experts in decision analysis.

This thesis is divided in two main parts. First, this thesis focuses in the study of the different MCDA methods that have been published in the last years by different expert authors in the decision analysis. The purpose here is to determine which one, from all the different MCDA methods, is the methodology that will fit better to the decision problem that this thesis faces. In order to carry out this task, several MCDA methods belonging to different MCDA methodology families will be exposed, by explaining their main features and analysing their procedures. After this, a comparison between all the methods will be made according to the methodology families these methods belong to, and also between the methods belonging to the same family. Once the comparison between the methods has been analysed, the proper method for the decision problem that this thesis wants to solve will be selected.

In the second part of this thesis, once the method is selected, the modellisation of the problem according to the chosen method will be carried out. The needed parameters for the method in order to allow it to provide the solution for the described problem will be calculated.

Finally, some suggestions for further research will be described in the thesis, as well as the discussion of some conclusions that have been reached during the elaboration of this thesis.

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Definitions and Abbreviations

MCDA: Multi-Criteria Decision Analysis. The use of methods that support people make decisions according to their preferences in the cases characterized by multiple conflicting criteria. See Section 2.2 for more details.

Decision-maker (DM): The person or entity that is responsible of making a decision. The DM can be an individual, a small and homogeneous group with common goals, a big group that represents the different elements of an organisation, or a number of groups of very diverse interests.

Stakeholder: Everybody who has a legitimate interest on the system, or "those ones who have the right to impose requisites on a solution". An alternative definition is those ones who "have demonstrated their need or willingness to participate in the searching of a solution". See Section 1.7 for more details.

Analyst: The person who models the studied situation, helps the DM to reach a satisfactory decision, and formulates recommendations for the final election. The analysts must not express their personal preferences, but must facilitate the obtaining of the DM's preferences, which should be dealt as objectively as possible.

Alternative. Projects, candidates and investment plans, among which a choice has to be made. The term is often used for actions that exclude between them in terms of execution. There can either be a finite number of explicitly defined discrete alternatives or implicitly defined continuous alternatives.

Optimal alternative: An alternative that results in the maximum performance value for each of the objective functions simultaneously. An ideal alternative will quite rarely be found in the real-world.

Dominance: If – in a pairwise comparison of two alternatives – an alternative A scores higher than alternative B on at least one criterion and does not score lower on any of the other criteria, then A dominates B, while B is dominated by A.

Objective: An objective is a statement of something that somebody wants to get and is characterized by a decision context, an object and a direction of preference.

Criterion: A tool constructed for the evaluation and comparison of alternatives and the degree to which they achieve objectives. Criteria offer integral and measurable representations of the DM's preferences.

Quantitative criterion: A criterion that can be measured on a clear, concrete defined scale.

Qualitative criterion: A criterion for which evaluations cannot be made on a numerical basis. Instead, a verbal scale or an ordinal ranking can be used.

Attribute: A quantitative measure of performance, used to evaluate directly or indirectly the degree to which the objectives are achieved. A good attribute both defines precisely what the associated objective means and serves as a scale to describe the consequences of the alternative.

Criteria weight: Assessment of the relative importance of a given criterion. The weight of a criterion can reflect both the range of difference of the options and how much that difference matters.

Table of Contents

1. Description of the problem

The European Union is the biggest provider of development aid in the world. The European Commission is a donor of Official Development Assistance (ODA). ODA is a statistic compiled since 1969 by the Development Assistant Committee of the Organisation for Economic Co-operation and Development to measure aid. In 2008, the EC provided €9.2 billion for ODA to over 160 countries.

The responsibility for the delivery of aid and for ensuring its quality lies with EuropeAid, the EC's office for the management of external aid operations.

1.1 The EuropeAid program

EuropeAid is an external cooperation program of the European Commission whose goal is to provide quick and effective help where it is most needed. This program carries on a detailed analysis and consultations before giving funds to development actions. EuropeAid enforces strict controls in order to guarantee that the millions of euros committed each year are used efficiently and responsibly. Actions are evaluated and monitored to ensure that they satisfy the high quality standards.

EuropeAid is very careful in order to guarantee that the help that is provided for the development is of high quality. The Project Cycle Management identifies five stages (Programming, Identification, Formulation, Implementation, and Evaluation & Audit) of a project's life cycle. Quality support groups carry on revisions of the external help measures provided by EuropeAid during the identification and formulation stages of the project's life cycle.

The European Commission has also strict processes in order to monitor and to evaluate development projects. The Results-Oriented Monitoring (ROM) system helps EuropeAid to evaluate the generated results of projects and programs.

Due to the large number of projects that the European Commission funds, the EuropeAid program needs to contract external organisations or groups in order to help them to realise strict and detailed analysis of the ongoing projects. One of these members is the National and Technical University of Athens (NTUA), specifically the Decision Support Systems laboratory.

Not all the members contracted by the European Commission are authorised to analyse the same projects. The EC splits the whole set of projects into lots and assigns each one of them to the appropriate contracted member, according to the member's staff and qualifications, the projects' importance in terms of budget and social and economic impact of each one.

For a detailed evaluation of the entire lifetime of the projects, the tool used by the EC is the ROM system. The ROM system is a systematic methodology that provides standards and methods in order to carry out the monitoring process of the projects and also establish the reports that must be provided by the responsible party for this evaluation. Therefore, EuropeAid, in order to guarantee a high quality in the evaluation process of the projects, it must provide all the information about the ROM system to the contract groups.

1.2 The ROM system

1.2.1 What is the ROM system?

As mentioned above, the ROM system is the tool used by the European Commission, through the EuropeAid program, in order to carry out effective evaluations and monitoring of the ongoing projects that receive financial support by the EC.

The ROM system was created in 2000, in response to the recommendation of the Council of the European Union (EU) in May 1999, whose objective was to make the monitoring, and evaluation process more effective and transparent, in order to better the community's assistance to their development.

After the initial conception in 2000, and after some tests, the ROM system was launched in January 2002, but this system was applied to just a few of the countries and regions it currently does. Since the introduction of the ROM system in a couple of small regions, ROM was completed for 2003 and then its use was expanded to its current state. Thus, the ROM system has become in the last few years the main tool of the European Commission in the process of the evaluation and analysis of the development of projects (Clauss & Hall, 2009).

1.2.2 Why is the ROM system important?

The Results-Oriented Monitoring (ROM) system is a very useful tool for day-to-day project management tool for providing information to the project's stakeholders. The project manager can inform the stakeholders about the level of performance of the project and let them know if the development of the project is progressing according to plan. Also, the ROM system includes the ability to provide feedback to the project managers as well, informing them about recommendations on how to improve their projects, if deemed necessary.

Moreover, the ROM system is also a useful tool for the European Commission, especially for the EuropeAid's policy making about the implementations and reviews of projects. All the data collected in the monitoring process of ROM are collected in EuropeAid's Common RELEX Information System (CRIS) database. More than 10.000 monitoring reports are included in this database. All the information allocated there is available to all the members contracted by the EC in order to get the necessary data for the efficient evaluation and monitoring of projects. Furthermore, this information is also useful for the EC, as these data provide an overview of the performance of its aid portfolio.

In addition, ROM also provides benefits at the level of programming and learning. Quantitative and qualitative studies based on ROM data contribute lessons learned and best practices to the programming and planning of new projects (Clauss & Hall, 2009).

1.2.3 The ROM system in practice

The ROM system is executed by the external organisations (in this case the Decision Support Systems laboratory of the National and Technical University of Athens), contracted by the European Commission, that are responsible for the monitoring of the projects in different geographical zones.

ROM monitors carry out onsite visits to projects and programmes in all countries, reviews of the most important documents of the project and, interviews with the main stakeholders, which are the beneficiaries of the project. Based on empirical data, they produce and deliver objective, impartial and concise reports.

1.3 Monitoring

The ROM system, as its name says, is a kind of monitoring system. This means that its task is to perform regular reviews in order to keep track of the progress of a project in terms of use of resources, execution, delivery of results and risk management. Monitoring is the systematic and continuous collection of data, analysis and use of management information in order to provide decision support especially at the level of operational management.

Monitoring often focuses only on inputs, activities and outputs. This means that the monitoring process evaluates the results obtained according to the outputs of the project and also, informs about how these outputs came to be according to the inputs and the activities that took place. However, the ROM system also focuses on the results (which are the benefits obtained from these outputs) and on the impact (contribution of the project to the solution of a problem).

Therefore, the European Commission expects that the organisations contracted by them (included the National and Technical University of Athens) will carry out the tasks of monitoring of the projects provided to each one of them.

1.4 Which projects should be monitored?

The Decision Support Systems laboratory, as mentioned above is a contracted member of the European Commission with the task to carry out the ROM process for a number of projects funded by the Commission.

The laboratory is provided with a list of projects to be monitored from EuropeAid. This list isn't limited to one thematic area or geographical region, unless the contract refers to a specific one.

The EC expects that the DSS laboratory will select a group of projects to monitor due to the high financial and human resources' cost that would be inflicted if all projects were to be monitored. The selection of the projects that will be monitored is a central organizational task for the laboratory, which is carried out using both qualitative and quantitative criteria.

1.5 Available input parameters

In order to decide which projects will be monitored it will be necessary to make use of all the information available for the projects. This information can be found in the CRIS database, which contains all the information related to all the projects funded by the European Commission. Information collected in this database can be accessed only by people authorised by the EC. The DSS laboratory, as a member organization contracted by the European Commission, has access to the CRIS database.

For each project there are 63 attributes that contains information on various aspects. The problem is that not all these attributes are given for all the projects, so for some projects this information has to be excluded from the decision process. Moreover, not all of these attributes are represented in the same data types. Therefore, there are attributes whose value is just a name (sometimes one name selected from a list of defaults) and other attributes whose value is just a date or even a number.

The list of all the attributes that are available for each project is shown in the Table 1.

1. Domain	2. Step number
3. Contract	4. Planned amount
5. Former system reference	6. Paid
7. Contract	8. Balance
9. Status	10. Payment currency
11. Title	12. Decision No
13. Delegation	14. Commitment type
15. Entity	16. Commitment ID
17. Contract type	18. Budget line
19. Nature	20. DAC Code
21. Sub-nature	22. Sector code
23. Type of services	24. Budget Management Type
25. Contractor's signature date	26. Legal justification
27. Expiry date	28. Payment class
29. EC signature date	30. Serial number
31. Closing date	32. Value date
33. Implementation starting date	34. Workflow type
35. Contracting party	36. Status
37. Payment currency	38. Mailing Entity Ref.
39. Geographical zone	40. Mailing Entity Ref.
41. Person in charge	42. Negotiated Procedure Type
43. DG	44. Signature refusal
45. Nationality	46. Action location
47. Call reference	48. Publication allowed
49. Procedure	50. Reason to restrict the publication
51. Negotiated procedure type	52. Final date for implementation (FDI)
53. Legal Entity (LEF)	54. Contractual currency
55. Geographical zone (LEF)	56. Specific payment currency
57. Bank Account Ref (BAF)	58. Previous amount in contractual currency
59. Report deadline	60. Paid amount in contractual currency
61. Document type	62. Balance amount in contractual currency
63. Received?	

Table 1: Set of the provided criteria

1.6 Required outputs

The result that must be provided in the solution of this problem is the collection of all of these projects, the ones that the Commission provided to the DSS laboratory, separated into three different groups:

1) Projects that should be monitored
2) Projects that should be considered for monitoring
3) Projects that are not recommended for monitoring

The separation of the projects into these groups must be done according to the importance of each one of the projects. Thus, the most important projects should be collected in the first group. The projects that are considered the less important should go to the third one. Finally, the second group will collect those projects whose level of importance is not so clear.

Separation of all the projects into these groups must be made in order to help the decision maker about choosing the projects on which the ROM system must be applied. However, some degree of freedom must be provided to the decision maker about the selection of the project to be monitored. This is the reason for which the second group must also be considered.

1.7 Stakeholder Analysis

In a monitoring investment-planning project, there will be many stakeholders. There are many ways to define a stakeholder. For example, stakeholders can be defined like "everybody that has a just interest in the system", "those who have a right to impose requirements on a solution", or those that "have demonstrated their need or willingness to be involved in seeking a solution" (Sproles, 2000). It is essential that all parts are interested in the beginnings of the decision process. This makes to be more probable their disposition to cooperate, as they know that decision has not been made yet. (Keeney, 1988).

It is common that several actors are directly involved in the planning process. However, in most of the planning problems, there are also many actors that have not been invited to take a direct roll in the decision process, but who would like to participate, because the decisions can affect to their own welfare or to the global stability of the environment (Diakoulaki, Antunes, & Martins, 2005). These actors can be called decision receivers, and it is essential to include some goals in the analysis process for these stakeholders. If it is not possible to involve all the interested ones personally, it could still be advantageous for the decision process asking somebody to play the position roll of the key stakeholders, ensuring in this way that their perspectives won't be ignored (Dodgson, Spackman, Pearman, & Phillips, 2001).

As the projects that are desired to be monitored can be destined to any kind of sector (education, sanitation, nutrition, etc.), the stakeholders that are involved in this problem are quite diverse. However, in the following lines, the most important stakeholders in monitoring-planning problems will be presented.

1.7.1 The European Commission and Internal Stakeholders

The most important beneficiary in a monitoring-planning problem provided by the European Commission is, obviously, this very organisation which desires to carry out a monitoring tasks among the projects that the EC funds. However, this organisation cannot be considered as a homogeneous group. Inside the EC, there are groups that not necessary share the same functions, for example, the leadership, the managers and the employees of the commission. Together, these groups are constituted as the internal stakeholders in the EC.

The EC's leadership will make decisions according to the strategies, plans and budget limits of the commission. For the managers, the most essential goal is usually to get the maximum benefits according to the tasks on which they are assigned to. The EC, as a part of the European Union carries out a large number of projects. The monitoring-planning of projects is just one of the big amounts of tasks realized by the EC. The proper managers are the ones that try to get as much benefits as possible for the monitoring-planning project, while the leaderships try to get the maximum benefit from the whole set of tasks carried out by the EC. The employees, on the other hand, desire the commission to make decisions which will protect their jobs and/or provide them interesting and challenging responsibilities and professional development. Consequently, is important for the EC to care about the wills and values of the employees, although it is possible that there are many different opinions between employees about how diverse actions will affect to the criteria. The employees are not the less value asset in an organisation, but the most valuable one (Bogetoft & Pruzan, 1997).

It is also fundamentally to take into account that in the EuropeAid program, the program funded by the EC and hence, which belongs to it, may have numerous divisions and subsidiaries that work in different sectors. Different divisions don't need to agree about the main goals of the organisation, and it is essential the DMs to be conscious about such a powerful differences.

Finally, as the funds that the EC and, hence, the European Union receive are from all the countries that constitute the EU, the set of these countries can be also considered stakeholders. Also, as the funds that each member country of the EU come from their population, the whole population among these country can be also considered stakeholders, because the economic resources that will be spend by the EC come from each country and, then, from the budgets of each person that lives in a member country of the EU.

1.7.2 Development companies

The main development companies are those ones which are involved in the realization of the projects funded by the EC (through the EuropeAid program). Development companies are often important interested parts in the monitoring-planning process because the monitoring of the projects that these companies carry out will de done (or not) according to the decisions made by the DSS's laboratory. Moreover, these companies are in contact with the EC, and in many cases evaluations made to their development process can be a useful tool for them to know how can them to improve their development process. Different development companies, obviously, have different criteria, but probably the objectives of a development company include the ending on time of the project that they carry out, without exceeding the funds invested by the EC.

1.7.3 The end-users/customers

The end-users of the monitoring-planning process are the customers of the different projects funded by the EC and which are provided to the DSS's laboratory in order to monitor the appropriate ones. The end-users are key actors in the system, because they will be the customers of the services delivered through the EuropeAid program. However, customers are in some measure neglected in the development projects process, because they usually don't know when the investment decisions are carried out. In some measure, it would be useful to include the opinions of the customers in the decision analysis by contacting the associations or groups related to each one of the projects that is wanted to carry out. However, as the task carried out by the DSS's laboratory is provided by the EC, this commission is which should care about the customer's opinions.

Also it can be necessary to distinguish between users and owners of the companies that will carry out the different projects. Users are the persons that will get any benefit in the implementation of each project. Owners of the companies can be the organisations or companies that will be selected by the EC through the EuropeAid program in order to develop the projects for which the EC makes investments on them. Therefore, the owners and leaderships of these organisations are also stakeholders in the monitoring-planning process.

Different end-users groups have not necessary the same interests or the same influence power for the important decisions. For example, the benefits of the end-users are not the same as the owner of the companies. End-users only will get the benefits related to the purposes on which different projects are focused on. On the other hand, the owners of companies will try to maximize the economical benefits of developing of the projects that they were assigned to implement by the EC.

1.7.4 Other companies

Many other companies will also be affected by the investment decisions carried out by the EC. Even the task developed by the DSS's laboratory is just to choose the set of projects that are better to monitor, this decision will make the EC to monitor and to analyze the selected projects. Because it has been proved that this monitoring of projects can help managers to get a better performance on them, it can be said that this decision will affect the develop process of several projects.

As mentioned above, companies selected by the EC to carry out specific projects are important stakeholders. However, these companies or organisations may also hire the services of another companies or organisations to realize specific tasks of the proper project. These new companies are also considered to be stakeholders of this monitoring-planning process. Nevertheless, these companies are unlikely to be between the main stakeholders.

Moreover, there will be also many rival companies that will try to be selected by the EC to develop each one of the different projects. However, they cannot be considered as stakeholders, because –obviously- the decisions of an organisation must not be based on the goals of other companies.

1.7.5 Third party

Third parties can include different kind of groups, like public in general, press, diverse non-governmental organisations (environmental, trade, etc.), and future generation. Some of these groups could be important actors for some projects. Public opinion will be important in many cases; the opinions of potential customers are especially important. This includes persons who live in areas specially affected by the decided projects. If some projects are developed with a bad reputation, some companies could refuse to carry on other projects. Also it will be essential to establish good communication with the people of the affected are. Maybe it will be difficult to carry out major projects if the affected people are against their development.

2. Bibliographical Review

A detailed analysis of the theoretical fundaments of different MCDA (Multi Criteria Decision Analysis) methods and its strengths and weaknesses is presented in (Belton & Stewart, 2002). MCDA methods use a decision matrix in order to provide a systematic focus on analysis to the integration of the risk and uncertainty levels and also allow the evaluation and classification of many alternatives. MCDA overcomes the limitations of the less structured methods like the comparative risk assessment (CRA), which suffers in the unclear way that combines performance over criteria. See (Bridges, 2005) to get more information about CRA. Inside of these resources, almost all the methodologies share similar measures of organization and resolution of the construction matrix, but each methodology synthesizes information in a different way (Yoe, 2002). Different methods require different types of valuable information and to follow different optimization algorithms. Some of them need techniques rank options, some need to identify a single optimal alternative, some provide an incomplete ranking, and others need to differentiate between acceptable and unacceptable alternatives.

Elementary MCDA methods can be used to reduce complex problems to simple problems for the selection of the appropriate alternative. However, these methods not always keep in mind the relative importance of the criteria and they combine the criteria to produce a total score for each alternative. Elemental methods are simple and can, in many cases, be executed without the help of computer programs. These methods are the most appropriates for the problems with an only one decision maker with a few alternatives or criteria, a condition that rarely appear on real projects.

Multi-Attribute Utility Theory (MAUT), the Multi-Attribute Value Theory (MAVT), and the Analytic Hierarchy Process (AHP) are more complex methods that use optimization algorithms, but avoid the complexity of the optimization by giving a dominance approach. Optimization approaches employ numerical results to establish the score of each option in a single scale. Scores are developed from the realization of alternatives with respect to individual criteria and aggregated into a global score. Individual scores can be just summed or averaged, or a weighting mechanism can be used to favour some criteria more heavily than others. The goal of MAUT is to find a simple expression to the global benefits of a decision. Through the use of the utility or value functions, the MAUT method converts diverse criteria in a utility common scale. MAUT is based in the supposition that the decision taking is rational (by preferring more utility than less utility; for example), that the decision-maker has a perfect knowledge and that the decision-maker is coherent in his judges. The goal of the decision-makers in this process is to maximize its utility or value. Due to the fact that the punctuations poor in criteria can be compensated with high calcifications in other criteria, MAUT is part of the MCDA techniques group known as "compensatory" methods.

Like the MAUT, AHP (Saaty, 1994) aggregates various facets of the decision problem with an only optimization function known as the objective function. The goal of AHP is to select an alternative with the highest value of the objective function. Like MAUT, AHP is focused on the compensation optimization. However, AHP uses a quantitative method of comparison based on pair comparisons of the criteria decision, instead of utility and weighting functions. All the individual criteria must be linked against all of the rest and the results written in matrix form. For example, examining the alternatives of the selection of non-lethal weapons, the AHP method would demand the decision-maker to be able to answer questions like: "With respect to the selection of an alternative of weapons, what is more important, efficiency or reduction of undesired effects (for example, health impacts)?" User makes use of a numerical scale to compare the options and the AHP method moves in a systematic way through all the pair-by-pair comparisons of criteria and alternatives. The AHP technique then is based on the supposition that all the human beings are able to do statements of absolute judges. Therefore, the rational postulation is more relaxed in AHP than in MAUT.

In difference of MAUT and AHP, outranking is based on the principle that an alternative can have a degree of dominance over other one (Kangas, Kangas, & Pykalainen, 2001). Dominance is produced when the behaviour of an option is better than another one in, at least, one criterion and is not worse than the other in all the criteria (ODPM 2004). However, outranking techniques don't presuppose that just one better alternative can be found. Outranking models by two (or more) alternatives simultaneously, initially in terms of each criterion, to identify the degree on which a preference for one over other can be asserted. Outranking techniques then aggregate the information preference techniques through all the appropriate criteria and tries to establish the strength of the selection tests favouring one alternative over other one. For example, an outranking technique can suppose to favour the alternative which is better in the more number of criteria. Then, outranking techniques let a lower performance on some criteria to be compensated for by superior performance on others. However, they do not necessary take into account the magnitude of relative underperformance in a criterion versus the magnitude of over-performance in another criterion. Therefore, outranking models are known as “partially compensatory”. Outranking techniques are more appropriated when the metrics of the criteria are not easy to be aggregated, the measurements scales vary over wide ranges and units are incommensurate or incomparable (Seager, 2004).

2.1 Decision Support Systems

Because of there are a lot of approaches about the decision taking and due to the big amount of areas on which decisions are taken, the concept of the **decision support systems** (DSS) is very wide. A **DSS** can take many different ways. In general, it can be said that a DSS is a computer system used to give support, more than to automate, the decision making process. The decision is a choice between alternatives based on estimations of the values of these alternatives. The support to a decision means to help the persons that work alone or in groups to gather intelligence, to generate alternatives and to take decisions. Supporting the decision making process implies the support of the estimation, the evaluation and/or the comparison between alternatives. In practice, references to DSS are usually references to computer applications that realize a support function.

2.1.1 Definitions

The *decision support systems* term has been used in very different ways and has been defined in different ways attending to the point of view of the author. Some of these definitions are:

- A DSS, in very general terms, is “a computer system that helps in the decision making process” (Finlay, 1994).
- In much more specific terms, a DSS is “an information system based on an interactive, flexible and adaptable computer, specially developed to support the solution of a management and non-structured problem in order to improve the decision making. Use data, provides a friendly interface and allows the decision making in the proper analysis of the situation” (Turban, 1995).

Other intermediate definitions between these two previous ones would be:

- A DSS is a “set of procedures based on models in order to process data and judges to support a management in his decision making” (Little, 1970).
- A DSS “combines intellectual individual resources with the capabilities of a computer to improve the quality of decisions (are an computer

support for the decision makers about semi-structured problems)" (Keen, 1978).

- "Extensible system able to give *ad-hoc* support for the data analysis and the modeling of systems, oriented to the future planning and used in non-regular intervals, not planned" (Moore & Chang, 1980).
- The DSS are "Interactive computer systems that help the decision makers by using data and models in order to solve non-structured problems" (Sprague & Carlson, 1982).
- **Keen** assets that is impossible to give a precise definition that includes all the features of the DSS because "it cannot be a definition of the *decision support systems*, just about the *support to the decision*" (Keen P. G., 1980).
- For **Power** the DSS term can refer to many types of information systems that give support to the decision making. Humorously adds that always that a computer system doesn't be a 'system to the on-line transaction process' (OLTP), somebody will have the temptation to call it **DSS** (Power, 1997).

As it can be seen there is no universally accepted definition of what a DSS is.

2.1.2 Brief history

By Keen (Keen P. , 1978), the **decision support** concept has evolved from two main areas of research: the theoretical studies of organization in the decision making, made in the Carnegie Institute of Technology in the end of the 1050's and beginning of the 1960's, and the technical work about the interactive computer systems, mainly carried out in the Technologic Institute of Massachusetts in the decade of the 1960's. It is considered that the DSS concept was converted into a research space in the middle of the decade of the 1970's; before taking intensity during the 1980's. In the middle and end of the 1980's, the executive information systems (EIS), the group decision support systems (GDSS) and the organizational decision support systems (ODSS) evolved from the individual user and the DSS oriented models. Since 1990 approximately, the data storages and the on-line analytic process (OLAP) started to wide the ambit of the DSS's. Like in the change of millennium, new based on web analytic applications were introduced.

It is evident that the DSS's belong to an environment with multidisciplinary basis, including (but not exclusively) the research in database, artificial intelligence, human-machine interaction, simulation methods, software engineering and telecommunications. The DSS's also have a weak connection with the paradigm of hypertext user interface. Both the PROMIS system (for medical decision making) at the University of Vermont, as the system ZOG / KMS (for military decision-making and business) at Carnegie Mellon were two systems of decision support that constituted great advances in user interface research. Moreover, although the hypertext researches, in general, have entered the information overload, some researchers, notably Douglas Engelbart, have focused on decision making in particular.

2.1.3 Function and features

The DSS's are very useful tools in Business Intelligence (Business Intelligence); allow the analysis of different variables to support business decision making process of managers:

- It can extract and manipulate information in a flexible manner.
- Help unstructured decisions.
- Allows the user to interactively define information needs and how to combine.
- It usually includes simulation tools, modelling, etc.
- It can combine information from transactional systems inside the company with another foreign company.

Its main feature is the capability of the multidimensional analysis (OLAP) that allows in-depth information to reach a high level of detail, analyzing data from different perspectives, make projections of information in order to predict what should happening in the future, trend analysis, prospective analysis, etc.

A **DSS** supports people who have to make decisions at any level of management, whether individuals or groups, semi-structured situations and in informal, through the combination of human judgment and objective information:

- Supports multiple interdependent or sequential decisions.
- Offers assistance in all phases of decision-making process-intelligence, design, selection, and implementation, as well as a variety of processes and decision-making styles.
- It is adaptable by the user at the time to deal with changing conditions.

- Generates learning, resulting in new demands and refinement of the application, which in turn results in further learning.
- Generally uses quantitative models (standard or custom made).
- DSS are equipped with an advanced knowledge management component that enables effective and efficient solution of complex problems.
- Can be implemented for use in web or desktop environments on mobile devices (PDA).
- Allows easy implementation of sensitivity analysis.

2.1.4 Taxonomies

As with the definition, there is no universally accepted taxonomy for DSS. Different authors propose different classifications. Using the relationship with the user as a criterion, Haettenschwiler (Haettenschwiler, 1999) distinguishes between:

- **Passive DSS**: Is a support system for decision-making process, but can not carry out decision suggestions or solutions.
- **Active DSS**: Can bring out such decision suggestions or solutions.
- **Cooperative DSS**: Allows the charge of making decisions (or their advisers), alter, expand or improve decision suggestions provided by the system before shipping back to the system for validation. The new system improves, complete and accurate the suggestions of the decision maker and sends them back to her for validation. Then, the whole process begins again, until it generates a consolidated solution.

Using the method of assistance as a criterion, Power (Power D. J., 2002) distinguishes between:

- **Model-driven DSS's:** Emphasis is placed on the access and manipulation of a statistical model, financial, optimization or simulation. Use data and parameters provided by users to assist decision makers in the analysis of a situation, which are not necessary intensive data. Dicodess is an example of a DSS based on open source models. (Gachet, 2004)
- **Communication-driven DSS's:** They have support for multiple people working on the same shared task.

- **Data-driven DSS's:** Also called data-oriented, emphasize access and manipulation of time series of internal company data and sometimes also external data.
- **Documents-driven DSS's:** Manage, retrieve and manipulate unstructured information in a variety of electronic formats.
- **Knowledge-driven DSS's:** They provide experience in the form of facts, rules, procedures, or similar structures specialized for solving problems (Power D. J., 2002)

2.1.5 Architectures

Again, different authors identify different components of a DSS. Sprague and Carlson, (Sprague & Carlson, 1982) identify three basic components which are explained in more detail by Haag and others (Haag, Cummings, McCubbrey, Pinsonneault, & Donovan, 2000):

- **The management system of the data base**: Stores information from various sources, may come from data repositories of a traditional organization, from external sources (such as Internet), or staff (of ideas and experiences of individual users).
- **The model management system**: It deals with representations of events, facts or situations by using various types of models (two examples are models of search optimization and target models).
- **The management system and the dialogs generator**: It consists on a user interface; is, of course, the component that allows to a user to interact with the system.

For Power (Power D. J., 2002) a DSS has four basic components:

- The user's interface.
- The data base.
- The analytic and modelling tools.
- The DSS's architecture and net.

Hättenschwiler (Haettenschwiler, 1999) identifies five components in a DSS:

- **Users:** With different roles or functions in the decision making process (decision maker, consultants, domain experts, system experts, data collectors).
- **Decision context**: Must be specific and definable.

- **Target system**: This describes most of the preferences.
- **Knowledge basis**: Composed of external data sources, knowledge databases, working databases, data warehouses and meta-databases, mathematical models and methods, procedures, inference and search engines, administrative programs, and systems reports.
- **Work environment**: For the preparation, analysis and documentation of decision alternatives.

Marakas (Marakas, 1999) proposes a general architecture consisting of five distinct parts:

- The management data system.
- The management models system.
- The engine of knowledge.
- The user interface.
- The users.

2.1.6 Development environments

The DSS systems are not totally different from other systems and require a structured approach. Sprague and Watson (Sprague & Watson, 1993) provided an environment of three main levels:

1- **Technology levels**: Is proposed a division in 3 hardware and software levels for DSSs:
   a. Specific DSS: Real application that will be used by the user. This is the part of the application that allows the decisions making in a concrete problem. User will be able to act over this concrete problem.
   b. DSS generator: This level contains environmental hardware and software that allows to persons be able to develop easily DSS specific applications. This level uses case tools. Also includes special programming languages, functions libraries and linked schedules.
   c. DSS’s tools: Contains low level hardware and software.

2- **People involved**: For the DSS's development cycle, 5 types of users are suggested:
   a. Final user
   b. Intermediary
   c. Developer
   d. Technical support
   e. Systems expert

3- **The development approach**: The approach based on the development of a DSS should be very iterative. That will allow the application to be changed and redesigned at different intervals. The initial problem is used to design the system and then it is tested and revised to ensure that it achieves the desired result.

2.2 Description of the Multi-Criteria Decision Support Systems

Nowadays, there exist several mathematical tools appropriate in order to support the decision makings with multiple criteria.

In the multi-criteria decision making the **attribute** term makes refer to the features that describe each one of the alternatives available in a decision situation. This concept refers to values related to an objective reality.

However, **criteria** constitute attributes, objective or goals that are considered relevant for a certain decision problem. In a general point of view, (Zeleny, 1982) defines criteria as measures, rules and standards that lead the decision. Therefore, the multi-criteria decision theory constitutes a general frame or decisional paradigm on which different attributes, objectives or goals underlie.

Several authors have described, in a general way, a multi-criteria decision problem, highlighting the different parts and phases of it. Between these authors are (Zeleny, 1982), (Chankong & Haimes, 1983) and (Goicoechea, Hansen, Duckstein, & Goicochea, 1982), which have constituted an obligated reference source in the elaboration of the algorithm for the steps of the multiple criteria decision problem.

The discrete multi-criteria methods suit to the problems on which the number of alternatives that must be considered by the decision centre is finite and normally not very elevated. Practical interest of the discrete multi-criteria problems (multi-attribute) is evident. In effect, there are so many decisional contexts on which a reduced number of alternatives and possible choices must be evaluated based on various attributes or criteria.

In order to take decisions is important to realize a set of actions that allow deciding acceptably between the possible choices. First of all, it must be determined the necessity of a decision that is generated by a problem or gap between a desire and the real condition of the moment. After, it will be required to identify the decision criteria and to assign weight to these criteria in order to give priority to the most important ones in the decision. Then, it must be developed all alternatives or possible solutions to the problem and, if it's not possible, to know all the ways that can be taken in order to solve the problem. The more alternatives are available, the more probably to find a satisfactory one. Evaluating each one of the alternatives would be the other action in this process. This means, to realise a detailed study of each one of the possible solutions in an individual way respect on the decision criteria. There exist tools, in order to evaluate different alternatives. Finally, must be selected the best alternative (decision making): When the best alternative is selected the decision making process has arrived to the end of the process. From this, is necessary to implement the decision in order to evaluate if the decision was or not successful and to evaluate the results.

2.2.1 Multi-Objective Decision Making (MODM) and Multi-Attribute Decision Making (MADM)

Multi-Criteria Decision Making (MCDM) is one of the most common methods of decision making. MCDM is divided into multi-objective decision making (MODM) and multi-attribute decision making (MADM) according to many authors (Zimmermann, 1996). Nevertheless, usually MADM and MCDM are used to refer the same class of models.

The MODM studies decision problems where the decision space is continuous. The typical examples are mathematical problems with several objective functions. Kuhn and Tucker (Kuhn & Tucker, 1951) wrote the first reference to this problem, also known as "vector-maximum" problem. However, MCDM/MADM concentrates on problems with discrete decision spaces. Problems with discrete decision spaces are the ones on which the set of alternatives has been predetermined.

In spite of MCDM methods can be really diverse, most of them have some common aspects. These are the notions of alternatives and attributes (that can also be called goals or decision criteria) as described below.

2.2.1.1 Alternatives

Usually they represent the different options of action that are available to the decision maker. Often, set of alternatives is assumed to be finite, ranging from several to hundreds. They are supposed to be screened, sorted and, sometimes, also ranked.

2.2.1.2 Multiple Attributes

The MCDM problems are associated with many attributes. The attributes are also referred as “goals” or “decision criteria”, because are the criteria on which the decision must be taken. They represent the different dimensions which the alternatives can have information on.

In the cases on which the number of criteria is large (i.e. more than a dozen), criteria may be collected in a hierarchical way. That means, some criteria may be major ones. In this case, each major criterion should be associated with several sub-criteria. Then, each sub-criterion should be associated with several sub-sub-criteria and so on.

2.2.1.3 Conflict among Criteria

Because different criteria represent different dimensions of alternatives, they can conflict with others. For example, cost can conflict with benefits etc.

2.2.1.4 Incommensurable Units

Often, different criteria are associated with different units of measure. For example, in the case of calculate the profit of a company, the criteria “costs” and “benefits” can be measured in different units; in this case, dollar and euros for example.

2.2.1.5 Decision Weights

Many of the MCDM methods require assigning weights of importance to the criteria. This is because not all the available criteria provide the same information, so one criterion can be much more important than another one(s) in terms to decide which alternative must be taken.

2.2.1.6 Decision Matrix

Any MCDM problem can be expressed in a matrix format. The decision matrix **A** is an (m x n) matrix in which element a_{ij} indicates the performance of alternative A_i when is evaluated in terms of decision criterion $\mathbf{C}_j$ (for $i = 1, 2, 3, ..., m$, and $j = 1, 2, 3, ..., n$). It is also assumed that the decision maker has determinate the weights of relative performance of the decision criteria (denoted as w_j, for $j = 1, 2, 3, ..., n$). This information is best explained in the definition given by Zimmermann (Zimmermann, 1996). But there, instead of the term "criteria", the author uses the term "goals".

Let A = {A_i, for i = 1, 2, 3, ..., n} be a (finite) set of decision alternatives and G = {g_j, for j = 1, 2, 3, ..., m} a (finite) set of goals according to which the desirability of an action is judged. Determine the optimal alternative A with the highest degree of desirability with respect to all relevant goals g_j.*

		Criteria			
	C_1	C_2	C_3	...	C_n
Alts.	(w_1	w_2	w_3	...	w_n)
A_1	a_{11}	a_{12}	a_{13}	...	a_{1n}
A_2	a_{21}	a_{22}	a_{23}	...	a_{2n}
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
A_m	a_{m1}	a_{m2}	a_{m3}	...	a_{mn}

Figure 1 A Typical decision matrix

2.2.2 Classification of MCDM Methods

There are a lot of MCDM available methods in the literature. Each one of them has its own features. There are a lot of ways to classify MCDM methods. One of them is by classifying them according to the data type they use. This means, that it can be *deterministic*, *stochastic*, or *fuzzy* MCDM methods [for an overview of fuzzy MCDM methods see (Chen & Hwang, 1999)]. The deterministic approach considers that the decision making problem (i.e. the alternatives, criteria, etc.) are perfectly described before applying the decision method. The stochastic (also known as probabilistic) corresponds to a type of modelling in which the criteria are viewed as random variables. Finally, fuzzy methods consider different types of uncertainty and imprecision in some of the elements of the decision making problem. However, there can be situations which involve combinations of all the above (such as stochastic and fuzzy) data types.

Another form to classify the MCDM methods is according to the number of decision makers that are involved in the decision process. Therefore, there exist *single* decision maker MCDM methods and *group* decision makers MCDM methods. In this thesis we will only focus our attention to single decision maker MCDM methods.

In conclusion, it must be stated that there are a lot of other alternative ways in order to classify MCDM methods (Chen & Hwang, 1999). But, these previous ones are the most common schemes.

2.3 Multi-Criterial Methodologies

According to Evangelos Triantaphyllou (Triantaphyllou, 2001) these are the three steps that must be followed when any decision-making technique involving numerical analysis of alternatives will be utilised:

1) Determine the relevant criteria and alternatives.
2) Attach numerical measures to the relative importance of the criteria and to the impacts of the alternatives on these criteria.
3) Process the numerical values to determine a ranking of each alternative.

This section is only concerned with the way the WSM, WPM, AHP, ANP, PROMETHEE, ELECTREE and MURAME methods process the numerical data in step 3. The central decision problem examined in this thesis is described as follows. Given a set of m alternatives denoted as $A_1, A_2, A_3, \ldots, A_m$ and a set of n decision criteria denoted as $C_1, C_2, C_3, \ldots, C_n$ it is assumed that the decision maker has determined (the absolute or relative) performance value a_{ij} (for $I = 1, 2, 3, \ldots, m$ and $j = 1, 2, 3, \ldots, n$) of each alternative in terms of each criterion. This is, the decision maker has determined the matrix **A** with the a_{ij} values, along with the criteria weights w_j. In this section a number of procedures for determining these data are discussed.

Therefore, given the a_{ij} and w_j values, then the problem examined in this section is how one can rank the alternatives according to the all the decision criteria. Next, several MCDM methods for solving the above problem (the indicated in the step 3 above) are presented.

2.3.1 The Weighted Sum Model (WSM) method

2.3.1.1 Explanation of the WSM method

According to Evangelos Triantaphyllou (Triantaphyllou, 2001), the weighted sum model (WSM) is probably the most commonly used approach, especially in single dimensional problems. If there are m alternatives and n criteria then, the best alternative is the one that satisfies (in the maximization case) the following expression:

$$A^{*}_{WSM-score} = max_i \sum_{j-1}^{n} a_{ij} w_j \, , for \; i = 1, 2, 3, \ldots, m$$

where: $A^{*}_{WSM\text{-}score}$ is the WSM score of the best alternative, n is the number of decision criteria, a_{ij} is the actual value of the *i-th* alternative in terms of the *j-th* criterion, and w_j is the weight of importance of the *j-th* criterion.

The assumption that governs this model is the **additive utility assumption**. That is, the total value of each alternative is equal to the sum of the products given in the equation of the above. In single-dimensional cases, where all the units are the same (e.g., dollars, feet, seconds), the WSM can be used without difficulty. Difficulty with this method emerges when it is applied to multi-dimensional MCDM problems. Then, in combining different dimensions, and consequently different units, the additive utility assumption is violated and the result is equivalent to *"adding apples and oranges"*.

2.3.1.2 Applying the WSM Method

Suppose that an MCDM problem involves four criteria, *which are expressed in exactly the same unit*, and three alternatives. The relative weights of the four criteria were determined to be: w_1 = 0.20, w_2 = 0.15, w_3 = 0.40 and w_4 = 0.25. Also, the performance values of the three alternatives in terms of the four decision criteria are assumed to be as follows:

$$A = \begin{bmatrix} 25 & 20 & 15 & 30 \\ 10 & 30 & 20 & 30 \\ 30 & 10 & 30 & 10 \end{bmatrix}$$

Therefore, the data for this MCDM problem are summarized in the following decision matrix:

	Criteria			
	C_1	C_2	C_3	C_4
Alts.	(0.20	0.15	0.40	0.25)
A_1	25	20	15	30
A_2	10	30	20	30
A_3	30	10	30	10

Figure 2 Decision Matrix obtained from the previous data

When the formula is applied on the previous data the scores of the three alternatives are:

$$A_{1,\ WSM\text{-}score} = 25\text{x}0.20 + 20\text{x}0.15 + 15\text{x}0.40 + 30\text{x}0.25 = 21.50.$$

Similarly, we get:

$$A_{2,\ WSM\text{-}score} = 22.00,$$

and $\quad A_{3,\ WSM\text{-}score} = 20.00.$

Therefore, the best alternative (in the maximization case) is alternative A_2 (because it has the highest WSM score; 22.00). Moreover, the following ranking is derived: $A_2 > A_1 > A_3$ (where the symbol ">" stands for *"better than"*).

2.3.2 The Weighted Product Model (WPM) method

2.3.2.1 Explanation of the WPM method

According to Evangelos Triantaphyllou (Triantaphyllou, 2001), the weighted product model (WPM) is very similar to the WSM. The main difference is that instead of addition in the model there is multiplication. Each alternative is compared by the others by multiplying a number of ratios, one for each criterion. Each ratio is raised to the power equivalent to the relative weight of the corresponding criterion. In general, in order to compare two alternatives A_K and A_L, the following product has to be calculated:

$$R(A_K/A_L) = \prod_{j=1}^{n}(a_{Kj}/a_{Lj})^{w_j}$$

where n is the number of criteria, a_{ij} is the actual value of the *i-th* alternative in terms of the *j-th* criterion, and w_j is the weight of importance of the *j-th* criterion.

If the term $R(A_k / A_L)$ is greater than or equal to one, then it indicates that the alternative A_K is more desirable than alternative A_L (in the maximization case). The best alternative is the one that is better than or at least equal to all other alternatives.

The WPM is sometimes called **dimensionless analysis** because its structure eliminates any units of measure. Thus, the WPM can be used in single- and multi-dimensional MCDM. An advantage of the method is that instead of the actual values it can use relative ones. This is true because:

$$\frac{a_{Kj}}{a_{Lj}} = \frac{a_{Kj}/\sum_{i=1}^{n} a_{Ki}}{a_{Lj}/\sum_{i=1}^{n} a_{Li}} = \frac{a'_{Kj}}{a'_{Lj}}$$

A relative value a'_{Kj} is calculated using the formula:

$$a'_{Kj} = a_{Kj}/\sum_{i=1}^{n} a_{Ki},$$

where the a'_{Kj}'s are the actual values.

2.3.2.2 Applying the WPM Method

Consider the problem presented in the example of the WSM method. However, now the restriction to express all criteria in terms of the same unit is not needed. When the WPM is applied, then the following values are derived:

$R\ (A_1/A_2) = (25/10)^{0.20} \times (20/30)^{0.15} \times (15/20)^{0.40} \times (30/30)^{0.25} =$

$= 1.007 > 1.$

Similarly, we also get:

$R\ (A_1/A_3) = 1.067 > 1,$

and $R\ (A_2/A_3) = 1.059 > 1.$

Therefore, the best alternative is A_1, since it is superior to all the other alternatives. Moreover, the ranking of these alternatives is as follows: $A_1 > A_2 > A_3$.

An alternative approach with the WPM method is for the decision maker to use only products without ratios. That is, to use the following variant of the previous formula:

$$P(A_K) = \prod_{j=1}^{n} (a_{Kj})^{w_j},$$

In this expression the term $P\ (A_K)$ denotes the performance value (not a relative one) of alternative A_K when all the criteria are considered under the WPM model. Then, when the previous data are used, exactly the same ranking is derived.

2.3.3 The AHP (Analytic Hierarchy Process) method

2.3.3.1 Explanation of the AHP method

This method was proposed by Tomas L. Saaty (Saaty T. L., 1980) and is based on the obtaining of preferences or weights of importance to the criteria and alternatives. For that, the decision maker establish "value judgments" through the Saaty's numerical scale (from 1 to 9) by comparing pair-by-pair both the criteria and alternatives.

For the application of this method is necessary that both criteria and alternatives can be structured into a hierarchical way. First level of the hierarchy corresponds to the general purpose of the problem, the second one to the criteria and the third one to the alternatives.

2.3.3.2 Applying the AHP Method

In order to present the AHP method and the way this method works an example of a decision problem solved by the AHP will be given. The example described below (the decision of selection of a route in a highway tram) is also one of the typical real-world decision problems o which MCDA are used to be applied.

Problem of the selection of a route in a highway tram

The decision problem consists in choosing the route of a highway's tram. There exist three routes or possible alternatives that will be denominated A, B, and C, that are evaluated based on three criteria:

A_1: Cost of execution,

A_2: Environmental impact,

A_3: Execution time.

The decision maker considers that the criterion cost is 2 times more important than the environmental impact criterion and 5 times more important that the execution time criterion. Moreover, the environmental impact criterion is 3 times more important than the execution time criterion.

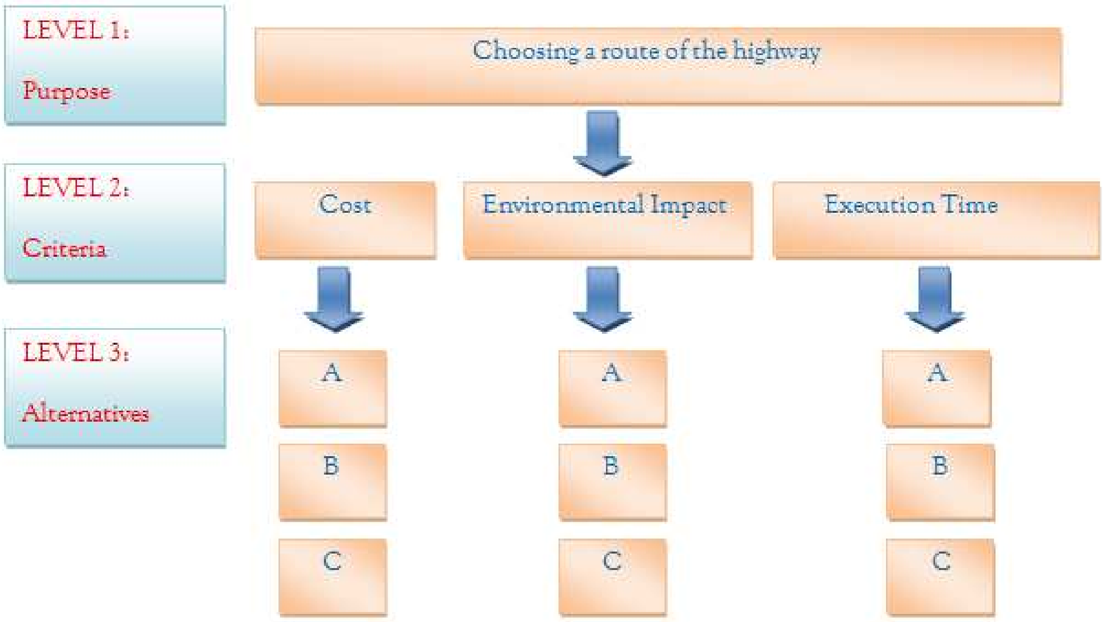

Figure 3 Diagram of the Levels in the AHP method

PAIR-BY-PAIR COMPARISON MATRIX FOR HIERARCHY LEVEL 2:

	Attributes		
Attributes	**A1**	**A2**	**A3**
A1: Cost	1	2	5
A2: Environmental Impact	1/2	1	3
A3: Execution Time	1/5	1/3	1

Then, the values of the weights *Wi* must be calculated:

$$Min\ n1 + p1 + n2 + p2 + n3 + p3$$

$$W1 - 2W2 \qquad + n1 - p1 = 0$$

$$W1 \qquad - 5W3 + n2 - p2 = 0$$

$$W2 - 3W3 + n3 - p3 = 0$$

$$W1 + W2 + W3 = 1$$

Therefore, the relative weights of level 2 are *W* = *(0.588, 0.294, 0.118)*

PAIR-BY-PAIR COMPARISON MATRIX FOR HIERARCHY LEVEL 3:

Cost:

	Alternatives		
	A	**B**	**C**
A	1	6	3
B	1/6	1	½
C	1/3	2	1

Environmental Impact:

	Alternatives		
	A	**B**	**C**
A	1	1/9	1/5
B	9	1	2
C	5	1/2	1

Execution Time:

	Alternatives		
	A	**B**	**C**
A	1	1/2	1/4
B	2	1	1/2
C	4	2	1

Therefore, the relative weights for the level 3 are:

Cost: $W = (0.667, 0.111, 0.222)$

Environmental impact: $W = (0.069, 0.621, 0.31)$

Execution time: $W = (0.143, 0.286, 0.571)$

So, the determination of the global weights is:

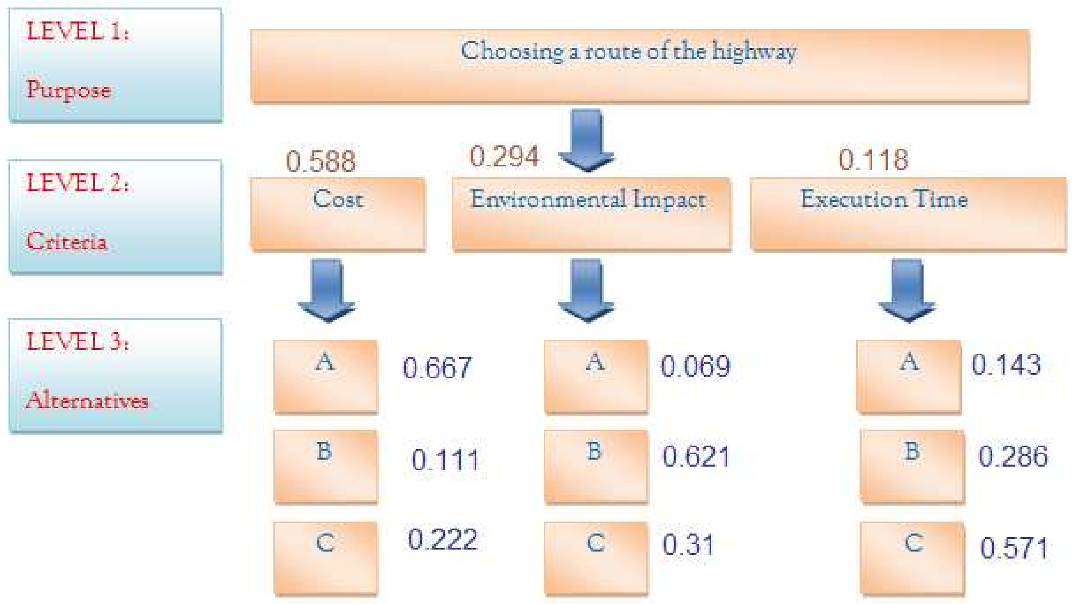

Figure 4 Diagram of the Levels in AHP after calculating the weights

Therefore:

A: 0.667*0.588 + 0.069*0.294 + 0.143*0.118 = 0.429

B: 0.111*0.588 + 0.621*0.294 + 0.286*0.118 = 0.282

C: 0.222*0.588 + 0.31*0.294 + 0.571*0.118 = 0.289

So, the route A of the highway's tram is the best solution

2.3.4 The Analytic Network Process (ANP) method

2.3.4.1 Explanation of the ANP method

The Analytic Network Process (ANP) is a more general way that the Analytic Hierarchy Process (AHP) used in multi-criteria decision analysis.

AHP structures a decision problem in a hierarchy with a goal, the decision criteria and the alternatives, while the ANP structures it like a network. Both then use a system of pairwise comparisons in order to measure the weights of the structure's weights and, finally, to classify the alternatives of the decision.

In the AHP, each element of the hierarchy is considered independent of all of the rest, the decision criteria are considered independents between them, and alternatives are considered independents of the decision criteria and of each other. But in many cases of the real world, there exist interdependence between the items and alternatives. ANP doesn't require the independence among the elements, so it can be used as an efficient tool in these cases.

In order to illustrate this, consider a simple decision about the buying of an automobile. The decision maker desires it, can choose among several sedans of complete size with more moderate prices. Decision maker could choose to base his decision in just three factors: buying price, security and comfort. Both the AHP and ANP provide useful frames to use in the decision making.

The AHP may suppose that the buying price, security and comfort are independents among them, and would evaluate each one of the sedans in a independent way in those criteria.

The ANP will allow the consideration of the interdependence of prices, security and comfort. If one person wants to get more safety or comfort features by paying more for the automobile (or less by paying less), the ANP could take this into account. Similarly, the ANP could allow the decision criteria to be affected by the traits of the cars under consideration. If, for example, all cars are very, very safety, the importance of security as an appropriate decision criterion could be reduced.

Academic articles about the ANP appear on the journals and take care about the decision sciences, and several books have been written about the subject (Saaty T. , 1996) (Saaty T. L., 2005) (Saaty & Vargas, 2006) (Saaty & Cillo, 2009).

There are a big number of practical applications of the ANP, many of them relative to the complex decisions about the benefits (B), opportunities (O), costs (C) and risks (R). The study of these applications can be very useful to understand complexities of the ANP. Literature has hundreds of elaborated process examples, developed by executives, managers, engineers, MBA and Ph.D. students and other persons from many countries. A hundred of those uses are illustrated and discussed in the Encyclicon, a dictionary of the decisions with the dependence and the feedback (Saaty & Cillo, 2009).

Academics and practitioners meet biennially at the International Symposium on the Analytic Hierarchy Process (ISAHP), which, despite its name, devotes considerable attention to the ANP.

2.3.4.2 Applying the ANP Method

Understanding of the ANP is better obtained by using the software of the ANP in order to work with the completed decisions. One of the field normative texts provides the steps that must be followed (Saaty T. L., 2005):

1- Make sure that the decision problem in detail is understood, including its objectives, criteria and sub-criteria, actors and their objectives and the possible outcomes of that decision. Give details of influences that determine how that decision may come out.

2- Determine the control criteria and sub-criteria in the four control hierarchies' one each for the benefits, opportunities, costs and risks of that decision and obtain their priorities from paired comparison matrices. You may use the same control criteria and perhaps sub-criteria for all of the four merits. If a control criterion or sub-criterion has a global priority of 3% or less, you may consider carefully eliminating it from further consideration. The software automatically deals only with those criteria or sub-criteria that have subnets under them. For benefits and opportunities, ask what gives the most benefits or presents the greatest opportunity to influence fulfilment of that control criterion. For costs and risks, ask what incurs the most cost or faces the greatest risk. Sometimes (very rarely), the comparisons are made simply in terms of benefits, opportunities, costs, and risks by aggregating all the criteria of each BOCR into their merit.

3- Determine a complete set of network clusters (components) and their elements that are relevant to each and every control criterion. To better organize the development of the model as well as you can, number and arrange the clusters and their elements in a convenient way (perhaps in a column). Use the identical label to represent the same cluster and the same elements for all the control criteria.

4- For each control criterion or sub criterion, determine the appropriate subset of clusters of the comprehensive set with their elements and connect them according to their outer and inner dependence influences. An arrow is drawn from a cluster to any cluster whose elements influence it.

5- Determine the approach you want to follow in the analysis of each cluster or element, influencing (the suggested approach) other clusters and elements with respect to a criterion, or being influenced by other clusters and elements. The sense (being influenced or influencing) must apply to all the criteria for the four control hierarchies for the entire decision.

6- For each control criterion, construct the super-matrix by laying out the clusters in the order they are numbered and all the elements in each cluster both vertically on the left and horizontally at the top. Enter in the appropriate position the priorities derived from the paired comparisons as sub-columns of the corresponding column of the super-matrix.

7- Perform paired comparisons on the elements within the clusters themselves according to their influence on each element in another cluster they are connected to (outer dependence) or on elements in their own cluster (inner dependence). In making comparisons, you must always have a criterion in mind. Comparisons of elements according to which element influences a third element more and how strongly more than another element it is compared with are made with a control criterion or sub-criterion of the control hierarchy in mind.

8- Perform paired comparisons on the clusters as they influence each cluster to which they are connected with respect to the given control criterion. The derived weights are used to weight the elements of the corresponding column blocks of the super-matrix. Assign a zero when there is no influence. Thus obtain the weighted column stochastic super-matrix.

9- Compute the limit priorities of the stochastic super-matrix according to whether it is irreducible (primitive or imprimitive [cyclic]) or it is reducible with one being a simple or a multiple root and whether the system is cyclic or not. Two kinds of outcomes are possible. In the first, all the columns of the matrix are identical and each gives the relative priorities of the elements from which the priorities of the elements in each cluster are normalized to one. In the second, the limit cycles in blocks and the different limits are summed and averaged and again normalized to one for each cluster. Although the priority vectors are entered in the super-matrix in normalized form, the limit priorities are put in idealized form because the control criteria do not depend on the alternatives.

10- Synthesize the limiting priorities by weighting each idealized limit vector by the weight of its control criterion and adding the resulting vectors for each of the four merits: Benefits (B), Opportunities (O), Costs (C) and Risks (R). There are now four vectors, one for each of the four merits. An answer involving ratio values of the merits is obtained by forming the ratio B_iO_i / C_iR_i for alternative i from each of the four vectors. The synthesized ideals for all the control criteria under each merit may result in an ideal whose priority is less than one for that merit. Only an alternative that is ideal for all the control criteria under a merit receives the value one after synthesis for that merit. The alternative with the largest ratio is chosen for some decisions. Companies and individuals with limited resources often prefer this type of synthesis.

11- Determine strategic criteria and their priorities to rate the top ranked (ideal) alternative for each of the four merits one at a time. Normalize the four ratings thus obtained and use them to calculate the overall synthesis of the four vectors. For each alternative, subtract the sum of the weighted costs and risks from the sum of the weighted benefits and opportunities.

12- Perform sensitivity analysis on the final outcome. Sensitivity analysis is concerned with “what if” kinds of questions to see if the final answer is stable to changes in the inputs, whether judgments or priorities. Of special interest is to see if these changes change the order of the alternatives. How significant the change is can be measured with the Compatibility Index of the original outcome and each new outcome.

2.3.5 The ELECTRE method

2.3.5.1 Explanation of the ELECTRE method

2.3.5.1.1 Brief History

The ELECTRE (Elimination Et Choix Traduisant la REalité) methods belong to multi-attribute methods that deal cardinal information. They have been developed from the LAMSADE of the Paris-Dauphine University (Paris IX) since year 1968, year on which Bernard Roy and his collaborators developed the first ELECTRE method. Since then, uses of ELECTRE methods have been extended all over Europe, as has been proved by the big amount of existent literature about these methods and its applications (Roy, 1985) .

ELECTRE was conceived by Bernard Roy (Roy, 1985) in response to deficiencies of existing decision making solution methods. ELECTRE is more than just a solution method; it is a philosophy of decision aid - the philosophy is discussed at length by Roy (Roy, 1985). However, other versions of this method, like the ELECTRE III (the most popular of them and the most used) have been published by several authors since then. ELECTRE has evolved through a number of versions (I through IV); all are based on the same fundamental concepts but are operationally somewhat different. It is important to note that ELECTRE is not being presented as the "best" decision aid. It is one proven approach. Simpson (Simpson, 1996) has compared both AHP and ELECTRE and she concludes that, "*There are obvious differences between the methods, but it is not obvious that one method is stronger than the other.*"

2.3.5.1.2 ELECTRE's versions

The first important parameter in the election of an ELECTRE method depends on the kind of problematic included in the project:

- For the election of a sub-set with the alternatives “best ones”, or “satisfactory ones” (α problematic) the appropriate methods are ELECTRE I and ELECTRE IS.
- For the distribution of the alternatives in categories predefined by reference alternatives (β problematic) the appropriate method is ELECTRE TRI.

- For the sort of the alternatives (γ problematic) it can be applied the ELECTRE II, ELECTRE III and ELECTRE IV methods.

Moreover, depending on the logic followed in the classification during the development the ELECTRE methods can be divided in two big groups:

- ELECTRE I and ELECTRE II use clear classification (description of the criteria in a classical way)
- ELECTRE III, ELECTRE IV, ELECTRE IS and ELECTRE TRI use logic with blurred classification (pseudo-criteria, quasi-criteria or pre-criteria).

2.3.5.2 Applying the ELECTRE Method

Despite of the existence of several versions of the ELECTRE Method, the funds of all these versions are the same. New versions of ELECTRE just add some improvements, but the common way on which they work is very similar and will be shown in next section with an example studied by (Buchanan & Sheppard, 2001).

2.3.5.2.1. Example of the ELECTRE Method

The example that will be explained in this section will show the way on which all the ELECTRE methods work. In this section will be only consider the common part of all of the different versions of ELECTRE.

A set of some projects is given:

- Project 1
- Project 2
- Project 3
- Project 4
- Project 5

For each project, there are a number of criteria that measure the impact of each alternative or project. The choice of appropriate criteria can be quite an art and is typically far more difficult than identifying alternatives. The five criteria eventually used to evaluate the projects are:

- *Financial* (F)
- *Solution delivery* (SD)
- *Strategic contribution* (SC)
- *Risk management* (RM)
- *Environmental* (E)

These are then combined to produce a score for each project for each criterion. The scores for the last four criteria use a 0-100 scale. The financial criterion (Strategic contribution) uses net present value (NPV). This input, where each alternative is assessed using each criterion, produces a matrix of impacts - referred to as performances. Next table provides an example of such a performance matrix, using a subset of five projects.

	F	SD	SC	RM	E
Project 1	-14	90	0	40	100
Project 2	129	100	0	0	0
Project 3	-10	50	0	10	100
Project 4	44	90	0	5	0
Project 5	-14	100	0	20	40

Figure 5 Performance Matrix

The subjective inputs are provided by the decision makers and relate specifically to the criteria and their relative importance. There are some methods to establish appropriate weight to each one of the criteria, but this subject is not important in this section and will be explained in next sections.

Two important concepts underscore the ELECTRE approach; thresholds and outranking. These will now be discussed. Assume that there exist defined criteria, g_j, j=1, 2… r and a set of alternatives, A. Traditional preference modeling assumes the following three relations hold for two alternatives (a, b) ∈A:

a**P**b (a is preferred to b) | g(a) > g(b)

a**I**b (a is indifferent to b) | g(a) = g(b)

a**J**b (a cannot be compared to b).

However, consider Project1 and Project3 for criterion F with values of -14 and -10 respectively (using data from the table). Does this mean that Project1 is preferred to Project3? Is the small difference of 4 sufficient reasons to make one more preferred than the other? If, for example, you have two cups of tea - one has 10 mg of sugar and the other has 11 mg of sugar - could you tell the difference? Traditional preference modeling says that because the amount of sugar is not equal, then one will be preferred over the other.

In contrast to the traditional approach, ELECTRE introduces the concept of an indifference threshold, q, and the preference relationships are redefined as follows:

a**P**b	(a is preferred to b)	|	$g(a) > g(b) + q$
a**I**b	(a is indifferent to b)	|	$\lvert g(a) - g(b) \rvert \leq q$, and
a**J**b	(a cannot be compared to b) remains.		

The indifference threshold is specified by the decision maker. While the introduction of this threshold goes some way toward incorporating how a decision maker actually does feel about realistic comparisons, a problem remains. There is a point at which the decision maker changes from indifference to strict preference. Conceptually, there is good reason to introduce a buffer zone between indifference and strict preference; an intermediary zone where the decision maker hesitates between preference and indifference. This zone of hesitation is referred to as weak preference; it is also a binary relation like **P** and **I** above, and is modelled by introducing a preference threshold, p. Thus we have a double threshold model, with the additional binary relation **Q** which measures weak preference. That is:

a**P**b	(a is strongly preferred to b)	|	$g(a) - g(b) > p$
a**Q**b	(a is weakly preferred to b)	|	$q < g(a) - g(b) \leq p$
a**I**b	(a is indifferent to b; and b to a)	|	$\lvert g(a) - g(b) \rvert \leq q$

The choice of thresholds intimately affects whether a particular binary relationship holds. While the choice of appropriate thresholds is not easy, in most realistic decision making situations there are good reasons for choosing non-zero values for p and q.

Using thresholds, the ELECTRE method seeks to build an outranking relation **S**. To say a**S**b means that "*a* is at least as good as *b*" OR "*a* is not worse than *b*." It should be noted that these binary relationships are applied to each of the *r* criteria; that is,

a$\mathbf{S}_j$b means that "a is at least as good as b with respect to the j^{th} criterion."

In order to develop this outranking relationship, two further definitions are required – that of concordance and discordance.

The j^{th} criterion is in **concordance** with the assertion a**S**b if and only if a$\mathbf{S}_j$b. That is, if $g_j(a) \geq g_j(b) - q_j$. Thus, even if $g_j(a)$ is less than $g_j(b)$ by an amount up to q_j, it does not contravene the assertion aS_jb and therefore is in concordance.

The j^{th} criterion is in **discordance** with the assertion a**S**b if and only if b$\mathbf{P}_j$a. That is, if $g_j(b) \geq g_j(a) + p_j$. That is, if b is strictly preferred to a for criterion j, then it is clearly not in concordance with the assertion that a**S**b.

These two concepts of concordance and discordance can be thought of as "harmony" and "disharmony." For each criterion j we are looking to see whether, for every pair of alternatives (a,b), there is harmony or disharmony with the assertion a**S**b; that is, a is at least as good as b.

With these concepts it is now possible to obtain a measure of the strength of the assertion a**S**b. This measure is called the concordance index **C** (a,b), for a given pair of alternatives (a,b) ∈ A. Let kj be the importance coefficient or weight for criterion j. A valued outranking relation is defined as follows:

$$C\ (a,b) = \frac{1}{k}\sum_{j=1}^{r} k_j c_j\ (a,b), \qquad where\ k = \sum_{j=1}^{r} k_j$$

where

$$C\ (a,b) = \begin{cases} 1, if\ g_j(a) + q_j \ \geq\ g_j(b) \\ 0, if\ g_j(a) + p_j \ \leq\ g_j\ (b) \\ \theta, if\ in\ between \end{cases}$$

And $$\theta = \frac{p_j + g_j\ (a) - g_j(b)}{p_j q_j}$$

A simple example using the data from the previous table can be provided and calculate the concordance index for the pair of projects P2 and P5. First, the thresholds and weights must be defined, as in next table.

	F	SD	SC	RM	E
Indifference threshold (q)	25	16	0	12	10
Preference threshold (p)	50	24	1	24	20
Weights	1	1	1	1	1

Figure 6 Thresholds and Weights

Then

C_1 (P2, P5) = 1, since 129 + 25 ≥ -14
C_2 (P2, P5) = 1, since 100 + 16 ≥ 100
C_3 (P2, P5) = 1, since 0 + 0 ≥ 0
C_4 (P2, P5) = 0.333, since 0 + 12 ≤ 20 and 0 + 20 ≤ 40,
then (24 + 0 – 20) / (24 – 12) = 0.333
C_5 (P2, P5) = 0, since 0 + 20 ≤ 40.

Therefore,

$$C(P2, P5) = \frac{(1)(1) + (1)(1) + (1)(1) + (1)(0.333) + (1)(0)}{1 + 1 + 1 + 1 + 1} = 0.667$$

This value of 0.667 measures the strength of the assertion that P2 is at least as good as P5. This table presents the complete concordance matrix.

	P1	P2	P3	P4	P5
Project 1	1.00	0.80	1.00	0.80	1.00
Project 2	0.60	1.00	0.80	1.00	0.67
Project 3	0.60	0.60	1.00	0.60	0.80
Project 4	0.60	0.80	0.80	1.00	0.75
Project 5	0.67	0.80	0.80	0.80	1.00

Figure 7 Concordance Matrix

The concordance values are easily interpreted. For example, a value of 0.80 for **C**(P1,P2) means that for four out of five criteria, P1 was at least as good as P2. Only for the financial criterion **F** was P2 strictly preferred to P1; that is, the difference exceeded the preference threshold of 50. As thresholds are made smaller, the concordance matrix becomes more symmetric. In the limiting case of no thresholds,

$$C(P_i, P_j) + C(P_j, P_i) = 1, \forall i, j; i \leq j.$$

Here, the concordance value is simply a count of the number of criteria where one alternative is preferred to the other.

At this point, two issues remain unresolved. The first is the explicit inclusion of discordance into the method and the second concerns how to produce a final project ranking from the pairwise outranking information. While it is beyond the scope of this paper to go into detail of these issues, a brief discussion follows.

In order to calculate discordance, a further threshold called the veto threshold is defined.

This veto threshold, v, allows for the possibility of a**S**b to be refused totally if, for any one criterion j, $g_j(b) > g_j(a) + v_j$. Assume for this example the veto threshold for the financial criterion **F** is 100, and P1 and P2 are compared. It is clear that:

$g_F(P2) > g_F(P1) + v_F$ or $129 > -14 + 100$

Therefore, the discordance index (**D**) for P1 and P2 in this case would be **D** (P1, P2) = 1.00. Thus a discordance matrix is derived which, when combined with the concordance matrix, produces what is called a "credibility" matrix. The credibility matrix provides a quantitative measure of the strength of the assertion a**S**b; that is, "a" is at least as good as b.

The process for determining a ranking from the credibility matrix is based on graph theory concepts. Essentially two preorders are derived and combined to give a final ranking. An outline of this process can be found in Roy (Roy, The outranking approach and the foundations of ELECTRE methods, 1990) and Vincke (Vincke, 1992) . Further information is available from the authors.

The final ranking of the projects in the example is:

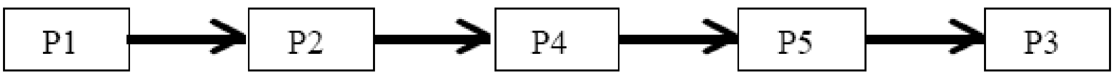

Figure 8 Ranking of Example Projects

2.3.5.2.2. *Study of the different versions of the ELECTRE Method*

In the previous chapter, the general methodology on which the different versions of ELECTRE work with was presented. But as different versions of ELECTRE were published in the last years, they introduced new improvements. These improvements can appear in very different ways, providing new tools to allow the decision makers to overcome some difficulties, purposing new alternatives in the exploitation phase of the methodologies, etc.

Several publications about the differences between the existing versions of the ELECTRE have been made in the last years, and many debates about the advantages and disadvantages of each version have taken place. One of the most popular books that express the information and features about all the versions of the ELECTRE is the one published by Figueira et al. (Figueira, Greco, & Ehrgott, 2005).

In the next sections, the new leads of each one of the existing versions of ELECTRE will be presented, analysing the way on which they allow the previous versions of ELECTRE to overcome the existing difficulties:

2.3.5.2.2.1 ELECTRE I

The purpose underlying the description of this method is rather theoretical and pedagogical.

In general, in a multi-criteria decision problem, it is said that the alternative **a** overcomes the alternative **b** if, given the knowledge level of the decision maker preferences and the quality of the information respect to the all available relevant criteria to evaluate each alternative, there exists enough arguments in favour of considering that alternative **a** is at least as good as alternative **b**, and does not exist strong arguments that can indicate the opposite.

Constructing the outranking relation, the definition must enrich in order to facilitate the solution of the decision problem. The ELECTRE method gets its enrichment through two different stages:

1- The construction of an outranking relation, and
2- The exploitation of the constructed relation.

In the ELECTRE I version, which was the first version of the model presented by Bernard Roy in 1968 (Roy, 1968) for the formulation and resolution of decision problems with multiple criteria, the goal consists on getting a sub set or kernel (N) of alternatives so that any alternative which does not belong to the N set is overcome by at least another alternative of N. Must be remarked that these are not a set on preferred alternatives, just a set on which a best solution can be found. Therefore, the ELECTRE I method tries to get a partition of the A set of alternatives, which is a finite set and that contains all the considered feasible alternatives, in two sub sets N and A\N such that:

1- Each alternative of A\N is overcome by at least one alternative of N,
2- Alternatives of N are incomparable between them.
3- $N \cap A \setminus N$ is the empty set
4- $N \cup A \setminus N$ is the A set

In the first phase of the ELECTRE I, construction of the outranking relation, to each criterion will be assigned a weight w_j, with j= 1, 2... n, where n is the number of criteria, that reflects the preferences of the decision maker. These weights are growing according to the bigger importance of the criterion. The concordance index C(a, b) is defined to each sort pair of alternatives (a, b) in this way:

$$C\ (a,b) = \frac{1}{W} \sum_{j/g_j(a) \geq g_j(b)} w_j$$

where $W = \sum_{j=1}^{n} w_j$, and $g_j(a)$ is the evaluation of the alternative ***a*** for the criterion g_j.

Therefore, the concordance index takes values between 0 and 1, and also measures the strength of the assertion "the alternative '***a***' overcomes the alternative '***b***'". Nevertheless, any overcome of the alternative b by alternative a can be weakened or considered doubtful by the discordance index D(a, b), which is defined as

$$D\ (a, b) = 0 \quad \text{if} \qquad g_j(a) \geq g_j(b), \text{ for } j = 0, 1, 2, \ldots, n$$

$$D(a,b) = \frac{1}{d} \left\{ \max_{\frac{a,b}{gj(a)} < gj(b)} \left(g_j(b) - g_j\ (a) \right) \right\}\ if\ g_j(a) < g_j(b), for\ any\ pair\ (a,b)$$

where d is the maximum difference to any criterion and any pair of alternatives.

In this way, D(a,b) is an index whose values are between 0 and 1, and increases if the preference of the **b** alternative over the **a** alternative is important in at least one criterion. This index can be used, only if the evaluations of the different criteria are comparable and are not of a qualitative nature. If the discordance index reaches a certain threshold value, the overcome of the **b** alternative by the **a** alternative that the concordance index could indicate, is rejected.

Then, the outranking relation of the ELECTRE I is constructed by comparing the concordance and discordance indices, after the specification of their respective thresholds. If c* is the supposed threshold value specified to the concordance index (concordance threshold equal to 1 as maximum), and d* is the threshold value specified to the discordance index (discordance threshold equal to 0 as minimum), then the S outranking relation, can be defined in this way:

$$a\ S\ b \Leftrightarrow C(a,b) \geq c* \quad \text{and} \quad D\ (a, b) \leq d^*$$

Regarding to the second phase, the exploitation of the outranking relation, the ELECTRE method, by the use of the previous indices, tries to get a partition of the A set of alternatives, which as has been explained previously, is a finite set and contains all the considered feasible alternatives, in two sub sets N and A\N such that:

1- ∀ b ∈ A\N, exists a ∈ N, such that a S b
2- ∀ a, b ∈ N, a notS b and b notS a
3- N ∩ A\N is the empty set
4- N ∪ A\N = A

If a graphical representation of the S relation is made, the N set constitutes the nucleus or kernel of the resultant graph. If this graph does not have circuits, this kernel exists and also contains only one element. In any case, the number of alternatives of the kernel could be reduced, relaxing the values of c* (decreasing from one), and of d* (increasing from 0).

Searching for the best compromise solution should be realised with a detailed analysis of the alternatives that share the kernel. Such analysis should be made by a sensitivity analysis, introducing variations in the different used parameters, and by a study of the hardiness of the obtained results, respecting to the mentioned variations. The sensitivity analysis is relatively a classic study in all aspects; software versions that are developed include it from the beginning. However, the hardiness analysis for the multi-criteria decision support is still in a discussion and studying phase. Not all authors are used to this kind of analysis, nor exists another methodology for this purpose yet. Is for this reason for which it must be remarked.

Is very important, in order to provide a bigger reliability to the model that is considered, to effectuate the hardiness analysis of the obtained results, subjecting the values of weights and defined thresholds to possible variations and observing the effects on the final results. Normally, the rank of the parameter values on which the result does not change is indicated, and also must be indicated the variables that are crucial to change the chosen alternative. Therefore, with a hardiness study is possible to overcome some of the doubts appeared during the decision process, both by the decision maker, and the analyst, respecting to the original values of parameters. If, introducing variations in both extremes of the established interval for its initial values, results don't suffer significant changes, then can be said that are robust.

Generally, studying the hardiness of provided results by ELECTRE I, the following values can experiment some variations:

- The rank of scales of the used values in the evaluation of the criteria
- Weights of criteria (w_j)
- The concordance threshold c*
- The discordance threshold d*

2.3.5.2.2.2 ELECTRE III

To build the upper-classification relation, ELECTRE III inserts two criteria thresholds, called indifference and preference thresholds in order to study the concordance.

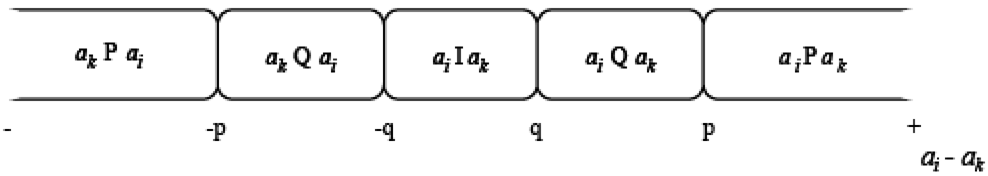

Figure 9 Types of preference according to indifference and preference thresholds

Also, a third threshold is included, the veto threshold, used to study the discordance.

<u>Agreement indexes</u>

Agreement index for each criterion

It will be defined an alternative *i* better than an alternative *k* for criterion *j* since the index $c_j(a_i, a_k)$, which is defined as:

$$\begin{cases} c_j(a_i, a_k) = 0 \Leftrightarrow p_j < g_j(a_k) - g_j(a_i) \\ 0 < c_j(a_i a_k) < 1 \Leftrightarrow q_j < g_j(a_k) - g_j(a_i) \leq p_j \\ c_j(a_i, a_k) = 1 \Leftrightarrow g_j(a_k) - g_j(a_i) \leq q_j \end{cases}$$

Global concordance index

The C_{ik} index indicates when the alternative i over-classifies the alternative k, since the formula:

$$C_{ik} = \frac{\sum_{j=1}^{m} p_j \cdot c_j(a_i, a_k)}{\sum_{j=1}^{m} p_j}$$

Global indices make a matrix ($i \times k$).

Discordance indexes

As new in ELECTRE III it includes the veto threshold (v_j), which, by definition, is the value of the difference between $g_j(a_k) - g_j(a_i)$ from which it is unwise to refuse the over-classification.

When the veto threshold value is passed the over-classification must be rejected, independently of what can happen in the rest of the criteria. The construction of the discordance index is shown as follows:

$$\begin{cases} d_j(a_i, a_k) = 0 \Leftrightarrow g_j(a_k) - g_j(a_i) \leq p_j \\ 0 < d_j(a_i, a_k) < 1 \Leftrightarrow p_j < g_j(a_k) - g_j(a_i) \leq v_j \quad \text{Lineal interpolation} \\ d_j(a_i, a_k) = 1 \Leftrightarrow v_j < g_j(a_k) - g_j(a_i) \end{cases}$$

Algorithm of the method

The ELECTRE III method makes two possible partial sorts from the potential alternatives collection. First, a classification of the alternatives is made, from the best one to the less good (descending distillation), which consists on several stages.

First, the Potency, Weakness and Qualification sets are defined in every stage of each distillation, which are:

- Potency of an action is the set of alternatives that are over-classified by the alternative that is being studied.
- Weakness of an action is the set of alternatives that over-classify the alternatives that is being studied.

- Qualification of an action is the set got by the difference between the sets of potent weakness for an alternative. An alternative is better when the biggest (in positive number) the set of Qualification.

From these sets several distillations are made until all alternatives have been selected.

2.3.5.2.2.3 ELECTRE IV

According to (Figueira, Greco, & Ehrgott, 2005) the name ELECTRE IV was an unofficial name created for designating ELECTRE I with veto threshold. This method is equipped with a different but extremely useful tool. The new tool made possible for analysts and DMs to overcome the difficulties related to the heterogeneity of scales. Whichever the scales type, this method is always able to select the best compromise action or a subset of actions to be analyzed by DMs.

The new tool introduced was the veto *threshold*, v_j, that can be attributed to certain criteria g_j belonging to the family of criteria F. The concept of veto thresholds is related in some way, to the definition of an upper bound beyond which the discordance about the assertion "a outranks b" can not surpass and allow an outranking. In practice, the idea of threshold is, however, quite different from the idea of discordance level like in ELECTRE I. Indeed, while discordance level is related to the scale of criterion g_j in absolute terms for an action a from A, threshold veto is related to the preference differences between $g_j(a)$ and $g_j(b)$.

In terms of structure and formulae, little changes occur when moving from ELECTRE I to ELECTRE IV. The only difference being the discordance condition, now called *no veto condition*, which may be stated as follows:

$$g_j(a) + v_j\big(g_j(a)\big) \geq g_j(b), \ \forall j \in I$$

To validate the assertion "a outranks b" it is necessary that, among the minority of criteria that are opposed to this assertion, none of them puts it s veto.

ELECTRE IV uses the same exploitation procedures as ELECTRE I.

But, this method is by no means complete; the problem of imperfect knowledge remains.

2.3.5.2.2.4 ELECTRE IS

How general an ELECTRE method can be when applied to choice decision-making problems? Is it possible to take into account simultaneously the heterogeneity of criteria scales, and imperfect knowledge about real-world decision-making situations? Previous theoretical research done on thresholds and semi-orders may, however, illuminate the issue of inaccurate data and permit to build a more general procedure, the so-called ELECTRE IS method.

The main novelty of ELECTRE IS is the use of pseudo-criteria instead of true-criteria. This method is an extension of the previous one aiming at taking into account a double objective: primarily the use of possible no nil indifference and preference thresholds for certain criteria belonging to *F* and, correlatively, a backing up (reinforcement) of the veto effect when the importance of the concordant coalition decreases. Both concordance and no veto conditions change. Now, the formulae for each one of theses conditions will be presented separately.

Concordance condition:

The following two indices sets are introduced:

1. Concerning the coalition of criteria in which aSb

$$I^s = \left\{j \in I : g_j(a) + q_j\left(g_j(a)\right) \geq g_j(b)\right\}$$

2. Concerning the coalition of criteria in which bQa

$$I^Q = \left\{j \in I : g_j(a) + q_j\left(g_j(a)\right) < g_j(a) \leq g_j(b) + p_j(g_j(b))\right\}$$

The concordance condition will be:

$$c(aSb) = \sum_{j \in I^S} w_j + \sum_{j \in I^Q} \varphi_j w_j \geq s$$

where,

$$\varphi_j = \frac{g_j(a) + p_j\left(g_j(a)\right) - g_j(b)}{p_j\left(g_j(a)\right) - q_j(g_j(a))}$$

the coefficient φ_j decreases linearly from 1 to 0, when g_j describes the range $[g_j(a) + q_j(a)), g_j(a) + p_j(g_j(a))]$.

No veto condition:

The no veto condition can be stated as follows:

$$g_j(a) + v_j\left(g_j(a)\right) \geq g_j(b) + q_j\left(g_j(b)\right)\eta_j$$

where,

$$\eta_j = \frac{1 - c(aSb) - w_j}{1 - s - w_j}$$

In the exploitation procedure, actions belonging to a cycle are no longer considered as indifferent as in the previous versions of ELECTRE for choice problems. Now, the concept of degree of robustness of "*a* outranks *b*" will be taken into account. It is a reinforcement of veto effect and allows building true classes of *ex aequo* (ties) and thus defining an acycle graph over these classes. In such conditions there is always a single kernel.

2.3.6 The Promethee method

2.3.6.1 Explanation of the Promethee methods

The PROMETHEE methods were purposed for first time in the year 1982 (Brans, 1982). Since then many developments and complementary adaptations to these methods have been carried out.

The PROMETHEE methods support the decision maker both in election problems and in classification problems and are based in three stages:

1. Enrichment of the preference structure: This stage is essential. The generalised criterion notion, defined since a preference function, is introduced with the goal of keep in mind the wide of the existent

difference between the evaluations of two alternatives according to the different criteria. This notion is easily understandable for the decision maker because of all the parameters that are needed to define the criteria correctly have a physical or economical interpretation.

2. Enrichment of the dominance relationship: Takes into account the purposed criteria set. For each pair of actions, a global preference index of one action over another one is established.
3. Supports to the decision: the PROMETHEE I method allows to obtain a partial sort of the alternatives.

Is possible to define in which way an alternative is more desired than another one by using the function $P_j\ (a, b)$ called function on preference for the criterion j, which is based on the existent difference between two evaluations: $d_j(a,b) = f_j(a) - f_j(b)$.

This preference function has these following four features:

$P_j(a, b) = 0$	if	$d_j(a, b) \leq 0$	No preference
$P_j(a, b) \approx 0$	if	$d_j(a, b) > 0$	Weak preference
$P_j(a, b) \approx 1$	if	$d_j(a, b) >> 0$	Strong preference
$P_j(a, b) = 1$	if	$d_j(a, b) >>> 0$	Strict preference

The pair $\{f_j(.), P_j(a, b)\}$ is called generalised criterion associated to the criterion $f_j(.)$.

If $d_j\ (a, b) \leq 0$, $P_j\ (a, b)$ is null, but $P_j\ (b, a)$ can be positive. In order to consider all the real line, and not only the positive part, the preference function $H_j\ (d_j)$ is introduced:

$H_j(d_j) = P_j(a, b)$	if	$d_j(a, b) > 0$
$H_j(d_j) = 0$	if	$d_j(a, b) = 0$
$H_j(d_j) = P_j(b, a)$	if	$d_j(a, b) < 0$

2.3.6.2 Applying the Promethee method

The PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) method, as a multicriteria decision technique, tries to establish, by the evaluation in function of *k* criteria, $f_1, f_2, ..., f_k$, a hierarchical sort in the *A* set of alternatives. The main idea of the PROMETHEE philosophy, consists on enrich the existent dominance relationship between the different alternatives. Because of this, it carries out these following stages:

1) Definition of the generalised criterion

This stage requires that each criterion f_j must be associated a generalised criterion, $p_j(x)$, that will value the preference of an alternative *a* by respect to another *b* alternative as a function of the difference between evaluations, $f_j(a) - f_j(b)$. With the purpose to facilitate the election of a generalised criterion associated to each criterion, Brans et al. (Brans, Vincke, & Mareschal, 1986) propose six different types, for each one of them; the decision maker must fix, as maximum, the level of two parameters with economical meaning. These parameters are the next ones: q (threshold that defines the indifference area), p (threshold that defines the strict preference area) and s (parameter that relates the values of p and q).

2) Construction of the multi-criteria preference index

The next step consists on defining a multi-criteria preference index, $\pi(a, b)$, that measures the degree on which *a* is preferred instead of *b* in all the criteria:

$$\pi(a,b) = \sum_{j=1}^{k} w_j P_j(a,b)$$

where $w_j > 0$ $(j=1, ..., k)$ is the weight of importance associated to the *j* criterion, having $\sum_{j=1}^{k} w_j = 1$.

3) Adoption of the final decision

Two sort flows will be considered, the outgoing and the ingoing, that reflect the grade on which *i* alternative dominates or is dominated by the other rest, and which are defined as follows:

$$\varphi_i^+ = \frac{1}{n-1} \sum_{x \in A} \pi\,(i, x)$$

$$\varphi_i^- = \frac{1}{n-1} \sum_{x \in A} \pi\,(x, i)$$

The outgoing flow represents the dominant feature of an alternative, its dominant power, because of that it will be better that alternative which has a bigger outgoing flow.

The ingoing flow represents the weakness of an alternative, that is to say, how is dominated by the others; therefore, it will be better that alternative which has a little ingoing flow.

Throughout these two flows it can be defined a partial order between the alternatives (PROMETHEE I Method).

In order to get a total sort of the alternatives (PROMETHEE II Method) the order clear flow is defined:

$$\varphi_a = \varphi_a^+ - \varphi_a^-$$

So an alternative *a* will overcome to another alternative *b* if $\varphi_a > \varphi_b$ and will be different if $\varphi_a = \varphi_b$. This clear order flow deletes the problem of the incomparabilities between alternatives; even part of the provided information by the previous flows gets loose.

2.3.6.2.1 PROMETHEE I and PROMETHEE II methods

In the last section, the standard methodology carried out by the PROMETHEE method was exposed, but as many versions of the PROMETHEE were published after the first approach, several variations of this first PROMETHEE version (PROMETHEE I) appeared during the last years. Therefore, the purpose of next sections is to analyse the difference between the existent versions of PROMETHEE. In the following paragraphs, difference among PROMETHEE I and PROMETHEE II is exposed.

The PROMETHEE decision process is funded in binary comparisons of alternatives and allows the consideration of different problems.

It consists on a order problem if the decision maker desires to order the A alternatives from the best one to the weakest one and on an election problem if the decision maker must select the best alternatives of A. In this way two techniques aimed to solve the order problem are presented, PROMETHEE I and PROMETHEE II, taking in account that a set of good commitment solutions can be obtained from the order to solve the election problem.

Once the preference functions have been associated to each criterion, aggregated preference indices (or multi-criteria preference indices) and the outranking flows must be defined.

a) Aggregated preference or multi-criteria preference indices

The multi-criteria preference index is obtained in the next way:

$$\pi(a,b) = \sum_{j=1}^{k} P_j(a,b)w_j$$

Where w_j is the weight which determines the relative importance of the $g_j(.)$ criterion.

For each pair *a* and *b* of alternatives, $\pi(a,b)$ expresses the total preference degree from *a* over *b*, that is to say, it expresses how and whit which intensity the *a* alternative is preferred than the *b* alternative for all criteria, while $\pi(a,b)$ indicates the preference of *b* over *a*. These numbers are usually and simultaneously positive and determine a *Weighted Outranking Relation* upon the A set. This relation can be represented by a *Weighted Outranking Graph*, whose nodes are the A alternatives.

The multi-criteria preference index has the following properties:

$\pi(a,b) = 0$
$0 \leq \pi(a,b) \leq 1 \ \forall \ a, b \in A$
$\pi(a,b) \sim 0$, implies a weak global preference of *a* over *b*
$\pi(a,b) \sim 1$, implies a strong global preference of *a* over *b*

b) *Outranking flows*

For each *a* node, in the weighted outranking graph, the positive or outgoing flow is defined:

$$\varphi^{+}(a) = \frac{1}{n-1}\sum_{b\in A}\pi(a,b)$$

which measures how intensely the *a* alternative is preferred over the *(n-1)* remaining alternatives, that is, the positive flow offers a measure of the outranking nature, the strength of *a*.

Symmetrically, the negative or ingoing flow is defined:

$$\varphi^{-}(a) = \frac{1}{n-1}\sum_{b\in a}\pi(b,a)$$

which measures how intensely other alternatives are preferred instead of the *a* alternative, that is to say, the negative flow offers a measure of the outranking nature, the weakness of *a*.

Therefore, one alternative will be as better than other as bigger will be its positive flow and smaller its negative flow. This is the basis of the partial order in PROMETHEE I.

c) *The partial order: PROMETHEE I*

From the positive and negative outranking flows, pre orders of two usually non-equally alternatives are deducted. Intersection of these orders leads to the partial order of the PROMETHEE I, which reflects a preference structure of partial pre-order.

In this way:

$$\begin{cases} aP^{I}b \Leftrightarrow \begin{cases} \varphi^{+}(a) > \varphi^{+}(b) \ and \ \varphi^{-}(a) < \ \varphi^{-}(b) \\ \varphi^{+}(a) = \varphi^{+}(b) and \ \varphi^{-}(a) < \ \varphi^{-}(b) \\ \varphi^{+}(a) > \varphi^{+}(b) and \ \varphi^{-}(a) = \varphi^{-}(b) \end{cases} \\ aI^{I}b \Leftrightarrow \varphi^{+}(a) = \varphi^{+}(b) and \ \varphi^{-}(a) = \varphi^{-}(b) \\ aR^{I}b \Leftrightarrow \ otherwise \end{cases}$$

where P^I, I^I and R^I indicate preference, indifference and incomparability according to the preference relation of the PROMETHEE I.

This partial pre order is proposed then to the decision maker in order to support him by considering his decision problem. It is important to remark that by using the PROMETHEE I Method some alternatives remain incomparable. Usually, two *a* and *b* alternatives are incomparable when *a* is good for a set of criteria for which *b* is weak and inversely, *b* is good for other set of criteria for which *a* is weak. Because of the correspondent information about both kind of flows is not consistent, it seems natural to consider alternatives as incomparable between them. The method should not decide which one is the best alternative; it corresponds to the decision maker to assume that responsibility.

d) *The complete order: PROMETHEE II*

It is very common that the decision maker desires to get a complete order of alternatives. In that case a complete pre order is the most appropriate preference structure in order to reach a decision, and it is based on the net outranking flow of each alternative:

$$\varphi\ (a) = \varphi^{+}(a) - \varphi^{-}(a)\ .$$

Each clear outranking flow arises from the balance between positive and negative outranking orders; the bigger the net flow, the better the alternative in question.

In this way the complete order of the PROMETHEE II is defined:

$$\begin{cases} aP^{II}b \Leftrightarrow \varphi(a) > \varphi(b) \\ aI^{II}b \Leftrightarrow \varphi(a) = \varphi(b) \end{cases}$$

All alternatives are comparable as the A set has been completely ordered, but the resultant information is more questionable because of a considerable part of it gets loose when the balance between ingoing and outgoing flows are made.

Both PROMETHEE I and II support the decision maker to end the decision process by the selection of a best compromise solution, offering a clear vision of the outranking relations between alternatives throughout the outranking graphs.

2.3.6.2.2 The GAIA Map

The GAIA process consists on a visual interaction schedule complementary of the PROMETHEE Methodology (Mareschal & Brans, 1988). The GAIA map offers to the decision maker a clear graphical description of his decision problem, by remarking existent conflicts between criteria and impact of weights in the final decision. This enrichment in the understanding of the problem structure is essential: actually it would be very difficult to reach a good decision without an appropriate comprehension and knowledge of the proper problem.

While the PROMETHEE I and II analysis are quite prescriptive, the GAIA analysis is more descriptive and is graphically oriented.

The complete GAIA analysis is funded in the net flows analysis obtained from the decomposition of the global net flow.

Then, a mono-criterion net flow is associated to each one of the criteria:

$$\varphi_j(a) = \frac{1}{n-1} \sum_{b \in A} \left[P_j(a,b) - P_j(b,a)\right]$$

where $\varphi_j(a)$ is the mono-criterion net flow obtained in case of considering only the $g_j(.)$ criterion.

In this way, the multi-criteria net flow can be expressed in terms of mono-criterion net flows:

$$\varphi(a) = \sum_{j=1}^{k} \varphi_j\,(a) w_j$$

Compared with the $g_j(.)$ criteria evaluations, $\varphi_j(.)$ mono-criterion flows contain more quantity of information about the preference structure of the decision maker due to the use of the preference functions. Moreover, such flows are expressed in similar scales, which are independent of the original scales of criteria.

Each alternative can be represented in the k-dimensional space by a vector whose components are the mono-criterion flows, $\varphi_j(.)(j=1,2,\dots,k)$:

$$a(a):\{\varphi_1(a), \varphi_2(a),\dots, \varphi_j(a),\dots, \varphi_k(a)\}$$

Consequently, the set of alternatives can be represented like a cloud of n points in the k-dimensional space R^k.

As the number of criteria, usually, is bigger than two, it results impossible to obtain a clear vision of the relative position of points by respect to criteria. Therefore, information included in the k-dimensional space will be projected into a map.

The GAIA Method uses the Principal Components Analysis technique to project, in an optimum way, this information on a map, which is called GAIA map. Therefore, on the GAIA map are projected the points that will represent the alternatives and the unitary vectors of the coordinates axes that will represent the criteria.

The GAIA map is the map which preserves the biggest quantity of possible information respecting to the cloud of points once the projection has been made.

This analysis allows to distinguish which alternatives are good under a particular criterion, because of these alternatives will be allocated in the direction of the correspondent axis on the GAIA map. In addition, criteria represented by axes with similar orientations express similar preferences, while those criteria whose axes are oriented in opposite directions correspond to criteria in conflict between them. Other element that must be taking in account is the length of each representative axis of the criteria as it constitutes a measure of the relative discrimination power of criteria respect to the set of alternatives.

Surely, the quality of the information that it can be obtained is directly related to the δ percentage, which indicates the amount of information that the GAIA map conserves after the projection. In most of the real-world applications, δ is higher the 70%; this means that the GAIA map offers a quite feasible representation of the decision problems. Nevertheless, it should be process very carefully at extracting conclusions since the inspection of the GAIA map as part of the information gets missing.

Despite the GAIA map includes a δ percentage of the total information, it becomes a powerful visualisation tool to the analysis of the multi-criteria problem structure. The discrimination power of criteria, the conflictive aspects and also, the quality of each alternative over different criteria are seen with many clarity and simplicity.

Up to now, the information that can be represented in the GAIA map is totally independent of the weights of criteria, but the weights can also be represented in the GAIA map by the use of a k-dimensional vector. How to get this vector and how is called is explained in the following lines.

According to the formula of the multi-criteria net flow, the net flow of an alternative is the scalar product between the mono-criterion net flows vector and the weights vector:

$$\begin{cases} \alpha_i: \left(\varphi_1(a_1), \varphi_2(a_i), \dots, \varphi_j(a_i), \dots, \varphi_k(a_i)\right) \\ \qquad w: (w_1, w_2, \dots, w_j, \dots, w_k) \end{cases}$$

This means that the net flow of a_i is also the projection of a_i over w in the k-dimensional space and that projections of all the a_i, $i = 1,2,\dots n$ over w offer the complete order of the PROMETHEE II. Clearly it can be observed that w is a decision axis and can be represented in the GAIA map by projecting the unitary vector among the w. Normally, that projection is known as π and is called *decision axis of the PROMETHEE*.

The π decision axis has important properties. If π is long then it has a strong decision power and the decision maker is invited to select the alternatives that are situated as far as possible from the origin but in its same direction. If π is short, its decision power is weak. In this case the w vector is almost orthogonal to the GAIA map; this means that, in concordance with weights, criteria are strongly conflictive between them and that a good compromise solution should be chosen next to the origin.

If weights are modified, the positions of the criteria and of the alternatives are not affected in the GAIA map. Moreover, curiously the vector of weights, w, appears like a "stick". Both this "stick" and the decision axis of the PROMETHEE move, so the decision maker can appreciate perfectly the consequences of such variations in the GAIA map.

The decision "stick" *(w)* and the decision axis of the PROMETHEE (π) constitute, in the GAIA map, a powerful tool for the visual sensitivity analysis.

Before determine concluded the decision process is recommended the decision maker to effect different sensibility analysis, by simulating diverse distributions of weights. In each case, situation can be seen directly in the GAIA map. For each weights vector the recommended alternatives will be the ones that are allocated in the direction of the decision axis in PROMETHEE. This sensitivity analysis results to be extremely useful for the decision makers, is very simple to perform and to interpret as the alternatives and criteria axes stay immovable while the decision "stick" moves.

2.3.6.2.3 PROMETHEE V

As it could be seen in the previous sections, PROMETHEE I and II Methods are particularly appropriate for choosing one alternative. However, in many cases must be selected a subset of alternatives under a set of restrictions that must be verified between the different subsets and inside them.

Boolean variables are especially appropriate to face such problems. Considering that $\{a_i, i=1,2,\ldots,n\}$ is the set of feasible alternatives and that to each alternative the following Boolean variables are associated:

$$x_i = \begin{cases} 1 \; if \;\; \alpha \; is \; chosen \\ 0 \; otherwise \end{cases}$$

The PROMETHEE V method is performed in two stages.

First stage: Initially the multi-criteria problem is considered, without segmentation restrictions. Net outranking flows are calculated $\varphi(a_i)$, $i=1,2,\ldots,n$ and the complete order of the PROMETHEE II is obtained. This can be made by the basic procedure PROMETHEE-GAIA already explained.

Second stage: Additional segmentation restrictions are incorporated to the problem by considering the following lineal program (0-1):

$$Max. \sum_{i=1}^{n} \varphi(a_i) x_i$$

$$\sum_{i=1}^{n} \alpha_{p,i} x_i \sim \beta_p \qquad i = 1,2,\ldots,n; \;\; p = 1,2,\ldots,P$$

$$\sum_{i \in S_r} \gamma_{q_r,i} x_i \sim \delta_{q_r} \qquad q_r = 1,2,\ldots,Q_r; \;\; r = 1,2,\ldots,R$$

$$x_i \in \{0,1\} \qquad i = 1,2,\ldots,n$$

where ~ remains for ≤, ≥ or =.

The *φ(a_i)* coefficients of the objective function are the net outranking flows. The goal of the maximization problem is to collect as much dominance flows as possible in favor to the sub set of alternatives that is going to be selected.

Relations $\sum_{i=1}^{n} \alpha_{p,i} x_i$ and $\sum_{i \in S} \gamma_{q_{r,i}}$ express, respectively, the segmentation restrictions between sub sets and also inside each one of them.

The P restrictions of the $\sum_{i=1}^{n} \alpha_{p,i} x_i$ type are restrictions that must accomplish all the sub sets. The different relations of the $\sum_{i \in S} \gamma_{q_{r,i}}$ type define restriction inside the sub sets. For each sub set, Q_r restrictions must be considered. The formulated restrictions, for both types, can express limitations of cardinality, of budget, of investment, of financing, of marketing …

Once the lineal program (0-1) is resolved by using classical tools (Branch and Bound Technique) is possible to obtain a sub set of alternatives that besides satisfying the formulated restrictions, also offers the highest net flow possible.

The advantage that PROMETHEE V offers is that allows combining the analysis of the evaluation matrix with a lineal program (0-1) considering segmentation restrictions formulated over the set of alternatives.

2.3.6.2.4 PROMETHEE VI

PROMETHEE VI is an extension of the PROMETHEE-GAIA Methodology that offers to the decision maker some information respect to his proper vision of the multi-criteria problem, allowing the decision maker to analyse according to his proper preference structure, depending if he faces to a "hard" or "soft" problem.

"Hard" and "soft" terms are frequently used in the United Kingdom to describe Operative Researching Methods. Then, the "hard" term is used to describe analytic methods that generally look for offering optimal solutions. On the other hand, the "soft" term, describes those Operative Researching methods that face to complex difficulties to the obtaining of results. In the multi-criteria ambit on which this thesis is focused on, words "hard" and "soft" have a different connotation: "hard" problems make reference to difficult or complex problems, while "soft" ones refer to easy or simple problems.

As it was seen in the previous sections of the PROMETHEE methods, distribution of weights has a relevant roll in all multi-criteria problems. As soon as weights are established, PROMETHEE recommends a final decision.

But in many situations, the decision maker has doubts when he assigns concrete values to weights. This doubt is due to several factors: indeterminacy, imprecision, uncertainty, control deficiency in the real-world situation.

However, the decision maker has, usually, in his mind a kind of magnitude for weights, therefore, despite his doubts, is able to formulate some intervals that include appropriate values for weights. Consider that those intervals have this form:

$$w_j^- \leq w_j \leq w_j^+ \qquad j = 1,2, \dots k$$

where w_j^- and w_j^+ are the lower and upper limit, respectively, of the values interval that the weight of the $g_j(.)$ criterion can take.

Considering the set of the whole extreme points of vectors associated to all the vectors of admissible weight vectors according to the last formula, it can be observed that such set defines a domain over unitary hyper sphere, centred in origin of the k-dimensional space. Projection of this domain onto the GAIA map is called *Decision Maker Freedom Space (DMFS)*. Obviously, the (DMFS) is the geometrical place of the extreme points of the PROMETHEE decision axis (π) for each probable weights set.

Two different situations respect to the (DMFS) can be indentified:

1) If (DMFS) does not include the origin of the GAIA map, the PROMETHEE decision axis will remain globally oriented in the same map area when modifications will be introduced in the weights inside the defined interval. In this case, each set of weights allows obtaining similar compromise solutions. Current values of weights are, moreover less relevant in the decision process.
   The multi-criteria problem is quite simple or easy to solve and therefore is called *soft multi-criteria problem*.

2) On the contrary, if (DMFS) includes the origin, the PROMETHEE decision axis can have any orientation, depending on the values of weights. In this case, it can be obtained quite different compromise solutions for different sets of probable weights. It results quite complex taking a final decision in this context. Therefore, according to his preferences and doubts, the decision maker faces to a *hard multi-criteria problem.*

It is important to take in account that visually it can be seen which is the difficulty or complexity degree of a multi-criteria problem. It is only necessary to analyse the position of the DMFS respect to the GAIA map origin. This process is called PROMETHEE VI.

In most of the practical applications and real-world situations deal up to the present days, problems are simple and not too much complex. This means that in most of the multi-criteria problems there exist good and appropriate compromise solutions. This information is of great utility in the decision process.

2.3.7 The MURAME method

2.3.7.1 Explanation of the MURAME method

This method is based in the construction of an outranking relation. Pair-wise comparison between alternatives results in the degree of dominance of the one over the other.

Such methods, introduced by (Roy, 1968) require less information from the Decision Maker (DM) than methods that create only one score to each alternative, like the multi-attribute utility theory (Keeney & Raiffa, 1976), or the hierarchy analytic process (Saaty T. L., 1980). On the other hand, MURAME can work even there are some evaluation that don't favour a project instead of another one. Finally, this method takes into account both qualitative and quantitative criteria. For a detailed description of the MURAME see (Goletsis, Askounis, & Psarras, 2001).

MURAME is carried out in two main phases, by the combination of the two most popular outranking methods, ELECTRE III (Roy, 1968) (Roy, 1990) and Prométhée (Brans & Vincke, 1985):

- In the first phase, the aggregation, the outranking relation is constructed. The DM's value system is modelled by the criteria definition and its weights, as well as thresholds. The DM's hesitations between preference and indifference are modelled in a fuzzy way. On the other hand, the use of the threshold is often considered necessary in some kinds of applications.
- In the second phase, the exploitation phase, outranking relation is used to provide a recommendation. Calculation of the flows in a similar way

of the Prométhée method produces a total pre-order. A generalised presentation in the net flows scope can be found in (Bouyssou, 1992).

2.3.7.2 Applying the MURAME method

The aggregation phase

In the aggregation phase the outranking relation S is constructed. Having two alternatives *ai* and *ak*, *ai* S *ak* means that alternative *ai* is at least as good as *ak*. It will be consider having a set of *m* alternative proposals ***A*** = {*a*1, *a*2, . . . , *ai*, . . . , *am*} and a consistent family of *n* criteria ***F*** = {*C*1,*C*2, . . . ,*Cj*, . . . , *Cn*}. The criteria could be both, quantitative and qualitative.

Inputs

The evaluation matrix. The evaluation matrix (m×n) contains the score *gij* of each *i* alternative in each *j* criterion. There is no need for a common measurement unit. Each quantitative criterion is counted in its own unit while for qualitative criteria a constructed scale should be used.

The thresholds qj, pj, vj. In order to reflect the DM's preference in a realistic way the use of pseudo-criteria was adopted. The three zones scheme (strict preference, weak preference, indifference) was modelled by the use of two thresholds for each criterion *j* the indifference threshold *qj* and the preference threshold *pj* . The values of *pj* and *qj* could be constant or have a form $a * gij + b$. In any case *qj (gij) - pj (gij)*.
There is also a veto threshold *vj* for each criterion *i*. This threshold is used for rejecting the hypothesis *ai* S *ak* , if in one criterion alternative *ai* is so much worse than *ak*, that $gij + vj < gkj$. Veto threshold *vj* cannot be less than *pj*.

The weights. The weight vector *W* = {*w*1,*w*2, . . . , *wj*, . . . , *wn*} provides the relative importance of each criterion. The weights in an outranking relation should be considered as votes in a voting procedure. We believe that direct weighting usually cannot reflect the DM's preferences in an effective way. A number of special methods have been developed.

There are several methods for the calculation of the weights of each criterion. One of the most common of these methods is the use of personal construct theory, proposed by Rogers and Bruen (Rogers & Bruen, 1998).

The calculation of criterion weights with the use of personal construct theory is based on the Personal Construct Theory – PCT (Kelly, 1955) and on its bipolar modelling of the human preferences system. Without analyzing the Kelly's

hypothesis, a bipolar construction (extreme) of the two possible cases is associated to each criterion, for example, by the cost: low cost / high cost.
For each construct, one of the two cases is the most preferable (for example, the low cost).
In a pair-wise comparison between constructors and assuming that the current state is the most preferable for each construct, the DM defines which one of the two constructions he is more willing to see changed to the non preferable situation (or vice versa, which one resists to change). By calculating this resistance-to-change the criterion weights are produced. A symmetrical matrix where the rows and columns represent the constructions can then be created. In a given cell within this resistance grid the following notation signifies the result obtained:

(1) a **X** indicates that the column of the construction "resists to change",
(2) a blank indicates that the row of the construction "resists to change",
(3) an **I** indicates that the two modifications are equally undesirable,
(4) an **e** indicates that the two constructs change at the same time.

The resistance to change is the result of adding the amount of "blanks" in the rows and the **X** corresponding to each construct. This resistance to change is considered like a measure to know the importance of each criterion. Criterion w_j is then

$$w_j = \frac{RtC_j}{\sum_{i=1}^{n} RtC_i}$$

where *RtC* means Resistance-to-Change.

Calculation of indices

The concordance–discordance indices. Local concordance cj (ai, ak), concordance Cik and discordance dj (ai, ak) indices are calculated according to the ELECTRE III model. The outranking index O aggregates the concordance and discordance indices in order to indicate how much ai outranks ak.

<u>The exploitation phase</u>

In order to rank the preferences, the outranking index O is used to calculate entering and leaving flows for each alternative:

leaving flow: $$\varphi^{+}(a_i) = \sum_{k \neq i} O(a_i, a_k)$$

entering flow: $$\varphi^{-}(a_i) = \sum_{k \neq i} O(a_k, a_i)$$

Leaving flow $\varphi^{+}(a_i)$ indicates the strength of alternative a_i over all remaining alternatives. Vice versa, entering flow $\varphi^{-}(a_i)$ indicates the weakness of alternative a_i (by indicating the strength of all other alternatives over it).

The net flow φ is defined as follows:

$$\varphi(a_i) = \varphi^{+}(a_i) - \varphi^{-}(a_i).$$

The alternatives can be then ranked according the net flow φ (in a descending order). In this way a total preorder is produced.

Missing evaluations

It is common, especially when the list of alternatives is long, that some evaluation have disappeared. MURAME ensures that missed evaluations do not affect to the pair-wise comparisons.

In case a grade g_{ij} is missing when alternative a_i is compared to a_k, under criterion j, it is assumed that $g_{ij} = g_{kj}$, which means that the missing grade is replaced by the one that it is compared to. In this way, there is

$$c_j(a_i, a_k) = c_j(a_k, a_i) = 1, \qquad \forall b \in A,$$
$$d_j(a_i, a_k) = d_j(a_k, a_i) = 0, \qquad \forall b \in A,$$

and it will be ensured that any alternative will not be favored.

Alternative solutions could include the removal of the criteria which corresponds with the missed value or the substitution of this missed value for another one (for example, the average or the most frequent value). However, first solution would alter the criteria weights giving too much importance to other criterion or criteria (especially if the deleted criterion is essential). In terms of the second solution, the missed values could not statistically been produced with the use of a statistical method or a more advanced data mining technique because there is no reason justifying such a replacement.

2.3.7.3 Group support techniques for the MURAME method

2.3.7.3.1 The aggregation of individual preferences

The aggregation of individual preferences does not get by the aggregation of the individual classification, as is suggested in some methods like (Cook & Seiford, 1982). On the contrary, with the purpose to take the preference intensities into account, the individual preference flows are used.

This is achieved with the technique suggested by Macharis et al. (Macharis, Brans, & Mareschal, 1998).

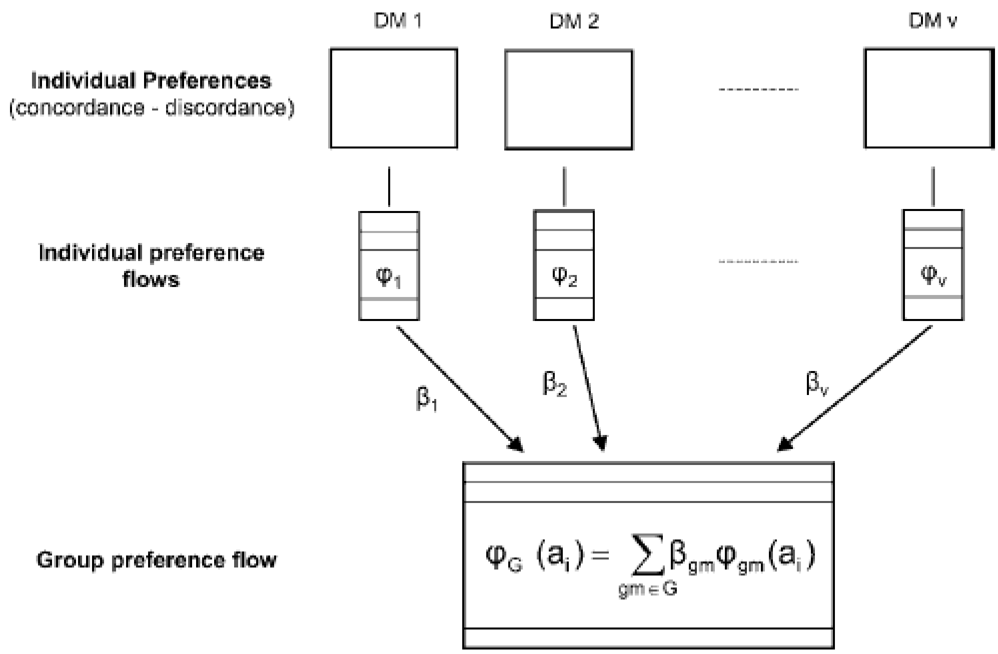

Figure 10 Aggregation of preferences

The main idea is the weighted addition of the individual preferences of each member *gm* of the group *G* (Ramathanan & Ganesh, 1994).

Flow φ_{gm} indicates that the individual net flow for alternative a_i, as produced by MURAME. Because of the fact that not all the members of the group cannot carry the same weight in the decision making process, a value β_{gm} indicates the weight (importance) of DM *gm* in the decision outcome. This can differ due to differences in decisional skills, problem knowledge and expertise, or hierarchical power in organizations (Bui, 1987). There is no general formal rule how β_{gm} values are decided. Often all group members are considered by the MoE of equal importance.

As it can be seen, for each alternative a group leaving flow

$$\varphi_G^+(a_i) = \sum_{gm \in G} \beta_{gm} \varphi_{gm}^+(a_i),$$

a group entering flow

$$\varphi_G^-(a_i) = \sum_{gm \in G} \beta_{gm} \varphi_{gm}^-(a_i)$$

And a net group flow $\varphi_G(a_i) = \varphi_G^+(a_i) - \varphi_G^-(a_i)$ can be defined.

Following the flow philosophy, $\varphi_G^+(a_i)$ indicates the degree that a_i outranks the other alternatives and $\varphi_G^-(a_i)$ the degree a_i is outranked, for the group of DMs.

By using the net flow, the total group pre order is produced.

2.3.7.3.2 Consensus check

Following the common proposal, consensus reaching is examined while, if not, its achievement is supported. This is done with the use of four new specific indexes.

The Personal Satisfaction Index (PSI):

PSI can be defined as the correlation coefficient between the individual and the preorders group. Taking in account that the decision problem belongs to problematic γ (ranking) and the fact that the above describes techniques that usually produce only a few cases of indifference, the Spearman Rank Correlation Coefficient (SRCC) can be applied. For a presentation of the Spearman Rank Correlation Coefficient (SRCC) see, for example (Lehmann & D'Abrera, 1998).

As a result, for each group member gm, having the individual order R_{gm} and the group order R_G:

$$PSI_{gm} = 1 - \frac{6 \sum_{i=1}^{m} d_i^2}{m^3 - m}$$

where d_i is distance of the ranks between R_{gm} and R_G, m is the number of alternatives.

PSI values are between -1 and +1. Since the SRCC is mainly sensitive to great differences between orders (differences of many positions) than to small differences (for example, on position differences),

- PSI close to 1 means that there are not big differences between two orders and, then, the agreement/satisfaction is big.
- PSI close to 0 means that there are many significant differences between the two orders. As a result, there is no agreement at all, any satisfaction by the group order.
- PSI close to -1 means that the group order is almost the personal order reversed. The discomfort/disagreement is then maximized.

The Group Satisfaction Index (GSI):

GSI is the weighted addition of the PSI providing in this way an index of group's satisfaction by the proposed as common proposal

$$GSI = \sum_{gm \in G} \beta_{gm} PSI_{gm}$$

The Rest Group Satisfaction Index (RGSI):

$RGSI_{gm}$ measures the satisfaction of the remaining members of the group, for example $G - \{gm\}$,

$RGSI_{gm} = \sum_{r \in G^*} \beta_r^* PSI_r$,

$G^* = G - \{gm\}$,

β_r^* = the weight value of group member r of the group G^* (normalized).

RGSI can be proved to be very useful in negotiations because, compared with the PSI, it could be determined if each DM has a different opinion than the rest of the team.

Research over the behavior of the group has demonstrated that members of the group are more disposed to alter their initial preferences when they feel "different" to the rest of the team (Whitworth & Felton, 1998) and vice versa.

The Agreement Indices (AI):

AI is the Sperman's ranks correlation between orders from two modalities.

$$AI_{gm_1gm_2} = 1 - \frac{6\ \sum_{1=1}^{m} d_i^2}{m^3 - m} = AI_{gm_2gm_1}$$

where d_i is distance of the ranks between R_{gm1} and R_{gm2}, m is the number of alternatives. In this way, an agreement matrix can be constructed. This is proved to be very useful for the analyst and facilitator, as he will keep in mind the assistance in the identification of participation subgroups with common features and common view of the problem. This can provide a better understanding of the decision problem and a more successful negotiation.

It should be noted here, that in the "agreement" test between two members of the group, and also in the calculation of the ISP, rarely the complete rank is interesting, the interesting is the positioning of the alternatives that appear in the first places in the rank orders and therefore can be selected. For this reason, the analyst and facilitator can (or should) limit the set of alternatives taking in account.

Summarizing, the analyst examines if the consensus is reached, mainly with the GSI. In the case is not reached, and depending on the other indices, the previous steps of the methodology must be repeated. Therefore, next modifications are possible:

- Modification of the criteria weights,
- Modification of the thresholds,
- Addition of new alternatives / subtraction of the existent ones.

- In case of dead-end, addition of new projects of modalities that will act as referees can also be accepted.

The exact decision that the modification must be suggested should be carried out by the analyst and facilitator who have a global vision of the decision problem. The use of a computer group-DSS (GDSS) where all the modifications could be entered on-line and the decision outcome would be produced immediately (together with satisfaction indices) will support the analyst/facilitator and the consensus reaching process as a whole.

2.4 Analysis of each methodology

The structure of the considered decision problem consists on a number *H* of alternatives and a number *N* of criteria decision. With these pertinent data, as was described above, it will be possible to construct a decision matrix. Since this decision matrix is created, the decision problem is how to determine which is the best alternative or to sort the whole set of alternatives.

In a simple MCDM situation, all criteria are expressed in terms of the same unit (for example, dollars). However, in the real life (and also in this concrete case of the Project Monitoring Portfolio) many MCDM problems different criteria can be expressed in different dimensions (units). Examples of these kinds of dimensions are the ciphers in dollars, the weight, the time, the politic impact, environment impact, etc. These kinds of problems with multiple dimensions make the typical MCDM problem more complex.

Taking in account the previous data, the goal of the decision maker is to classify the alternatives. Alternatives are sorted according to their final preferences P_i $(i=1, 2, 3,\ldots, M)$.

Different multi-criteria methods have been applied to many kinds of real problems. The main methods can be classified according to the type of the decision model they apply. In many situations, the alternatives that could be considered are infinite. The use of multiple objective programming methods to solve these cases is very well known. However, in our case is recommendable to make use of discrete MCDA techniques as in our case the number of alternatives is finite, even the quantity of alternatives is big. It will be given in this chapter an analysis of each methodology.

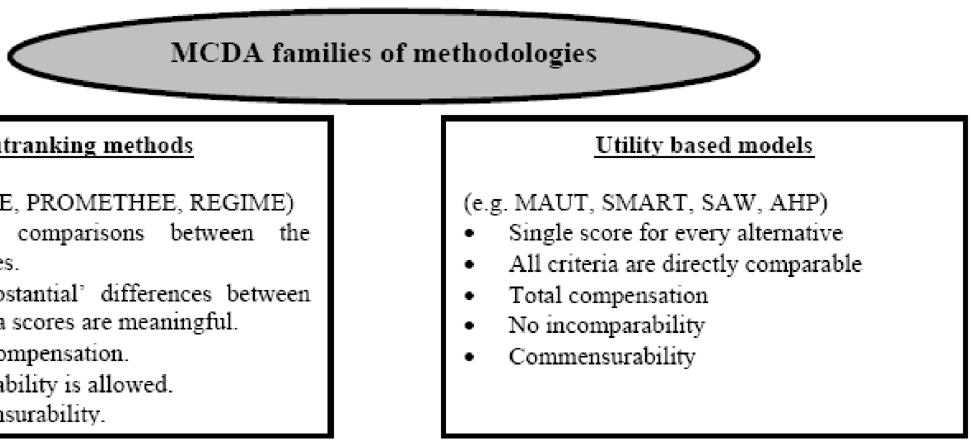

Figure 11 Main MCDA families

The main families of methodologies include:

A. Outranking methods, like the ELECTRE family (Roy, 1990) and the PROMETHEE I and II methods (Brans & Vincke, 1985).
B. Utility function-based methods, like the Analytic Hierarchy Process (AHP) (Saaty T. L., 1980), and
C. Other methods like Weighted Sum Model (WSM), Weighted Product Model (WPM) (Triantaphyllou, 2001)

A question arises now on how can be chosen an appropriate method for a specific decision problem?

Many of the MCDA methods have some of the requisites explained in the previous chapters, but any method is able to incorporate all of them at the same time. Especially the condition of temporal dimension in analysis seems to escape to the researcher's attention. This is thought to reduce the applicability of the MCDA methods. To include the time-varying of the criteria weights, a framework which incorporates Integrated Assessment, Transition Management and Multi-Criteria Analysis was recently proposed. However, does not exist any explicit MCDA technique which originally operates with the temporal dimension and this subject is considered to need more research.

Also, new methods could be developed to deal the complex nature of real problems and the decision making. The analysis of real applications could show the disadvantages of the procedures and could imply modifications or new schedules that would improve the methodologies.

In order to know which of the whole set of MCDA methods will fit better with the given problem, a detailed analysis of each one of the methodologies will be make. This analysis will be focused to study the advantages and disadvantages of each one of the methods. Therefore, it will be possible to know that is the MCDA method that will be better to apply to the problem.

2.4.1 Analysis of the WSM method

Probably the simplest one, this Weight Sum Model method is the widest used in the MCDM methods. The preference P_i of the alternative A_i $(i = 1,2,3,\dots, M)$ is calculated according to the next formula:

$$P_i = \sum_{j=1}^{N} a_{i,j} W_j, \qquad for\ i = 1, 2, 3, \dots, M.$$

Then, in the maximization case, best alternative is that one which has the biggest preference value. The supposition on which this model is based on is the additive utility supposition. However, the WSM must be used only when the decision criteria can be expressed in equally measure units (for example, only dollars, or only pounds, or only seconds, etc.).

2.4.2 Analysis of the WPM method

The Weighted Product Model (WPM) is very similar to the WSM. Main difference is that instead of addition this model uses the multiplication. Each alternative is compared with all of the rest ones, by multiplying a number of ratios, one for each criterion. Each ratio is raised to the power equivalent to the relative weight of the correspondent criterion. In general, in order to compare alternatives A_p and A_q (where $M \geq p, q \geq 1$) the next product (Chen & Hwang, 1999) must be calculated:

$$R\left(\frac{A_p}{A_q}\right) = \prod_{j=1}^{N} \left(\frac{a_{p\,j}}{a_{q\,j}}\right)^{W_j}$$

If the relation $R\,(A_p / A_q)$ is bigger or equal than one, then the conclusion is that the A_p alternative is more desirable than the A_q alternative (in the case of maximization). The best alternative is the one that is better or at least equal than all the rest of alternatives. The WPM is sometimes called dimensionless analysis because its structure eliminates all the measurement units. Therefore, the WPM can be used in the individual decision making and multidimensional problems.

2.4.3 Analysis of the AHP method

This method can be used by persons that work in the direct decisions. However, the Analytic Hierarchy Process (AHP) is more useful than the teams composed by persons that are working in complex problems, specially those ones with high stakes, involving human perceptions and judgments, whose resolutions have long-place repercussions. The AHP has unique advantages when the main elements for the decision are difficult to quantify or to compare, or when the communication between the members of the team becomes difficult because of their different specializations, terminologies, or perspectives.

Decision situations on which the AHP can be applied are:

- **Option:** Selection of an alternative from a set of alternatives, in general where several decision criteria are involved on.
- **Classification**: Establish a set of alternatives with the purpose to sort them from the most desirables to the less ones.
- **Priority establishment**: Determine the relative merit of a set of alternatives, instead of choosing an only one or merely ranking them.
- **Resources allocation**: Calculation resources among a set of alternatives.
- **Benchmarking**: Comparison between processes in the very organization against other organizations, the best ones of their class.
- **Quality management**: Dealing the quality multidimensional aspects and improvement of quality.

There are thousands of applications of the Analytic Hierarchy Process to complex decision situations, and have produced wide results in the planning problems, resources assignment, priorities establishments and selection between several alternatives. Other areas have included previsions, total quality management, business process engineering, quality function deployment, and the Balanced Scorecard. In general, many of the AHP applications are never shown to the world, because they will be carried out at the highest levels of the big organizations where the security and privacy conditions forbid their divulgation. But some of the uses of the AHP are discussed in the literature. Recently, these ones have been:

- Deciding the best way to reduce the impact of the global climatic change (Fondazione Eni Enrico Mattei).
- Quantification of the global quality among the software systems (Microsoft Corporation).

- Selection of university professors (Bloomsburg University of Pennsylvania).
- Evaluation of risks in the operating cross-country petroleum pipelines (American Society of Civil Engineers).
- Deciding the best way to manage the U.S. watersheds (U.S. Department of Agriculture).

AHP is sometimes used in the very specific procedures design for particular situations, like the classification of buildings according to their historic importance. It was recently applied to a project that uses video sequences, in order to evaluate the state of the Virginia's highroads. Highroad engineers used this method first to determine the optimum scope of the project, and then, to justify their budget to legislators.

The AHP is included nowadays in most of the operations research and science textbooks management, and is taught in many universities. Moreover, is used so much in the organizations that have carried out detailed researches on its theoretical funds. The general consensus is technically valid and useful in practice, but this method has its critics.

In the beginning of 1990 a series of debates between critics and defenders of the AHP was published in Management Science and The Journal of the Operational Research Society. These debates seem to have resolved in favor of the AHP:

- An in-depth paper discussing and rebutting the academic criticisms of AHP was published in Operations Research in 2001.
- A 2008 Management Science paper reviewing 15 years of progress in all areas of Multi-criteria Decision Making showed that AHP publications have overcome in number to any other methodologies, qualifying its grow as "enormous".
- Also in 2008, the international society in the area of operations research and sciences management recognized the wide impact of the AHP method at its fields.

Occasional criticisms are still appearing. A document in 1997 examined possible flaws in the verbal scale often used in AHP pairwise comparisons. Another, in the same year affirmed that inoffensive changes to the AHP model can introduce order where no order exists. A 2006 paper found that the addition of new criteria can alter the priorities of the alternatives.

The decisions making implies classification of alternatives in terms of criteria or attributes of those criteria. An axiom of some decision theories (including AHP) is that when new alternatives are aggregated to a decision problem, the ranking of the old alternatives must not change – that "rank reversal" must not occur.

Validity of this hypothesis is discussed by some people. Addition of new alternatives can change the rank of the old ones. These rank reversals do not occur frequently, but the possibility this can occur has important logic implications of the used methodology to the decisions making, the underlying assumptions of several decision theories, etc.

The presidential elections of the U.S. in 2000 are an example of a decision that can be understood like a case of rank reverse. Ralph Nader was an 'irrelevant' alternative, in that he was dominated both democrat and republic candidates. However, since he engaged more votes from those ones that voted to the democrats instead of republicans, his presence caused the ranks to reverse. In another way, if Nader wouldn't have been in the race, it is widely accepted that Al Gore would have won.

There are two schools of thoughts about the rank reverse. One of them establishes that new introduced alternatives without additional attributes must not cause the rank reverse at all. The other one establish that there are two situations on which the rank reverse is not reasonable; also there are situations on which rank reverse is possible. Current version of the AHP can accommodate these two schools – its Ideal Mode preserves rank, while it's Distributive Model allows the ranks to change. Either mode is selected according to the proper problem.

Rank reversal and ideal alternative was widely debated in the document mentioned above, Operational Research. Also, was debated in a chapter entitled Rank Preservation and Reversal, in the basic book in AHP. This last one published examples of rank reverses due to the copies of an alternative, due to the intransitivity of decision rules, due to addition of phantom and decoy alternatives, and due to the changing phenomenon in the utility functions. Also, the Distributive and Ideal Modes of the AHP is discussed.

2.4.5 Analysis of the ANP method

The Analytic Network Process (ANP) is a more general form that the Analytic Hierarchy Process (AHP) used in the multi-criteria decision analysis.

AHP structures a decision problem in a hierarchy with one goal, the decision criteria, and the alternatives, while the ANP structures the decision problem like a net. Both then use a system of pairwise comparisons to measure the weights of the components of the structure, and finally to rank the alternatives in the decision.

In the AHP, each element of the hierarchy is considered to be independent of all of the rest, the decision criteria are considered to be independent between them, and alternatives are considered to be independent on the decision criteria and on the other alternatives. But in many cases of the real world, there exist interdependence between the items and the alternatives. ANP does not require interdependence between elements, so it can be used as an efficient tool in these cases.

In order to illustrate this, a simple decision about the buy of an automobile can be considered. The decision maker can decide between some sedans full-sized with moderate prices. The decision maker could base his decision in only three factors: buying price, the security and comfort. Both the AHP and the ANP provide useful frames to use in the decision making.

The AHP could suppose that the buying price, security and comfort are independent among them, and to evaluate each one of the sedans in an independent way in these criteria.

The ANP will let consider the interdependence of prices, security and comfort. If it would be possible to get more security or comfort by paying more for the automobile (or less, by paying less), the ANP would take this into account. In the same way, the ANP could let the decision criteria to be affected by the features of the different cars. If, for example, all cars are very, very secure, the importance of the security as an adequate decision criterion could be reduced.

2.4.6 Analysis of the ELECTRE methods

Despite of the fact that there are several versions of the ELECTRE method (in the previous section [Chapter 2.3.5.1] the ELECTRE I, ELECTRE II, ELECTRE III, ELECTRE IV, ELECTRE TRI and ELECTRE IS methods were introduced) all of them have many characteristics in common. Different versions of the first ELECTRE method add to this one some improvements in the exploitation of data phase.

Therefore, in spite of the existence of several versions of the ELECTRE method, all of them have almost the same properties and are suitable to work in projects with the same particular properties. Many authors have discussed about the kind of projects on which the ELECTRE methods (independent of the version that will be used) are more suitable to work with.

According to José Ruiz Figueira et al. (Figueira, Greco, & Ehrgott, 2005), ELECTRE methods are relevant when facing decision situations with the following characteristics:

1- The Decision Maker (DM) wants to include it the model at least three criteria. However, aggregation procedures are more appropriate in those models on which more than five criteria are wanted to be included (up to twelve or thirteen).

And, at least one of the following situations must be verified:

2- Actions are evaluated (for at least one criterion) on an ordinal scale or on a weakly interval scale. These scales are not suitable for the comparison of differences. Hence, it is difficult and/or artificial to define a coding that makes sense in terms of preference differences of the ratios $\frac{g_j(a)-g_j(b)}{g_j(c)-g_j(d)}$, where $g_j(x)$ is the evaluation of action x on criterion g_j.
3- A strong heterogeneity related with the nature of evaluations exists among criteria (for example, duration, noise, distance, security, cultural sites, monuments …). This makes it difficult to aggregate all the criteria in a unique and common scale.
4- Compensation of the loss on a given criterion by a gain on another one may not be acceptable for the DM. Therefore, such situations require the use of non-compensatory aggregation procedures.
5- For at least one criterion the following holds true: small differences of evaluations are not significant in terms of preferences, while the accumulation of several small differences may become significant. This requires the introduction of discrimination thresholds (indifference, preference and veto, which where mentioned in the previous section of this thesis) which leads to a preference structure with a comprehensive intransitive indifference binary relation.

2.4.7 Analysis of the PROMETHEE methods

Last decade has experienced a growing number of publications referred to the Multi-Criteria Decision Support Systems on which new and interesting methods are proposed.

This researching field is getting enriched with the pass of the years and is getting more the improvements on this field. All these methods solve the very basic problem but they differ according to the additional information that they require. Advantage of the PROMETHEE Methods against the rest of its competitors is that the additional information that it requires is very clear and concise, this information can be easily gotten by the decision maker with the constant and active help of the analyst.

PROMETHEE Methods were developed and carried out in practice in order to resolve multi-criteria problems where the set of alternatives, A, is a finite set of feasible alternatives. In this case, the decision maker has to deal with a decision matrix.

Is important to remark that the matrix must always be ready for possible evolutions, this means that additional alternatives must be considered as a bigger amount of information are gotten during the decision process progress, new evaluation criteria or the temporal elimination of others. Structuring of the matrix is making in a progressive way and because of that, normative, constructive, descriptive and prescriptive arguments must be considered.

The additional information required by the PROMETHEE Methods consists on:

- Information between the different criteria (inter-criteria)
- Proper information of each criterion (intra-criterion)

Information between different criteria consists on the establishment of weights that will reflect the relative importance of each one of them. Therefore, a criterion will be more important than another one when the value of its weight will be bigger. Weights are supposed to be always positive.

The work of the determination of weights is not trivial or simple. Because of the strength of the existent subjective component, it can be assert that the selection of weights is the “freedom space” of the decision maker, that is to say, that scope on which the decision maker can freely express his preferences according to the structure of the criteria he has in mind.

The proper information of each criterion refers to the way on which the decision maker perceives the specific scale that each criterion is expressed in. For each criterion a particular preference function $P_j(. , .)$ is defined. This function indicates the preference degree associated to the best alternative in the case of binary comparisons, according with the deviation between the evaluations of the alternatives to that particular criterion. Therefore, for small deviations the decision maker will assign a reduced preference to the best alternative, while for big deviations the preference will be bigger. In this way, in the PROMETHEE Methods is suggested to modify the modelling of the decision preferences, by considering for each criterion, some possible extensions. These extensions receive the name of generalized criteria.

The preference functions allow converting the deviations observed in the scale for a specific criterion into preference degrees that are independent to the scales.

In order to support the decision maker in the selection of these preference functions six basic types have been purposed (Brans, 1982) (Brans & Vincke, 1985) (Brans, Vincke, & Mareschal, 1986). Is the decision maker who decides which one of the different types is going to be used and which one is going to be the value of the correspondent thresholds. In general, is considered that both the nature of criteria and the value of the thresholds can be established according to the economic significance associated to them in each particular case.

Also is considered that the six types published in the literature are enough to solve most of the real practice cases. More sophisticated functions could be considered, but in any case, is the analyst the one who must help the decision maker in order to evaluate the associated parameters in an economical meaning way.

2.4.8 Analysis of the MURAME method

As was mentioned in previous sections, MURAME method is a hybrid of the ELECTRE III and the PROMETHEE methods. MURAME carries out its methodology for the decision problems by combining the advantages of each one of these two methods.

Therefore, in the first phase, the aggregation phase, the MURAME constructs the outranking relation following, that is, the defining of the criteria, their weights and the value of the thresholds (concretely, the indifference, preference and veto thresholds). The way on which the Decision Maker defines these values in the MURAME method is by following the ELECTRE III technique.

In the second phase, the exploitation phase, all the calculations made to the outranking relation constructed in the first phase are made. Calculations of flows are then made in MURAME by following the PROMETHEE method.

As both ELECTRE III and PROMETHEE methods are outranking methods inside the family of the MCDA families of methodologies, the MURAME method can also be considered a method of the family of the MCDA outranking methodologies.

Outranking methods are seemed to be very popular for most kind of problems. For example, outranking has been used in many evaluations of alternative strategies. In fact, the most popular outranking methods on these evaluations have been the different versions of PROMETHEE (Diakoulaki & Karangelis, 2007) (Tzeng, Shiau, & Lin, 1992) (Georgopoulou, Sarafidis, & Diakoulaki, 1998) and ELECTRE (Siskos & Hubert, 1983) (Beccali, Cellura, & Ardente, 1998) (Beccali, Cellura, & Mistretta, 2003) (Georgopoulou, Lalas, & Papagiannakis, 1997) (Capros, Papathanassiou, & Samoulidis, 1988) (Assimakopoulos, Charalambopoulos, & Samoulidis, 1991).

The use of the MURAME method, as hybrid of the ELECTRE III and PROMETHEE, has been significantly more reduced that such these methods. One may reason is that the MURAME method is not as widely known by analysts and other possible manager like different versions of the ELECTRE and PROMETHEE methods. However, the MURAME method has been applied successfully in some real-world decision problems. One example of its use was the ranking of projects in the Armenian Energy Sector (Goletsis, Psarras, & Samoulidis, 2003).

Goletsis et al. (Goletsis, Psarras, & Samoulidis, 2003) think that one of the main advantages of the outranking focus is that these methods (on which the MURAME method is included) require less information from the Decision Maker than other MCDA methods. MURAME even works when some information or evaluations are missing. Other authors like Georgopoulo et al. (Georgopoulou, Sarafidis, & Diakoulaki, 1998) (Georgopoulou, Lalas, & Papagiannakis, 1997) and Haralambopoulos (Haralambopoulos & Polatidis, 2003) have focused on other advantages of the outranking methods. Moreover, authors think that the way on which results are represented in the outranking methods like the MURAME is simpler and easier to understand than results provided by another MCDA methods, like AHP.

A main difference between MURAME (and other outranking methods) and the rest of methodologies are the calculation procedure. PROMETHEE (and so MURAME method) provides a transparent calculation procedure, so then is easy to understand and accept by decision makers (Georgopoulou, Sarafidis, & Diakoulaki, 1998) (Haralambopoulos & Polatidis, 2003), while decision makers often find calculations in ELECTRE III too much complex and incomprehensible. Consequently, ELECTRE method is finally seen like a 'black box' by the decision makers, which see this method not very satisfactory.

MURAME, as a hybrid between ELECTRE III and PROMETHEE methods does not constitute such a complex calculation procedure. The reason is that MURAME is a methodology implemented from the ELECTRE method, but in difference with ELECTRE, the calculation procedure (the exploitation phase) is implemented in MURAME from the PROMETHEE method, which, as mentioned before, provides a simple and understandable calculation procedure. Therefore, MURAME method includes the advantages of the outranking MCDA method ELECTRE III, but excludes the disadvantages underlying its calculation procedure, so it can be understood and accepted by decision makers.

2.4.9 Combination of methods

The purpose of this section is to provide a brief analysis of the possible combinations between the methods mentioned in previous sections. As the MURAME method is a hybrid between the ELECTRE III and PROMETHEE methods, other hybrid methods can result by the combination of two other MCDA methods. In the last years, some authors proposed new MCDA methods by the combination of two popular methodologies, while others have carried out some publications on which they analyse the advantages and disadvantages of these new proposed methods.

As it is being mentioned, some researchers have tried to combine the use of different MCDA methods. AHP has been a very popular choice in order to combine with other methods. Tzeng et al. (Tzeng, Shiau, & Lin, 1992) studied the combination of the AHP and the PROMETHEE II, while Yang and Chen (Yang & S.L., 1989) combined the AHP and the TOPSIS methods (TOPSIS method was not explained in this thesis as it was not considered one of the main MCDA methods that have been published in the last years) in their evaluations of energetic strategies. Ramanathan and Ganesh (Ramanathan & Ganesh, 1995) combined the AHP and the GP methods (GP method was not explained in this thesis because of the same reasons than the TOPSIS method) into a one that they called weighted sum of deviations in order to solve an energy resources assignation problem in India.

An appropriate combination of two (or more) methods could be a very good strategy. This kind of integration can make use of the strengths of both methods. On the other hand, in spite of both methods have some limitations, their limitations can be complementary. Ramanathan and Ganesh (Ramanathan & Ganesh, 1995) argue that the GP and the AHP are appropriate for a combination to solve a resources assignation problem. It is possible that adequate combinations of MCDA methods also can be found in other kind of problems in order to provide a satisfactory solution of the decision problem.

Therefore, although there are a lot of possible combinations between two or more MCDA methods into one in order to eliminate the disadvantages of each one of them, there are not many publications or studies about the combination of methods. So, for the purpose of this thesis the only MCDA hybrid method that will be considered is the MURAME method, as some publications and examples carried out successfully are available in the literature. Taking in account hybrid methods on which there is not enough information is considered to be risky considering the purpose of this thesis.

2.5 Comparison between each multi-criteria method

Once the analysis of each MCDA method has been exposed in the previous sections, the purpose of this chapter is to compare the different methods that have been carefully explained in this thesis. The purpose is to simplify the task of deciding which one, from all the MCDA methods, is the most appropriate to use in the project on which this thesis is focused.

2.5.1 The WSM and the WPM methods

According to the analysis of the Weighted Sum Model and the Weighted Product Model methodologies provided in the previous sections, and with the publications made in the last years by many authors, like Evangelos Triantaphyllou (Triantaphyllou, 2001), these methods are probably the most commonly used all over the world, especially in single dimensional problems.

The most important property of these two approaches is the simplicity of their methodology, which basically consists on assign a concrete value to each alternative. So then, the ranking of alternatives is a quite easy task.

The main, and the only one, difference between these two methods is that the WPM instead of addition in the model there is multiplication. So each alternative is compared with the others by multiplying a number of ratios, one for each criterion (Triantaphyllou, 2001).

Both the WSM and the WPM methods are specially thought for single-dimensional problems. Difficulty with these methods emerges when they are applied to multi-dimensional problems. The reason is that, when different dimensions are combined, the additive (or productive in the case of the WPM method) assumption is violated. This disadvantage results to be a quite big problem for the case that is being considered in this thesis as a set of criteria measured in different dimensional units is given. Therefore, this disadvantage doesn't place these methods in a good situation in order to select them to carry out the problem described here.

But the biggest disadvantage of these two methods is that they cannot work with missing values. This means that if the value of an attribute of the whole set of alternatives is missing; these methods will not be able to work. As in the problem which this thesis is focused on, many values of the attributes provided are missing, it can be said that the use of both the WSM and the WPM is not a good idea.

Taking in account these two big disadvantages that the WSM and the WPM have, the use of any of these methodologies to carry out the task described in this thesis is refused.

Therefore, the reason for which these methods are refused is, basically, because they will not be able to work with the information of the alternatives provided. Moreover, it will not be necessary to compare these methods with the other ones exposed in this thesis as is already known that is not possible to use them in order to perform the ranking of the projects, which the task that is wanted to carry out.

2.5.2 Utility Based Models and Outranking Methods

In order to compare the rest of the MCDA methods, the most simple and clear way to carry out this task, is by comparing and analysing in a general way the main properties of the MCDA methodological families on which the other methods, explained in the previous sections, belong.

In this way, the purpose of this section is to analyse and compare the *utility based models* (MCDA family on which the ANP and the AHP methods belong) and the *outranking methods* (methodological family on which the ELECTRE, the PROMETHEE and, hence, the MURAME methods belong).

2.5.2.1 Utility Based Models

2.5.2.1.1 Main Features

According to E. Løken (Løken, 2007), in the utility based models (also called *value-measurement methods*), a numerical value (or score) V is assigned to each alternative. These values produce a preference order of the alternatives so that a

is preferred to *b* if and only if *V(a)* > *V(b)*. When this focus is used, the DM defines a set of pertinent criteria for the planning problem. For each *i* criterion, a partial v_i value function that reflects the performance in the considered *i* criterion must be defined. The partial value function must be normalized to a proper scale (for example, 0-100). The different parameters takes scores that represent their partial contribution to the global score, based on the importance that the DM assigns to each criterion. Criteria weights must indicate how much the DM is willing to accept in the trade-off between criteria. Due to poor performance values on some criteria, utility based models are also known as compensatory methods (Linkov, Satterstrom, Kiker, Batchelor, Bridges, & Ferguson, 2006). Use of the utility based models supposes that the DM is able to provide precise answers to a wide spectrum of preferences obtaining questions (Belton & Stewart, 2002) (Catrinu, 2006) (Stewart, 1992).

In most utility based models, it is common to suppose that the additive form of the multiple attributes value function can be used to measure the DM's preferences. Utility based models are more intuitive and easy to understand and construct than alternative models. However, the use of additive utility functions is only valid if the criteria are preferentially independent. Preferential independence means that the DM is "able to express his preferences and needs between achievement levels in a criteria sub set, in the case that progress levels over other criteria are fixed, without the need of worrying about these fixed achievement levels are". The alternative with the highest total value is chosen.

The Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP) methods, which have been described in the previous sections of this thesis, are included in this MCDA methodology family. Comparison between these two concrete methods is exposed in the following lines.

2.5.2.1.2 Analytic Hierarchy Process (AHP) vs. Analytic Network Process (ANP):

The Analytic Hierarchy Process (AHP) for the decision making uses objective mathematics to process the inevitable subjective and personal preferences of an individual or a group in the decision making. With the AHP, hierarchies with a first level of strategic or politic criteria are constructed, then, each one of these criteria, is expanded, like branches, in more specific sub-criteria until reach the terminal criteria, the behaviour indicators.

By the other hand, the Analytic Network Process (ANP) is an extension of the mathematical theory of the AHP. Here, feedback process and all kind of relations are admitted. ANP has clusters of elements connected in nets instead of having the elements placed in levels. Any element can be connected to other ones that have influence on it. Once the model is constructed, judgements about the elements that can influence to a specific one are made. Then, the super-matrix limit is calculated, relation scales are derived. Finally, the ANP prioritizes in a form that reflects all the different interactions between groups, nodes and alternatives. This process has a higher level of strategic hierarchy which controls all the benefit, cost, risk and opportunities of subnets, which the specific shiftwork may need.

2.5.2.2 Outranking Methods

2.5.2.2.1 Main Features

In the outranking methods, it is assumed that the DM cannot (or doesn't want) define the tradeoffs between the criteria (Daellenbach, 2005). Consequently, these methods cannot suppose that a low performance in a criterion can be compensated by any enough good value scores in other criteria, like in the utility based methods.
In the outranking approaches, alternatives are pair-by-pair compared in order to determine which one of both alternatives is preferred for each criterion. The result of the comparison is an outranking relation between alternatives. By aggregating outranking relations of all pertinent criteria, the model allows to determine in which measure one alternative is situated over the other one. It can be said that an alternative *a* outranks another alternative *b* if there is enough prove to conclude that *a* is at least as good as *b*, and there is any strong evidence to prove the opposite, if all criteria are considered (Belton & Stewart, 2002).
Methods based on this way of think are usually called the French (or European) decision school of multi-criteria decisions. The two main methodology families in the French school are ELECTRE and PROMETHEE, which have already carefully explained in the previous sections.
The outranking approach is based on less restrictive assumptions than utility based methods, and requires less precise inputs for describing the criteria and preferences (Belton & Stewart, 2002). Consequently, these methods can correspond better to the way the DMs think.

Outranking techniques are especially useful if the values of performance alternatives are not easily aggregated or if the measure scales vary in wide ranges (Linkov, Satterstrom, Kiker, Batchelor, Bridges, & Ferguson, 2006). In many cases, outranking methods are not used for the selection of real alternatives, but just for the initial selection process (to classify alternatives as acceptable or unacceptable) for those cases on which these methods are appropriate (Greening & Bernow, 2004). After the selection process, another method can be used to obtain a complete suggests classification or real among alternatives.

Therefore, unlike utility based models like the AHP and ANP, outranking methods is based on the principle that an alternative can have a dominance degree over another (Kangas, Kangas, & Pykalainen, 2001). As it was explained in the above, dominance is produced when one option is better performed than another one in at least one criterion and is not worse than the other in all the criteria (ODPM 2004). However, outranking techniques don't presuppose that only one best alternative can be identified. Outranking methods compare two (or more) alternatives at a time, initially in terms of each criterion, to identify the degree on which some criteria are preferred than others. Outranking methods, aggregate information techniques on their preferences over all the proper criteria, and tries to strength the selection proves in favour of one alternative over another. For example, an outranking technique may suppose favouring the alternative that performs better in the highest number of criteria. In this way, outranking techniques allow a lower performance in some criteria to be compensated for by superior performance on others. Outranking techniques are specially appropriated when criteria metrics are not easily aggregated, measure scales vary in wide ranges, and units are disproportionate or unique (Seager, 2004).

2.5.2.2.2 ELECTRE vs. PROMETHEE:

The ELECTRE (ELimination Et Choix Traduisant la REalité) methodology family was developed like an alternative to the utility based methods. More detailed information about the ELECTRE methods can be found in (Roy B. , 1996). The most common ELECTRE method in real-world problems seems to be ELECTRE III, so in this comparison between the ELECTRE and the PROMETHEE methodologies only the ELECTRE III will be considered. The main idea in ELECTRE III is to choose alternatives that are the preferred ones for most of the criteria. However, alternatives which are very unfavourable for any of the criteria must not be chosen, even if the alternative is favourable for all of the rest criteria. This method, as was explained in the previous sections, makes use of the *indifference thresholds* and the *strict preference thresholds*. Remember that these thresholds are used to calculate the concordance and discordance indices, which can be used to calculate the graphics of strong and weak relations. These graphics are used to classify alternatives through a n iterative process. This method sometimes is not able to find the “best alternative”. However, often is useful to apply the ELECTRE III method, in the beginning of the decision process in order to produce a list of the best alternatives. These alternatives can be dealt throughout a new analysis with any other, more detailed method (Belton & Stewart, 2002) (Pohekar & Ramachandran, 2004).

The other alternative approach, exposed in this thesis, is the outranking PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) methods family, developed by Brans and other work companions (Brans, Vincke, & Mareschal, 1986). In this approach, as explained in previous sections of this thesis, pair-by-pair alternatives comparisons are carried out in order to find a preference function for each criterion. Based on the preference function, a preference index for *a* over *b* is determined. This index is a supporting measure of the hypothesis that *a* is preferred to *b*. This index is defined like the weighted average of the individual criteria preferences. This preference index is used in PROMETHEE to make a value outranking relation, which determines a hierarchy of alternatives (Belton & Stewart, 2002) (Pohekar & Ramachandran, 2004). The most popular versions inside the PROMETHEE methodology family are the PROMETHEE I and II. The main difference between these two methods is that the PROMETHEE I obtains a partial preorder for solving the order problem, while the PROMETHEE II obtains a complete preorder.

2.5.2.2.3 The MURAME Method:

As already was explained in this thesis, the MURAME method is an outranking MCDA method that is a hybrid of the ELECTREE III and the PROMETHEE methods. As an outranking method, MURAME has the same main properties that the PROMETHEE and ELECTRE methods. Therefore, like PROMETHEE and ELECTRE, the MURAME method doesn’t presuppose that only one best alternative can be identified. Moreover, as an outranking method, MURAME compares two (or more) alternatives at a time to identify the degree on which some criteria are preferred than others. MURAME, also, is specially appropriated when criteria metrics are not easily aggregated, measure scales vary in wide ranges, and units are disproportionate or unique as it belongs to the outranking method family.

A main difference between the outranking methods is the calculation procedure. PROMETHEE II and MURAME have a transparent calculation procedure, which is easy to understand and accept for the DMs (Georgopoulou, Sarafidis, & Diakoulaki, 1998) (Goletsis, Psarras, & Samoulidis, 2003), while the DMs sometimes find calculations in ELECTRE III too much complex and incomprehensible.

Finally, it must take in account that the MURAME method, as a hybrid between the ELECTRE and PROMETHEE methods, does not present the same disadvantages than these ones. That is, MURAME combines these two methods performing a methodology in order to complement the disadvantages of ELECTRE and PROMETHEE. Therefore, the idea of MURAME is to choose the alternatives that are the preferred ones for most of the criteria according to the ELECTRE III method. Hence, alternatives which are very unfavourable for any of the criteria must not be chosen, even if the alternative is favourable for all of the rest criteria. Hence, as was mentioned above, one of the problems of the ELECTRE III is the complexity of the calculations. For this reason, MURAME includes a second phase, the exploitation phase on which calculations are made, which is based on the PROMETHEE method, because these calculations are easier to understand and accept by the decision makers.

Therefore, due to the fact that the MURAME method combines the ELECTRE and PROMETHEE methods in order to eliminate their respective disadvantages, it can be said that between these three methods (ELECTRE, PROMETHEE and MURAME), the one which performs in a better way is the MURAME method.

2.6 Conclusion

A variety of experiments, for example (Hobbs & Meier, 1994) (Hobbs, Chankong, Hamadeh, & Stakhiv, 1992), have proved that the choice of the method may have a significant influence in the decision result. According to Hobs et al. (Hobbs, Chankong, Hamadeh, & Stakhiv, 1992), the choice of the method is as much important, or evens more, than the person who is using the methods. There are many possible explanations for these differences, the DM may not understand completely the method, or some methods may not offer a valid representation of the DM's preferences.

2.6.1 Choosing an MCDA method

Choosing a MCDA method means to choose a compensation logic (Guitouni & Martel, 1998). This may be a difficult choice, so there are many criteria to take into account (Hobbs, 1986). Between the most important ones is validity, that is, that the method measures what is supposed to be measured. Different methods can provide different results, so the method that reflects the 'true values' of the user with the highest possible precision in case of be chosen. However, is important to be conscious that different persons have different ways to think and to express the values (Hobbs & Meier, 2000). Consequently, the most appropriate method for a DM is not necessary as valid for other DMs as well. Another important property is the adequacy of the method, that is, that the method is compatible with the provided data and that the DMs can provide to the method all the information that it needs. The MCDA method must be also easy to use and to understand, even for the non-experts. If logic behind the method is not transparent, a DM can perceive the methodology like a black box. The result may be that the DM does not trust in the recommendations of the method. In this case, it has no sense spend time applying the MCDA method.

In practice, the choice of the method usually depends on the DM's and analyst preferences. Consequently, the most important criteria for choosing the MCDA method are frequently the familiarity and affinity with a specific method (Guitouni & Martel, 1998). Consequently, instead of looking for the most appropriate method, the decision problem is adapted so that it fits to the DM's or analyst's favourite method. The result is that important limitations and underlying suppositions of methods are usually ignored.

The choice between the existent MCDA methods can be said to be a multi-criteria problem in itself. Each one of the methods have their own advantages and disadvantages, and is not possible to assert that anyone of them, in general, is more appropriated than another one. However, some methods are more appropriated if the uncertainty is the main problem, while other methods are more appropriated if values in conflict are more important (von Winterfeldt & Edwards, 1986). It is important to take into account that the use of different methods will probably give different recommendations.

2.6.2 Indentifying the appropriate method

Like has been mentioned in the last section, the choice of the MCDA method is a non-trivial task as the decision of the method that will be implemented can have an important influence on the decision result. So, the selection of the MCDA method is a decision problem in itself, that must be carried out in a detailed and carefully way.

Therefore, the selection of the MCDA method is the first main goal that is addressed in this thesis, which must be realized in detail. That is the reason for which several methods from different MCDA method families have been described in this thesis. Once the main properties and performance of each approach has been studied, as well as the analysis and comparisons between each methodology families (and also between the methods in themselves) has been realized, then it is possible to find out which one can be the method that will fit better to the problem on which this thesis is focused on.

First of all, remember that we can exclude the WSM and WPM methods as they are specially thought for single-dimensional multi-criteria problem and especially because these methods cannot work when for any attribute there are missing values (See Chapter 2.5.1). Taking into account that in the problem which this thesis faces, the criteria are multi-dimensional and there are several attributes with missing values, it is simple to realize that any of these two methods will be able to solve the problem which this thesis wants to solve.

Then, the decision problem is now to choose between a utility based and an outranking methodology family.

In the comparison between these two methodology families exposed in Chapter 2.5.1 was analysed the main properties of each one of these methods as well as the kind of problems on each one of these methodologies fit better in order to provide a satisfactory solution to the decision makers.

Therefore, utility based models assign a score to each one of alternatives enabling, hence, the ranking of alternatives. These methods are quite intuitive and easier to understand by the analysts and DMs. However, these methods assume that the DM is able to provide precise answers to a wide range of questions.

Unlike utility based models, outranking methods assume that the decision maker is not able to define tradeoffs between the criteria. In these approaches alternative are pair-by-pair compared to determine which one is the best for each criterion. When all comparisons are aggregated then it will be possible how much an alternative outranks another one for all the considered criteria. These methods are based on less restrictive assumptions than utility based methods and so, these methods correspond better to what the decision maker really thinks. Therefore, as also was mentioned in Chapter 2.5.1, outranking techniques are specially appropriated when criteria metrics are not easily aggregated, measure scales vary in wide ranges, and units are disproportionate or unique

In terms of the problem that this thesis faces, in the data provided by the European Commission to the DSS's laboratory, for the attributes of each alternative there are several values of different measure units (numbers, dates, words, codes, ...) that make the criteria difficult to be aggregated. Also, measure scales vary in wide ranges as for many attributes the values they can have are quite diverse. Also, as a data provided by an extern organism (in this case the data are provided from the EC) the DM may have some difficulties in order to give concrete answers to a big number of questions, what is a quite big disadvantage for the utility based methods.

Therefore, considering the problem to solve in this thesis, it can be said that the MCDA methodology family that fits better in order to provide a satisfactory solution for the problem is the outranking methods. As all the attributes of the data provided are not measured in the same kind of units and so, criteria are not easy to aggregate, this family of MCDA methodologies are the most proper for the problem described in the beginning of this thesis.

Then, the problem now is to decide which method among this methodology family is the most appropriate to implement for the problem tat is wanted to solve.

As exposed in Chapter 2.5.1.2, among the MCDA outranking methods, MURAME is the one that performs better according to the advantages and disadvantages of each methodology. The main difference between the outranking methods is the calculation procedure. As the calculations in ELECTREE are found to be quite complex for analysts and decision makers, the PROMETHEE and, hence the MURAME methods are preferred. Moreover, unlike PROMETHEE, MURAME can even work with missing values. Due to the fact that in the data provided there are many missing values for some criteria, the MURAME method is the one from these outranking methods that fits better to the properties of the considered problem.

In conclusion, taking in account the analyzes and comparisons carried out for each one of the different MCDA methodology families, and the main properties for each one of the methods among each method family it can be said that the MUlticriteria Ranking Method (MURAME) is the most appropriate method by considering the features of the described problem. Therefore, MURAME is the method that will be chosen to apply for the problem of this thesis and, according to the analysis that have been carried out; this method will be able to solve in a quite satisfactory way the given multi-criteria decision problem.

3. Proposed Methodology

The Chapter 2 presented a set of Multi-Criteria Decision Analysis systems that might carry out the problem described in the beginning of this thesis. Each MCDA method was explained, by describing the main features of the method and also detailing the development of each proper method. For the methods on which different versions are available (like the ELECTRE and PROMETHEE methods) each one of these versions were described, and also differences between these versions of each methodology were explained.

After the exposition of all the relevant methodologies that have been published and analysed by different authors in the last years, a comparison between these methods has been made (see Chapter 2.5). After analysing the WSM and the WPM methods, this thesis concluded that these two methods wouldn't provide a satisfactory solution for the problem considered in this thesis. So, the comparison was then made between the utility based methods and the outranking methods, as the other MCDA methodologies (unlike the WSM and the WPM methods) analysed here belong to one of these method families.

The performed comparison concluded that outranking methods fit better to the decision problem this thesis faces to, than the utility based models. Then, the problem was to select, among all the methods that belong to this methodology family, the one that might provide better results according to the purpose of the given problem that is wanted to solve.

Then, it was necessary to compare the ELECTRE, PROMETHEE and MURAME methods, as these methodologies are the main ones inside the outranking methods family. The comparison between these methods concluded that the MURAME method is the most appropriate to carry out the multi-criteria decision problem provided to the DSS's laboratory (see also chapter 2.5.2.2.3). As MURAME is a hybrid method of the ELECTRE and PROMETHEE, it excludes the main disadvantages of each one of these methods.

Therefore, once the method that is going to be used for solving the multi-criteria decision problem is known, the next step is to realize a detailed analysis of this concrete method (the MURAME) in order to know how it can be implemented, and the necessary steps that must be followed to perform a better implementation of the method. By performing a good analysis about how the implementation of a MCDA method must be carried out, the development of this method will become easier and the results provided by the methodology will be more satisfactory according to the necessities of the DMs.

Therefore, the purpose of this chapter is to perform a specific analysis for the MURAME method according to the given problem. So, in this chapter will be explained the different steps that must be followed to perform a satisfactory implementation of this method. This analysis will include also the different main criteria that will be considered for the multi-criteria decision problem, as well as the weights that will be given to each one of the different attributes by discussing their importance and the way they can help to solve the problem in a proper way according to the needs of the EC.

3.1 Introduction

Once the MCDA method that will be used is know, the next step (which is also the purpose of this section) is to describe how to apply the selected method, in this case the MURAME method, and to describe which steps should be followed as well.

As described in the Chapter 1 (Description of the Problem), the project proposals were collected from the EC, through the EuropeAid program. The source of information concerning projects, on which monitoring is wanted to carry out, is the CRIS database, a EuropeAid's database (see Chapter 1.2.2).

A big number (851) of project proposals coming from the EuropeAid program were identified.

All the necessary information about the projects must be available in order to be able to perform a ranking of the projects in order to decide which ones should be monitored. For this reason, all the proposals of projects are codified in a systematic way with the use of data sheets of the projects. In this way, the 851 projects have a uniform "appearance" providing then a better management and recovery of information.

A4 | Domain

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Selection criterion (criteria)														
2	DG = AIDCO F 03														
3															
4	Domain	Contract	Former syste	Contract	Status	Title	Delegation	Entity	Contract typ	Nature	Sub-nature	Type of servi	Contractor's	Expiry date	EC signat
5	CDC	2001	MAR/2001/1	48028	Ongoing	CDC/2001/4-		AIDCO F	Grant	Action Grants			28/09/2001	01/01/2004	
6	CDC	2001	MEX/2001/1	48032	Ongoing	CDC/2001/08 - "Renforcer		AIDCO F	Grant	Action Grants			18/10/2001	01/11/2003	01/10/2
7	CDC	2001	PLE/2001/14	48043	Ongoing	CDC/2001/30 - "Renforcer		AIDCO F	Grant	Action Grants			17/12/2001	01/10/2004	04/12/2
8	CRIS	1993	CHL/1993/21	72626	Ongoing	FUNDACION EMPRESARIA		AIDCO F	Grant	Not applicable					
9	DCI-EDUC	2007		142413	Ongoing	Annual Contribution to th		AIDCO F	Grant	Action Grant	D03		27/12/2007	31/12/2013	20/12/2
10	DCI-EDUC	2007		142419	Cancelled	Annual Contribution to the FTI Catalyti			Grant	Action Grant	D03			01/12/2011	
11	DCI-EDUC	2007		142420	Cancelled	Annual Contribution to the FTI Catalyti			Grant	Action Grant	D03			01/12/2011	
12	DCI-EDUC	2008		153661	Ongoing	Support to Education in E		AIDCO F	Grant	Action Grant	D03		22/12/2008	01/01/2011	19/12/2
13	DCI-EDUC	2008		153831	Ongoing	Contribution to Fast Track		AIDCO F	Grant	Action Grant	D03		05/11/2008	06/11/2010	31/10/2
14	DCI-EDUC	2009		200536	Decided	""Providing, keeping and		AIDCO F	Grant	Action Grant	D03			31/12/2012	
15	DCI-ENV	2007		139385	Closed	Organisation and co-ordir		AIDCO F	Implementa	Specific cont	A27	AT	18/06/2007	20/06/2007	18/06/2
16	DCI-ENV	2007		141300	Closed	Atelier en Kinshasa sur l"I		AIDCO F	Implementa	Specific cont	A27		30/07/2007	01/08/2007	30/07/2
17	DCI-ENV	2007		142620	Ongoing	Updating of publication m		AIDCO F	Specific cont	Services	A27		18/09/2007	31/10/2007	17/09/2
18	DCI-ENV	2007		143176	Ongoing	Support Study in view of t		AIDCO F	Specific cont	Services	A11		14/09/2007	30/04/2008	12/09/2
19	DCI-ENV	2007		143947	Cancelled	Analytical cooperation an		AIDCO F	Grant	Action Grant	D03			31/12/2004	
20	DCI-ENV	2007		145637	Closed	Assessment, 4 pillar verifi		AIDCO F	Specific cont	Services	A09		06/12/2007	31/03/2008	06/12/2
21	DCI-ENV	2007		146818	Ongoing	Cross-border flows of tim		AIDCO F	Specific cont	Services	A11		27/12/2007	30/06/2008	20/12/2
22	DCI-ENV	2007		146822	Ongoing	PROTECTION DE GORILLES		AIDCO F	Specific cont	Services	A11		19/12/2007	31/07/2008	19/12/2
23	DCI-ENV	2007		147214	Closed	Evaluation of the techical		AIDCO F	Specific cont	Services	A11	AT	28/12/2007	30/11/2008	27/12/2
24	DCI-ENV	2007		147331	Ongoing	""Management of a partic		AIDCO F	Grant	Action Grant	D01		12/12/2007	11/12/2009	12/12/2
25	DCI-ENV	2007		147567	Ongoing	Assessment of targeted p		AIDCO F	Specific cont	Services	A11		31/12/2007	15/05/2008	27/12/2
26	DCI-ENV	2007		147693	Ongoing	Water Knowledge Manag		AIDCO F	Grant	Action Grant	D02		21/12/2007	31/12/2008	21/12/2
27	DCI-ENV	2007		147722	Cancelled	Cross-border flows of tim		AIDCO F	Specific cont	Services	A11	ST		30/06/2008	

Projects managed by F3_1

Figure 12: Microsoft Excel document with the whole set of alternatives

Therefore, all the information about these 851 projects is collected in a spreadsheet, concretely in a Microsoft © Office Excel document. The Figure 12 and Figure 12 show the document available for the DSS's laboratory in order to perform a multi-criteria decision problem that will allow the laboratory to choose, among the whole set of projects, the ones that are more interesting to monitor.

A4 | Domain

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
829	SANTE	2004		80276	Ongoing	Averting Maternal Death		AIDCO F	Grant	Action Grants			07/12/2004	14/07/2008	26/11/200
830	SANTE	2004		81520	Ongoing	Partial Contribution to th		AIDCO F	Grant	Action Grant D02			29/04/2004	01/06/2005	19/04/200
831	SANTE	2004		85369	Ongoing	Amendment n°2 to Admir		AIDCO F	Grant	Action Grant D02			27/07/2004	31/12/2005	16/07/200
832	SANTE	2004		89265	Ongoing	Support for the UN Specia		AIDCO F	Grant	Action Grants			27/12/2004	02/01/2009	23/12/200
833	SANTE	2004		89285	Ongoing	Fourth Multilateral Initiat		AIDCO F	Grant	Action Grants			15/12/2004	31/12/2005	10/12/200
834	SANTE	2004		89735	Ongoing	Second Generation Surve		AIDCO F	Grant	Action Grants			07/12/2004	30/06/2008	23/11/200
835	SANTE	2004		89780	Ongoing	Country Analyses to Accel		AIDCO F	Grant	Action Grants			30/12/2004	31/12/2008	23/12/200
836	SANTE	2004		91041	Closed	Support for the Implemer		AIDCO F	Grant	Action Grants			27/12/2004	14/02/2006	23/12/200
837	SANTE	2005		101843	Ongoing	Amendment n°3 to the ac		AIDCO F	Grant	Action Grant D01			04/07/2005	31/12/2006	28/06/200
838	SANTE	2005		109201	Closed	The XVI International AID		AIDCO F	Grant	Action Grant D03			24/12/2005	31/12/2006	19/12/200
839	SANTE	2005		110196	Closed	African Ministerial Confe		AIDCO F	Grant	Action Grant D01			23/12/2005	01/01/2007	22/12/200
840	SANTE	2005		110208	Closed	Launch of a Global Call to Action on Se			Grant	Action Grant D01			23/12/2005	01/09/2006	22/12/200
841	SANTE	2005		110209	Closed	Confronting HIV/AIDS as		AIDCO F	Grant	Action Grant D01			20/12/2005	30/08/2006	12/12/200
842	SANTE	2005		110210	Closed	Consultative Meetings on		AIDCO F	Grant	Action Grant D01			23/12/2005	30/06/2007	21/12/200
843	SANTE	2006		116494	Ongoing	Amendment n°4 to the ac		AIDCO F	Grant	Action Grant D01			20/06/2006	31/12/2007	31/05/200
844	SANTE	2006		119308	Cancelled	Microbicides 2006			Grant	Action Grant D01			19/05/2006	18/09/2006	16/05/200
845	SANTE	2006		120064	Closed	1st Eastern European and		AIDCO F	Grant	Action Grant D03			23/05/2006	14/11/2006	11/05/200
846	SANTE	2006		123521	Ongoing	First Asia-Pacific Action A		AIDCO F	Grant	Action Grant D03			09/10/2006	14/08/2007	04/10/200
847	SANTE	2006		126239	Ongoing	The World AIDS Campaigr		AIDCO F	Grant	Action Grant D01			28/12/2006	31/12/2007	22/12/200
848	SANTE	2006		126818	Ongoing	Increasing access to new		AIDCO F	Grant	Action Grant D01			21/12/2006	30/09/2008	19/12/200
849	SANTE	2006		127714	Ongoing	Partnerships for Microbic		AIDCO F	Grant	Action Grant D01			30/12/2006	30/12/2009	21/12/200
850	SANTE	2006		130464	Ongoing	The Aid Effectiveness Age		AIDCO F	Grant	Action Grant D03			28/12/2006	14/04/2008	22/12/200
851	SANTE	2007		127366	Ongoing	Access to Sexual and Rep		AIDCO F	Grant	Action Grant D01			04/12/2007	05/12/2010	03/12/200
852	SANTE	2008		159563	Closed	Reconciliation for old RAL CC97-MED-L			Reconciliation						
853	SANTE	2008		159566	Closed	Reconciliation of old RAL			Reconciliation						
854	SANTE	2008		159570	Closed	Reconciliation of old RAL CC/PVD-ASIE			Reconciliation						
855	SANTE	2008		159575	Closed	Conciliation old RAL CC97-MED-LOT-B7			Reconciliation						

Projects managed by F3_1

Figure 13: Available information of projects

After the collection and defining of the whole set of alternatives, that in this case are the different projects that are expected to be monitored, the next stage is to define the different steps that will be necessary to carry out in order to make possible the implementation of the MURAME method.

As mentioned in previous sections, the MURAME method is implemented in two main phases, combining in this way the ELECTRE III and the PROMETHEE methods (see Chapter 2.3.7.1).

In the first phase, the aggregation phase, is where the outranking relation gets constructed. Here, the key criteria are defined, as well as the different weights for each one of these defined criteria. Weights for the criteria must be assigned according to the importance of each one of them over the global decision process. Also, in this phase the thresholds for each one of the whole set of the criteria used to solve the decision problem must be defined. The thresholds that must be calculated for each one of the criterion are the indifference *(q_j)* and the preference *(p_j)* thresholds. In the implementation of the MURAME method for the solution of the given problem, also the veto threshold *(v_j)* will also be assigned to each one of the criteria, as it has been proved that the use of this threshold provides a better performance in the solution of the decision problems.

In the second phase, the exploitation phase, the outranking relation, which includes the weights and the three thresholds (indifference, preference and veto thresholds) for each one of the criteria, used to solve decision problem, are used to produce a total pre-order. In this way the whole set of projects will be ranked according to the values for each one of the criteria.

This modellisation of the problem is the one that must be carried out, as is the way the MURAME method performs, and is the method which resulted chosen after comparing it with the rest of the methods (see Chapter 2.6.2).

However, before detailing the concrete steps that must be followed to carry out this modellisation, it is also important taking into account some aspects. First of all, as described in Chapter 1.6 is wanted to classify the set of projects into three different groups: the projects that should be monitored, the projects that should be considered to be monitored, and the projects that are not recommended to be monitored. As the method which resulted to be chosen is the MURAME method, then total preorders of the projects should be produced by it. Then, with a total preorder list of projects, assignment of each one of the projects to these three groups will become a simple task.

Also, the use of the veto threshold v_j is not strictly necessary for the implementation of the MURAME method. However, as in the identification of the critical criteria some of them can be of special importance, it will be quite useful to include this threshold in the modellisation of the problem. Moreover, the use of the veto ensures that an alternative with a bad performance in such a critical criterion will not receive high priority (Goletsis, Psarras, & Samoulidis, 2003).

Once the main features of the MURAME modellisation are know as well as the parameters that must be valued (the weights of criteria and the indifference, preference and veto thresholds) for each criterion, it can then be possible to define the steps to follow to carry out a proper performance of the MURAME method.

The first step will consist on identifying the relevant attributes. As the number of attributes available for each alternative is quite large (63) it will be necessary to select a set of relevant attributes, which will be the used criteria for the implementation of the methodology. The selection of the relevant criteria must be carefully carried out because the results provided by this modellisation will be highly according to the criteria on which their values for each alternative are considered to be interesting. The way to decide the proper criteria for the given problem will be explained in the next section.

After knowing the criteria that will be used in the decision problem, then it will be necessary to assign to each one of the criterion its weight according to its degree of importance between the selected criteria.

Finally, the values of the indifference, preference and veto thresholds must be assigned for each one of the selected criteria. These values will be used for the MURAME methodology to perform the final preorder list of projects. The meaning of each one of these thresholds, as well as which vale they get for each criterion will be described in further sections.

3.2 Identifying the Relevant Attributes

As described in the previous section, the first task in order to perform the modellisation of the MURAME method consists on identifying the relevant attributes or the criteria family. These selected criteria will be the parameters of each one of the projects (in this case the projects are the alternatives of the decision problem) that will be taking into account by the MURAME method to provide the final total preorder of the projects in the multi-criteria decision problem.

According to (Bouyssou, 1990), the criteria family must be readable (contains a sufficiently enough small number of criteria), operative, exhaustive (contains all points of view), monotonous and not redundant (each criterion must be considered only once). These rules provide a coherent criteria family.

As established by (Goletsis, Psarras, & Samoulidis, 2003), to perform a successful approach, after a detailed presentation of the methodology to be followed, main goals of the decision problem must be agreed. In order to select an appropriate criteria family, the parameters that must be taking into account were studied. The most important are:

- The finances security,
- The existence of experienced staff,
- The existence of the needed infrastructure that may facilitate the execution of the projects,
- The experience in similar projects,
- The technical and financial risks,
- Other national goals, like the employment and the transfer of knowledge to the country,
- The environmental impacts (health included).

Therefore, these are the main concepts that will be taken into account in order to decide which must be the most appropriate criteria family for the modellisation used for this decision problem.

So, before deciding the criteria that will be used in the methodology, first it will be necessary to analyse the whole set of attributes that were provided by the EC to the DSS's laboratory. The whole set of attributes are described in the table 2:

Criterion	Description
1. Domain	Area on which the project is focused on
2. Contract	Year of contract of the project
3. Former system reference	Reference of the year and country on which the project was signed
4. Contract	ID number of the project's contract
5. Status	Current situation of the develop process of the project
6. Title	Title of the project
7. Delegation	Responsible delegation for the development of the project
8. Entity	Responsible entity for the development of the project
9. Contract type	Type of the signed contract
10. Nature	Nature of the signed contract
11. Sub-nature	Specific nature of the signed contract
12. Type of services	Type of services required for the project
13. Contractor's signature date	Signature date of the contractor
14. Expiry date	Date of expiration of the contract
15. EC signature date	Signature date of the European Commission
16. Closing date	Date on which the contract is finished
17. Implementation starting date	Date on which the implementation of the project must start
18. Contracting party	Organisation contracted for the implementation of the project
19. Payment currency	Currency on which the payments will be carried out
20. Geographical zone	The geographical zone on which the project is destined
21. Person in charge	Person responsible of the satisfactory development of the project
22. DG	Delegation responsible of the development of the project
23. Nationality	Nationality of the project
24. Call reference	Call reference
25. Procedure	Procedure to be followed in the development of the project
26. Negotiated Procedure Type	Type of the procedure negotiated in the contract
27. Legal Entity (LEF)	Code of the Legal Entity responsible of the development of the project
28. Geographical zone (LEF)	Geographical zone of the Legal Entity
29. Bank Account Ref (BAF)	Code reference of the Bank Account
30. Report deadline	Time on which the report of the project must be done
31. Document type	Type of document on which the report must be followed
32. Received?	Indicates if the report of the project was received
33. Step number	Step number
34. Planned amount	Amount of money planned to carry out the project
35. Paid	Amount of money that was already paid to develop the project
36. Balance	Amount of money left to pay for the development of the project
37. Payment currency	Currency of the payment of the project
38. Decision No.	Protocol number appointed by the Commission to distinguish the political decisions that result to projects
39. Commitment type	Determines the way on which the payment is carried out
40. Commitment ID	Code that identifies the commitment type

41. Budget line	It refers to how the project got its money
42. DAC Code	Refers to the sector the project belongs to
43. Sector code	Refers to the sector the project belongs to
44. Budget Management type	Code that identifies the budget management type
45. Legal justification	Code that identifies if some legal justification is needed for the project
46. Payment class	Code that identifies the class of the project's payment
47. Serial number	Code that identifies the serial number for the project
48. Value date	Value date
49. Workflow type	Code that identifies the workflow type for the project
50. Status	Identifies the concrete state of the implementation of the project
51. Mailing Entity Ref.	Code that identifies the mailing entity
52. Mailing Entity Ref.	Name of the mailing entity
53. Negotiated Procedure Type	Code of the procedure type negotiated in the contract
54. Signature refusal	Indicates if the contract was decided to be refused
55. Action location	City and country on which the project will be implemented
56. Publication allowed	Indicates if is allowed any publication about the development of the project
57. Reason to restrict the publication	Determines the reason for which publications about the project are not allowed, if necessary
58. Final date for implementation (FDI)	Date on which the implementation of the project must have been finished
59. Contractual currency	Currency for the payment that was indicated in the contract
60. Specific payment currency	Currency for the payments that have already been made
61. Previous amount in contractual currency	Amount of money needed to pay for the project with the contractual currency
62. Paid amount in contractual currency	Amount of money that was already made for the project with the contractual currency
63. Balance amount in contractual currency	Amount of money left to pay for the project with the contractual currency

Table 2: Description of the criteria

After studying the Table 2, which contains the whole set of the attributes that represent the available information for each one of the projects, and considering the main concepts that must be taking into account to generate a satisfactory criteria family, a list of 21 criteria were selected. The list of these 21 criteria that were decided to include in the criteria family are described below:

Socio-political criteria:

- Domain
- Nature
- Type of services
- Contracting party
- Geographical zone
- Nationality

Technical criteria:

- Former system reference
- Status
- Delegation
- Entity
- Contract type
- Expiry date
- Closing date
- Person in charge
- Procedure
- Negotiated procedure type
- Report deadline
- Document type
- Sector code
- Workflow type

Economic criteria:

- Balance

For each one of these criteria, the purpose and the measurable parameters of each criterion must be provided, in order to facilitate the understanding of the use of these criteria in the modellisation described in previous sections. The list of the 21 criteria family under three main bases (socio-political, technical and economic) is presented in table 3:

Criterion	Purpose/scope of the criterion	Measurable parameters
1. Domain	Promotion of the projects belonging to the desired domain	Degree of the desired domain
2. Nature	Development of projects of a specific nature	Different scores for each types of Nature
3. Type of services	Technical need for the project	Degree of the difficulty of getting the services
4. Contracting party	Reduce risks due to non-reliable parties	Degree of the contracting party's confidence
5. Geographical zone	Promotion of projects through different areas	Different scores for each geographical zone
6. Nationality	Reduce risks due to non-reliable nationalities	Different scores according to each nationality
7. Former system reference	Promotion of projects according to the year and place where were signed	Degree of the desired former system reference
8. Status	Reduce risks in the implementation of the project	Different scores for each phase of the project
9. Delegation	Reduce risks due to management problems	Higher scores for more tested successful delegations
10. Entity	Secure the possibility for implementation of the project	Degree of the entity's confidence
11. Contract type	Promotion of projects according to the kind of contract	Different scores for each contract type according to the desired exploitation of contracts
12. Expiry date	Secure the possibility for implementation of the project	Number of days left for the expiry date
13. Closing date	Secure the possibility for the development of the project	Number of days left for the closing date
14. Person in charge	Reduction of risks for the implementation of the projects	Different scores for each person in charge according to his experience
15. Procedure	Secure the possibility for implementation of the project	Different scores for each kind of procedure
16. Negotiated procedure type	Secure the possibility for implementation of the project	Different scores for each procedure type
17. Report deadline	Reduction of risks for the development of the project	Time left to the deadline

18. Document type	Enhance quality for the implementation of project	Different scores according to the type of document
19. Sector code	Promotion of the desired sector	Different scores for each sector
20. Workflow type	Secure the possibility for implementation of the project	Higher scores for workflow types that are tested to perform better
21. Balance	Secure viability of the project	Amount of money

Table 3: Ranking criteria

Therefore, all these criteria were considered to be included in the criteria family. However, due to the lack of information over many alternatives (the proposed projects) it will be necessary to ignore, at this stage of the planning process, some evaluation criteria, for which there is no information for significant number of projects. In order to get a satisfactory result by the application of the MURAME method for the given decision problem, it will be recommendable to include just those criteria for which more than the 50% of the proposed projects (that is, the alternatives) are evaluated.

The percentages of the evaluations among the proposed projects, for each one of the selected criteria were calculated. This task was carried out in order to know for which criteria the number of missing values is under 50%. The results obtained are shown below:

Criterion	Number of missing values	Percentage of missing values
1. Domain	0	0%
2. Nature	6	0.71%
3. Type of services	759	89.19%
4. Contracting party	56	6.58%
5. Geographical zone	61	7.17%
6. Nationality	168	19.74%
7. Former system reference	693	81.43%
8. Status	0	0%
9. Delegation	792	93.07%
10. Entity	83	9.75%
11. Contract type	0	0%
12. Expiry date	25	2.94%
13. Closing date	492	57.81%
14. Person in charge	0	0%
15. Procedure	6	0.71%
16. Negotiated procedure type	849	99.76%
17. Report deadline	426	50.06%
18. Document type	482	56.64%
19. Sector code	253	29.73%
20. Workflow type	0	0%
21. Balance	0	0%

Table 4: Missing values for each criterion

As was mentioned above it is recommended, for a good performance of the MURAME method, to exclude those criteria for which the 50% of the evaluations, or more, are missing (Goletsis, Psarras, & Samoulidis, 2003).

According to the results showed in the table 4, there are 7 criteria for which the number of missing values exceeds the 50%. These criteria are:

- Type of services
- Former system reference
- Delegation
- Closing date
- Negotiated procedure type
- Report deadline
- Document type

Then, these criteria will be excluded for the modellisation of the problem, as not enough evaluations of such criteria among the set of alternatives are available. So, the set of attributes that will be taking into account for the exploitation phase of the MURAME method are:

1. Domain
2. Nature
3. Contracting party
4. Geographical zone
5. Nationality
6. Status
7. Entity
8. Contract type
9. Expiry date
10. Person in charge
11. Procedure
12. Sector code
13. Workflow type
14. Balance

Therefore, these 14 the criteria are the ones that will compose the criteria family. These remaining criteria will be used in the second phase (the exploitation phase) in order to produce the final total preorder list of the projects.

3.3 Thresholds for the Different Attributes

Once the criteria family for the decision problem has been established, next step is to assign the indifference q_j, preference p_j and veto v_j thresholds to each one of these criteria.

According to Goletsis et al. (Goletsis, Psarras, & Samoulidis, 2003), the purpose of the use the indifference, preference and veto thresholds is to reflect the DM's preference in a realistic way.

The three zones scheme (strict preference, weak preference, indifference) is modelled by the use of two thresholds for each criterion *j*: the indifference threshold q_j and the preference threshold p_j. The values of p_j and q_j may be constant or have the form: $a * g_{ij} + b$. In any case, $q_j (g_{ij}) \leq p_j (g_{ij})$.

Also, a veto threshold v_j is retained for each criterion *i*. This threshold is used to reject the hypothesis a_i S a_k, if in one criterion alternative a_i is much worse than a_k, that $g_{ij} + v_j < g_{kj}$. Veto threshold cannot be less than p_j (see chapter 2.3.7.2).

Therefore, as an input for the MURAME method the set of these three thresholds (indifference, preference and veto thresholds) must be calculated for each criterion, in order to provide the methodology the required information to be able to produce the total preorder list of projects. It is not strictly necessary the calculation of the veto threshold, but as mentioned above its inclusion in the modellisation is recommended in order the MURAME method to provide a satisfactory solution for the decision problem.

In order to assign the different thresholds values to each criterion the next guidelines were followed (Goletsis, Psarras, & Samoulidis, 2003): according to the approach published by Rogers and Bruen (Rogers & Bruen, 1998) the thresholds were not be interpreted as uncertainty, error or imprecision margins as was suggested by Roy et al. (Roy, Present, & Silhol, 1986), but the *q* threshold was defined as the point at which one alternative is distinguishable from the other under a specific criterion and the *p* threshold as the point at which one alternative is perceived to be clearly preferable to the other.

In the following paragraphs, the way on which the q_j, p_j and v_j thresholds were established for each one of the criteria is presented.

C1 – Domain. This is an important criterion. Projects may want to be promoted according to the area on which they are destined to. As a result the indifference threshold q_1 is small, with a value of 5 (i.e. 5%) while the preference threshold is three times more, i.e. $p_1 = 15$. In the same way, v_1 is only twice as p_1, as is not wanted to promote a project which is destined to a sector that is not desired at the moment, instead of a project whose purpose is more desirable.

C2 – Nature. This criterion determines the purpose of the project, but unlike the 'Domain' criterion (which determines the area on which the project is focused on: education, sanity, etc.), this criterion reflect if the project it will be carried out as an action grant, a specific service or whatever. Therefore, even is a less important criterion than the last one, this is also a criterion to take into account. The veto threshold has here a high value. As a result, $q_2 = 10$, $p_2 = 20$, $v_2 = 60$.

C3 – Contracting party. Knowing the company that will be the responsible of the development of the project may be also important to decide which projects must be promoted. However, this one is not a main attribute to consider for the decision problem. Therefore, $q_3 = 20$, $p_3 = 40$, $v_3 = 60$.

C4 – Geographical zone. The region on which the project will be carried out may be a significant criterion in order to decide if the considered project must be promoted. As may be wanted to give more importance to those projects that are developed in a specific zone, the veto threshold here will have a medium value, as veto should happen often. As a result, $q_4 = 10$, $p_4 = 30$, $v_4 = 50$.

C5 – Nationality. This criterion indicates the nationality of the project considered to carry out. In this case, this criterion cannot help from being an important decision parameter. In this cost evaluation $q_5 = 10$, $p_5 = 20$, $v_5 = 40$.

C6 – Status. Knowing the status of the project (if it's ongoing, cancelled, provisional, etc.) is an important criterion in order to know the urgency of this project. By setting $q_6 = 0$, $p_6 = 10$, $v_6 = 50$ the indifference zone is suppressed, what means that has a strict preference to occur early. However, the veto may happen often.

C7 – Entity. Like the 'Nationality' of the project, this criterion is not considered to be one of the most important ones. However, unlike the nationality of the project, the entity that will carry out the project can provide more specific information. Therefore, $q_7 = 5$, $p_7 = 15$, $v_7 = 40$.

C8 – Contract type. The contract type of the project also doesn't provide quite relevant information in order to decide if the project must be promoted. Then, $q_8 = 20$, $p_8 = 40$, $v_8 = 60$.

C9 – Expiry date. The expiration of the date to develop the project is an important criterion. In order to give preference to occur early, the indifference zone is suppressed here as well. As a result, $q_9 = 0$, $p_9 = 20$, $v_9 = 70$. The high value of the veto will make rather hard to exclude the project.

C10 – Person in charge. Knowing the person that will be the responsible of the development of the project it may be very useful to decide if the project must be promoted. The veto threshold here is high. $q_{10} = 10$, $p_{10} = 30$, $v_{10} = 70$.

C11 – Procedure. This criterion indicates the procedure that must be followed to develop the project. As this criterion could not easily exercise a veto, the veto threshold takes here a high value. As a result, $q_{11} = 10$, $p_{11} = 40$, $v_{11} = 90$.

C12 – Sector code. The sector code indicates the sector that the project belongs to. This information is considered to be important in order to decide if the project must be considered to monitor. As it may be possible that projects that belong to a specific sector are wanted to be promoted the indifference threshold should be small. On the other hand, the veto threshold must not have a quite high value, as probably it will be preferred to promote a project of another sector, instead of the sector that a project belongs to. As a result, $q_{12} = 10$, $p_{12} = 20$, $v_{12} = 40$.

C13 – Workflow type. Like the procedure of the project, the workflow type indicates how to carry out a good performance in the develop process of the project. Therefore, knowledge of the workflow is of great value in the implementation phase. As a result, $q_{13} = 10$, $p_{13} = 30$. However, veto for these projects should occur rather than hard. Hence, the veto threshold is very high, $v_{13} = 90$.

C14 – Balance. This criterion indicates the amount of money that is left to pay. In any case the balance of the project cannot be considered to be an important parameter. In this "quantitative" balance evaluation $q_{14} = 10$, $p_{14} = 25$, $v_{14} = 40$.

Therefore, these are the indifference, preference and veto thresholds values that have been assigned to each one of the criterion. These set of thresholds values will be provided to the MURAME method in order to calculate, in the second phase of the methodology, the final preorder list for the whole set of projects. The values for the different thresholds of each criterion is summarised in the table 5.

Once the three thresholds have been evaluated for each criterion, the next step is to calculate the weights for each one of the criteria. As not all the criteria have the same importance, will be necessary to establish in which measure each criterion is stronger (or weaker) than the others. The methodology followed to decide which ones are the proper weights for the different criteria is explained in the next section.

Criterion	q	p	v
C1. Domain	5	15	30
C2. Nature	10	20	60
C3. Contracting party	20	40	60
C4. Geographical zone	10	30	50
C5. Nationality	10	20	40
C6. Status	0	10	50
C7. Entity	5	15	40
C8. Contract type	20	40	60
C9. Expiry date	0	20	70
C10. Person in charge	10	30	70
C11. Procedure	10	40	90
C12. Sector code	10	20	40
C13. Workflow type	10	30	90
C14. Balance	10	25	40

Table 5: Thresholds' values for each criterion

3.4 Weights for the Different Attributes

Once the criteria family has been identified and the thresholds to each one of the criteria have been evaluated, next step is to calculate the weights for each one of the criteria.

The weight vector (which contains the weights for each one of the criteria family) provides the relative importance of each criterion. According to (Vincke, 1992), weights in an outranking relation must be considered like a vote in a vote process. It is thought by Goletsis et al. (Goletsis, Psarras, & Samoulidis, 2003) that a direct weighting usually cannot reflect the preferences in an effective way. Several special methods have been developed in the last years by many authors. It is suggested to study (Figueira & Roy, 2002) (Ramathanan & Ganesh, 1994) (Rogers, Bruen, & Maystre, 1999) (Roy B. , 1990) . In any case, the method to be follow must be – relative simple – and easily understandable.

In the decision problem which this thesis focuses on, the method proposed by Rogers and Bruen (Rogers & Bruen, 1998), which is based on the personal construction of the theory published by G.A. Kelly (Kelly, 1955) was applied. The description of this method is detailed in the following paragraphs.

The method proposed by Rogers and Bruen (Rogers & Bruen, 1998) is based on the Personal Construct Theory - PCT (Kelly, 1955) and its bipolar modellisation of the human preferences system. Without analysing the Kelly's theories, finally, a bipolar construction (extreme) of the two possible cases is associated to each criterion, for example, by the cost: low cost/high cost. For each construction it must be selected which one of the two cases is the most preferable (for example, by low cost).

In a pair-by-pair comparison between the constructs and assuming that the current state is the preferable one for each construct, it must be defined which one of the two constructions it is better to see changed to the non-preferable situation (or vice versa, that one resists to change). By the calculation of this resistance to change the criteria weights are calculated. A symmetrical matrix where rows and columns represent the constructions can then be created. Each cell inside this matrix represents the obtained result by using the following notation:

- An **X** determines that the column of the construction "resists to change",
- A blank indicates that the row of the construction "resists to change",
- An **I** indicates that the two modifications are equally undesired,
- An **e** indicates that two constructs change at the same time.

The resistance-to-change is calculated by adding the number of "blanks" in the rows and the **X** in the columns for each construct. This resistance-to-change is considered to be a measure of the importance of each criterion. Criterion weight w_j is then

$$w_j = \frac{RtC_j}{\sum_{i=1}^{n} RtC_i}$$

(RtC: Resistance-to-Change).

Therefore, by using the Personal Construct Theory – PCT for the calculation of the criteria weights, the following matrix was constructed:

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	RtC
C1	-					X			X		X	e	X	X	7
C2		-		X	X	X		e	X	X	X	X	X	X	2
C3			-	X		X	X		X	X	X	X	X	X	2
C4				-		X			X			X		X	8
C5					-	X		X	X	X	X	X	X	X	2
C6						-			X					X	11
C7							-				X	X		X	5
C8								-	X	X	X	X	X	X	1
C9									-					X	11
C10										-	X	X		X	5
C11											-	X		X	8
C12												-		X	9
C13													-	X	5
C14														-	13
														Total	89

Table 6: Criteria weights definition with the use of PCT

Once the RtC value has been calculated for each criterion associated to the criteria family, is possible now to calculate the weights for each criterion by applying the formula that Rogers and Bruen (Rogers & Bruen, 1998) proposed in their method. Therefore, the resultant weights for the criteria are shown in table 7:

Criterion	Weight *w*
C1. Domain	7.9%
C2. Nature	2.2%
C3. Contracting party	2.2%
C4. Geographical zone	9.0%
C5. Nationality	2.2%
C6. Status	12.4%
C7. Entity	5.6%
C8. Contract type	1.1%
C9. Expiry date	12.4%
C10. Person in charge	5.6%
C11. Procedure	9.0%
C12. Sector code	10.1%
C13. Workflow type	5.6%
C14. Balance	14.6%

Table 7: Criteria weight values

Therefore, these weights will be provided to the MURAME as inputs for the methodology. The set of weights of the criteria family, as well as the indifference, preference and veto thresholds for each criterion, and the scores of the alternatives for each one of them (the 'evaluation matrix') constitute the whole set of inputs, that will be provided to the MURAME method in order to be able to perform a total preorder list of the projects. The outputs that will be provided by the MURAME are described in the next section.

3.5 Analysis of required outputs

Once the proper inputs are provided to the MURAME, this methodology will be able then to start to perform the modellisation in order to solve the decision problem described in this thesis.

First of all, the MURAME method will need to calculate the *local concordance, concordance* and *discordance* indices for each criterion. These indices will be calculated according to the ELECTRE III model (Roy B. , 1968). After these two indices are calculated, then the MURAME will be able to calculate the outranking index *O*, which aggregates the concordance c_j and discordance d_j indices in order to indicate how much one alternative outranks another one for a specific criterion.

After these intermediate parameters are calculated, the MURAME then can start the exploitation phase in order to rank the preferences for providing a total preorder list of projects as an output. For the rank of the preferences, the outranking index *O* will be used in order to calculate the entering (φ^-) and leaving (φ^+) flows for each alternative. The leaving flow indicates the strength of an alternative over all remaining alternatives. On the other hand, the entering flow indicates the weakness of an alternative over all remaining ones. The net flow φ aggregates the entering and leaving flows.

Once the net flow has been calculated by the MURAME method, the alternatives can be then ranked according to their net flow φ, in a descending order. In this way a total preorder of the alternatives (which in this decision problem are the projects considered to monitor) can be produced.

Therefore, the output that will be provided by the MURAME method consists on a list of projects ordered according to the importance of being monitored. However, for the solution of this decision problem is wanted, not just to provide an ordered list of the projects, but the collection of all the projects separated in three groups: those ones that are recommended to monitor, those ones that should be considered to monitor and the ones that are not recommended to monitor. On the other hand, as the output provided by the MURAME method is a total preorder list of the projects, it may be a efficient approach the collection of the first projects of the ranking list to the group of projects that are recommended to monitor. In the same way, the next first projects in the list can be collected in the group of the projects that should be considered to monitor, and the last projects of the final list can be collected to the group of projects that are not recommended to monitor. Anyway, this problematic will be also exposed in next sections for future research.

In conclusion, the expected output of the MURAME method will be a preorder list of the projects according to the importance to be monitored. The position of the projects in this preorder list will depend on socio-political, technical and economic properties of the projects. Finally, it is necessary to take into account that projects in low positions in the preorder does not mean that are less important , but more demanding in terms of monitoring.

4. Suggestions for Further Research

This thesis can be the basis for future research in some areas.

First of all, more studies can be made in order to take conclusions about the method that fits better to monitor-planning of projects. For example, it is suggested to investigate further hybrid MCDA methods, that is, those methods which arise by the combination of other two MCDA methods. As until today, the number of publications about hybrid MCDA methods is not so large, it will be recommended to study next publications about hybrid MCDA methods in order to find out if some new MCDA methods, resulted by combining other two methods, can fit to the decision problem described in this thesis. As the MURAME method was the only hybrid method for which a sufficiently small number of publications have been made, as well as tests with this method in real-life problems, this method was the only hybrid method considered for this decision problem.

Second, it is recommended to study and analyse the criteria family selected for the modellisation of the MURAME method, as well as the thresholds and weight values assigned to each criterion. As the assignation of these values is considered to be a subjective task, maybe the reader of this thesis may consider necessary to change some of these parameters. This does not mean that the values of some parameters might be wrong, but as this task depends on the DM's desires, maybe can consider, according to his experience or his knowledge about the problem, to assign different values for the thresholds or weights of the criteria when is needed.

Third, an interesting possibility that can be researched further is to distinguish between economical and non-economical criteria. All direct economical effects can be included in a standard economical analysis, while no attempt is made on monetising non-economic criteria. In place, non-economical criteria must be considered in an analysis of such resources by using any MCDA method. This analysis will determine the DM's total valuation of performance value among the alternatives in the non-economical criteria. Then, this total valuation can be negotiated against the economical results of the different alternatives. This way of thinking may be closer with the way of thinking usually employed in companies.

A fourth fruitful area of research would be to further study the different theories for the calculation of the criterion weights. As one of the purposes of this thesis was to decide the MCDA method that will be best suited for the decision problem described here, a detailed study of each one of the different methods was presented here, as well as an analysis of the different comparisons between the methods. However, when deciding the theory for calculating the criterion weights, any kind of comparison with other methods or theories was made. So, as this thesis is not focused in the comparison between different methods for calculating the criterion weights, the Personal Construct Theory – PCT was selected. Nevertheless, it would be interesting for future research to compare the different methodologies published by different authors in order to analyze which method or theory it will be more appropriated for this decision problem.

Fifth, once the bases of the MURAME methodology have been carefully explained (by detailing the calculations that must be made) and the weights and thresholds for each criterion have been assigned, the next main step consists on the implementation of the method. In order to get the final preorder list of projects it will be necessary to implement the method according to the calculations that will be needed to carry out for the method to be able to provide the rank list of the projects (see chapter 2.3.7.2). The application to be implemented should provide a rank list of projects according to the modellisation of the MURAME method, and also it would be interesting to let the user establish the inputs of the method according to his desires. According to his experience and specific knowledge of the decision problem, the user may want to change some of the parameters assigned to the criteria, that is, the thresholds or the weights. Actually, it would be quite satisfactory letting the user to decide the criteria he considers to be relevant in order to get an efficient solution for the decision problem.

5. Conclusions

This section summarizes the main conclusions of the thesis:

- Decision-planning problems, and hence the monitoring projects-planning, are usually characterized by many conflicting criteria.

- The multi-criteria decision analysis (MCDA) is designed for the identification of the best solution when several criteria are considered, by the calculation of numbers/scores or results that reflect the total value of each one of the proposed alternatives.
    - MCDA allows the decision maker (DM) to express his preferences over the different criteria in an explicit way. MCDA provides a representation of the DM's values and subjective preferences.
    - With the use of MCDA, the DM is not limited to any basically fixed rules, but is free to include or exclude the different aspects of the analysis, based on his own suppositions about what is important. Moreover, MCDA allows tradeoffs to be nonlinear if is desired.
    - Many MCDA methods allow the including of qualitative criteria in a coherent way.

- For this monitoring-planning project to be successful, it is essential to spend enough time and resources in the definition and structuring of the problem, in order to ensure that there will not be any kind of disagreements or confusion regarding to the nature of the problem and the desired goals.

- Inside the MCDA methods there are several methodology families. Methods belonging to the same MCDA methodology family have the same main properties. However, it is not possible to say which one is the best MCDA family, as each one of the diverse families has different properties. But each family fits better to different decision problems. Therefore, the use of the MCDA method family will depend largely on the properties of the decision problem for which a satisfactory solution is wanted for it.

- Between the whole set of MCDA method families the one that fits better to the problem described in this thesis, according to the properties of such problem, are the outranking methods. As a ranking of projects, in order to know which ones are better to monitor, is wanted, outranking methods are the most appropriate methods because they are able to produce a total preorder list between the set of alternatives available in the decision problem.

- Considering the MCDA methods that belong to the outranking method family, the MURAME method was considered to be the most appropriate for the development of the decision problem. As hybrid between the ELECTRE and PROMETHEE methods, the MURAME method is able to combine the advantages of these two methodologies and to remove the main disadvantages of both of these methods. Moreover, the MURAME method is able to work even some values are missing. These are the main features for which this method was chosen in order to solve the decision problem. However, as was proposed in the previous chapter, it would be advisable to suggest the reader of this thesis, to study as many MCDA methods as possible in order to ensure that there is not any other method which will fit better to this decision problem.

- Due to the large amount of data that was needed to study and analyze, and also the large amount of information about non-relevant criteria, it was necessary to select, from the whole set of attributes, those ones that were considered to be useful in order to obtain a satisfactory solution. As many irrelevant criteria were provided, it wouldn't be right to use all the information available for the modellisation of the problem. Therefore, a detailed selection of the proper attributes was necessary in order to perform a sufficiently efficient development of the method

- Usually, in the decision problems, like the one described in this thesis, not all the information has the same relevance. Because the information provided by some attributes may be more important than the information provided by other attributes, not all the attributes have the same importance. For this reason it was necessary to assign a weight for each criterion that was included in the modellisation of the problem. By weighting the different criteria it is ensured that each criterion has a difference importance with the others in order to reach a satisfactory solution for the decision problem.

- In order to allow the DM to express his preferences and uncertainties for each one of the different criteria, the MURAME method includes the *preference*, *indifference* and *veto* thresholds. For the modellisation of the problem, it was necessary to assign a value for each threshold (among the whole set of the criteria family). In this way, the preferences and uncertainties for the different attributes were provided to the methodology.

- By providing all the necessary inputs to the method, MURAME would be able, after calculating some parameters, in the exploitation phase to produce a total preorder list of the projects according to the importance of being monitored. The MURAME method will not ordered the list according to the importance of the projects on themselves. MURAME will order the projects according to their importance to be monitored.

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