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Rachel Perez Palha

**A GROUP DECISION AND NEGOTIATION FRAMEWORK  
FOR HIRING SUBCONTRACTORS IN CIVIL  
CONSTRUCTION INDUSTRY**

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CONSTRUCTION INDUSTRY**

PhD thesis submitted to UFPE to obtain the degree of doctor as part of the requirements of the Programa de Pós-Graduação em Engenharia de Produção (Research Area: Production Management).

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PRESENTATION OF**

*RACHEL PEREZ PALHA*

**“A GROUP DECISION AND NEGOTIATION FRAMEWORK FOR  
HIRING SUBCONTRACTORS IN CIVIL CONSTRUCTION  
INDUSTRY”**

**RESEARCH AREA: PRODUCTION MANAGEMENT**

The PhD evaluation committee with the following examiners, coordinated by the first, considers the PhD candidate **RACHEL PEREZ PALHA, APPROVED.**

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## ABSTRACT

The literature presents several supplier selection models which discuss what features might be present in this type of analysis, such as plant localization, organizational structure, structures for governance, and models which consider uncertainty in information levels. Usually, models that focus on the selection itself impose the same method for running the selection process on all decision makers (DMs), even when a group of DMs makes the decision. However, a given problem might be evaluated differently depending on the DM, due to his/her having different objectives for the same problem and, due to the diversity found in civil construction projects, different activities have to be hired, and these have different effects on the project. Usually, in the civil construction industry, the hiring process ends up with a negotiation phase between the contractor and the top rated subcontractors. Thereby, in order to support DMs of contractors to follow a structured decision process to reach a better deal, this thesis presents a framework to aid DMs in selecting subcontractors. The framework considers two models to deal with each phase of the hiring process. The first model to be employed is the Additive-veto model for sorting problematic. Thus, an analyst lists the activities to be hired, and the DMs' preferences are used to sort them into classes. This procedure enables DMs to apply a governance process compatible with the effect such activity may produce in the project, client, and contractor. Following a selection model is used. The analyst has to evaluate the rationality of each DM to choose a compatible MCDM/A method. Later on, when the framework directs the process to a group decision, a voting procedure chosen based on the preferences of the DMs is used to aggregate the DMs' preferences. At last, the DMs follow a negotiation phase with the top-ranked subcontractors to decide which the best deal is. All models are illustrated with a numerical application in the civil construction industry. It can be verified that the framework proposed brings flexibility and allows DMs to make more informed decisions, enabling them to feel more secure about the hiring process of subcontractors. Since it requires less DMs to get involved in the decision process, the project benefits from reducing the time required from DMs, thus, reduces the cost of the decision process. In addition, the framework proposed can be used in other contexts, due to its flexibility.

*Keywords: Voting procedure. MCDM/A. Negotiation. Additive-veto model. sorting problematic.*

## RESUMO

A literatura apresenta vários modelos para seleção de fornecedores que discutem as características que podem estar presentes neste tipo de análise, tais como localização de plantas, estrutura organizacional, estrutura de governança e modelos que consideram níveis de incerteza na informação. Normalmente, modelos que focam na seleção em si, impõem a todos os decisores o mesmo método para o processo de seleção, ainda que um grupo de decisores seja responsável pela decisão. Entretanto, uma determinada situação pode ser analisada de diferentes formas a depender do decisor, devido aos diferentes objetivos que estes apresentam e, devido a diversidade encontrada nos projetos de construção civil, diferentes atividades precisam ser subcontratadas e estes impactam o projeto de forma diferente. Normalmente, na indústria da construção civil, o processo de contratação termina em uma fase de negociação entre a construtora e os subcontratados que apresentaram as melhores propostas. Desta forma, a fim de dar suporte para que os decisores de construtoras possam tomar decisões utilizando um processo decisório estruturado, esta tese apresenta um *framework* para auxiliar decisores na escolha de subcontratados. O *framework* utiliza dois modelos para tratar cada fase do processo de contratação. O primeiro modelo a ser utilizado é o modelo Aditivo com veto para a problemática de classificação. Um analista deve listar todas as atividades a serem contratadas e as preferências dos decisores são utilizadas para classifica-las em categorias. Esse procedimento permite que os decisores administrem cada subcontratado de acordo com o impacto da atividade sob o projeto, cliente e construtora. Em seguida, o analista precisa avaliar a racionalidade de cada decisor para escolher um método multicritério de ordenação compatível. A agregação das preferências dos decisores é realizada usando um procedimento de votação, o qual é escolhido pelo grupo quando o *framework* assim o indicar. Por fim, os decisores negociam com os subcontratados que apresentaram as melhores propostas para escolher um. Todos os modelos são apresentados com aplicação numérica na construção civil. Pode ser verificado que o *framework* proposto traz flexibilidade e permite aos decisores tomarem decisões com informação, permitindo que eles se sintam seguros a respeito do processo de contratação. Uma vez que requer que menos decisores se envolvam no processo decisório, pode haver redução no tempo em que se requer a atenção dos decisores, reduzindo o custo do processo. Adicionalmente, o *framework* pode ser usado em outros contextos devido à sua flexibilidade.

*Palavras-chave: Procedimento de votação. MCDM/A. Negociação. Modelo aditivo com veto. Problemática de classificação.*

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## 1 INTRODUCTION

In the Civil Construction (CC) context, outsourcing activities is a common practice (HOLT, OLOMOLAIYE & HARRIS, 1995). The outsourcers, or subcontractors, as they are called in the CC environment, are hired to perform particular activities, which represent different risks to any given project and to the Decision Makers (DMs) involved in managing such projects. Usually these selection processes do not follow a structured model. Thus, it is difficult for DMs to include subjective aspects of the hiring in their evaluation and to conduct trade-offs among criteria. Several different types of activities can be found in this sector. Therefore, the companies involved in carrying them out vary in size, in their potential to expose the contractor to liabilities and in their place in the economic sector. Usually, the DMs of a CC project decide to hire subcontractors to undertake activities that the contractor does not usually do, such as structural project, food supply, transportation of personnel. Sometimes, to accelerate a project, the contractor even outsources activities that it itself would normally do, such as outsourcing precast concrete. Hence, it is important to emphasize that the outsourcing process is subjective, because the DM evaluates the cost of hiring but takes into account other criteria, such as quality, the necessity of maintenance and interaction with other activities, which depend on the activity to be outsourced.

In order to choose subcontractors, the selection must follow a structured framework and the methods have to be compatible with the DMs' rationality and the characteristics of the problem (DE ALMEIDA *et al.*, 2015). The method chosen has to consider that a wide variety of types of activities, risks, and contract sizes could be present. To avoid losses and liabilities, DMs usually choose to manage these contracts by focusing on worst-case situations. This behavior can lead to making more costly decisions. Hence, the question arises as to which contracts should be subjected to more expensive investigation and which should not.

Kumaraswamy & Matthews (2000) discussed the importance of subcontractor selection, due to the oversupply of specialist firms and the problems that had already been caused by this culture in the construction industry. They advocate that since it is easy to enter this marketplace, many of these companies were set up with little capital investment and many are unable to work satisfactorily. This problem has also been addressed by Holt, Olomolaiye & Harris (1994) and Sönmez *et al.*, (2002) who proposed using prequalification criteria prior to the selection itself in order to avoid issues such as lack of quality, delays, and additional cost. There is a wide range of methodologies which might be used to carry out the selection of subcontractors, but

Keshavarz Ghorabae *et al.* (2014) classify this process as a multicriteria problem that includes qualitative and quantitative criteria.

In the literature, papers that address the supplier selection problem and discuss ways to outsource activities, such as to evaluate inventory orders and control (PAN & CHOI, 2016), plant location (BEHZADIAN *et al.*, 2012), relations between supplier and the hiring party (TSUI & WEN, 2014), and trust issues (MANU *et al.*, 2015), can be found. In addition, models to aid the decision process involving a group of DMs in the supplier selection have been proposed. These are divided into those that aggregate DMs' initial preferences, and those that aggregate DMs' individual choices (DE ALMEIDA *et al.*, 2015). Some models do not aggregate at all, but instead present DMs with a general evaluation to help them reach a consensual decision. Moreover, great concern with the uncertainty involved in the preference elicitation process is addressed.

Usually, when the selection process is considered as a group decision, the proposed methods consider DMs have the same objectives regarding the problem. When they aggregate DMs' individual choices, they do not consider that the DMs might have different objectives and different rationalities. In addition, there is no proposition to evaluate the activities and subcontractors differently, in line with their effect on a project. The literature does not take into consideration that after receiving a bid, a negotiation is required and the process might be impacted by the effect that the activity and/or the subcontractor has on the project. Therefore, it is important to propose a framework to aid DMs to conduct the process for hiring subcontractors in a more informed and structured way to include the nuances of the CC environment with a view to reducing the number of liabilities, delays and avoiding additional costs. This framework should take into account the whole hiring process, from the identification of activities to be hired to the negotiation of the contract between contractor and subcontractor to accomplish the activity.

### **1.1 Motivation for the study**

It is important for contractors to have a structured methodology to guide the hiring processes in CC projects. These should associate theoretical and practical concepts, and be developed based on a mathematical modelling, thus allowing the selection process to be structured and informed while taking the DMs' preference structure into consideration. This structured methodology should allow contractors and their teams to feel more confident about their decisions, and help them to avoid liabilities caused by a subcontractor.

Lately, these processes have been evaluated subjectively without using a structured methodology to aid the DMs to identify the best criterion to evaluate subcontractors. In addition, no study has suggested how to categorize analysis based on the effect of hiring an activity may have on a project, and to date, contractors evaluate all criteria in terms of cost, and therefore ignore that some criteria cannot be evaluated in such a way, e.g. risk of loss of life or of serious injuries to people.

Studies in this area tend to focus on allowing DMs to represent their fuzziness and vagueness in such analyses, without realizing that DMs do not evaluate the processes by following the same rationality and objectives as other DMs. Besides, these studies do not allow DMs to use different methods to evaluate processes, because they overlook or fail to acknowledge that different people have different perceptions about the same problem. Moreover, the literature on negotiation as to dealing with supply chain problems behaves as if selection and negotiation were two independent processes.

The decision process of a CC project starts by analyzing the project's activities, so as to determine their cost, duration, and location. The method used to solve such a problem has to take into account that, in a single project, a wide variety of activities will be outsourced and these activities will be diverse as to their risk, size, cost, time, etc. When an activity is outsourced, this brings uncertainty to the project about the subcontractor and therefore a formal contract is set between contractor and subcontractor to allow the parties to manage their relationship. In order to avoid losses and liabilities related to these contracts, contractors usually manage them by focusing on worst-case situations. This behavior results in more cost to the project in terms of time required from DMs to be engaged in the selection and negotiation process, as well as subject subcontractors to requirements incompatible with the effect they may cause to the project, the contractor or the client. Hence, the question that arises is how best to outsource activities considering the preference structure of a group of DMs and minimizing the costs of this selection. By minimizing costs it means if all DMs actually need to get involved in every hiring process all together or if they could split this effort and evaluate the hiring processes as a group only on those activities that could bring more issues to the project.

## 1.2 Objectives of this Research

### 1.2.1 Main Objective

The main objective of this research is to propose a framework in which activities in Civil Construction projects are sorted into classes prior to running a process for selecting subcontractors by using the additive-veto model for sorting problematic and, thereafter, to select the best supplier by aggregating DMs' individual choices and negotiating the contract with the top ranked subcontractors.

### 1.2.2 Specific Objectives

The specific objectives of this research are:

To propose a sorting model to sort activities into classes considering a compensatory rationality in conditions compatible with the CC environment;

To propose a ranking model to subcontractors by considering that DMs might present different rationalities and different objectives in each selection process;

To propose a methodology to aggregate DMs' individual choices using a method compatible with the context that they are in;

To propose a negotiation phase after the selection process by considering that not all DMs will get involved in this phase.

## 1.3 Methodology

The modeling process starts by looking at many different possibilities. During this process, several decisions are made, which leads to possible models being eliminated. This occurs because this process includes assumptions, choices of approach and simplifications that work as filters of the process for drafting a model (DE ALMEIDA *et al.*, 2015). Slack *et al.* (2008) present the modelling process as a funnel, which has several spheres that represent the models available and inside the decision funnel filters represent are the choices the DMs make which act as restrictions during this modeling process.

A twelve-step procedure for modeling decision processes which had a single DM was proposed by de Almeida *et al.* (2015) and is based on this way to refine initial ideas. Figure 1.1 is a graphical representation of this procedure. It is divided into three phases: a preliminary phase, a phase for modeling preferences and choosing a method, and a finalization phase.



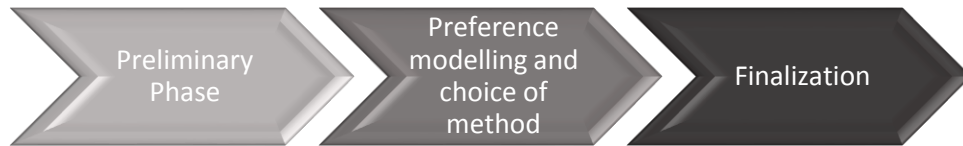


Figure 1.1 – Procedure for solving a MCDA/M problem (Adapted from de Almeida *et al.* (2015))

In the preliminary phase, the authors involved in the decision process are identified. They can be divided into DM, client, analyst, experts and stakeholder (de Almeida *et al.*, 2015). After all actors have been characterized, the DM's objectives are identified. In order to help this process, structuring methods might be used, which helps the DM to identify his/her fundamental and mean objectives, thereby creating a hierarchical structure in order to identify attributes and alternatives, which are available for this analysis. This methodology focuses on creating opportunity rather than on solving problems. The fourth step identifies the set of actions and determines the problematic. In the fifth step, it is necessary to identify if there are any non-controlled factors, and if so, what these are. They are also called states of nature, and when they exist, they drive the analysis to a probabilistic approach.

The preference modeling phase includes choosing the method, and the intra-criterion and the inter-criteria evaluation. There are several ways of defining the types of methods and definitions of the type of criteria will directly influence the choice of the method.

The last phase is the finalization. It starts after the chosen method has been applied. A recommendation is presented to the DM and to guarantee the solution, a sensitivity analysis should be undertaken. This might use a Monte Carlo simulation on one or more characteristics of the model, such as intra-criterion evaluation or/and inter-criteria evaluation. This analysis presents the number of cases in which a rank reversal takes place or a different alternative is chosen or the number of cases in which the alternatives are assigned to different classes. This phase ends by presenting the DM with recommendations and implementing the decision itself.

This 12 steps procedure has been used to develop the models included in the proposed framework. Thus, in every one of the models, the analyst has to verify all the actors, who are the DM, which are his/her objectives and which is his/her rationality. In the first model, it is not necessary to verify the rationality of the DM. As follows, the preferences of the DMs are modelled and a recommendation in each of the models is presented to the DMs.

#### 1.4 Structure of the Thesis

This thesis is organized into five chapters as presented in figure 1.2.

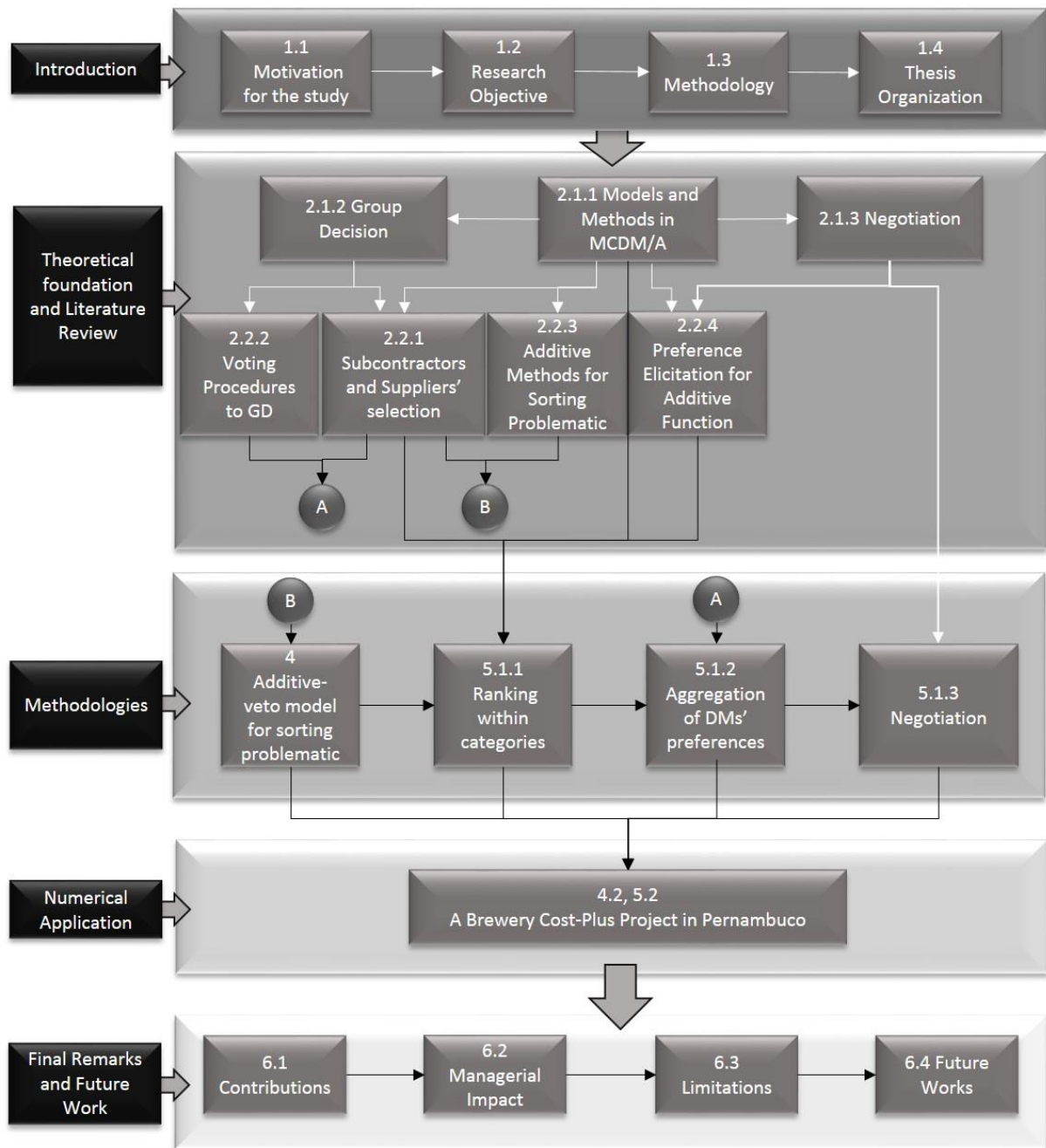


Figure 1.2 – Flow Chart of thesis organization

Chapter I, Introduction, presents the motivation of the study, the research objectives, methodology and the structure of the thesis.

Chapter II presents the theoretical foundation of this research on models and methods in MCDM/A, Group Decision and Negotiation; gives a Review of the Literature on Subcontractor and Supplier Selection, Voting Procedures for Group Decision, Additive Methods for the Sorting Problematic, Preference Elicitation for the Additive Function, E-Negotiation and on the Role of Agents in Negotiation.

Chapter III presents the context, the problem and a framework to aid DMs in contractors to hire subcontractors.

Chapter IV presents the Additive-veto model for sorting problematic.

Chapter V presents a subcontractors' selection model divided in assessment of DMs' preferences, aggregation using voting procedures, and negotiation.

Chapter VI summarizes this research, presenting managerial impacts and limitations, and makes suggestions for Future Works.

## **2 THEORETICAL FOUNDATION AND LITERATURE REVIEW**

In this chapter is presented a theoretical foundation which covers the areas of multicriteria decision making/aid, group decision, and negotiation. In addition, a literature review on Subcontractor and Supplier Selection, Voting Procedures for Group Decision, Additive Methods for the Sorting Problematic, Preference Elicitation for the Additive Function, E-Negotiation and on the Role of Agents in Negotiation is presented

### **2.1 Theoretical Foundation**

The theoretical foundation used in this research is presented below and covers the areas of models and methods in Multicriteria Decision Making/Aid (MCDM/A), Group Decision and Negotiation.

#### **2.1.1 Models and Methods in MCDM/A**

In general, organizations drive their DMs to make decisions every day which may or may not be based on the Strategic Plan of their corporation, whereas the objective may or may not be clear. These decisions are based on information connected with consequences, but rarely ever are they taken based on a unique criterion, such as cost or deadline, when this involves hiring a service, supply chain or merging enterprises. This information is evaluated considering several objectives that stimulate a DM to follow a course of action. When a DM has to take into account several objectives, these can be translated into criteria or attributes. These are then quantified and evaluated based on their effect on the consequences of that decision. The methods built to aid DMs to make decisions that consider at least two criteria are called Multicriteria Decision methods.

Roy (1996) divides the problematics into four main types: (1) the choice problematic ( $P.\alpha$ ), where the objective is to find the smallest subset that contains the optimal actions; (2) the ranking problematic ( $P.\gamma$ ), the objective of which is to aid the DM to rank the set of actions according to his/her preferences; (3) the sorting problematic ( $P.\beta$ ), where the set of alternatives is sorted in homogenous, preordered classes; and (4) the descriptive problematic ( $P.\delta$ ), which focuses on characterizing the set of actions and describes them based on these characteristics. On identifying which of these problematics will be tackled, several methods are excluded from the analysis, thus making subsequent choices of methods more restrictive.

In the literature, several ways of classifying MCDA/M methods are found, but those most commonly found are divided into three main groups: (1) unique synthesis criterion, which aggregate all criteria in one unique criterion for analysis; (2) outranking methods, which take a non-compensatory approach; and (3) interactive methods, which include holistic methods (DE ALMEIDA *et al.*, 2015).

The first set of methods is compensatory. It includes well-known methods such as Multi-Attribute Utility Theory (MAUT) (KEENEY & RAIFFA, 1976), which considers aggregating criteria in multilinear, additive and multiplicative functions. Under this approach, the set of alternatives can be discrete or continuous and it takes into account the state of nature, and so takes a probabilistic approach. The additive method presents several modifications: the Simple Additive Weight (SAW) method in which the scale constants are assessed by using the trade-off method (KEENEY & RAIFFA, 1976), SMARTS/SMARTER which uses swing weights (EDWARDS & BARRON, 1994), the Analytic Hierarchy Process (AHP) (SAATY, 1980), the Additive-veto model for choice and for ranking problematics (DE ALMEIDA, 2013), and UTA (*Utilités Additive*) (JACQUET-LAGREZE & SISKOS, 1982), which is holistic and considers an underlying additive function for evaluating alternatives. Equation 2.1 is the one used to aggregate criteria when analyzing a set of actions and uses the additive method.

$$V(x_j) = \sum_{i=1}^n k_i v_i(x_j) \quad \text{Equation 2.1}$$

where:  $V(x_j)$  is the overall value of alternative  $x_j$ ;

$k_i$  is the scaling constant of criterion  $i$  and  $\sum_{i=1}^n k_i = 1$ ;

$v_i(x_j)$  is the value of the consequence of criterion  $i$ .

Note that the axiomatic structure of Utility Theory helps to avoid inconsistencies during the modelling process. The verifications of the axioms allow the DM to realize when he/she is being inconsistent (KEENEY & RAIFFA, 1976).

The second set of methods is non-compensatory. They include the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) (BRANS, VINCKE & MARESCHAL, 1986) and ELECTRE (*Elimination et Choix Traduisant la Réalité*) (ROY & BOUYSSOU, 1993) families. There are six variations in the ELECTRE family: (1) ELECTRE I and IS, which aid the DM in the choice problematic considering true criteria and pseudo-criteria, respectively; (2) ELECTRE II, III and IV that aid the DM in the ranking problematic considering true criteria, pseudo-criteria and pseudo-criteria without weights, respectively; and (3) ELECTRE TRI, which aids the DM in the sorting problematic and considers pseudo-criteria

(ROY & BOUYSSOU, 1993). To evaluate alternatives, these methods use the concepts of concordance and discordance indices (FIGUEIRA, MOUSSEAU & ROY, 2005). Concordance means that the subset of criteria agrees that alternative  $a$  is strictly or weakly preferable to alternative  $b$ . Discordance means that no criterion has an intensity of preference for alternative  $b$  over alternative  $a$  which is greater than the acceptable limit. Thus, this last concept works as a veto. The analysis is made by building a subset of alternatives called a kernel. The alternatives that are not outranked by any other alternative belonging to the kernel are those which are assigned to this subset.

The PROMETHEE family also presents six variations: (1) PROMETHEE I and II for the ranking problematic, where the former presents a partial pre-order and the latter a complete pre-order; (2) PROMETHEE III and IV, which aid DMs with more complex problems, especially any which involve stochastic components; (3) PROMETHEE V based on the net flow of PROMETHEE II but to aid DMs in the portfolio problematic; and (4) PROMETHEE VI, which does not use specific weights, but it is suggested that intervals be used to define them, when the DM cannot assign one single weight to the criterion. In this family of methods, the evaluation can be made by using or not using preference and/or indifference thresholds and a veto on all variations because this analysis is made in the pairwise comparison phase. An analysis is made based on the positive outranking flow and the negative outranking outflow, where the former represents the intensity of preference of alternative  $a$  over the other alternatives, called subset  $b$ , and the latter is the intensity of preference of  $b$  over  $a$ .

The last set of methods is interactive, and in which preferences are built progressively, differently from the first two, where the preferences are assessed prior to applying the method. The most well-known interactive methods are Multi-objective Linear Programming (STEUER, 1986; DE ALMEIDA *et al.*, 2015), UTA (JACQUET-LAGREZE & SISKOS, 1982) and UTADIS (*Utilités Additive DIScrimantes*) (JACQUET-LAGREZE, 1995; ZOPOUNIDIS & DOUMPOS, 1997) and its modifications (DOUMPOS & ZOPOUNIDIS, 2004; KÖKSALAN & BILGIN ÖZPEYNIRCI, 2009; GRECO, MOUSSEAU & SŁOWIŃSKI, 2010; CAI, LIAO & WANG, 2011; GRECO, KADZIŃSKI & SŁOWIŃSKI, 2011; KADZIŃSKI & TERVONEN, 2013; KADZIŃSKI, CIOMEK & SŁOWIŃSKI, 2015).

### 2.1.2 Group Decision

In all types of cultures and economic systems, using formal methods to aid group decisions and negotiations is of great importance in helping DMs to reach informed and

appropriate collective decisions (KILGOUR & EDEN, 2010). Kilgour & Eden (2010) stated that group decision is a decision context which involves two or more parties who have to make a choice and will take some responsibility for it. In these situations, DMs have to make a decision, differently from negotiation, where the parties may or may not reach a decision (KILGOUR & EDEN, 2010). In addition, a group decision process involves an analytical process to aggregate DMs' preferences and to find a collective decision (DE ALMEIDA *et al.*, 2015). In these processes, there is a great concern about respecting the rules of rationality, related to the normative perspective, and dealing with paradoxes presented in the descriptive perspective (DE ALMEIDA *et al.*, 2015). Moreover, there is a strong connection between group decision and Social Choice Theory and the procedures used to aggregate these decisions might involve MCDM/A, political sciences and group decision support systems.

A concern in developing those models is about the process of aggregating DMs' preferences. Usually, the analyst is responsible for choosing the form of aggregation, after all the actors have been identified (DE ALMEIDA & NURMI, 2015). The range of actors involved in this process are the same as those found in a MCDM/A model, but in this environment, the analyst might be a facilitator and the process involves at least two DMs. Two types of aggregation procedures are described by de Almeida *et al.* (2015): (1) aggregation of DMs' initial preferences, and (2) aggregation of DMs' individual choices.

In the first type of aggregation, the DMs are willing to set aside their personal objectives in order to look for a group decision. Therefore, the DMs furnish the model with information in an integrated way and behave as one. Thus, it is not possible to visualize the preference of individual DMs. They share the same objective regarding the problem and agree to try and find a consensual decision. In these cases, a multicriteria method is used. When a non-compensatory MCDM/A method is used, the DMs share the same consequence matrix, but their inter-criteria evaluations are different. However, when the additive method is used, each DM has his/her own intra-criterion evaluation and additionally the inter-criteria evaluation is also individual, but the criteria are the same. In these cases, an additional scale constant is used to aggregate the preferences and represent the effect of the consequence chosen by the DM for the group, not the relative importance of the DM to the group (DE ALMEIDA *et al.*, 2015).

In the second type of aggregation, the DMs do not share the same objectives. Therefore, each DM produces a ranking of alternatives, which is aggregated by using an analytical method. Moreover, it is not expected that the DMs have the same perception of the criteria. Thus, they do not have to evaluate the alternatives by considering the same criteria or using the same

method. This type of aggregation does not seek a consensual decision, but all DMs agree to accept the group's decision, even when it does not reflect their personal choices, as long as they have the feeling that they have expressed their preferences. An ordinal MCDM/A method or a suitable voting procedure is used to aggregate the DMs' final ranking. There are several organizational and contextual considerations to be taken into account in order to choose one of these approaches (DE ALMEIDA *et al.*, 2015).

In addition, in the context of group decision, there is a third type of aggregation that does not aggregate decisions, but the knowledge of experts. When DMs desire to aggregate as much knowledge as possible about some issue, several experts are hired. These experts have different backgrounds and perceptions about the issue. Therefore, the DMs have to aggregate their knowledge. The procedure might be to build consensus by using a voting procedure or betting.

### 2.1.3 Negotiation

Negotiation processes are characterized by interactions among two or more actors, who have different objectives towards this iteration and who may or may not reach a decision (KILGOUR & EDEN, 2010). In this context, the actors will be called decision makers (DMs) or negotiators and will consider their own structure of preference in order to evaluate the offers and counter-offers that might come up during interactions and they may finalize a negotiation with or without a deal (DE ALMEIDA *et al.*, 2015). This preference structure has to be analyzed by applying a method that can bring to light how the DM feels about each compromise solution that might arise. Therefore, Raiffa (1982) explained that it might not be convenient to reduce all evaluations to money, and therefore proposed applying Multi-Attribute Value Theory – MAVT (KEENEY & RAIFFA, 1976) - to run non-monetary evaluations and recognized that other multicriteria methods might be applied as well.

Negotiation processes emerge in several scenarios: during proceedings for divorce; in businesses in order to contract a supplier or to hire an activity that needs to be carried out, or to buy a house. Negotiation processes might be distributive or integrative. Whenever a negotiation is distributive, this means that two parties are considering one single issue in the negotiation and the negotiators have strictly opposing interests on that issue. Therefore, to close the deal, the parties have to find a point within the zone of agreement. On the other hand, in an integrative negotiation, the two parties are considering more than two issues and the negotiators are not strictly competitors. Thus, they cooperate to enrich the agreement, thereby improving the benefits for both parties. In addition, the negotiation may involve more than two parties, in



which case a subset of negotiators usually forms a group and creates a coalition. The coalition works as a monolithic entity and will help this subset of people to negotiate their own interests. Later on, to share the benefits achieved by the coalition, fair division methods must be used (RAIFFA, 1982).

Due to communications restrictions in the past, those processes had to be run on a face-to-face basis, but with the evolution of telecommunication and informatics, starting in the late 1970s the use of software to support negotiation processes began to be studied (BRAUN *et al.*, 2006). Studies on Negotiation Support Systems (NSS) and Group Decision Support Systems (GDSS) led to the development of tools to support the negotiation process. NSS are designed to help and support negotiators during a negotiation process, and help them to structure the problem and analyze it, to elicit their preferences, to analyze feasible and efficient alternatives or to improve the communication among negotiators (BRAUN *et al.*, 2006). When these NSS are web-based, the negotiation process is called e-negotiation and the tool is called an e-negotiation system (ENS). Several NSS and ENS have been presented in the literature, such as Inspire (KERSTEN & NORONHA, 1999), WebNSS (YUAN, ROSE & ARCHER, 1998), ICANS (THIESSEN, LOUCKS & STEDINGER, 1998) and the Negoist (SCHOOP, JERTILA & LIST, 2003), which had different objectives regarding the support that they offered during the negotiation process.

Applying Internet and Information Technology for the purposes of negotiating has increased over the years, and this has become a very important aspect of negotiations (KOUMOUTSOS & THRAMBOULIDIS, 2009). However, only a few websites are commercially available to customers, and one explanation for this is that negotiations require cognitive effort from the negotiators, especially when they have to tackle many issues (VAHIDOV, KERSTEN & SAADE, 2014). Usually WNSS have different approaches and objectives regarding the negotiation process, and focus on the processes of communication, mediation or elicitation, without combining all of them to create a structured negotiation process where the parties are able to present offer and counter-offers based on their preferences, and are assisted by a mediator.

## **2.2 Literature Review of supply chain choice methods, voting procedures, the sorting problematic and negotiation**

The literature review for this thesis was exploratory, because the main objective was to look for and identify previous studies that could be drawn on with a view to proposing a model

based on sorting activities into classes and presenting different propositions for the selection and negotiation in each of these classes. The selection process only takes place after the sorting procedure for which a multicriteria model is used to rank the bidders and negotiate a contract with those at and near the top of the ranking. The data used in this thesis was provided by a CC project. The literature review sought to find discussion on the following items in order to support this research: (1) models for selecting subcontractors and suppliers, to examine the methods used; (2) voting procedures for group decision, in order to aid how to choose voting procedures to aggregate DMs' preferences; (3) additive sorting methods, to make the first step of the model feasible; (4) preference elicitation for additive methods, (5) electronic negotiation and (6) the role of agents in negotiations, to support the last phase of the model which takes place on a negotiation platform.

### 2.2.1 Models for selecting Subcontractors and Suppliers using MCDM

Outsourcing different services and searching for flexibility is a reality of current supply chain management (MAHADEVAN, HAZRA & JAIN, 2017). Due to the need to outsource or subcontract services, several problems have been addressed in the literature, such as a single supplier and multiple firms forming a coalition for cooperative replenishment (BEN, KRICHEN & KLIBI, 2017), for the purposes of jointly setting the control policies for production and subcontracting while taking environmental legislation into account (GHARBI & HAJJI, 2016), to evaluate the price of the product to be supplied (MAITI & GIRI, 2017), and to select outsourcers/subcontractors. Outsourcing activities in the CC is part of the culture of this sector (HOLT, OLOMOLAIYE & HARRIS, 1995), about which several authors have expressed concern. The oversupply of specialist firms and the ease with which they can enter the marketplace are two of the main concerns (KUMARASWAMY & MATTHEWS, 2000). This directly affects procedures for selecting such subcontractors, because it is necessary to verify if they are reliable. In addition, Keshavarz Ghorabae *et al.* (2014) classifies the selection process as a Multicriteria problem, because DMs have to take into account qualitative and quantitative criteria.

Holt, Olomolaiye & Harris (1995) made a literature review on contractor selection in the United Kingdom and found that clients' greatest concerns were about deadlines, cost and quality rather than any other criteria. However, the trade-off among criteria varied depending on clients' preferences. Besides being a multicriteria problem, since more than one criterion is considered when evaluating problems, some of those criteria were probabilistic and subjective.

In order to reduce the problems created by contractors, Holt, Olomolaiye & Harris (1994) proposed using the following prequalification criteria: Contractors' Organization, Financial Considerations, Management Resources, Past Experience, and Past Performance. In their model, the selection itself only happens after these prequalifications and is conducted using MAUT and specific criteria, which will be built with the client.

In addition, Sönmez *et al.* (2002) advocated using prequalification criteria and argued that several selection problems involve impreciseness and uncertainty. Therefore, they proposed to use a model called the Evidential Reasoning Approach (YANG & SEN, 1994; YANG, 2001), which is based on the Dempster-Shafer Theory of Evidence. This approach sets out to aggregate uncertain, imprecise and vague elicitation data, by allowing the DM to provide preference information using a degree of belief. Lam, Lam & Wang (2010) proposed using prequalification with a Support Vector Machine to sort contractors into two classes. The selection process itself only starts after the prequalification.

Several models combine TOPSIS with other tools, such as fuzzy methods. Chen, Lin & Huang (2006) presented a fuzzy decision-making approach to deal with the supplier selection problem in a supply chain system that was used to analyze qualitative and quantitative variables, such as quality, price, flexibility and delivery performance using linguistic values to assess the ratings and weights for these factors. Razmi, Songhori & Khakbaz (2009) proposed an integrated framework involving two stages: evaluating suppliers and allocating orders. In the first phase, a fuzzy TOPSIS (FTOPSIS) model with a combination of two validated coefficients was conducted and an integer programming with fuzzy objectives and constraints was formulated to assign an optimal quantity of orders allocated to suppliers in the second phase. Dalalah, Hayajneh & Batieha (2011) presented a modification to the DEMATEL model in order to capture the influential relationship between evaluation criteria. These were divided into two groups: cause and effect. The cause criteria influence the effect criteria, and these effects are used to calculate the weights of the criteria. It is only at the end of the procedure that TOPSIS is used to evaluate the alternatives. Boran *et al.* (2009) proposed a model using an Intuitionistic Fuzzy Weighted Averaging (IFWA) operator in order to aggregate DMs' individual opinions in order to rate the importance of alternatives and criteria.

Roshandel, Miri-Nargesi & Hatami-Shirkouhi (2013) presented a model applying the fuzzy hierarchical TOPSIS to select and evaluate suppliers in the detergent production industry. Shen *et al.* (2012) incorporated aspects related to the environmental impact of suppliers during the selection process by using fuzzy sets combined with a multi-criteria decision-making model,

TOPSIS. Kannan, de Sousa Jabbour & Jabbour (2014) proposed a framework using FTOPSIS to select green suppliers for the electronic industry in Brazil. The main idea was to identify the most significant criteria for this problematic. Lin *et al.* (2008) proposed a group decision method to select subcontractors, which combined the Minkowski distance function and grey numbers with TOPSIS. This function has been used to solve the over-weighted problem in the original TOPSIS technique, and the grey number operations deal with the problem of uncertain information. Yue (2013) proposed a modification to TOPSIS where the attribute values, attribute weights and DMs' weights are expressed in data intervals.

Models using the Analytic Hierarchy Process (AHP) or the Fuzzy Analytic Hierarchy Process (FAHP) were very popular too. They were studied individually, to modify other methods, such as the TOPSIS method, or combined to create a new framework. Chen & Yang (2011) combined FAHP and FTOPSIS in order to reduce the uncertainty that arises when assessing DMs' preferences. Wang, Cheng & Huang (2009) verified that by using FTOPSIS with weights directly provided by experts, some basic concepts of TOPSIS were violated. Therefore, they proposed a parametrization in the distance calculations combined with FAHP to avoid these issues. Lee (2009) proposed an analytical model that incorporates a Fuzzy Analytic Hierarchy Process (FAHP) model with the Benefits, Opportunities, Costs and Risks (BCOR) concept in order to evaluate various aspects of suppliers. Aydin & Kahraman (2010) presented an analytical tool for decision support, thereby enabling a multi-criteria supplier selection process to be effective in an air conditioner seller firm under fuzziness. In this tool, the DM can present his/her evaluation using linguistic expressions, crisp numerical values, fuzzy numbers and a range of numerical values to allow the evaluation to be more flexible than that usually used in FAHP. Jaskowski, Biruk & Bucon (2010) presented a model, which has a prequalification stage, to evaluate bidders by using FAHP. The analysis considers criteria such as economic and technical capability in the construction field. The FAHP method is used to aid the definition of criteria weights in the context of group decision. Deng *et al.* (2014) extended the AHP method by D numbers and proposed the D-AHP method. The idea is to incorporate the uncertainty often found in supplier selection processes.

In supplier selection, uncertainty is one source of errors. Therefore, several methods try to deal with this issue and improve the robustness of the solution presented to the DM. To incorporate part of this uncertainty, several articles address the use of fuzzy operators with other methods. Wang & Chin (2008) presented a method, which uses a Linear Goal Programming (LGP) model (a priority method) to derive normalized fuzzy weights for fuzzy pairwise

comparison matrices. Kar (2014) presented an approach that integrates FAHP with fuzzy goal programming for discriminant analysis for the supplier selection problem in the context of group decision, where the DMs seek consensus. Ertay, Kahveci & Tabanlı (2011) presented an integrated method for supplier evaluation and selection that incorporates quantitative and qualitative calculations together to deal with vague and uncertain data available to DMs using AHP to weight the established criteria, and ELECTRE III to evaluate, rank and classify suppliers' performance regarding relative criteria. Tsui & Wen (2014) also presented an approach that integrates ELECTRE III and FAHP, but, in the context of green suppliers.

Chen (2014) proposed an outranking method based on ELECTRE for multi-criteria group decision within the environment of interval type-2 fuzzy sets. The method uses a hybrid method to measure distances and builds a collective decision matrix, which identifies the concordance and discordance sets. Xu & Shen (2013) proposed Atanassov's method for choosing Interval-Valued Intuitionistic Fuzzy Sets (AIVIFS) for outranking to solve MCDM problems in the context of group decision. In the first part, they propose an entropy measurement for the AIVIFS and establish an entropy weight model, which is later used to assess the weights of the alternatives and is combined with ELECTRE I.

Wan & Li (2013) proposed a model for supplier selection under heterogeneous information. Their proposal is to extend the Linear Programming Technique for Multidimensional Analysis (LINMAP) to MCDM problems that involve Intuitionistic Fuzzy Sets (IFSs), trapezoidal fuzzy numbers (TrFNs), intervals and real numbers. The DMs provide preference information using pairwise comparison with hesitation degrees using IFSs. De Almeida (2001) proposed to use a multiattribute function to do the tradeoff between cost and system performance in repair contracts selection and the combination of cost and risk in a multiattribute function in the spares provisioning decision model. De Almeida (2005) proposed to combine response time, quality service, dependability and related cost in the selection of repair contract for a system by combining ELECTRE with utility functions. De Almeida (2007) proposed to integrate the evaluation of criteria under MAUT, by using the ELECTRE method to avoid the rigid axioms of MAUT to select outsourcers considering cost and quality of service. The last one might include probabilistic delivery time and confidence in quality commitment.

Sanayei *et al.* (2008) proposed a model that integrates MAUT with linear programming (LP) to rate and choose the best suppliers and define optimum order quantity among those selected in order to maximize the total additive utility. Wang, Zeng & Zhang (2013) suggested using two new operators: a Dependent Intuitionistic Fuzzy Ordered Weighted Averaging

(DIFOWA) operator and a Dependent Intuitionistic Fuzzy Hybrid Weighted Aggregation (DIFHWA) operator. Yue & Jia (2013) proposed a soft computer model for multi-attribute GDM problems that aggregates all individual decisions on an attribute into an Interval-Valued Intuitionistic Fuzzy Number (IVIFN), in which each individual decision is treated as an attribute value and is expressed in crisp value.

Sanayei, Farid Mousavi & Yazdankhah (2010) proposed a group decision approach combining the VIKOR method with fuzzy operators and linear programming to select suppliers. Shemshadi *et al.* (2011) used linguistic values to assess DMs' preferences in the form of linguistic terms that were converted to fuzzy numbers, and later extend to the VIKOR method with a mechanism to extract and deploy objective weights. Vahdani *et al.* (2013) presented a case study on selecting contractors considering quantitative and qualitative conflicting criteria. The intra-criterion and inter-criteria were evaluated using fuzzy operators and aggregated using the VIKOR method.

Gonçalo & Alencar (2014) proposed a two-step supplier selection model. In the first step, the activities to be hired and the material to be bought were sorted into classes according to their impact on the company's strategic results by using PROMSORT (ARAZ & OZKARAHAN, 2005). In the second step, a selection process took place using PROMETHEE II. The main idea was to focus on activities or products that had the greatest effect on the results of the business. This approach allows DMs to save time that would otherwise be spent on the selection process on an activity that does not cause a positive effect on the project. Palha, de Almeida & Alencar (2016) proposed to sort alternatives into classes based on the risk and impact that the activities cause to a CC project for which they used ROR-UTADIS. Therefore, in the model to be proposed in this research, one of the steps should consider this sorting phase in order to present different approaches depending on the class of assignment. Thus, DMs will be able to avoid liabilities and risks to the contractor and its client, yet will save time which they can then spend on making more strategic decisions.

The literature review on supply chains exposed a great preoccupation with the uncertainties arising from the selection process. In many cases, the methods involved fuzzy operators in order to reduce the effects caused by vagueness and imprecision in the DMs' preferences. Selection processes, usually, rely only on one-step which is devoted to implementing MCDM methods to solve choice or ranking problematics, even when this is a group decision situation. However, some authors have realized how important it is to prequalify subcontractors due to such companies being able to enter this marketplace too easily e.g.

without sufficient capital for investment (KUMARASWAMY & MATTHEWS, 2000) and two authors expressed the concern that bidders should be dealt differently, as measured against some conditions previously defined by the hiring party.

In today's businesses scenarios, decisions are no longer individual; they often require a group to participate in them (RIGOPOULOS, KARADIMAS & ORSONI, 2007). The idea is to reduce the risks that might be caused by one single DM or to allow DMs to make decisions in a decentralized environment. In the first case, the DM might be risk prone, which could drive the company to bankruptcy, or he/she might be risk averse, which may well dam the company's growth. In the second case, group decision-making, due to geographic constraints, the decision process cannot be centralized in one DM, because this would make the decision process excessively slow. Therefore, some companies decide to decentralize their decision process and in each business unit, a group of DMs makes all the decisions until some predefined level. In each group, there must be one Supra Decision Maker (SDM) because, at some level, the decisions will be made by him/her alone, and he/she is at the highest level within the business unit.

In many cases, supplier selection does not present uncertainty on data or DMs' preferences. In addition, several models consider that all the DMs present the same type of rationality and will behave in the same way, which is manifestly not true in the real world. In addition, DMs might well have different objectives with regard to a supplier selection process, even though they belong to the same company. This feature is caused by the position they occupy inside the company and the area they manage. In the CC context, for example, the structure is based on projects and each manager is focused on the objectives of their area. Hence, hardly ever, when it comes to supplier selection, will they be willing to work as if they were a single being, and seek consensus. Under this environment, each DM has different objectives which therefore requires the process to be based on their individual choices. In addition, one DM might be compensatory when facing one process and non-compensatory in another one and the DMs might evaluate the same problem differently.

Even though several model have been proposed, it is possible to find a gap in literature, since the methods do not allow the analyst to evaluate DMs differently and use a method compatible with their rationality. In addition, even when the methodology proposed considers aggregation of DMs' individual choices; it does not consider the different objectives the DMs might present. Therefore, this study presents a model that allow the analyst to evaluate the DMs' rationality in order to use a more compatible model and these DMs have to present a ranking to

be aggregated, thus, they do not have to evaluate the subcontractors considering the same objectives.

### 2.2.2 Voting Procedures for Group Decision

The foundation of voting systems is Social Choice Theory (NURMI, 1987). This theory relies on behavioral assumptions, which are used to analyze DM's preferences and to compare these with the voting procedures to choose alternatives. One of the most important assumptions is that the decision setting is non-strategic; in other words, the voters are honest when voting (NURMI, 1999). This assumption means that the DMs use their own preference to vote and do not manipulate the other voters so as to change the outcome.

All voting systems present shortcomings, which are severe enough to be called paradoxes (NURMI, 1999). The outcomes of a voting when these paradoxes arise might be unfair or implausible given the opinion expressed by voters. Therefore, it is important to know how to deal with them (NURMI, 1999). The best-known paradoxes are Borda's Paradox, where the social choice does not reflect the individual choice of the members of the group, and Condorcet's Paradox, in which the method does not present transitivity. In addition, several other paradoxes have been studied over the years such as the no-show paradox, which deals with the cost of voting or of not voting, and monotonicity paradoxes, which might drive the electoral process to not reflect the group's choice due to manipulation or to the choice of a method that cannot reflect the group's opinion (NURMI, 1999).

Arrow (1963) proposed the Arrow Impossibility Theorem, where he questioned if it was possible to build a social welfare function based on a set of individual choices by imposing some conditions. The conditions presented were: (1) the social welfare function is defined for every feasible pair of alternatives; (2) the Pareto optimality: if  $x$  is strictly preferable to  $y$  ( $xPy$ ) for all individuals, then, collectively  $xPy$ ; (3) independence of irrelevant alternatives; (4) the social welfare function is not imposed; and (5) the social welfare function is not dictatorial. Moreover, it is important to consider that for every two alternatives  $x$  and  $y$ , and a preference or indifference relation  $R$ , two axioms have to be taken into account: (1) for every pair  $x$  and  $y$  either  $xRy$  or  $yRx$ ; and (2) when there is transitivity, which, therefore, considers three alternatives  $x$ ,  $y$  and  $z$ , if  $xRy$  and  $yRz$  then  $xRz$ . By imposing these conditions and axioms, Arrow's Theorem states that if three alternatives do not violate conditions (2) and (3) and provide a ranking that satisfy the two axioms, the ranking has to be imposed or dictatorial (ARROW, 1963).



Voting procedures are typical methods for making social choices. They consider a fixed set of voters, and a fixed and finite set of alternatives, unless otherwise established. Each individual has a complete, transitive and irreflexive strict preference relation over the set of alternatives. A social choice function is a rule that links a set of alternatives to each set of individual preferences and subset of alternatives. Other methods, besides voting procedures, can be used to make a social choice.

Among voting procedures, several methods can be found, and these can be divided into binary methods, one-stage procedures and multi-stage non-binary methods (NURMI, 1983). The input to all Binary Methods is a pairwise comparison, the output is a ranking, and some rules are well known, such as the Simple Majority Rule, Copeland's rule, Dodgson's rule, Schwartz's rule and the Maximin Method. In one-stage procedures, the alternatives are evaluated simultaneously (NURMI, 1983). However, it does not cover all non-binary methods. Examples of one-stage procedures are the Plurality Method (BRAMS & FISHBURN, 1978), Borda's rule (BORDA, 1781), and Approval Voting (BRAMS & FISHBURN, 1978). The multi-stage non-binary methods are elimination methods created to reduce the sets of alternatives progressively. In addition, hybrid methods use more than one choice function in several stages of the procedure. However, these are not the sum of other methods (NURMI, 1983). As examples, one can find Black's Method, the Plurality Runoff, Nanson's Borda-elimination Procedure and Hare's Procedure (NURMI, 1987).

Nurmi (1983) stated that the voting procedures should be evaluated in terms of a group of criteria: (1) Condorcet Criteria, which are about analyzing whether or not the procedure is compatible with the Condorcet winner and/or loser; (2) Rationality Criteria, which include monotonicity, Pareto optimality, and the criteria of choice set invariance. In addition, it is important to analyze the implementation criteria, which are related to the complexity of the system as seen through the eyes of the voters and of the analyst.

The Condorcet Procedure (CONDORCET, 1785) consists of each voter voting in pairwise comparison. Thus, it is possible to find a winning option. The alternative that beats every other alternative is called the Condorcet winner and the one which is defeated by all the other alternatives is called the Condorcet loser (NURMI, 1999). When three or more alternatives are available, a cycle may arise, due to transitivity issues, which enables a winner to be defined. This proposition is known in the model as impossible, contradictory or absurd (NURMI, 1999). In order to get out of this situation, Condorcet suggested that in such a case the alternative with less plurality should be dismissed in order to achieve a new classification

of the alternatives (CONDORCET, 1785). If there are only three alternatives, it is satisfactory, but if there are four or more, an equilibrium is not reached. Young (1988) suggested a modification to reduce inconsistencies and its interpretation is consistent with the objective of finding a ranking of options which are more likely to be correct.

Kemeny's rule (KR) is considered as an extension of Condorcet (NURMI, 2004). KR is a one-stage procedure allows ties. The intention of this method is to achieve consensus, so to find the result of the election one might minimize Kemeny's score. i.e. the sum of the distances of the preference ranking of the voters (HEMASPAANDRA, SPAKOWSKI & VOGEL, 2005). Saari & Merlin (2000) presented a study of the geometry of Kemeny's rule and compared it with the Borda Rule. This study confirmed that Kemeny's rule always ranks the Borda winner in a better position than the Borda loser. In addition, the same findings were presented for the Borda rule in comparison with Kemeny's rule.

Kim & Roush (1996) proposed a voting procedure called balanced voting. It can be described as considering a set of  $n$  voters and  $m$  alternatives, in which each voter ranks all the alternatives. The alternatives with a number of votes less than the ratio  $n/m$  are eliminated. If there is only one alternative left, it is the winner, if not the candidates with a number of last place votes higher than  $n/k$ , where  $k$  is the number of remaining alternatives, are eliminated and so on, until a decision is reached. Lepelley & Valognes (1999) made a probabilistic analysis on balanced voting using two probabilistic procedures and realized that the process is not susceptible to being manipulated.

Morais & de Almeida (2012) proposed a voting procedure, where the voters present a ranking of alternatives. The rankings are divided per quartiles, thereby creating three regions: first and last quartiles and the median position. To evaluate the alternatives, only the first and last quartiles are analyzed by considering a strength index and a weakness index. The main idea is to penalize alternatives positioned in the last quartile and evaluate differently those positioned in the first quartile. This method reduces the effect of dependence on irrelevant alternatives. The method has been used to plan preventive maintenance activities in a water supply system and considers the managers and customer's opinions (DE ALMEIDA-FILHO, MONTE & MORAIS, 2016).

Konczak & Lang (2005) proposed an approach to deal with situations where, in the voting procedure, elicitation issues appear and a partial winner is determined when the preference profile is not fully known. This kind of problem appears when: (a) only some of the voters express their preferences (epistemic incompleteness); (b) all voters express their opinion about

all candidates, but new options appear; (c) voters cannot express their opinion about all alternatives, since they do not want to or know all of them (intrinsic incompleteness); or (d) preferences have been partially elicited or are expressed in a language for compact representation. Other authors addressed the same concern in proposing methods when the DMs are unable to provide a complete order..

Ackerman *et al.* (2013) proposed an approach to deal with group decision when the DMs have to explicitly consider the characteristics of alternatives and these DMs have a relatively small number of options on which they might express their preferences. In this context, it might be cognitively inadvisable to rank all possible alternatives. Therefore, the authors present two forms of obtaining preference information: (1) the characteristic points method, and (2) the characteristic sets method. In the former, the DMs award points to the characteristics surveyed and the number of points an alternative receives is the sum of points of the characteristics they possess. In the latter, the alternatives are evaluated by considering the number of desirable characteristics they possess and comparing these with the set of alternatives. Then, the authors presented two forms of aggregating this preference information: (1) the linear extensions method, and (2) the direct method. The first one adapts other methods, either positional or pairwise, to partial buckets and the second one only uses the information provided by the characteristic points method or the characteristic sets method, without extrapolating to every alternative.

Cullinan, Hsiao & Polett (2014) presented a voting method called the Borda count for partially ordered ballots. In this approach, Borda's rule is adapted to the situation where the voter is unable to compare all alternatives. Equation 2.2 is an adaptation of Borda's weighting procedure used to calculate the value of the alternatives with partially ordered ballots.

$$w_{\leq}(a) = 2 * down_{\leq}(a) + incomp_{\leq}(a) \quad \text{Equation 2.2}$$

where:  $w_{\leq}(a)$  is the position of alternative  $a$

$$down_{\leq}(a) = \{b \in A \mid b \prec a\}$$

$$incomp_{\leq}(a) = \{b \in A \mid b \text{ is incomparable to } a\}$$

The authors prove that this procedure holds the properties of transitivity, reflexivity and antisymmetric. They also state that it is the unique social choice function, which is consistent, faithful, neutral, and has the cancellation property. In addition, it satisfies the monotonicity and Pareto conditions. However, it does not satisfy the plurality condition.

Nowadays, groups of DMs increasingly make managerial decisions (DE ALMEIDA & NURMI, 2015). Therefore, their preferences have to be aggregated in order to reach a social

choice and to do that one of the aggregation procedures considered to be democratic is that of voting (NURMI, 1999). Because an analyst chooses the voting procedure, it may not be suitable for the decision process faced by the DMs. Therefore, de Almeida & Nurmi (2015) proposed a framework to help DMs choose the voting procedure by considering their preferences with respect to the problem. The choice is made by considering the voting procedures as alternatives and their characteristics as criteria. Two propositions were presented: before the DMs present their preferences or after they do so. They note that when the aggregation is after the DMs present their preferences, the process is subject to manipulation. Nurmi (2015) presented paradoxes which could be considered as criteria and compared the choices of the voting system by aggregating the DMs' preferences using different procedures.

There are some issues concerning the framework proposed by de Almeida & Nurmi (2015) that need to be explored, such as the aggregation method that should be used, whether or not the DMs should have the same weight in this process, and if they do not, whether or not a SDM should decide the weight of each DM. In addition, Nurmi (2015) presented the criteria's evaluation as binary. However, this type of evaluation hardens the aggregation and a question that arises is whether or not the paradoxes are presented in different procedures with the same intensity. The framework was proposed with an ordinal analysis, but it could be presented more quantitatively, which would require the SDM to take great care when assigning weights to the DMs. In addition, research interest in a voting procedure which deals with partial information is growing, which requires a criterion that considers this property to be included in the analysis. Therefore, it is important to run an experiment in order to evaluate the frequency at which these paradoxes emerge in each method and in addition to evaluate adaptation for voting procedures in order to allow partial orders to be aggregated.

Even though some gaps can be found regarding this methodology, this study does not address any solution, instead it applies the framework proposed by de Almeida & Nurmi (2015) to aid the DMs to choose the voting procedure to be used in the aggregation of every hiring procedure considered. The main idea of using this procedure is to enable the analyst to manipulate the hiring process and give to the DMs the idea that they have decided every step of the analysis, including the methods used.

### 2.2.3 Methods for Sorting Problematic

In the multicriteria decision aiding (MCDA) literature, the methods developed recently for the sorting problematic were mainly based on artificial intelligence and operational research

techniques (ZOPOUNIDIS & DOUMPOS, 2002). In this type of problematic, the alternatives are sorted into homogeneous, predefined, preference-ordered classes (ROY, 1996). The two main kinds of preference modeling are preference elicitation or inferred, and holistic preference assignments, also known as example-based methods (VETSCHERA *et al.*, 2010). The former refers to methods in which the DM has to express his/her preferences by means of parameters for building a preference function used to assign alternatives into predefined classes. The latter refers to methods in which the DM has to express his/her preferences by means of reference alternatives, and the parameters are calculated using a disaggregation approach.

In a sorting method, consider a finite set of  $m$  alternatives  $A = \{x_1, x_2, \dots, x_m\}$ , which is evaluated using a finite set  $g = \{g_1, g_2, \dots, g_n\}$  of  $n$  evaluation criteria. Let  $C_h$ , be the  $q$  predefined preference-ordered classes in such a way that  $C_q > C_{q-1} > \dots > C_2 > C_1$ . The assignment of an alternative to a class is conducted by comparing an alternative with the reference alternative of the class under consideration. The profile is the reference alternative that is the boundary between two classes (DOUMPOS & ZOPOUNIDIS, 2002), thus,  $b_h$  is the vector of performance of this reference alternative with respect to each criterion and represents the limit between class  $C_h$  and class  $C_{h+1}$  (ROY & BOUYSSOU, 1993).

One of the most popular inferred methods is ELECTRE-TRI-B (ROY & BOUYSSOU, 1993), which is an outranking method developed for the sorting problematic. In this method, the profiles elicited use pseudo criteria and the classification is based on the boundaries of the classes. Recently, Almeida-Dias, Figueira & Roy (2010) presented a new method based on ELECTRE-TRI-B, called ELECTRE-TRI-C, in which the profiles are defined based on characteristic reference actions instead of boundaries. Bouyssou & Marchant (2015) compared the two methods and concluded they are very different. Thus, they proposed three streams for studies: (1) identify other methods based on central profiles that have simpler relations with ELECTRE-TRI-B; (2) identify the theoretical properties of ELECTRE-TRI-C; and (3) propose an elicitation methodology for ELECTRE-TRI-C. The ELECTRE-TRI-C method has also been modified into ELECTRE-TRI-nC (ALMEIDA-DIAS, FIGUEIRA & ROY, 2012), which takes into account several reference actions to categorize each group. Thus, it can be classified as a holistic preference assignment method.

There are a few well-known holistic methods. The reason why they were developed is because the preference elicitation methods require the DM or the analyst to specify a range of technical and preferential information to calibrate the sorting model. In other words, on using the preference disaggregation approach, the preference information is built using regression-

based techniques. Therefore, since they require less cognitive effort by the DM, most of the methods designed for sorting and classification use the disaggregation approach (DOUMPOS & ZOPOUNIDIS, 2002). Among the holistic methods are: the Dominance-Based Rough Sets Approach (DRSA) (GRECO, MATARAZZO & SŁOWIŃSKI, 2001), Case-Based Distance Sorting (CBDS) (CHEN *et al.*, 2008), ELECTRE-TRI-C (ALMEIDA-DIAS, FIGUEIRA & ROY, 2010), ELECTRE-TRI-nC (ALMEIDA-DIAS, FIGUEIRA & ROY, 2012) and UTADIS (UTilités Additives DIScriminales) (JACQUET-LAGREZE, 1995; ZOPOUNIDIS & DOUMPOS, 1997).

One well-known example-based method is the Dominance-based Rough Sets Approach (DRSA), which is based on “If... then...” rules. Pawlak & Słowiński (1994) made the first attempt to turn Rough Sets into a MCDM/A method, but it could not incorporate the DM’s preferences. After several modifications and relaxations of rough set properties, the DRSA was finally proposed (GRECO, MATARAZZO & SŁOWIŃSKI, 2001). Later on, some modifications were suggested to incorporate incomplete statements (GRECO, MATARAZZO & SŁOWIŃSKI, 1999, 2000) and, subsequently, Kadziński, Greco & Słowiński (2014) implemented the principles of Robust Ordinal Regression (ROR) within the DRSA approach.

Out of the family of preference disaggregation methods, several proposals emerged, starting with the UTADIS method (*UTilités Additives DIScriminales*) (JACQUET-LAGREZE, 1995; ZOPOUNIDIS & DOUMPOS, 1997). These methods include an underlying additive aggregation and use linear programming to calculate the parameters based on reference alternatives provided by the DM. Zopounidis & Doumpos (2000) presented a software, PREFDIS (*PREFerence DIScrimination*), to support DMs when using UTADIS, which incorporated three modifications of the original method to correct misclassification errors. Doumpos & Zopounidis (2004) run an extensive experimental investigation on UTADIS to shed light on some critical problems on the construction of the preference model and proposed a heuristic (HEUR2) to improve the stability of the data and the performance of the method.

Later on, Greco, Mousseau & Słowiński (2010) proposed UTADIS<sup>GMS</sup>, a modification of the original UTADIS, which applies ordinal regression to solve problems and incorporated imprecise statements to the method by considering interval data and presenting the solution by means of possible and necessary assignments. Greco *et al.* (2012) extended the method to a group decision context, known as UTADIS<sup>GMS</sup>-GROUP, by combining the DMs’ necessary and possible assignments so as to provide a group recommendation. Greco, Kadziński & Słowiński (2011) extended the concept of ROR to the UTADIS<sup>GMS</sup> method in order to consider

complete sets of instances of the preference model that were compatible with the information provided by the DM. This also extended the method to a group decision context (KADZIŃSKI, GRECO & SŁOWIŃSKI, 2013).

Kadziński & Tervonen (2013) presented a novel approach by applying the possible and necessary assignments, based on ROR, and enriched the analysis with SMAA (Stochastic Multicriteria Acceptability Analysis) (LAHDELMA, HOKKANEN & SALMINEN, 1998) to verify the possible assignments. Lately, Kadziński, Ciomek & Słowiński (2015) proposed a new method, ROR-UTADIS, which allows the use of pairwise comparisons. Also, Köksalan & Bilgin Özpeynirci (2009) presented a method to reduce the misclassification errors of the original UTADIS method, in which there is no estimation of utility parameters. Instead, they impose some restrictions on the linear programming to verify if the alternative might be selected. Cai, Liao & Wang (2011) proposed PUTADIS to build a DM's preference information interactively and to allow the use of imprecise information.

Case-Based Distance Sorting (CBDS) methods are another type of holistic methods, which use Euclidean distance to calculate the parameters and assume an underlying additive function so as to consider evaluating the alternatives (CHEN *et al.*, 2008). Vetschera *et al.* (2010) ran a simulation to verify the misclassification errors in holistic methods and compared the CBDS with SAW. In the latter, thresholds were estimated so as to sort the alternatives into classes. Moreover, they proposed a compatibility index ( $I_C$ ), a validity index ( $I_V$ ) and a robustness index ( $I_R$ ) to verify if the differences between the two methods were significant. The authors found that the quality of assignments in the CBDS was dependent on the quality of the information provided while increasing the number of cases in the CBDS did not necessarily lead to improvements in the final solution. Therefore, extending this analysis to other holistic methods it can be investigated whether, besides having many compatible functions with the preference information, the model could lead to misclassification due to the DM providing poor information.

Thus, the holistic methods might be dependent on the quality of the information that the DM provides, and, since the parameters are all calculated, several profiles might be compatible with the reference alternatives provided. To reduce this problem, Doumpos & Zopounidis (2004), Kadziński & Tervonen (2013) and Kadziński, Ciomek & Słowiński (2015) proposed solutions but kept the disaggregation approach. Besides it being possible that case-based methods are unfeasible, when they are feasible, they often present several profiles compatible with the preference information that the DM has provided, as stated by Vetschera *et al.* (2010)

and Kadziński & Tervonen (2013). Even when considering the possible and necessary assignments, Kadziński & Tervonen (2013) verified that the range of possible assignments can be wide, while the set of necessary assignments is often empty, thus making the solution uncertain.

Holistic methods require a DM to have knowledge of reference alternatives, as this enables him/her to assign that reference alternative to a class or compare reference alternatives. These items of information are used to calibrate the model and extend the parameters to the whole set of alternatives. The drawback is that the preference information is built using the DM's judgment, and, as stated by Vetschera *et al.* (2010), such pieces of information might be compatible with several profiles. Several authors have been addressing this problem and have presented solutions to reduce it, for example, Doumpos & Zopounidis (2004), Kadziński & Tervonen (2013) and Kadziński, Ciomek & Słowiński (2015).

Vetschera *et al.* (2010) stated that due to the disaggregation analysis, three possible solutions to the optimization problem can be found: (1) the minimization problem has one single solution with a value greater than zero, while it presents, it calculates approximate parameters; (2) a unique solution with zero value is found to the minimization problem, which means that the DM's preferences can be represented by a single profile; and (3) several solutions equal to zero are found; in this case several profiles are compatible with the DM's preference information. The authors analyzed the last situation by running a simulation to compare a holistic method with a preference elicitation method by analyzing three indices. They verified that the quality of sorting in the holistic method chosen was dependent on the quality of information that the DM provided and the results presented by using SAW were not significantly different from those presented when using CBDS. It is important to emphasize that SAW sorts alternatives into classes in a very simplistic way, namely, a rank of alternatives is created, and based on the profiles a threshold is calculated to sort the alternatives into classes.

The disaggregation approach became popular because it requires less cognitive effort from the DM and the sorting problematic requires more preference information from the DM than other problematics, which is why most sorting methods are holistic (DOUMPOS & ZOPOUNIDIS, 2002). However, the above-mentioned experiment showed that the quality of preference information remains a problem. In addition, no significant difference can be found between the two types of methods in term of compatibility, validity and robustness. Furthermore, the solution of the optimization problem might be unfeasible or might cause misclassification among the alternatives due to parameters being identified which do not reflect



the DM's preferences. Even by considering the possible and necessary assignments, Kadziński & Tervonen (2013) verified that the range of possible designations found in the set of possible classes is too wide and the set of necessary assignments might be empty, which drives the conclusion to uncertainty. Moreover, in order to apply holistic methods, computational systems are required which means that the DM is necessarily dependent on a DSS.

In CC Industry, in the beginning of the project, the DMs do not have any knowledge about the local market and might bring bias from previous projects. Thus, it is not recommended that they use a holistic method in the right beginning of the project, even though in a later stage it would not be a problem. In addition, they tend to evaluate the aspects related to the activities to be hired by doing the trade-off among criteria, because they realize that in this case, by decreasing the risk in one criteria, they could well compensate it in another criterion and analyze different activities by considering the same procedure. Thus, a compensatory method should be considered. However, the methods proposed for preference elicitation are non-compensatory and the ones compensatory are holistic. Hence, in this study, an additive method for the sorting problematic is proposed to solve this issue.

#### 2.2.4 Preference Elicitation for Additive Function

Weber (1987) stated that in traditional methods for preference elicitation, such as MAUT, the decision situation has well defined alternatives; the DM knows the probability distributions of the outcomes; the objectives/attributes are known; and the preference structure of the DM is stable. However, these requirements are extremely strong and frequently the probabilities of the outcomes are unknown; the DM's preference structure is unstable or not precisely defined or the evaluations of the alternatives are not precise, and this leads to a situation of incomplete information.

Due to the lack of information, sometimes the elicitation process becomes tedious and time-consuming. This characteristic drove Salo & Hämmäläinen (1992) to propose a method for preference assessment by imprecise ratio statements (PAIRS) which was based on SMART (EDWARDS, 1977), and elicited the attribute weights/constant scales from pairwise judgment of relative importance. Therefore, as in the SMART method, the DM expresses his/her preferences by means of pairwise judgment. However, in PAIRS this information is provided in interval judgments of relative importance of the attributes and the DM is allowed to compare any two attributes. Later on, Edwards & Barron (1994) suggested a modification in the SMART method and proposed the swing weights elicitation method and presented the

SMARTS/SMARTER method. They recognized that as an additive method, SMART could not rely on using the relative importance of attributes to elicit have the scale constants.

After the proposition of Edwards & Barron (1994), Salo & Hämäläinen (2001) proposed the Preference Ratio in Multi-attribute Evaluation (PRIME) method, which is based on swing weights. In PRIME, possibly imprecise ratio judgments are converted into an imprecisely specified preference model; the decision recommendations are derived from decision rules and dominance structures; and the sequencing of the elicitation process is based on a series of elicitation tasks. The elicitation resembles the one of PAIRS, since it provides dominance results throughout the analysis to preserve the consistency of the information. However, it differs from PAIRS because the ratio comparison is linked to the value ranges of the alternatives to avoid the confusion of the concept of “relative importance” in the attributes. Mustajoki, Hämäläinen & Salo (2005) presented a study to incorporate interval judgment in SMART and Swing weights methods as a way of handling preferential and informational imprecision in a multicriteria decision model. Salo & Punkka (2005) presented the Rank Inclusion in Criteria Hierarchies (RICH) method, in which the DM is able to specify subsets of attributes, which contain the most important attribute, or to associate a set of rankings with a given set of attributes. Analogously to PRIME, the DM provides preference information interactively and receives recommendations continuously, but the elicitation process is built upon ordinal preference statements. Another way of dealing with incomplete information is by using holistic methods, such as UTA (JACQUET-LAGREZE & SISKOS, 1982). This was proposed considering an underlying additive function and building the preference information based on exemplary alternatives.

The tradeoff (KEENEY & RAIFFA, 1976) procedure, due to its axiomatic properties, is considered more robust than other methods at eliciting scale constants for the additive model, but experimental studies showed that several inconsistencies can be found when it is applied (WEBER & BORCHERDING, 1993). Therefore, de Almeida *et al.* (2016) proposed the FITradeoff method to overcome some of these inconsistencies. This is a method with a flexible elicitation procedure, which does not assume imprecise or incomplete information. It seeks complete information from the beginning, but allows a recommendation to be reached when the DM is not able to give more information or a unique solution can be found by considering the incomplete set of information. The method was built in a DSS (decision support system) and the idea is to require less effort from the DM by reducing his/her cognitive effort.

The process of flexible elicitation is a way of modifying the elicitation process based on the conditions and circumstances, requiring less effort from the DM, since he/she does not have to undergo all the steps of the tradeoff procedure (DE ALMEIDA *et al.*, 2016). The heuristic of FITradeoff considers a continuous evaluation during the elicitation process, and thus it can be suspended whenever a solution is reached. The solution is found by applying linear programming to the partial information provided by the DM during the preference assessment. To calculate the feasible alternatives, the system considers dominance relations and provides the DM with recommendations. The objective of requiring less cognitive effort from the DM was to avoid errors, but de Almeida *et al.* (2016) could not confirm this hypothesis and therefore postponed evaluation to another study.

The evaluation process in the FITradeoff (DE ALMEIDA *et al.*, 2016) may require several steps prior to finding a recommendation. Therefore, the authors proposed a heuristic to test the flexibility of the procedure in order to transform the preference information into restrictions of the linear programming problem (LPP). The unidimensional value functions are considered to be linear, as proposed by Edwards & Barron (1994). The DM provides his/her preference order of the criteria and after this procedure has been completed, the system makes a first attempt to find a set of feasible solutions. If the DM decides not to choose one of the available alternatives presented in the set of recommendations or if it is not possible to find a recommendation, the core of the procedure starts based on a heuristic, which depends on the answer the DM presents to each question on the assessment of preferences.

Several forms of preference elicitation have been presented. Each procedure has its own drawbacks, it being necessary to apply some conditions in order to avoid misunderstandings when building the DM's value function. The process of flexible elicitation is a way of modifying the elicitation process based on conditions and circumstances, requiring less cognitive effort from the DM, since he/she does not have to go through all steps of the tradeoff procedure (DE ALMEIDA *et al.*, 2016). The DSS built to apply FITradeoff considers a heuristics to evaluate the elicitation process while it is being conducted. Thus it can be suspended whenever a solution is reached. The solution is found by applying a linear programming to the partial information provided by the DM during the querying step. To calculate the feasible alternatives, the system considers dominance relations and provides the DM with recommendations. The objective of requiring less cognitive effort from the DM is to avoid errors. This idea of giving flexibility to the DM in the elicitation process was already presented by Salo & Hämäläinen (2001) and Salo & Punkka (2005).

Because some additive methods might require more cognitive effort, the FITradeoff method might be well considered for the elicitation during the negotiation step, since the DMs will be subjected to the preference elicitation procedure several times. Thus, the use of a method that allows elicitation with incomplete information might be better than using a method with well-known axioms and driving the DMs to compromise the results.

### 2.3 Synthesis of the State of the Art and Stance of the Study

In literature, the main preoccupations concerning the selection of subcontractors are to prequalify the subcontractors or to take into account uncertainties in the analysis. However, none of the models was built to be adapted to different realities. In most supplier selection processes, the DMs decide to consider more than one criterion. Thus, the use of an MCDM/A approach is the most appropriate way to solve this type of problem. Some of the group decision models considered the aggregation of DMs' initial preferences, which are MCDM/A methods. However, when the decision is not consensual, the best way to aggregate DMs' individual choices is using voting procedures. In this context, each DM ranks the alternatives and these are aggregated to provide a final ranking and reflect the social choice. In addition, this approach allows the DMs to evaluate alternatives under different criteria and different methods.

Some MCDM/A methods do not provide a complete order, because non-compensatory methods allow incomparability in their preference structure, which provides a partial pre-order. Sometimes the DM is whiling to solve the incomparability searching for more information, but sometimes he/she is not, because he/she does not want to spend resources browsing such information (ROY, 1996). Therefore, sometimes incomparability has to be taken into account in the aggregation process. This issue will impact the choice of the voting procedure, because most voting procedures only deal with complete pre-orders. In addition, voting procedures present different characteristics that influence the final solution. Hence, the question of which voting procedure to choose in order to reach a social choice arises. As presented in item 2.2.2, de Almeida & Nurmi (2015) proposed a framework to aid DMs in businesses contexts to decide which voting procedure to use in each group decision process.

Another common assumption is that every selection process in a company should be run in the same way. However, in the supply chain, it is well-known that the evaluation of inventory orders and control is categorized. This procedure is called ABC analysis (SLACK *et al.*, 2008), and the amount of time and effort spent in items sorted into class C is certainly not the same as that spent on class A. Since class A has a great financial impact on just a few items, it is

important to be careful with the inventory orders involved in this category. However, a significant number of items with low financial impact are found in class C. Thus, the analysis is less strict for inventory orders of these items. The main idea is that this type of analysis should be used when dealing with selection of subcontractors to undertake activities. The analysis ends up being made in a very subjective and non-structured form and the DMs end up evaluating every process or categorizing without a formal procedure. Thus, it may lead DMs to spend a lot of time evaluating subcontractors of one activity that does not represent great impact to the project and neglecting others that should be evaluated more carefully.

The selection of subcontractors varies in size, risk and deadline set. Therefore, models have to incorporate these differences to aid DMs to make a more structured decision and evaluate these selection processes according to their consequences. These processes include several constraints to avoid liabilities and these might be relaxed depending on the level of impact that the activity is sorted into. Hence, the whole selection process might be less expensive and besides, the DMs would not need to get involved in every selection process but could devote their valuable time to more strategic issues.

Therefore, a sorting phase is included in the framework and a method should be chosen. Due to the characteristics of this problematic, only a few methods were developed, narrowing this choice. As in the other problematics, the DM's rationality must be verified, and so too whether or not: a) a group decision will be made, b) the SDM will work alone during this step, since some information on the profiles of the classes comes from the governance of the business, and c) a preference elicitation method or a holistic one will be used.

As aforementioned, there are preference elicitation methods, which are outranking methods, and holistic ones, in which additive versions can be found. Within the CC context, the DM usually thinks in a compensatory rationality fashion. This type of DM cannot evaluate the criteria based on importance. Therefore they are usually willing to compensate the criteria by carrying out some trade-offs (KEENEY & RAIFFA, 1976). Even when the activity consists of a long-term relationship, if its cost and impact over other activities are below some predefined level, the DM will not consider placing it in high impact classes. Thus, if it was a short-term relationship with high cost, the activity could be considered medium impact. However, if it was a long-term relationship with high costs, it would possibly be considered in the high impact class, meaning that neither cost nor schedule is evaluated over its importance, but on the way they relate to each other. Therefore, it is not possible to use an outranking method in this

context, eliminating ELECTRE-TRI-B and PROMSORT, and requiring the use of an additive method.

In the case of the additive method, there are two possibilities: the holistic methods or SAW. The main problem with the former is that the projects greatly vary in size, risk and activities involved. In addition, the localization of the project itself might change the class of assignment of an activity. Therefore, by applying a holistic method right at the beginning of the project, the DM could present biased preference information, because he/she could evaluate the alternatives based on previous projects that did not relate in anyway with the situation faced in the current project. Thus, it is not possible to use a holistic approach either. The last possibility would be to use SAW. In this case, the alternatives are sorted into classes simply by considering the thresholds and allowing criteria to be fully compensated when calculating the overall value of alternatives, which is used to carry out the comparisons with the classes profiles. Nevertheless, problems of unbalanced set of alternatives might arise and the compensation faced in this method might be undesirable at certain levels. De Almeida (2013) proposed the Additive-Veto model for choice and ranking problematics, where the idea is to bring balance to the set of alternatives and still preserve the compensatory aspect of the additive model by considering a veto condition. In the choice problematic, the idea is to eliminate alternatives that are incompatible with the DM's preferences, even if their overall value is good, by refusing to let such an alternative to have a low performance in one criterion compensated for by a good performance in another. In the sorting problematic, the idea of veto is to refuse to accept that an alternative belongs to a class.

This study presents a framework for the selection of subcontractors problem in the context of CC. The framework considers the process of subcontracting activities from its very beginning, when the activities to be outsourced are listed, until the negotiation process with top-ranked subcontractors. This framework sets out to allow the DMs to better use their time and resources by evaluating the selection processes according to the impact they represent to the contractor, the project and the client. In order to sort the alternatives into classes, an additive method with veto has been proposed to fit the DM's rationality towards this problem. It allows the analyst to take into account the different rationalities among the DMs, by not imposing the used of only one method and obtaining a solution that does not reflect his/her preferences. It uses a procedure which permits DMs to decide on the voting procedure to be used to aggregate their preferences, and does not oblige them to try to reach a consensual decision but allows them to evaluate the alternatives considering their own objectives. In addition, it is emphasized the need to use

voting procedures which take into account partial votes, a feature that has not been thoroughly explored in the literature. Finally, it suggests to the DMs a negotiation phase by assessing the preferences of the DMs using a compensatory method, and considering an integrative negotiation.

### **3 THE CONTEXT, THE PROBLEM AND THE FRAMEWORK**

#### **3.1 The context and the Problem**

In the heavy construction industry, contractors work with a decentralized structure. This configuration is due to geographical and communication constraints imposed by the type of projects to be engaged on, such as constructing a highway, railways, airports, harbors, bridges and industrial buildings. These types of construction usually are far from urban centers, and thus require DMs to have autonomy to make decisions. However, the Chief Executive Officer (CEO) of the company has to guarantee that the Director of Construction (DC) in charge of the project will maintain the values of the contractor. Thus, usually the decision process in each project includes other managers besides the DC responsible for the project.

In this environment, each project works as if it were an autonomous company that has a board which is in charge of every decision. Thus, the decision process is not individual, but a group of DMs makes all the decisions guided by the governance defined by the contractor. The DMs present different characteristics and backgrounds. Therefore, it is important to use a model or framework to guide this decision process in the CC context from which the DMs can benefit by being flexible and fitting their needs to the aims of the project in terms of structure and information.

In a construction project, the actors involved are the DMs, the analyst, the experts and the stakeholders. The DMs of a project normally include a Director of Construction (DC), a Finance Manager (FM), an Engineering Manager (EM) and an Operations Manager (OM). Depending on the size and type of project, a Maintenance Manager (MM) and the Client may also take part in the procedure. The analyst is usually an individual who is head of his own team, and who organizes the processes of the subcontractors and deals with them, with regard to payments, documents, and managing the contractual relationship. The analyst should have a background on decision theory, group decision and negotiation, multicriteria decision making methods and structuring methods to be able to structure the problem and guide the decision process, aiding the DMs to reach the best compromise solution. The expert might be a Senior Engineer who usually is not involved in the selection processes of subcontractors and is knowledgeable about the activity to be selected or has specific knowledge about the project itself. The stakeholders are environmental agencies, the Ministry of Labor, the City Hall, the Government, the population affected, the Union and the Client, as the enterprise, which actually hired the whole



project. The Client might be from either the private or public sector and may play the role of DM in Alliance Contracts or Cost-Plus Contracts because it will be one of the hiring parties in all outsourced contracts.

In heavy construction projects, the Chief Executive Officer (CEO) of the contractor usually works with a decentralized structure. Thus, the decision process becomes a group decision to avoid the concentration of power only on the DC. Hence, the managers are treated as DMs and legally answer for the project as well. The DC behaves as a Supra Decision-Maker (SDM), and he/she has to choose his/her team and win the contract and the client. (S)He usually sees the project in a global manner and balances the contributions of the other DMs in the decision process. The SDM is responsible to provide preference information in the classification process and decide the weights each DM might have in the decision process. In addition, the SDM is responsible to define the governance used in the project and this will guide the other DMs. The EM has a global view of the project as well, but tends to focus on projects, risks and liabilities that may result from the outsourcing. The OM focuses on the executive project and has a limited view on the corporative environment and the legal risks to which the project might be exposed. Usually, the OM is concerned with the schedules of the activities, their interaction, and executive methods. The FM has a good perception of the corporative environment but a poor one of the executive project. He/she is usually responsible for liabilities and the contractual relationship, as well as the quality of the services hired during the outsourcing.

In some types of contracts, such as Cost-Plus, the Client plays the role of DM. In these cases, he/she behaves as the SDM, instead of the DC. This happens because legally his/her company is responsible for the relationship with the subcontractor. Moreover, he/she is not only concerned with problems during construction, but also with long lasting problems that might result from the construction. In those cases, the Contractor manages the project and is obliged to make decisions regarding building schemes, as well as advising the Client, and is legally responsible for the project. However, hierarchically, it is not at the same level as the Client.

Nowadays, the process for hiring subcontractors does not follow a structured model. Usually, three companies are invited to take part in the selection during which information such as the nature of the structural project, deadlines, localization and documents required are presented. These companies visit the construction site to evaluate subjective issues, such as labor conditions, labor union of affiliation, interaction with other activities, the need for lodgings, and transportation conditions. During the selection, the companies present their

proposal, including price, the time they need to get ready to start the activity, the time they need to undertake the service considering the price presented and their assumptions about the project. DMs evaluate the proposals intuitively. All DMs together take part in the evaluation, but sometimes they decide that if costs are below some predefined level, decisions can be made by only one DM that could be either the manager that required the service to be hired or the DC.

Once the subcontractors are ranked, a negotiation process starts. The subcontractors' proposals are evaluated based only on cost. However, previous experiences with the subcontractor can be taken into account and a tradeoff may occur intuitively. This negotiation is made with the subcontractors whom the DMs define as the best ones. Sometimes a selection process includes ten companies, but the DMs will not negotiate with all of them, only with the companies that they feel are the most reliable. This evaluation is subjective and sometimes relies on previous experiences with the subcontractor, or a pre-qualification step is included to analyze legal documents and verify if the company fulfills the legal requirements. The negotiation process ends when the DMs find a subcontractor who fulfills all legal requirements, by presenting documents to prove they do not have legal issues, and technical requirements, such as the lowest price, best working practices and are able to accomplish the activity in the schedule planned for the project. Satisfying the legal issues serves as a pre-qualification at this stage, and is a binary process. However, criteria such as quality, maintenance service level, and experience are evaluated based on information inferred during the negotiation step.

The hiring process starts with a manager requiring a service to be outsourced and furnishing the analyst with all technical information a subcontractor would need to formalize a bid. During the selection and negotiation phases, all DMs get involved in the analysis and interactions with the subcontractors in every possible hiring process. Sometimes, during a project over 50 activities have to be hired. Considering that, it is necessary to engage four DMs in every possible interaction, and each activity requires three negotiation interactions (for three subcontractors) plus the selection process. If each interaction lasts one hour, it would mean that the DMs would spend a total of 800 hours of their time only to evaluate hiring processes. In Brazil, an engineer has 40 labor hours per week, therefore, it would be necessary to spend 20 weeks of the board of the project to evaluate the 50 hiring processes. The question is: do all DMs actually need to get involved in every hiring process all together or if they could split this effort and evaluate the hiring processes as a group only on those activities that could bring more issues to the project?

An objective of this research is to offer DMs and analysts a framework to enable the costs associated with the hiring procedures to be reduced by reducing the time and number of DMs devoted to make decisions and play a role in negotiation when hiring subcontractors in the CC industry. The idea is to allow the actors to focus on situations that are truly dangerous to the project and relax the constraints imposed on those that do not strongly affect it. Therefore a framework to aid contractors to hire subcontractors in the CC industry is proposed.

This framework starts by categorizing activities in classes compatible with the impact they may cause to the project, client or contractor. Thus, a selection model can be used to choose a subcontractor to execute that activity. Differently from other models, in the proposed selection model the method used have to take into account the rationality of the DM and further on the DMs' ranking are aggregated to provide a final recommendation for the subcontractor selection of each activity. Finally, the hiring process is only ended when the DMs negotiate the contract with the top-ranked subcontractors in order to reach the best deal.

### **3.2 A framework to aid subcontractors' hiring in the CC industry**

A Framework to aid DMs in the Civil Construction (CC) Industry to hire subcontractors is proposed and presented in figure 3.1. This Framework takes into account that different activities are hired during a project that represents different impact to the project, also, the DMs have different objectives regarding the problem. Therefore, it is necessary to apply a method to aggregate DMs' individual choices, meaning that the aggregation will take place at the end of the process, over the individual ranking of the DMs. Moreover, the framework also includes a peculiarity of allowing the analyst to apply different methods so that the DM can rank his/her alternatives, depending on the DM's rationality. By the end, a negotiation between contractor and subcontractors takes place.

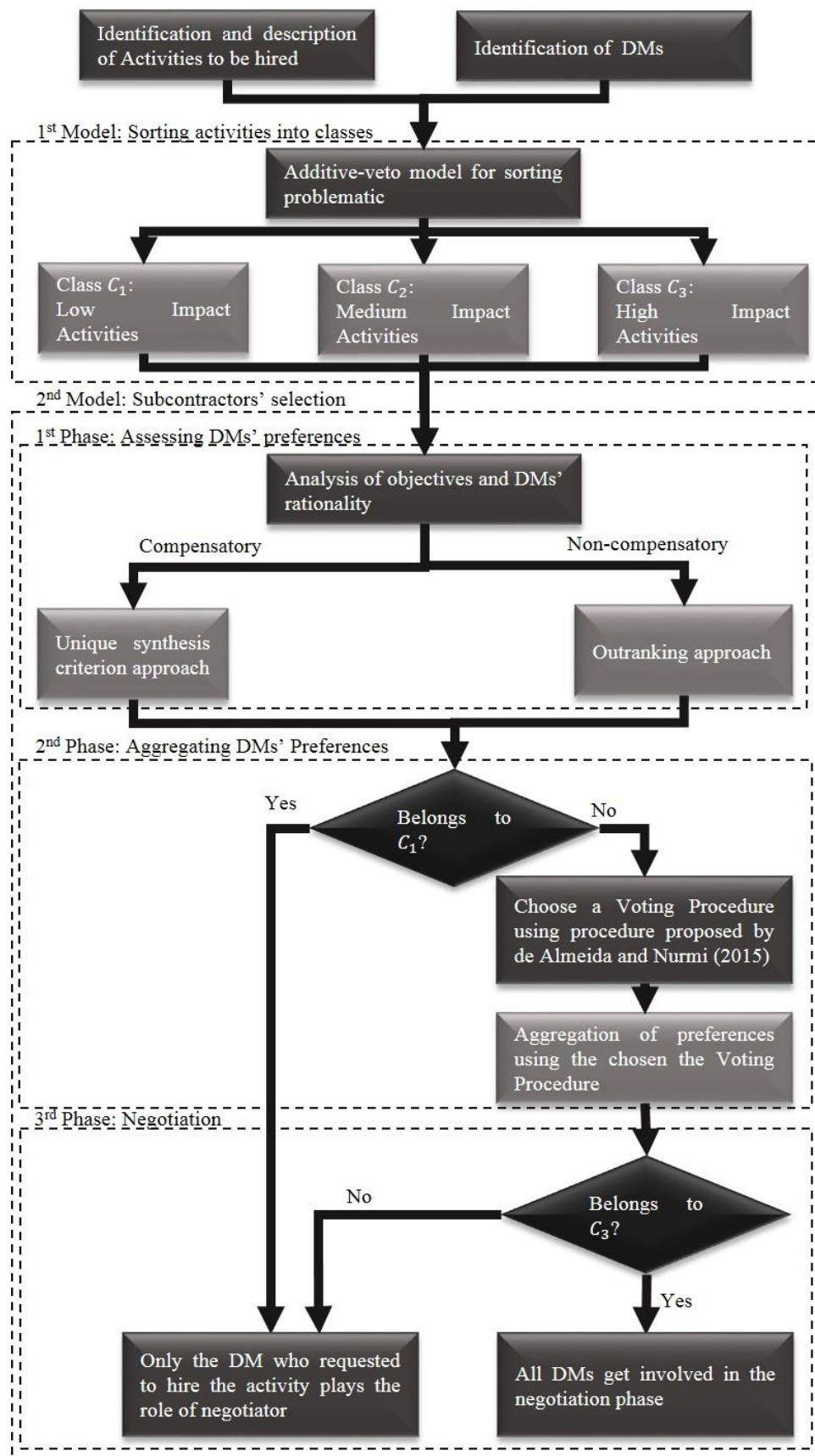


Figure 3.1 – Flow-chart of the framework proposed

De Almeida *et al.* (2015) showed that the modeling process includes analysis of several possibilities that are associated with different hypotheses, such as the alternatives available, the attributes used to analyze the alternatives, and the DMs' rationality. This analytical process works as a funnel in which the possibilities are refined to obtain one model that is compatible with the DM's preference structure and the information available. The funnel presented in Slack *et al.* (2008) represents this model, where the filtering layers usually are: the actors involved and the DMs' rationality; the attributes used to describe the alternatives and; the alternatives themselves. Therefore, the selection of subcontracts should take into account not only the characteristics of the project but also the DMs' rationality. The framework presented in Figure 3.1 to aid DMs to hire subcontractors in a CC project follows the procedure proposed by de Almeida *et al.* (2015) to model multicriteria decision problems. This framework uses two models to support contractors in their hiring processes in the CC industry.

Within the CC context, the managers usually present a compensatory rationality when evaluating the risks they might face by outsourcing an activity. Therefore, some trade-off (KEENEY & RAIFFA, 1976) among criteria might be required. This characteristic eliminates outranking sorting methods. Moreover, this step of analysis usually takes place right at the beginning of the project. Projects vary in size, budget, location and types of activities. Thus, it is very difficult for a DM to present preference information based on holistic assignment, since he/she does not have information *a priori*. In addition, by using SAW (Simple Additive Weighting), the alternatives are sorted based only on thresholds, ignoring some nuances of the sorting problematic. Therefore, in Chapter 4 the Additive-veto Model for the sorting problematic is proposed to sort activities into classes and manage them considering them in a more compatible way.

After all activities were grouped according to their effect on the project, the selection model is used. This model is divided into three phases: the preference modeling, the aggregation of DMs' preferences and a negotiation phase. In the first phase of this model occurs the assessment of each DMs' preferences to allow all DMs to rank the subcontractors', which took part of the selection process. At this moment, the analyst might decide to use a compensatory method or a non-compensatory method. This decision will depend on the DM's rationality. The second phase occurs in high and medium impact classes, because in those the process will be that of a group decision. Therefore, an aggregation process is proposed. The output of this model will be a ranking of the subcontractors, either by being analyzed by a single DM or by the group. At last, a negotiation phase starts, where the manager who required the service will

negotiate with the top-ranked subcontractors for low and medium impact classes or all DMs will run the negotiation for high impact classes.

Thus, the proposed framework was built to aid analysts and DMs in contractors to structure the hiring processes of subcontractors from the very beginning. This way, the team is able to manage the subcontractors and activities in a way compatible with the risk they might bring to the contractor, the project and the client while saving money and time of the DMs involved in the project.

## **4 THE ADDITIVE-VETO MODEL FOR THE SORTING PROBLEMATIC**

Even though several sorting methods are available, they do not fit the problem faced by the CC Industry, because either they are non-compensatory or holistic. Therefore, in this study, the Additive-Veto model is proposed for the sorting problematic as an adaptation of the Additive-Veto model for the ranking problematic (DE ALMEIDA, 2013). All parameters of this model are elicited, and some new indices based on decision rules are suggested to introduce the idea of vetoing the classification of an alternative when assigning it to a class profile. A numerical application in the CC Industry is presented to illustrate the use of the model.

### **4.1 Description of the model**

To deal with the sorting step presented in Chapter 3, it is proposed the Additive-veto model for the sorting problematic presented in Figure 4.1. This model is an adaptation of the Additive-Veto model for ranking problematics (DE ALMEIDA, 2013).

In this model, all parameters are elicited. Some parameters are suggested to introduce the idea of vetoing the classification of an alternative when assigning it to a class profile because such compensation is incompatible with the DM's preference due to one or more criteria having a low performance. The idea here is to preserve the DMs' compensatory rationality, thereby allowing them to express their preference information without having prior knowledge of exemplary alternatives, and yet preserving the characteristics of the sorting problematic. In addition, the veto does not permit an alternative to be sorted based only on its overall value but must also take into account restrictions that the DM has included in his/her preference information. Therefore, the DM has to provide several pieces of parametric information, such as the profiles of classes, the upper and lower thresholds needed to apply penalties to the set of alternatives, as well as two veto conditions: the criterion veto index, and the criteria weight coalition veto.

The procedure considers three steps. In the first step, the global value of the alternatives and profiles are calculated and the alternatives are analyzed in order to determine the class of assignments. In the second step, decision rules are applied to the alternatives to veto their classification to classes of assignment. Once the analysis is completed, a recommendation is presented to the DM as a third step, after which, the DM can review his/her preference information and run a sensitivity analysis.

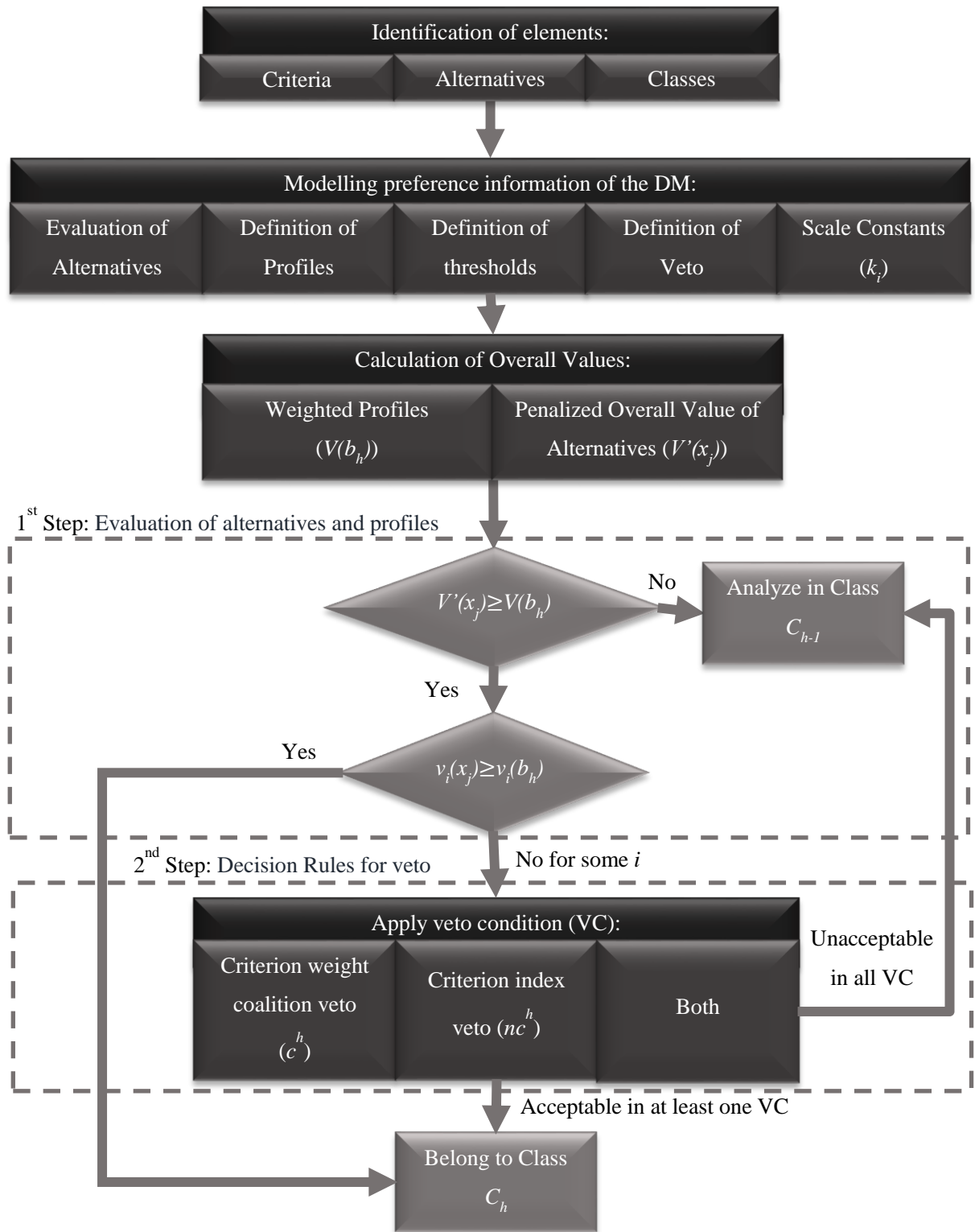


Figure 4.1 – The Additive-veto model for the sorting problematic



#### 4.1.1 Evaluation of alternatives and profiles

In the sorting problematic, the alternatives are sorted in homogeneous, predefined-preference ordered classes (ROY, 1996). The DM has to specify the profile for each class and his/her preference information is assessed by employing the trade-off method (KEENEY & RAIFFA, 1976). A set of  $q$  predefined preference-ordered classes, in such a way that  $C_q \succ C_{q-1} \succ \dots \succ C_2 \succ C_1$ , is described by considering a reference alternative. This reference alternative is called a profile and is the boundary between two classes (DOUMPOS & ZOPOUNIDIS, 2002). Thus,  $b_h$  is the vector of performance of class  $C_h$  and represents the boundary between class  $C_h$  and class  $C_{h+1}$  (ROY & BOUYSSOU, 1993). The overall value of this vector is the threshold of that class and is calculated using Equation 4.1, where the alternative is now the profile. The threshold might be specified with an aggregate value  $V(b_h)$  or by specifying  $v_i(b_h)$ .

$$V(x_j) = \sum_{i=1}^n k_i v_i(x_j) \quad \text{Equation 4.1}$$

Where:  $V(x_j)$  is the overall value of alternative  $x_j$ ;

$k_i$  is the scaling constant of criterion  $i$  and  $\sum_{i=1}^n k_i = 1$ ;

$v_i(x_j)$  is the value of the consequence of criterion  $i$ .

The overall value of each alternative is calculated using Equation 4.1 and a penalization is imposed over this value by using Equation 4.2 and 4.3. The penalization is used as a veto condition in de Almeida (2013).

$$z_i(x_j) = \begin{cases} 0, & \text{if } v_i(x_j) \leq l_i \\ 1, & \text{if } v_i(x_j) \geq u_i \\ \frac{v_i(x_j) - l_i}{u_i - l_i} & \text{if } l_i < v_i(x_j) < u_i \end{cases} \quad \text{Equation 4.2}$$

Where:  $z_i(x_j)$  is the penalization function of alternative  $x_j$  for criterion  $i$ ;

$u_i$  is the upper threshold for criterion  $i$ ;

$l_i$  is the lower threshold for criterion  $i$ ;

$$V'(x_j) = r(x_j) \sum_{i=1}^n k_i v_i(x_j) \quad \text{Equation 4.3}$$

Where:  $V'(x_j)$  is the penalized global value of alternative  $x_j$ ;

$r(x_j)$  is the penalization index of alternative  $x_j$ , where  $r(x_j) = \sum_{i=1}^n r_i(x_j)$ ;  
 $r_i(x_j)$  is the weighted penalization function for alternative  $x_j$ , where  $r_i(x_j) = z_i(x_j)k_i$ ;

The model presented is divided into a global and a local analysis. The main idea of the global analysis is to compare the penalized global value of each alternative  $x_j$  ( $V'(x_j)$ ) with the limit profile  $V(b_h)$  and asserting if the alternative can belong to class  $h$  or not. When it cannot, then it is compared to lower classes until a suitable class is found. When the alternative might belong to class  $h$ , the appropriateness of this classification must be verified. This comparison is executed by the following rule presented in Equation 4.4. This is the first type of veto considered in this model. And it is presented in the first step of Figure 4.1.

$$\begin{cases} \forall x_j \in A, & j = 1, \dots, m; & h = 1, \dots, q \\ \text{if } V'(x_j) \geq V(b_h) & \text{then } x_j \in P_h \\ \text{if } V'(x_j) < V(b_h) & \text{then } x_j \notin P_h \end{cases} \quad \text{Equation 4.4}$$

Where:  $P_h$  is the subset of  $A$  that might belong to class  $C_h$ .

Every alternative has to be assigned to one class, and, since Class  $C_1$  is the worst possible class, if one alternative cannot be assigned to any other class, it will be assigned to Class  $C_1$ . Therefore, for  $h=1$ ,  $V(b_1) = 0$ . The verification of the suitability of an alternative to a class occurs only over the alternatives belonging to  $P_h$ . These will be further verified to confirm whether or not the alternative belongs to Class  $C_h$ , and consists on the local analysis.

In the local analysis, the alternatives belonging to subset  $P_h$ , have their performance compared with the reference alternative  $b_h$ . This analysis consists of the last analysis of the first step, namely, to confirm if the alternative belongs to class  $C_h$  or if it is necessary to use the second step. Equation 4.5 presents the rule for the second filter of the model. If the alternative is at least as good as the reference alternative for class  $C_h$ , then it certainly belong to it. If at least one criterion the alternative fails, then the procedure is taken to the second step.

$$\begin{cases} \forall x_j \in P_h, & j = 1, \dots, m, & i = 1, \dots, n, & h = 1, \dots, q, \\ \text{if } v_1(x_j) \geq v_1(b_h) \wedge v_2(x_j) \geq v_2(b_h) \dots \wedge v_m(x_j) \geq v_m(b_h) & \text{then } x_j \in C_h \\ \text{if } v_i(x_j) < v_i(b_h) & \text{for some } i & \text{then apply decision rule for veto} \end{cases} \quad \text{Equation 4.5}$$

#### 4.1.2 Decision Rule for Veto in the Sorting Problematic

The second step consists of determining if the alternatives belonging to subset  $P_h$  must belong to class  $C_h$ . Therefore, two other analyses have to be carried out, once again whereby one is local and the other global. The veto condition is considered by the introduction of two

novel veto indices: the criteria weight coalition veto ( $c^h$ ), which provides a global veto, and the criterion veto index ( $nc^h$ ) that provides a local one.

**Definition 1:** The criterion veto index ( $nc^h$ ) is a value that reflects preference information provided by the DM such that the performance of the alternatives cannot be below the performance of the reference alternative in  $nc^h$ - $h$  classes below it. For instance, if  $nc^h$  is 2 for the fourth class, the performance in any other criterion cannot be less than that expected for the second class. Hence, if the alternative has an overall value compatible with the fourth class but in some criterion, its performance is lower than the reference alternative of class two, the alternative has to be analyzed in class three.

**Definition 2:** The criteria weight coalition veto ( $c^h$ ) is the lower limit of the sum of the scaling constants of the criteria having a performance at least as good as the one required for the class of analysis that allows an alternative to being assigned to that group. This preference condition disallows an alternative to be assigned to Class  $C_h$  whenever the number of criteria with a performance lower than the limit profile is weighted, and the result is lower than the one provided by the DM.

The DM may provide preference information for only one of these indices or for both of them. Equation 4.6 represents the application of the criteria weight coalition veto ( $c^h$ ), Equation 4.7 of the criterion veto index ( $nc^h$ ) and Equation 4.8, which is more restrictive, represents their combination.

$$\left\{ \begin{array}{l} \forall x_j \in P_h, j = 1, \dots, m, i = 1, \dots, n, h = 1, \dots, q, \\ \text{if } \sum_{i \in v_i(x_j) \geq v_i(b_h)} k_i \geq c^h \text{ then } x_j \in C_h \\ \text{if } \sum_{i \in v_i(x_j) \geq v_i(b_{hi})} k_i < c^h \text{ then } x_j \notin C_h \end{array} \right. \quad \text{Equation 4.6}$$

$$\left\{ \begin{array}{l} \forall x_j \in P_h, j = 1, \dots, m, i = 1, \dots, n, h = 2, \dots, q, \\ \text{if } v_i(x_j) \geq v_i(b_{h-nc^h}) \forall i, \text{ then } x_j \in C_h \\ \text{if } v_i(x_j) < v_i(b_{h-nc^h}) \text{ for some } i, \text{ then } x_j \notin C_h \end{array} \right. \quad \text{Equation 4.7}$$

$$\left\{ \begin{array}{l} \forall x_j \in P_h, j = 1, \dots, m, i = 1, \dots, n, h = 1, \dots, q, \\ \text{if } \sum_{i \in v_i(x_j) \geq v_i(b_h)} k_i \geq c^h \wedge v_i(x_j) \geq v_i(b_{h-nc^h}) \forall i, \text{ then } x_j \in C_h \\ \text{if } \sum_{i \in v_i(x_j) \geq v_i(b_h)} k_i < c^h \vee v_i(x_j) < v_i(b_{h-nc^h}) \text{ for some } i, \text{ then } x_j \notin C_h \end{array} \right. \quad \text{Equation 4.8}$$

Figure 3.1 presents the framework in a situation with three classes based on the impact that the activity might bring to the project. The DMs might decide to add one more class, but mainly on heavy construction projects, these are the classes found, varying only their profiles. In addition, the DC has to describe the profiles by using criteria he/she has chosen and his/her scale constants regarding this problem have to be assessed by using the trade-off method (KEENEY & RAIFFA, 1976).

Usually in those cases the objectives are quite simple. Hence, the evaluation will mainly be based on qualifier criteria and costs. The qualifiers usually focus on the suitability and financial health of subcontractors. The framework presented in Figure 3.1 was created to deal with subcontractors and to take subjective criteria into account but it is also well suited to selecting suppliers. The main difference between these two types of selection is that suppliers only supply materials while subcontractors or outsourcers supply services with or without materials, which leads to decision-making on the latter involving more subjective judgments than the former does.

Activities of lower impact usually involve a very simple hiring process, so a single DM can manage the bidding and negotiation. On the other hand, higher impact activities involve higher risks and budgets, and several criteria might be evaluated subjectively. Hence, a more structured model should be used and more DMs involved in the selection and negotiation processes. The three classes presented are based on the application presented by Palha, de Almeida & Alencar (2016). The classes are: high impact activities ( $C_3$ ), medium impact activities ( $C_2$ ), and low impact activities ( $C_1$ ). In low impact activities, the analyst drives the whole process; assesses the preference information of the manager who requested the hiring of that activity and this manager negotiates the contract in the fifth phase. In the medium impact activities, all DMs need to provide preference information for the third phase, but only the one who requested hiring a subcontractor to accomplish that activity will get involved with the negotiation. In high impact activities, all DMs are involved in the last three phases of the process.

#### 4.1.3 Recommendation and sensitivity analysis

The evaluation ends with the third step, which consists of the recommendation to the DM based on employing Steps One and Two and considering the DM's preference information. To verify the robustness of the recommendation, it is important to run a sensitivity analysis of all parameters since this might bring some degree of hesitation to the solution if the results are sensitive to small modifications. Sensitivity analyses can be carried out using a Monte Carlo simulation in the limit profiles, on the upper or lower threshold, to verify if by changing these values, alternatives would emerge that would change classes, or in the criteria weight coalition index or the criterion veto index or both. It has to be run using whichever parameters the DM does not feel comfortable, and it is important to determine if, by introducing any modification to the set of parameters, this would represent significant modifications to the recommendation. The model might be sensitive to modifications on either the criteria weight coalition index or criterion veto index.

#### 4.2 Numerical Application

To present how this approach works in practice, it is applied to the example presented in Palha, de Almeida & Alencar (2016) which is based on a real situation. The illustrative example is the construction of a brewery in the state of Pernambuco, Brazil. The expected cost of this construction was US\$ 70 million, and it was a cost-plus contract, meaning this budget is only an approximation. Since, in this kind of contract, the contractor usually outsources most of the activities, it is important to take great care in how they are managed. In addition, when liabilities arise, both the contractor and the client, who is the owner of the brewery, are prosecuted. This means that the satisfaction of this client relies not only on the development of the project itself but also on avoiding legal suits being brought against the client.

In this model, it is necessary to consider the list of activities to be outsourced. These activities are considered here as alternatives to be sorted in the classes provided by the DM. The analyst listed the shown in Table 4.1.

*Table 4.1 – Alternatives analyzed in the Brewery Project*

<b>Alternatives</b>	<b>Description</b>
Air Conditioning	Activity includes the supply of air conditioning system and installation.
Concrete	Concrete supply according to mix informed by the contractor and includes installation of the concrete batching plant inside the project

	area and availability of concrete mixer truck and concrete pump in the quantity required.
Containers	Activity includes the supply of containers for the building site and installation (electricity and logistics).
Heavy Equipment	Activity includes the supply of heavy equipment as planned by the contractor and preventive and corrective maintenance.
Molds, shoring and scaffolding	The activity includes the supply of molds, shoring and scaffolding, as well as shoring and scaffolding projects for the activities and projects presented by the contractor.
Gypsum Liner and partition	The activity includes the supply and installation of gypsum liners and partitions.
Continuous Flight Auger Stake (CFA stake)	The activity includes equipment supply, activity and dynamic and static load reports.
Hydroseeding	The activity includes material and equipment necessary for Hydroseeding growth.
Waterproofing	The activity includes material, equipment and providing the waterproofing layer.
Asphalt Paving	The activity includes equipment and materials needed for the asphalt pavement of the designated area.
Concrete Paving	The activity includes equipment and guarantee for the concrete paving activity, the material is supplied by the contractor.
Precast Concrete	The activity includes precast concrete adaptation project, material, equipment, transportation and installation of concrete elements.
Food Supply	The activity includes food supply for the personnel designated by the contractor and for consumption in the dining hall at the building site.
Property Security	The activity includes 24h of armed security and patrol of the property.
Vegetal Suppression	The activity includes equipment and licenses to suppress vegetal matter.
Earthwork	The activity includes equipment and personnel for the earthwork in accordance with the project provided by the contractor.
Transportation of personnel	The activity includes equipment to transport personnel from and to their residencies at the start the end of each shift of business hours in accordance with the routes provided by the contractor.

*Source: Palha, de Almeida & Alencar (2016)*

In this application, the DC was a woman and the other DMs were men. The DC as SDM drives the decision process and is in charge of the relationship between client-contractor. Even though she is also responsible for her team and is accountable for the team's performance, she is nevertheless willing to share the risks and profits of the project with them to achieve better results for the company. Thus, all managers will be concerned about the consequences of the hiring processes, since the responsibility for this is shared.

The EM will be more concerned with the schedule, costs and technique involved in the project. He will have to deal with all liabilities related to outsourcing, meaning he may be risk averse during the procedure. The OM is concerned with achieving his goals: finishing the project. Therefore, he will not be concerned about risks unless they are executive risks. Since his main problem is always time, he is expected to be risk prone. The FM is usually concerned only about costs since his goal is to increase profitability. Unless the contract is for administrative matters, in this context, namely, the construction of a brewery, he will be concerned about technical issues, such as the availability, capacity, and suitability of equipment.

In the context of this application, the DM is responsible for the project, both legally and inside the Contractor's environment. The DM taken into account in this model is the DC. The criteria were built by considering her objectives regarding the problem and are presented and explained in Table 4.2. The project had many activities to be outsourced, but only seventeen were considered under this analysis so as to simplify matters. All the values presented in Table 4.3 are factual and were used to evaluate the alternatives.

*Table 4.2 – Criteria used to analyze the activities of the construction of the brewery*

Criteria	Description	Scale	Min/ Max
Cost (g <sub>1</sub> )	Budget cost to conduct the activity.	Monetary	Max
Activity Duration (g <sub>2</sub> )	Time expected to complete the activity.	Days	Max
Number of Suppliers (g <sub>3</sub> )	Number of suppliers available in nearby markets.	Unit	Min
Available resources (g <sub>4</sub> )	Availability of resources, such as labor, equipment and	Qualitative (1 to 5): 1 – No available resources, labor, equipment and materials must be taken from another city center;	Min

	material in the neighborhood	<p>2 – No availability of materials or equipment, but the local labor can be trained for qualification purposes;</p> <p>3 – Qualified labor, but materials and equipment must be taken from another city center;</p> <p>4 – Availability of equipment and materials, but labor must be trained;</p> <p>5 – All resources are available.</p>	
		Qualitative (1 to 5):	
		1 – No labor permanence required and subcontractor is not technically responsible for the activity (equipment renting without activity).	
	Risk exposure related to technical responsibility and labor permanence of the workforce on the construction site.	<p>2 – No labor permanence required and subcontractor is not technically responsible for the activity, but some visits are necessary (equipment renting without operator but with maintenance).</p> <p>3 – Labor permanence required, but subcontractor is not technically responsible for the activity (equipment renting with activity, steel cutting and bending, etc.).</p> <p>4 - No labor permanence required, but subcontractor is technically responsible for the activity (projects and project evaluation).</p> <p>5- Labor permanence required, and subcontractor is technically responsible for the activity.</p>	Max
		Qualitative (1 to 4):	
	Need for Maintenance (g <sub>6</sub> )	<p>1 – Maintenance is not necessary;</p> <p>2 – Only corrective maintenance is necessary;</p> <p>3 – Only preventive maintenance is necessary.</p> <p>4 – Preventive and corrective maintenance are necessary.</p>	Max



Interaction with other activities (g <sub>7</sub> )	Proxy attribute to take into account possible impact from the activity on other activities regarding security risks and duration.	Qualitative (1 to 5):	Max
		1 – Activity does not occur in building site; 2 – Activity occur in the building site but without interaction with other activities or teams; 3 – Activity is carried out inside the building site and in contact with other outsourcers’ teams and contractor’s teams, but without interaction with the activities; 4 - Activity is carried out inside the building site, without contact with other outsourcers’ teams and contractor’s teams, but with interaction with the activities; 5 – Activity is carried out inside the building site and in contact with other outsourcers’ teams and contractor’s teams and interacts with the activities;	

Source: Palha, de Almeida & Alencar (2016)

Table 4.3 – Evaluation matrix of the alternatives considered

Alternatives	Criteria						
	g <sub>1</sub>	g <sub>2</sub>	g <sub>3</sub>	g <sub>4</sub>	g <sub>5</sub>	g <sub>6</sub>	g <sub>7</sub>
Air Conditioning	70,000.00	90.00	3.00	3.00	3.00	1.00	3.00
Asphalt Paving	90,000.00	4.00	2.00	5.00	5.00	4.00	2.00
Concrete	4,000,000.00	360.00	5.00	3.00	5.00	4.00	5.00
Concrete Paving	700,000.00	60.00	4.00	1.00	5.00	4.00	5.00
Containers	370,000.00	360.00	5.00	1.00	1.00	1.00	1.00
Continuous Flight							
Auger (CFA)	700,000.00	180.00	12.00	1.00	5.00	4.00	4.00
Stake							
Earthwork	1,800,000.00	90.00	6.00	5.00	5.00	4.00	5.00
Food Supply	1,200,000.00	360.00	5.00	2.00	3.00	1.00	3.00
Gypsum Liner	35,000.00	21.00	2.00	1.00	5.00	1.00	2.00
Heavy Equipment	400,000.00	360.00	6.00	4.00	3.00	3.00	5.00

Hydroseeding	110,000.00	15.00	2.00	1.00	5.00	4.00	2.00
Molds, shoring and scaffolding	150,000.00	360.00	4.00	4.00	5.00	1.00	5.00
Precast Concrete	2,700,000.00	270.00	2.00	5.00	4.00	1.00	4.00
Property Security	500,000.00	360.00	4.00	5.00	3.00	1.00	3.00
Transport of personnel	1,500,000.00	360.00	4.00	5.00	3.00	4.00	3.00
Vegetation Suppression	19,000.00	15.00	1.00	5.00	5.00	1.00	4.00
Waterproofing	25,000.00	60.00	2.00	5.00	5.00	1.00	2.00

*Source: Adapted from Palha, de Almeida & Alencar (2016)*

Three clearly defined classes were found (PALHA, DE ALMEIDA & ALENCAR, 2016): high impact activities ( $C_3$ ), medium impact activities ( $C_2$ ), and low impact activities ( $C_1$ ). It is expected that the activities sorted into each class can be managed according to their impact on the project, the risks involved, and the client's perceptions. The high impact activities are costly, might be a specialized service, directly affect the schedule of the project and the client's perception of success, and several of the subcontractor's workers develop their work inside the construction site. The medium impact activities may consist of long-term relations, have many available suppliers, possess delays that can be recovered by splitting the activity among different subcontractors, and strongly affect the client's satisfaction. The low impact activities could be handled more easily. They usually involve short-time relationships with lower costs, have a low impact on the client's satisfaction, and usually do not include workers' activities on the construction site. In this problem, since the DC is worried about the impact of the activity on the project, it is assumed that the higher impact class will have greater values and is the preferable class. The idea is that the activities sorted into this class will require more attention from the DM, unlike those sorted into the lower impact classes.

The DC had to specify the reference alternatives for each class that were used to calculate the limit profiles. The cost was analyzed considering the governance model set between the contractor and the client, and the other criteria were analyzed based on the DC's preferences. The scale constants were elicited by using the tradeoff method (KEENEY & RAIFFA, 1976). For the DC, risk to exposure was in the first position, because it could cause problems for the contractor and decrease the satisfaction of the client. Cost was in the second position because this would certainly influence the client's perception and the profits of the project. Next was

the expected duration since there was a clause in the contract between the contractor and the client regarding delays in the schedule of the project. The other scale constants were the available resources, the number of suppliers, the interaction with other activities and, lastly, the need for maintenance.

The DC had to consider the approach presented in Section 4.1.2 so as to have the upper and lower thresholds elicited. By considering this preference information, the DM does not directly veto the alternatives but penalizes them in some criteria that, he/she believes, have an unacceptable performance. For instance, if the cost of the activities strongly varies and could be compensated for by the amount of time required to complete them, the DM could specify a lower threshold for cost, such that no activity that had a performance below this, would have that criterion considered in its overall value. If she specified an upper threshold and the given activity had a performance between the upper and lower thresholds, then the criterion would be partially considered for inclusion in the calculation of the overall value of the alternative. Finally, if the performance were above the upper threshold, then no veto would be levied. Table 4.4 presents the upper and lower thresholds, the scale constants and the profiles of the classes.

Table 4.4 – Parameters from the DM

DMs	Criteria						
	g <sub>1</sub>	g <sub>2</sub>	g <sub>3</sub>	g <sub>4</sub>	g <sub>5</sub>	g <sub>6</sub>	g <sub>7</sub>
Scaling constants ( $k_i$ )	0.2276	0.1561	0.0728	0.1085	0.3704	0.0204	0.0442
upper threshold ( $u_i$ )	400,000	50	10	5	2	2	2
lower threshold ( $l_i$ )	220,000	20	10	5	2	2	2
$v(b_2)$	600,000	21	5	4	3	2	2
$v(b_3)$	1,200,000	180	2	2	4	3	4

The DM has to evaluate these criteria regarding their scale. Otherwise they have no meaning to her. Also, recall that the idea of the framework is to build a hiring process less costly than the usual way the process is run in CC industry. Therefore, it is important to identify the alternatives which have to receive more attention and the ones that do not need so much effort in their selection and negotiation process. Thus, higher impact classes will present higher values of criteria that usually are intended to be minimized, such as cost and time to accomplish a task as is presented in Table 4.4.

The decision rules for a veto, even though they can be classified in the two kinds of approaches, behave differently and have a different meaning to the DM. The criterion veto index ( $nc^h$ ) is classified as the second approach, and when the DM decides to use it, it means that he/she will be comparing the alternatives not only with the class of analysis but also with classes below it. In this problem, the DC specified a criterion veto index of 1, thus,  $nc^h = 1$ , meaning that she only wants to compare the performance of the alternative with the class immediately below it.

The criterion weight coalition veto ( $c^h$ ) is classified in the first approach, and the DM's perception is no longer relative to the other classes. He/she wants to analyze the performance of the alternative only with the assignment class. The DM believes that if an alternative has a performance at least as good as one certain percentage of the one required for that class, the alternative could be considered sufficient enough for fulfilling the assignment. In this problem, the DC specified a criterion weight coalition veto of 0.5, thus,  $c^h = 0.5$ , which means that when comparing the alternative with the profiles, its performance is at least as good as that required in at least 50% of the criteria. In this problem, the DC wanted to be as restrictive as possible and decided to apply both decision rules for veto purposes. The results are presented in the next subsection.

#### 4.2.1 Discussion of Results

The results of this application are presented in Table 4.5. The findings were coherent with the DC's perception of the alternatives. Most of the alternatives were sorted into the medium impact class. This behavior is compatible with what the DC expected regarding this problem since most of the activities should be long-term relationships with subcontractors who could be easily replaced whenever needed, or more than one subcontractor could be hired. Only two activities were sorted into the higher impact activities: concrete and concrete paving. Both should be managed as higher impact activities since the success of the project relies on the supply of concrete and paving with concrete is a very demanding activity. Eleven activities were sorted into the medium impact class. The DC felt comfortable about all of them, except for earthwork which, she considered, might have been managed as a higher impact activity. This misclassification may have occurred because of criteria the DM could not identify, such as long lasting effects of the hiring. The last four activities were sorted as lower impact activities, and they were compatible with the DC's expectations.

Table 4.5 – Results of the example

Classes	Activities
C <sub>3</sub>	Concrete; Concrete Paving
C <sub>2</sub>	CFA; Earthwork; Food Supply; Gypsum Liner; Heavy Equipment; Hydroseeding; Molds, shoring and scaffolding; Precast Concrete; Property Security; Transport of personnel; Waterproofing
C <sub>1</sub>	Air Conditioning; Asphalt Paving; Containers; Vegetation Suppression

It is also important to verify what the behavior of the model would be if the DC had decided to relax some of the parameters and to compare the model with SAW. Therefore, Table 4.6 presents an analysis of the alternatives by considering this relaxation of parameters. When using SAW, none of the alternatives were assigned to the lower impact classes, which is compatible with the behavior mainly found in the CC industry. Six of the alternatives were assigned to the higher impact class and eleven to the medium one, which means that managing these contracts would require great effort and time-consuming procedures. By applying only the penalization, two of the alternatives previously classified as Class C<sub>3</sub> were vetoed and directed to Class C<sub>2</sub>: Molds, Shoring and Scaffolding; and Hydroseeding. In addition, Containers and Air Conditioning (material and installation), which were previously sorted into Class C<sub>2</sub>, when using SAW, were redirected to Class C<sub>1</sub>. These results are compatible with the DM's perception regarding the impacts these activities may represent to the project.

The use of the criterion veto index represented more impact by directing two activities to Class C<sub>2</sub>: CFA, and Precast Concrete. In this project, this evaluation is compatible with the impacts these activities may have on the project. The use of the criterion weight coalition veto only directed Vegetal Suppression and Asphalt Paving from Class C<sub>2</sub> to Class C<sub>1</sub>. This is coherent with these activities and their impact on the project. When analyzing the use of both conditions, their impact together is much more restrictive than applying each of them individually, thereby keeping the activities in the lowest possible classes of assignment.

Table 4.6 – Analysis of the alternatives by applying different methods over the alternatives

Alternatives	SAW	Only Penalization	$c_q$	$nc_q$	$nc_q$ and $c_q$
Concrete	C <sub>3</sub>	C <sub>3</sub>	C <sub>3</sub>	C <sub>3</sub>	C <sub>3</sub>
Concrete Paving	C <sub>3</sub>	C <sub>3</sub>	C <sub>3</sub>	C <sub>3</sub>	C <sub>3</sub>
Continuous Flight Auger (CFA) Stake	C <sub>3</sub>	C <sub>3</sub>	C <sub>3</sub>	C <sub>2</sub>	C <sub>2</sub>
Precast Concrete	C <sub>3</sub>	C <sub>3</sub>	C <sub>3</sub>	C <sub>2</sub>	C <sub>2</sub>
Molds, shoring and scaffolding	C <sub>3</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>
Hydroseeding	C <sub>3</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>

Earthwork	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>
Food Supply	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>
Gypsum Liner	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>
Heavy Equipment	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>
Property Security	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>
Transport of personnel	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>
Waterproofing	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>	C <sub>2</sub>
Asphalt Paving	C <sub>2</sub>	C <sub>2</sub>	C <sub>1</sub>	C <sub>2</sub>	C <sub>1</sub>
Vegetal Suppression	C <sub>2</sub>	C <sub>2</sub>	C <sub>1</sub>	C <sub>2</sub>	C <sub>1</sub>
Air Conditioning	C <sub>2</sub>	C <sub>1</sub>	C <sub>1</sub>	C <sub>1</sub>	C <sub>1</sub>
Containers	C <sub>2</sub>	C <sub>1</sub>	C <sub>1</sub>	C <sub>1</sub>	C <sub>1</sub>

The additive-veto model for sorting problematic can be appreciated when applying it to this problem. The parameters are intuitive, and the DM can specify the required information, without prior knowledge about reference alternatives. The results are coherent with the DM's preference structure, and the veto conditions corrected several misclassification errors. When compared to the results presented by Palha, de Almeida & Alencar (2016), it can be seen that most alternatives were assigned to the same class. However, the class of assignment of the Hydroseeding activity, which was criticized by the DM, was assigned to a class compatible with the DM's beliefs. These results are dependent on the criteria used to evaluate the activities. For instance, if some other criteria were taken into account, neither Precast Concrete nor Earthwork would have been directed to the medium class, especially if the Director had evaluated long lasting impacts, such as the ones that are guaranteed. The use of the approach was carried out using a free software that is available upon request.

## **5 A MODEL TO AID DECISION MAKERS IN THE CIVIL CONSTRUCTION INDUSTRY TO SELECT SUBCONTRACTORS**

In this Chapter, a framework to aid DMs in the Civil Construction (CC) Industry to select subcontractors is proposed. This framework takes into account that the DMs have different objectives regarding the problem. Therefore, the model presents some flexibility, because the DMs do not have to be subjected to the same MCDM/A procedure. The framework allows the analyst to use a method that fits a DM's rationality. If all DMs were to have the same objectives, the aggregation would take place at the beginning of the process, and all DMs would analyze the problem using the same criteria and procedure. In this context, though, the DMs have different objectives that vary according to their background and the role they play in the project, even though they might have common objectives, such as increasing profitability and upholding the Company's reputation. Thus, the model focuses on an aggregation based on the DMs' final priorities.

### **5.1 Description of the model**

As previously explained in Chapter 3, in heavy construction projects, the governance of contractors are built to work in a decentralized structure. Thus, as a group decision process, the DC behaves as a SDM, seeing the project in a global manner and balancing the contributions of the other DMs in the decision process. The other DMs usually are the EM, the OM and the FM. In some types of contracts, it may be the case that the Client plays the role of DM. When this situation exists, he/she behaves as the SDM, instead of the DC.

Once the alternatives have been sorted into classes, and the DMs already know who should get involved in the selection process under analysis, the selection process begins. The process presented in Figure 5.1 is divided into two phases: assessment of DMs' preferences and aggregation of DMs' preferences.

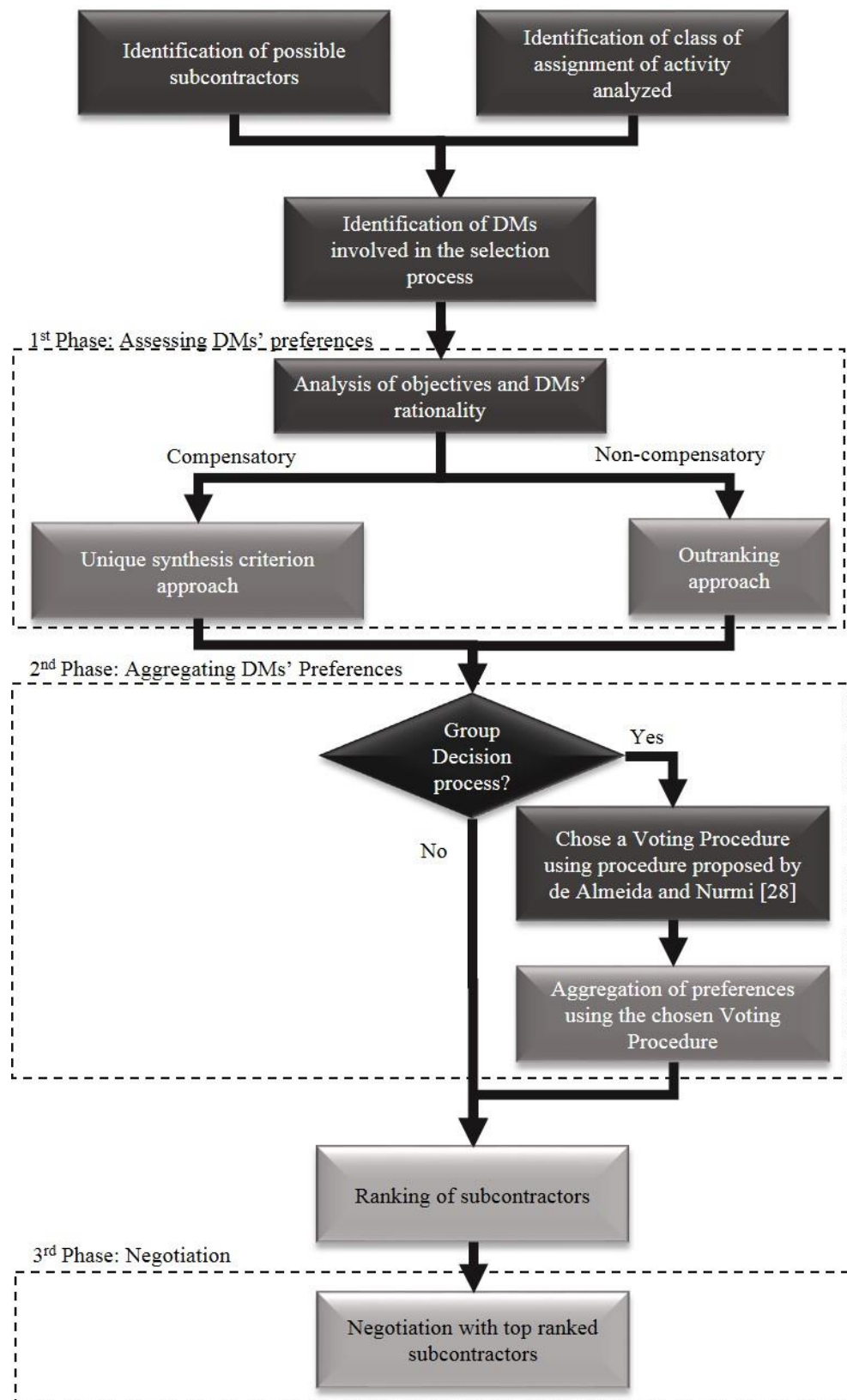


Figure 5.1 – Flow-chart of the subcontractors' selection model



### 5.1.1 Phase 01: Assessing DMs' preferences

The assessment of DMs' preferences regarding the selection process will be conducted for every class. The main difference is the second phase of the selection model, which will be used only for high impact classes. To build the ranking of each of the DMs, steps 2 to 11 described in Figure 1.1 are used for each DM individually. Thus, for each DM, the analyst has to aid him/her to express his/her objectives to decide the criteria to be used to evaluate the available alternatives. A multicriteria method is used to model the preferences of the DM and evaluate the available alternatives. Once a recommendation is presented, a sensitivity analysis should be run over the parameters to verify the robustness of the solution. By the end of this procedure, each DM will have provided a ranking which will be used to aggregate their preferences and provide a final ranking based on the group's preferences.

In this phase of the framework, each DM has to analyze the problem and specify his/her objectives with regard to outsourcing the activity under analysis. These will change depending on the activity. In addition, the DMs will analyze the problem differently from each other because they will be influenced by their personal experiences, background, and degree of accountability for the consequences of the service in the project. Under this environment, the problematic will always be a ranking problematic because it may take some time to reach a recommendation and the best alternative might not be available if a lot of time is spent before reaching a recommendation. Besides, during the length of the Project, some other problems may arise and the DMs may decide to hire more than one subcontractor, so a global verification of the alternatives is necessary. The alternatives, in this case, are the outsourcers taking part in the selection. Some of the criteria might be linked to probabilistic events, in which case it is important to make sure that these variables will be treated with a method compatible with this information, such as MAUT (KEENEY & RAIFFA, 1976). These probabilistic events might be related to such matters as the civil construction market, the economic situation of the country, the size of the company or its capacity to carry out the activity.

After obtaining all the information above, the consequence matrix can be built with the intra-criterion evaluation of all alternatives. It is usually the analyst who does by using the information collected during the selection or information collected from previous negotiations with the company. The analyst has to be careful when building the consequence matrix to provide information that will be compatible with the method required to provide a recommendation to the DM. The definition of the method relies upon the DM's rationality which the analyst must also verify.

A DM's rationality will also change in accordance with the problem. The rationality of any DM may be compensatory for some problems and non-compensatory for others (DE ALMEIDA *et al.*, 2015). Usually, in this context, it will be compensatory in situations when the DM has enough knowledge to evaluate the criteria and knows how to trade-off between them. Moreover, whenever a DM is not entirely aware of the technical details, it may be harder to use compensatory rationality, since his/her evaluation of the criteria might relate to the consequences of outsourcing the project instead of on the activity to be outsourced. The perception of a DM's rationality is very subtle and subjective.

There are no structured models to support evaluating this, although such evaluation should be considered in the building process of decision models (DE ALMEIDA *et al.*, 2015). Thus, to define the non-compensatory relation, the definition provided by Fishburn (1976) can be adopted. It says that a relation is considered non-compensatory when the preference relation between two alternatives depends only on the subset of criteria that favours the alternatives, irrespective of the differences of performance of the alternatives in each criterion. In addition, Roy & Słowiński (2013) proposed some questions to assist how to choose a multicriteria method, some of which are designed to evaluate if the DM has a compensatory or a non-compensatory rationality regarding the problem. Therefore, the model prescribes two options to perform the inter-criteria evaluation: one for DMs whose rationality is compensatory and another for DMs whose rationality is non-compensatory.

The compensatory approaches considered are the unique synthesis criterion approach and as to the ranking problematic, possibilities include Multi-Attribute Utility Theory (MAUT) (KEENEY & RAIFFA, 1976), SMARTS/SMARTER (EDWARDS & BARRON, 1994), AHP (SAATY, 1980), SAW (KEENEY & RAIFFA, 1976), UTA (JACQUET-LAGREZE & SISKOS, 1982), and the Additive-veto model for the ranking problematic (DE ALMEIDA, 2013). Some criteria might be probabilistic, which drives the process to be dealt with by applying MAUT. However, this is unusual because the information is based on the selection data, which are usually deterministic. Moreover, the UTA method is holistic and requires DMs to have information about some reference alternatives, which might be unfeasible in several projects. Usually the analyst defines which method among the unique synthesis criterion approaches is used. All these approaches are based on the aggregation presented in Equation 4.1.

Some DMs may decide to use qualifier criteria to evaluate the alternatives. In those cases, SAW will not reflect their preference information. This method could drive the set of

alternatives to be unbalanced and the ranking would not reflect the DM's preferences. Therefore, the analyst would need to use the Additive-veto model for the ranking problematic (DE ALMEIDA, 2013). Some additional preference information must be assessed when using this model. The DM has to provide an upper and lower threshold for each criterion which are used to penalize the overall value of the alternative. This method can be applied by using Equations 4.2 and 4.3.

DMs find the additive model easy to understand (DE ALMEIDA *et al.*, 2015). In addition, it has a strong axiomatic foundation (WEBER & BORCHERDING, 1993). However, misunderstandings on how to interpret the scale constants can arise if DMs are not alert to tricky aspects of the model. Thus, the analyst has to be careful, during the elicitation stage, to make clear to the DMs that the model only gives an indication of relative importance among attributes (KEENEY & RAIFFA, 1976). When it is hard for the DM to understand the trade-off process, it might be better to use SMARTS (EDWARDS & BARRON, 1994). Therefore, when the DM has a compensatory rationality, the analyst can apply the Additive-veto model for the ranking problematic, which can be set to behave like SAW by not using the thresholds, or SMARTS, which are unique synthesis criterion approaches.

When the DM presents a non-compensatory rationality, for a ranking problematic with true criteria, either PROMETHEE I, PROMETHEE II (BRANS, VINCKE & MARESCHAL, 1986) or ELECTRE II (ROY & BOUYSSOU, 1993; FIGUEIRA, MOUSSEAU & ROY, 2005) can be used. ELECTRE II is a more complex method and it may be harder for the DM to understand the results of its analyses. Moreover, inconsistencies may arise due to the DM's lack of knowledge of the method. PROMETHEE tends to make assessing the DM's preferences easier and its results can be easily understood. Therefore, it is less likely to produce inconsistencies. Once the analyst decides to use PROMETHEE, he/she should use PROMETHEE I, since PROMETHEE II suppresses incomparability, thus causing information to be lost.

After the DMs' evaluate the alternatives, it is important to run a sensitivity analysis to assure the robustness of the solution found. This is particularly important if some degree of hesitation was aroused when preference information was being assessed. If the results do not vary greatly, then the aggregation phase must be started.

### 5.1.2 Phase 02: Aggregating DMs' Preferences

The second phase of the selection model consists of aggregating the DMs' preferences. In this study, this final procedure is used, because the managers have different objectives as to selecting each subcontractor and are not inclined to renounce their primary preferences to reach a consensual decision. Since they have different objectives, a voting procedure (VP) is used to aggregate their final ranking. This type of process does not seek a consensual decision. However, the DMs are willing to come to an agreement and accept the group's decision, even when it differs from their choice as long as they feel they can express their preferences. The weights of each DM is reflected as the number of votes they have and this weight is defined in this framework by the SDM. This evaluation is subjective and usually takes into account the DM's experience, involvement in accomplishing the activity and/or the consequences of this contract.

The aggregation process requires choosing a voting procedure compatible with the problem faced. Usually the analyst decides which procedure is to be used, without a structured procedure guide for this decision. De Almeida & Nurmi (2015) proposed a procedure to help a group of DMs to choose a VP when facing managerial decisions. In this procedure, the group of DMs instead of the analyst chose the procedure. To make this feasible, two forms of applying the procedure are available: before generating the ranking or after doing so.

The drawback of the *a posteriori* evaluation is that the DMs may be able to manipulate the VP in order to approve their preferred alternative. Manipulation issues are a problem present in all VPs available and are unavoidable. Therefore, the group has to be careful when choosing a VP to avoid voting properties that may drive them to a social choice incompatible with the group's preferences.

Another problem is how best to define the method applied to aggregate DMs' preference information in the procedure to choose the VPs. The framework evaluates the VP, which plays the role of alternatives, while considering the voting properties and characteristics, which are the criteria, of each VP. Some authors consider that these properties should be analyzed by considering whether or not the method presents the property (NURMI, 2015). Thus, the consequence matrix is binary. Whenever the procedure has the property sought, it will be represented by 1 (one), and when it does not, the representation is 0 (zero). To aggregate this information a VP or some multicriteria method is used. Because the criteria are binary, only ordinal methods may be used. In the illustrative example presented here, the Borda Rule (BR)

is employed to aggregate the DMs' preference and all DMs have the same weight in the decision process.

In order to evaluate each alternative, namely voting rules, voting properties should be considered. The criteria suggested by Nurmi (2015) to evaluate the voting procedures are as follows:

(a) the procedure should always choose a Condorcet winner when there is one. A Condorcet winner is the alternative which defeats all alternatives in pairwise comparisons (NURMI, 1999);

(b) the procedure should never choose a Condorcet loser when there is one. The Condorcet loser is the opposite of the Condorcet winner. Thus, it is an alternative that is defeated by all other alternatives in pairwise comparisons (NURMI, 1999);

(c) the procedure makes use of the strong Condorcet criterion, which is satisfied by all systems that always end up with a strong Condorcet winner when there is one. A strong Condorcet winner is an alternative that is ranked first by all individuals (NURMI, 1999);

(d) the procedure makes use of monotonicity. This can be expressed as "if an alternative  $x$  wins in a given profile  $P$  when a certain procedure is being applied, it should also win in the profile  $P'$  obtained from  $P$  by placing  $x$  higher in some individuals' preference rankings, *ceteris paribus*." (NURMI, 1999). This means that additional support cannot transform a winning alternative into a non-winning alternative;

(e) The Pareto criterion exists whenever all voters strictly prefer  $x$  to  $y$ , and thus  $y$  cannot be elected (NURMI, 1999);

(f) the procedure presents consistency that is satisfied by those systems that have the following property. Suppose that the group is split into two groups so that the same alternative is chosen in both groups. Then the procedure is consistent, if the same alternative is chosen if the procedure is applied to the group as a whole (NURMI, 1999);

(g) the procedure presents the Chernoff property, which means that if an alternative is a winner in a set of alternatives, it has to be the winner in every subset of these alternatives (NURMI, 1999);

(h) the procedure is consistent with the property of independence of irrelevant alternatives. A procedure presents this property if two profiles have identical rankings over a pair of alternatives. Thus, the collective ranking over this pair is the same in these two profiles, regardless of the rankings over the other pairs (ARROW, 1963); and

(i) the procedure presents the invulnerability of the no-show paradox, which is a condition in which an elector may achieve a better result by not voting, thus prompting him/her to manipulate the voting result by abstaining (NURMI, 1999).

Additionally, an analysis of the applicability to partial voting was considered because of the preference structure of PROMETHEE I and ELECTRE II since they allow the incomparability preference relation and VP were built to aggregate only complete pre-orders. Nurmi (2015) analyzes several voting procedures, but some of them are not applicable to the subcontractors' selection problem.

The procedures considered in the framework in the context of the proposed model are Kemeny's Rule (KR) (SAARI & MERLIN, 2000), Dodgson's Rule (DR) (NURMI, 1987), Hare's Procedure (NURMI, 1987), Borda's Rule (BR) (BORDA, 1781; NURMI, 1987), Copeland's Procedure (NURMI, 1983), and two procedures that consider partial voting: the one proposed by Ackerman *et al.* (2013), and the adaptation of BR to partial voting proposed by Cullinan, Hsiao & Polett (2014). KR and DR are considered as extensions of the Method of Condorcet (CONDORCET, 1785; NURMI, 1987), where the first search is for a solution as near as possible to consensus, even though a group decision based on the DMs' final preferences is not a consensual decision. Both methods are dependent on irrelevant alternatives, since analyzing them is based on distance calculations. Copeland's Procedure is a binary method that relies on the pairwise comparison by using a score, where the alternatives are ranked based on a decreasing score (NURMI, 1987). BR (BORDA, 1781; NURMI, 1987) is an one-stage procedure in which all DMs present their order of preference of all alternatives and the worst positioned alternative receives a score of zero and one is added to the next worst and so on.

All voting procedures present lacks in at least one property and none of the methods presents solution independent of irrelevant alternatives. Therefore, when using the framework to analyze the procedures, it is important to verify which of them are compatible with the DMs' preferences and the context of the problem. Some procedures, such as the Plurality method (BRAMS & FISHBURN, 1978), the one proposed by Morais & de Almeida (2012) and Approval Voting (BRAMS & FISHBURN, 1978), are not applicable to this type of problem, and thus were not considered in the application that is presented in the next section, in which a proposition concerning the last phase is presented.

### 5.1.3 Phase 03: Negotiation

Negotiations in recent years have been strongly supported by NSS. The main idea is to help negotiators to structure the negotiation process, as well as to improve the efficiency and effectiveness of the deal. These NSSs emerge in different forms: to help the negotiators to structure their preferences; to improve their communication; or even as a way of documenting the final commitment. Since there are rarely geographical restrictions on where businesses operate nowadays, having a method that, to a large extent, allow negotiators to negotiate with companies from other places is imperative. Therefore, some requirements have to be met to reach a commitment that suits the parties involved.

In this phase of the model to select subcontractors, DMs or the DM, depending on the class of assignment of the activity, negotiate with the top ranked subcontractors to make a final decision. It is expected to have an integrative environment (RAIFFA, 1982). As formalized by Raiffa (1982), when a negotiation is integrative, the negotiators convert a single-factor problem into a multiple-factor problem. This type of bargaining is called cooperative because it is no longer true that by increasing one's profits, the profits of the other party must be reduced. Thus, they can work together to enlarge their joint gains. To take into account the multiple factors, the negotiators might use a compensatory MCDM/A method to assess their preferences, such as FITradeoff (DE ALMEIDA *et al.*, 2016), SAW (KEENEY & RAIFFA, 1976), SMARTS/SMARTER (EDWARDS & BARRON, 1994), AHP (SAATY, 1980) or the Additive-veto model for ranking problematics (DE ALMEIDA, 2013). In this context, the negotiators are willing to compensate criteria.

Some businesses are characterized by one negotiator searching for several other negotiators in order to hire a service or supply of materials. These negotiations are neither bilateral nor multilateral because the parties do not all negotiate with each other; only one party negotiates the same set of issues with several other parties. This is what happens in the construction industry; for example, one contractor needs to hire the supply of concrete and contacts several suppliers to decide which one would be the most appropriate. The contractor does not contact one enterprise at a time, but all of them concomitantly. To prevent one negotiator starting several similar processes, in this context the contractor, which contacts several parties, will be called the dominant party.

In this case, the negotiators do not define the negotiation protocol together. The dominant part defines it and presents it to the other parties. Therefore, this negotiator has to define the number of issues to be discussed, to provide specifications of the object of negotiation, and to

define which criteria will be used to evaluate the offers/counter-offers and the time constraint. Therefore, the last phase of this model consists of one DM or a group of DMs negotiating an activity to be hired with the top ranked subcontractors to finish the process with a deal with at least one of the subcontractors.

## 5.2 Numerical Application

The application chosen for this subsection was the selection process to hire a subcontractor to accomplish the CFA pile activity, which later would be negotiated with the top three subcontractors. This activity was sorted as class  $C_2$  in Section 4.2.2 and class  $C_3$  in Palha, de Almeida & Alencar (2016).

### 5.2.1 Phase 01: Assessing DMs' preferences

In this phase of the analysis, it is important to recall that each DM has to provide a ranking of the available subcontractors. In addition, the DMs could also decide to use different criteria to evaluate these alternatives. However, to simplify matters, they only had access to five criteria: cost; the time taken before starting the service; the time to perform the service; quality; and maintenance service level. Hence, the DM could use all five criteria or choose to take into account only the criteria that were meaningful to him/her. The first three criteria were presented in a ratio scale, and the last two were proxy attributes, as shown in Table 5.1. The analyses of subjective criteria were not considered in this model. Moreover, all analyses were based on real values. Therefore, all the information presented in this application is factual, except for the weights, which were subjective.

*Table 5.1 – Criteria used to analyze the CFA pile under this approach*

Criteria	Description	Unit of Value used for the Scale
Cost	Cost to execute the activity	In dollars (US\$)
Time needed before starting the service	Period after which the company expects to be ready to start the service	In days



Time allowed to conduct the service	Period for conducting the service	In days
Quality	Quality of the company's service	<p>Qualitative (1 to 5):</p> <p>1 – The Company does not work with quality control and requires the intervention of the Contractor.</p> <p>2 – The Company does not work with quality control, neither its own nor an outsourced one but it will contract;</p> <p>3 – The Company has a quality control team, but outsources it to a partner;</p> <p>4 – The Company has a quality control team but it is not certified by any agency;</p> <p>5– The Company is certified in quality control;</p> <p>Qualitative (1 to 5):</p> <p>1 – Company does not keep an acceptable maintenance service level;</p> <p>2 – The maintenance team is working for the project for 1 or 2 days per week, but has no flexibility as to day or shift;</p> <p>3 – The maintenance team is working for the project for 1 or 2 days per week in any shift, but is not flexible about the day;</p> <p>4 – The maintenance team is working for the project for 1 or 2 days per week and is flexible about both day and shift;</p> <p>5 – The maintenance team is working for the project every day of the week and during any shift;</p>
Maintenance service level	The maintenance team is able to work on its own equipment used in the activity: either preventive or corrective, when needed	

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The assessment of each DM's preferences was made individually, in order to avoid one DM influencing the preferences of the others. Table 5.2 presents the original data of each company that took part in the selection process.

Table 5.2 – Information available for the Continuous Flight Auger Pile (CFA pile) service

Subcontractors	Criteria				
	Cost	Time needed before starting the service	Time needed to conduct the service	Quality	Maintenance service level
S01	\$473,700.00	15	90	3	3
S02	\$563,823.33	21	60	3	5
S03	\$463,133.33	30	90	3	1
S04	\$848,500.00	15	270	2	5
S05	\$853,200.00	21	90	3	4
S06	\$575,000.00	21	180	4	3
S07	\$709,933.33	15	240	4	3

#### 5.2.1.1 Director of Construction (DC)

The DC usually shares the company's objectives, such as ensuring a good corporate image, maximizing profitability, finishing projects on time, and performing high quality services. To protect the corporate image, only suitable companies that are financially healthy may be hired. To maximize profitability, costs should be minimized. In order not to spoil a project, services must start on time and finish on time, and maintenance of equipment must be ahead of time. Moreover, the company hired must render high quality services to avoid additional costs arising from work done improperly and it must honor guarantees.

The DC might also be the DM with the most complex set of responsibilities because she is not only concerned about the project itself, but also with the contractor, thus broadening her evaluation to problems such as liabilities result from outsourcing, problems with licenses, population, and government requests. Thus, this DM will probably consider placing limits on some criteria and make them work as qualifiers. In a general sense, this DM is compensatory, but when evaluating the alternatives, these have to accomplish at least some minimum level of performance to be considered in the analysis. Based on her previous experiences, the DC can judge if the alternative might entail liabilities or reduce profitability. Therefore, to bring balance to the alternatives and make an evaluation consistent with this DM's preferences, the Additive-veto Model for ranking problematic (DE ALMEIDA, 2013) was used to model the DC's preferences.

The intra-criterion function was considered linear. The upper veto threshold ( $u_i$ ) considered was 0.15 and the lower one ( $l_i$ ) was 0.05. Table 5.3 presents the results of the veto equation over the criteria.

*Table 5.3 – Veto function of the DC applied to the service data on the Continuous Flight Auger Pile (CFA pile)*

Subcontractors	Criteria				
	Cost (C)	Time needed before starting the service (TB)	Time needed to conduct the service (TC)	Quality (Q)	Maintenance service level (M)
S01	1	1	1	1	1
S02	1	1	1	1	1
S03	1	0	1	1	0
S04	0	1	0	0	1
S05	0	1	1	1	1
S06	1	1	1	1	1
S07	0	1	0.9280	1	1

Based on the DC's preferences and on her concerns about the consequences of this hiring process, the following scaling constants were found after applying the trade-off (Keeney and Raiffa, 1976) method:  $k_c = 0.18$ ;  $k_{tb} = 0.09$ ;  $k_{te} = 0.54$ ;  $k_q = 0.08$  and  $k_m = 0.11$ . These are coherent with her preferences, since the technical issues seemed to be her most relevant concern, and the scale in the criteria of quality and of time before starting the service did not present a significant variation among alternatives. After the analysis, the ranking found by using the additive-veto model for ranking problematic was as follows: S02 P S01 P S04 P S07 P S05 P S03 P S06.

The other DMs may present different objectives from the DC, as well as their rationality, might be different with this same problem. The EM usually is more focused on the same objectives of the DC, but same concerns of the DC are completely ignored by him. This behavior occurs because he will not have to deal with the consequences of problems that shall arise during the project, such as litigation due to bad labor conditions. The OM usually is focused on finishing activities and avoiding problems caused by the influence of one activity over another. Thus, several problems will not catch his attention. However, he usually will prefer to compensate the criteria he is taking into account. The FM is not worried about the

project itself, but the workers and the support they need during the project, he is also worried about the stakeholders and the image the contractor presents to society. Thus, his evaluation will not take into account the variation of any of the criteria, because the criteria he decides to evaluate will keep the preference relation between two alternatives irrespective of the difference in performance between them, only by analyzing the criteria that favor one alternative over the other. This behavior is compatible with Fishburn's (1976) definition of a non-compensatory method.

#### 5.2.1.2 Operations Manager (OM)

The objectives of this DM may sometimes diverge from those of the contractor because he focuses, usually, on finishing the activities on time without concerning himself about cost, quality, and safety. To correct this behavior, the company usually includes those criteria as obligations. Thus, he considers all five criteria as his objectives but is focused on finishing the activities on time. He usually does not plan ahead of the problems and is resistant to new technologies and methodologies.

Based on his resistance, for this DM, it was decided to apply the swing-weights procedure (EDWARDS & BARRON, 1994) with the Additive-veto Model for ranking problematic (DE ALMEIDA, 2013) because it is easier to explain this elicitation than the tradeoff procedure. In addition, a veto function was considered because he might consider that the criteria have a qualitative threshold. As the DC, his intra-criterion function was considered linear, the upper veto threshold ( $u_i$ ) considered was 0.15 and the lower one ( $l_i$ ) was 0.05. Therefore, the results in Table 5.3 are applicable to this DM.

Based on his preferences, the ranking of criteria was as follows: time needed before starting the service; time needed to render the service; maintenance service level; quality; and cost. After normalizing the weights, the results found for the scaling constants were  $k_c = 0.102$ ;  $k_{tb} = 0.408$ ;  $k_{te} = 0.204$ ;  $k_q = 0.122$  and  $k_m = 0.164$ . These are coherent with his concerns since time was his most relevant concern, even though the criterion of cost showed a great variation among the alternatives. After the analysis, the rank found employing the additive-veto model for the ranking problematic with elicitation using swing-weights was as follows: S01 P S02 P S07 P S06 P S05 P S03 P S04.

#### 5.2.1.3 Engineering Manager (EM)

The objectives of this DM are consistent with those of the director, but he may evaluate the consequences differently. In addition, he considers that all criteria should be completely

compensated. Therefore, no threshold was considered for this DM. He is mainly concerned with technical issues, especially quality and the time needed to render the service; he might not be very worried about the time he needs to start the service because he normally works ahead of schedule. He will focus, though, on cost and maintenance service level, but not as much as on quality or the time by which he must end the service, unless there is no variability. Since he is prone to changes, the model chosen applies SAW. It is important to recall that the Additive-veto model for ranking problematic (DE ALMEIDA, 2013) is the same model as SAW with proper parametrization.

Based on the EM's preferences and concerns about the consequences of this process, and after normalizing the weights, the results found for the scaling constants were:  $k_c = 0.353$ ;  $k_{tb} = 0.106$ ;  $k_{te} = 0.353$ ;  $k_q = 0.07$  and  $k_m = 0.118$ . These are coherent with the EM's concerns since the time needed to render the service was his greatest concern, and he worries about cost, due to its great variability. Quality, though, even though he regards this as a priority, does not vary strongly among the alternatives. After the analysis, the rank found using SAW was as follows: S01 P S02 P S03 P S07 P S05 P S04 P S06.

#### 5.2.1.4 Finance Manager (FM)

The application is different for this DM, due to his technical knowledge and experience so he might have a non-compensatory rationality. The service evaluated is a civil engineering one. This professional is an accountant. Thus, he has little understanding of the technical information available. Therefore, he will rank his alternatives based on what he is familiar with, mainly cost and the time needed to render the service because he has no perception for the criterion of the time needed to start the service. He may also wish to consider quality, since if he fails to attend to this, it might cause him guarantee problems.

Considering his non-compensatory rationality, the model specifies an outranking method in this type of situation, which was chosen to be PROMETHEE I. Even though the DM may chose a threshold in this methodology, this DM chose not to use it, and the usual criteria were applied. Based on the DM's preferences, a weight of 0.5 for cost was assigned; 0.3 for the time needed to render the service and 0.2 for quality. He did not consider the other two criteria since they were not meaningful to him. After the analysis, the following partial ranking was found by employing PROMETHEE I: S02 R S03 P S06 R S01 P S07 P S05 P S04. In order to solve the incomparability between alternatives S02 and S03 and S06 and S01, the PROMETHEE II method was used later and the ranking order found was S02 P S03 P S06 I S01 P S07 P S05 P

S04. Since which aggregation method will be applied is not known, it is important to have both rankings, just in case the voting procedure chosen does not accept partial ballots.

### 5.2.2 Phase 02: Aggregating DMs' Preferences

This phase starts by deciding which voting procedure will be employed to aggregate the DMs' preferences. To aid the DMs, the procedure proposed by de Almeida & Nurmi (2015) was used and presented in section 5.1.2. As presented in section 5.1.2, in this numerical application the VP were evaluated by considering the following criteria: (a) the Condorcet winner; (b) the Condorcet loser; (c) the strong Condorcet criterion; (d) monotonicity; (e) Pareto; (f) consistency; (g) the Chernoff property; (h) the independence of irrelevant alternatives; (i) the invulnerability of the no-show paradox; and (j) partial voting. Table 5.4 presents the consequence matrix of all voting procedures considered in the analysis and their performance in each criterion. It is important recall that the evaluation of the criteria is binary, since it is considered that the method may or not present the property.

Table 5.4 – Consequence matrix to choose the voting procedure

Voting	Voting Properties									
Procedure	a	b	C	d	e	f	g	h	i	j
Kemeny	1	1	1	1	1	1	0	0	0	0
Dodgson	1	0	1	0	1	0	0	0	0	0
Borda	0	1	0	1	1	1	0	0	1	0
Copeland	1	1	1	1	1	0	0	0	0	0
Hare	0	1	1	0	1	0	0	0	0	0
Ackerman <i>et al.</i> (2013)	0	0	0	1	1	0	0	1	1	1
Cullinan, Hsiao & Polett (2014)	0	1	0	1	1	1	0	0	1	1

In order to choose the voting procedure using the procedure proposed by de Almeida & Nurmi (2015), the DMs have to provide their preference information by means of the voting properties used to analyze the VPs. However, this is not an easy task. The analyst plays a very important role in the assessment of the DMs' preferences since the criteria have no meaning to the DMs. Therefore, to assess their preference information, it is necessary to give an explanation

of the meaning and consequences of every one of the voting properties, to help the DMs build a preference structure of these criteria. Thus, the analyst should introduce the definitions presented in section 4.1.2 to the DMs. Since the analysis is binary, to aggregate the DMs' preferences only ordinal methods can be employed, namely outranking methods and VPs. Because to use BR the DMs only have to provide the ranking of criteria, this method was used to aggregate the DMs' preferences in the choice of the VP. In addition, all DMs had the same weight. The ranking presented by each DM regarding the criteria to evaluate the voting procedures is shown in Table 5.5 and the result of the aggregation is given in Table 5.6.

Table 5.5 – The DMs' preference order concerning the voting procedures

DC	h f a b d c e j i g
OM	b a c e f d h j g i
EM	e a c b h d f j i g
FM	j h a b f d c e g i

Table 5.6 – Analysis of each procedure considering Borda's Rule to aggregate preferences

Voting	Voting Properties										
Procedure	a	b	c	d	e	f	g	h	i	j	Sum
Kemeny	30	27	21	17	20	21	0	0	0	0	136
Dodgson	30	0	21	0	20	0	0	0	0	0	71
Borda	0	27	0	17	20	21	0	0	2	0	87
Copeland	30	27	21	17	20	0	0	0	0	0	115
Hare	0	27	21	0	20	0	0	0	0	0	68
Ackerman <i>et al.</i> (2013)	0	0	0	17	20	0	0	25	2	15	79
Cullinan, Hsiao & Polett (2014)	0	27	0	17	20	21	0	0	2	15	102

Table 5.6 presents the results of BR divided into the number of votes that each method received in each criterion and their sum. The winner is KR. This result could be modified if the DMs had presented different rankings for the criteria or if the DMs had different weights. Note that, for all DMs, criteria *g* and *i* were irrelevant. This was coherent since none of the procedures had the Chernoff property and only three had the invulnerability of the no-show paradox. One criterion that would have been considered important was independence of irrelevant

alternatives. However, none of the methods analyzed had this property. Therefore, even though some DMs ranked it in first or second, since none of the evaluated methods had this property, it did not contribute to the final value of alternatives.

As previously explained, the DC did not consider that all DMs had the same weight. For this study, the OM and the EM were considered to have the same weight, since this was an engineering service and both were more involved with the consequences of this decision than the FM. These DMs' consequences were considered with four times the weight of the FM and those of the DC were twice the weight of the EM or the OM. Thus, the following weights were found:  $k_D = 8$ ;  $k_{EM} = 4$ ;  $k_{OM} = 4$  and  $k_{FM} = 1$ .

As presented in section 5.2.1.4, the FM presented incomparability in his ranking, providing a partial pre-order of alternatives. However, KR is a VP that was not built to deal with partial pre-orders, only with complete pre-orders. Therefore, it is necessary to solve this problem by getting rid of the incomparability. To eliminate this preference relation, more criteria could be included in the analysis, more information could be provided to this DM or the whole process could be simplified. The FM decided he did not want more information. Thus, to solve the incomparability, PROMETHEE II was used. Table 5.7 presents the ranking order of the alternatives based on the information introduced in the previous section, but with the result presented for the FM when PROMETHEE II was used.

*Table 5.7 – Partial ranking of the DMs*

<b>Rank</b>	<b>DC (8 votes)</b>	<b>EM (4 votes)</b>	<b>OM (4 votes)</b>	<b>FM (1 vote)</b>
1	S02	S01	S01	S02
2	S01	S02	S02	S03
3	S04	S03	S07	S06
4	S07	S07	S06	S01
5	S05	S05	S05	S07
6	S03	S04	S03	S05
7	S06	S06	S04	S04



Table 5.8 presents the pairwise comparison based on KR, which is based on score calculations of the distance between the best alternative for the group and the alternative analyzed. The considerations are made by deconstructing each ranking in pairwise comparisons and calculating the distance from the pair to the one assigned by the majority of voters. When  $x_{i,j} < 0$ , this means that  $a_i$  beats  $a_j$ ; when  $x_{i,j} > 0$ , this means that  $a_j$  beats  $a_i$ ; and when  $x_{i,j} = 0$ , then  $a_i$  and  $a_j$  are tied (SAARI & MERLIN, 2000). The analysis of Table 3.14 shows that the solution found is S02 P S01 P S07 P S05 P S03 P S04 P S06.

*Table 5.8 – Result of the aggregation when using Kemeny's Rule*

Pair of Subcontractors	$x_{i,j}$	Pair of Subcontractors	$x_{i,j}$	Pair of Subcontractors	$x_{i,j}$
{S01;S02}	-0.06	{S02;S04}	1.00	{S03;S07}	-0.41
{S01;S03}	0.88	{S02;S05}	1.00	{S04;S05}	-0.06
{S01;S04}	1.00	{S02;S06}	1.00	{S04;S06}	0.41
{S01;S05}	1.00	{S02;S07}	1.00	{S04;S07}	-0.06
{S01;S06}	0.88	{S03;S04}	0.06	{S05;S06}	0.41
{S01;S07}	1.00	{S03;S05}	-0.41	{S05;S07}	-1.00
{S02;S03}	1.00	{S03;S06}	0.53	{S06;S07}	-0.88

#### 5.2.2.1 Comparison with other methods

In order to compare the ranking found using KR with the result that could have been found by using other methods, we compared it with DR, the BR, and the extension of the BR to partially voted ballots (CULLINAN, HSIAO & POLETT, 2014), this last one to consider the incomparability presented in the FM's preferences. It can be verified from the results presented in Table 5.9 that the first three positions were constant but the last four switched places depending on the method. In addition, the results from using DR and BR for partial voting had ties.

It was expected that the result reached after applying DR and KR would be alike since both methods are distance-based extensions of the Condorcet method but these were quite different for the alternatives in the middle. From the results presented for alternatives 03, 04 and 05, note that KR deals with cycles in a smoother and more coherent way than DR. In addition, KR succeeded in providing a ranking that was in agreement with the number of votes that each alternative received, while DR positioned alternative 05 as worse than alternatives 03 and 04, even though 05 received a greater number of votes. This happened because of its

relation with alternative 07. In addition, the result for BR was different in the alternatives classified in the middle for all the results, and only presented results close to its extension for partial voting.

*Table 5.9 – Comparison of KR with other rules*

Order	KR	BR	BR Partial Voting	DR
1	S02	S02	S02	S02
2	S01	S01	S01	S01
3	S07	S07	S07	S07
4	S05	S03	S04	S03 I S04
5	S03	S04	S03 I S05	S05
6	S04	S05	S06	S06
7	S06	S06		

After running an isolated sensitivity analysis to verify if the constant scales and weights were robust, it was found that only changes in the DC's scale constants produced any modifications in the ranking presented above. Even so, after reducing the scale constants of criterion quality, the time needed before starting the service or the maintenance service level by 20%, there were modifications in the ranking that could affect the solution since alternatives 03 and 07 switched places.

### 5.2.3 Phase 03: Negotiation

In the last phase, for activities sorted in class  $C_2$ , the DM who required the service or the DC has to negotiate the activity with the top ranked subcontractors. In the case of the CFA pile activity, the OM required the service. Thus, he has to negotiate with top-ranked subcontractors. These are S02, S01, and S07. During this negotiation, the OM can learn about each of the negotiators and use his knowledge of previous experiences in this process. For the previous part of the application, the framework suggests the same procedure for activities sorted in class  $C_2$  or  $C_3$ . However, in this phase, one single DM runs the negotiation when the activity is sorted in class  $C_1$  or  $C_2$ . Otherwise, all DMs have to take part of the negotiation phase. The whole example was presented as if the activity to be negotiated was classified in class  $C_2$ . However, as previously mentioned, by using the ROR-UTADIS method (KADZIŃSKI, CIOMEK & SŁOWIŃSKI, 2015), this same activity was sorted in class  $C_3$ . Under this condition, the

proposition of Chapter 03 is that all DMs take part in the negotiation process. This would drive this negotiation to Many Parties, Many Issues position as presented by Raiffa (1982). When it comes to this point, then the DMs have to be considered as one unique coalition, since all of them share the same objectives regarding the Contractor and its interests. Moreover, even though they have individually different preferences when it comes to the negotiation itself, they will probably share the same objectives. Thus, it consists of an aggregation of DMs' initial preferences and the scale constants to be used are the aggregation of the DMs' preferences.

## **6 FINAL REMARKS AND FUTURE WORK**

### **6.1 Contributions**

In this thesis, a framework for selecting subcontractors considering two models was presented. The framework starts by considering a sorting step, where the activities are sorted into classes according to their risk and impact on the project, the client and the contractor. This step allows the project to consider different forms of governance in the selection process and negotiation processes within the project. In addition, the DMs usually present a compensatory rationality at this step, therefore, it was proposed the additive-veto model for sorting problematic to be compatible with the DM's rationality and avoid the requirement of previous knowledge of exemplary alternatives found in the holistic methods. Moreover, the DMs present different objectives towards the problem, thus, the selection model considers that the analyst might assign different methods to each DM based on the DM's rationality. Additionally, the aggregation of preferences is run with the DMs' final preferences, which is compatible with the fact that they usually present different objectives regarding the same problems, while defining the aggregating method depends on the DMs' preferences, since a procedure to choose the voting procedure is used and the decision is based on DMs' preferences. At last, a negotiation phase occurs to decide which subcontractor should be hired among the top ranked.

For the sorting step, the Additive-veto model for the sorting problematic was presented. This model is a modification of the Additive-veto model for ranking problematic proposed by de Almeida (2013). In order to adapt the original model to the sorting problematic, in this model, two veto approaches were used to disallow the alternatives being assigned to a class: by vetoing the specific alternative to be sorted into a class or by penalizing it, which also veto the alternative being sorted into the class of assignment. In addition, two decision rules were proposed to implement the veto condition in the additive method. Decision rules have been previously used in other methods such as DRSA (GRECO, MATARAZZO & SŁOWIŃSKI, 2001) and PRIME (SALO & HÄMÄLÄINEN, 2001). The procedure was built focusing on the CC context, because it is appropriate to model DMs' preference structures which are related to this kind of problem. In addition, it does not require previous knowledge of reference alternatives, thus avoiding biased assignments.

The CC industry can improve the management of their subcontractors by implementing this model to sort the activities prior to their selection. Aside from saving money in the process

itself, it is possible to decrease the time spent on the selection procedure and to simplify the whole process, yet without causing further liabilities to the contractor. The model, not only helps to keep the compensatory rationality of the DM but also ensures that he/she uses only the conditions that are compatible with his/her preference structure. Therefore, it is flexible, and the veto conditions are intuitive, thus avoiding misunderstandings during their elicitation.

The decision of which parameters to use has to be conducted by the analyst with the DM. The analyst has to verify which pieces of preference information the DM feels comfortable about providing, and which of them are compatible with his/her rationality regarding the problem. The model presented, can be also applied in different domains, such as selection of personnel. In this model, the compensatory rationality of the DM can be preserved without prior knowledge of reference alternatives to build the preference information.

The framework is easy to be used and is a novel methodology in the sense that methods compatible with the DMs' rationality will be used. Besides, it permits the DMs to express their own objectives and evaluate the alternatives based on their perception of the criteria. The procedure presented by de Almeida & Nurmi (2015) brings to the methodology a characteristic that makes the process flexible yet robust, by allowing the DMs to use their preferences to choose a voting procedure compatible with the problem faced. The idea of presenting a set of methods for the selection process has been previously addressed in the literature, but no other model emphasized the need to use methods that are compatible with DMs' rationality. This possibly has not been addressed before due to the lack of methods that help the analyst to evaluate a DM's rationality. Besides, the analyst is always responsible for choosing the voting procedures which gives him/her the power to manipulate the whole process. In addition, the last phase of the framework is a negotiation step, which varies according to the class of assignment of the activity.

In sum, the framework offers a flexible form of analysis to the supplier selection process in the CC context and other environments, which select workers, projects, etc. It allows a detailed and structured analysis process that might help DMs to feel more comfortable about decisions during a project.

## **6.2 Managerial Impact**

The proposed framework presents a different way of dealing with selecting subcontractors, namely by allowing the DMs to manage hiring procedures in a manner compatible with their impact on the project. In addition, it allows the DMs to use a method

which fits their rationality. Moreover, the DMs do not have to consider the same criteria, and thus, can take their own objectives towards the problem into account. Finally, they can feel more secure about the aggregation procedure, since it is chosen based on their preferences.

The results of the first model showed that when applying SAW to sort the alternatives into classes, management might require more effort and time from the DMs, which is when most alternatives are sorted into the higher impact class. In a real life context, such as in this application, the DMs present the perception that some of the contracts sorted into higher impact classes could be managed as medium impact classes and the same happens with activities assigned to the medium impact class, namely they could be managed as in a lower impact class. The proposed model is useful for helping to manage subcontractors because this can be done in a realistic way, thereby reducing costs associated with these contracts, liabilities and the risks involved in carrying out the activity and, by reducing their impacts on other activities and workers.

The analysis of rationality presented in the second model is still a question to be discussed, which has not been fully explored, and a very important one because the definition of the method to be applied depends on it (DE ALMEIDA *et al.*, 2015). The model also allows the SDM to adapt the decision process to the problem, and to change the weights of the DMs when necessary. These are important features when selecting subcontractors in the construction industry. This is because it is important to recognize that the DMs will have different objectives related to each selection process; that their rationality might change depending on the problem and their impact on the decision may have to be balanced depending on their relation to the consequences of that decision. The framework only suggests deterministic methods because it is unusual to consider different scenarios in a selection process. Nevertheless, if it is important and if there is enough information available, then the analyst can apply MAUT (KEENEY & RAIFFA, 1976) instead of a deterministic method.

The procedure to choose voting methods proposed by de Almeida & Nurmi (2015) is very interesting and easily applicable, as can be seen in the application. This allows the voting procedures to be chosen according to the DMs' objectives in each selection. This feature makes the process more flexible. The framework can be applied considering different forms of analysis, while the criteria do not need to be binary, since some of the properties do not occur 100% of the time in each method, such as the Condorcet Winner and the Condorcet Loser. This was not explored in the application because the ordinal aggregation method was used but an additive model could be considered which aggregates the probabilities in which the methods

fails to present each property and incorporates these into the analysis in each method. The aggregation of the voting methods, even when considering non-compensatory relations, does not need to be under a voting rule, Nurmi (2015) presented a proposition of applying PROMETHEE to aggregate preferences.

The framework allows the DMs to adapt the method to the problem, thus making the process flexible and allowing the DMs to choose the method while considering the characteristics of the problem. If for some reason many incomparabilities arises, for example, the DMs could choose this criterion as the most important one, thereby driving the process to a method that allows partial voting. However, the research on partial voting is still very recent, needing some developments in the future.

This model is not only for the outsourcing problem, but it can also be applied in many business decisions. Instead of analyzing the hiring process, an analysis of the company's investments could be made in order of importance to the DMs. Similarly, how to choose people to occupy a work position in a company or how to choose which projects to carry out when the company has to make choices, could be analyzed. One characteristic of this model is the sorting problematic at the start of the process, and thus it is considered to be a multicriteria problem.

### 6.3 Limitations

The Additive-veto model for sorting problematic was built considering that the scale constants were to be elicited using the trade-off method. However, these are not the only piece of preference information provided by the DM. The veto conditions should be assessed, and no elicitation method has been proposed yet. In addition, there was no proposition on how to elicit the classes' profiles. There are some studies on the elicitation of part of these parameters, such as the one presented by Cailloux, Meyer & Mousseau (2012). Thus, it is necessary to run some experiments to verify if the methods already presented in literature fit the method.

In the selection model, the analysis of the rationality can be guided by the questions presented by Roy & Słowiński (2013), but no structured method was proposed in this thesis to guide this process. However, it could be built some DSS to help the analyst in the querying task of evaluating the DMs' rationality. As for the procedure proposed by de Almeida & Nurmi (2015), the decision matrix needs further studies to evaluate the frequency in which the voting properties occur in each of the voting procedures. This feature could improve the choice of the VPs making the process more reliable and allowing the use of non-ordinal methods to aggregate the preferences. The weight assigned for each DM and the definition of the aggregation method

also consist of limitations in the use of the framework, because they can conduct to choices that do not represent the social choice. In addition, it is not an easy task to clarify the meaning of the voting properties to DMs. So the analyst still is a requisite in the choice of the VP, because he/she has to explain what is a voting properties, which of them are going to be considered and their effect on the social choice.

At last, the model presents a negotiation step in a peculiar condition, where one negotiator deals with several other negotiators in order to hire at least one of them and he/she negotiates the same issues with all of them. However, no proposition concerning a web-based platform of e-negotiation was presented.

#### **6.4 Future Works**

In future works, the framework should be used in other types of environment in order to analyze its applicability. In addition, the additive-veto model for sorting problematic should be used in other types of problems. This model should be extended to group decision, since in CC decisions are usually made in a group, in which a consensus is not required. An experimental study should also take place to evaluate the robustness of the analysis and verify the frequency in which the more correct misclassification. Moreover, it is important to investigate the frequency with which procedures present voting properties in order to improve the use of the framework proposed by de Almeida & Nurmi (2015). At last, an e-negotiation platform should be built on a web-based tool and experiments involving students should be run to evaluate people's behavior when they use this model.



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