Comparative evaluation of PROMETHEE and ELECTRE with application to sustainability assessment

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ABSTRACT

Comparative evaluation of PROMETHEE and ELECTRE with application to sustainability assessment

Iman Majdi

The selection of robust method for sustainability assessment of companies is a challenging decision, particularly for manufacturers with high safety requirements and large number of consumers such as aerospace, automotive components and, oil & gas companies. These overriding industries consider environmental, social and governance (ESG) criteria as well as non-financial factors that have direct effect on infrastructure investments to reach monetary value for its stakeholders and development of a sustainable long term strategy for their portfolio company. These factors however may be often associated with internal and external uncertainties making it difficult to obtain precise sustainability measurement. Actually, the problem comes from addressing 'how' and 'which' questions to select a solid ranking method for sustainability assessment.

In this thesis, we investigate the application of outranking based Multi-Criteria Decision Making (MCDM) methods called ELECTRE III and PROMETHEE I & II for sustainability assessment of industrial organizations. ELECTRE III is a preference based method that considers pseudo-criteria which can be applied for uncertain, imprecise and ill-determined data. PROMETHEE I is a positive and negative flow based multi-criteria method that generates partial rankings. PROMETHEE II is net flow based method and generates complete ranking for alternatives. PROMETHEE methods are more compatible with human judgments.

To compare the performance of ELECTRE III and PROMETHEE I & II, we conducted a sustainability assessment case study and performed model verification and robustness analysis, model validation and sensitivity analysis. The data for the study was obtained from Sustainalytics, a firm specializing in sustainability. The results of our study show that ELECTRE III method outperforms PROMETHEE I & II and is therefore recommended for sustainability assessment of industrial organizations.

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I acknowledge my wife for her patience and support during my study.

Dedication

To my devoted mother.

Her words of inspiration and encouragement

in pursuit of excellence, still linger on.

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List of acronyms

AHP- Analytic Hierarch Process
ANN- Artificial Neural Network
ANP- Analytic Network Process
CA- Cluster Analysis
CM- CRITIC Method
DEA- Data Envelopment Analysis
DEMATEL- Decision Making Trial and Evaluation Laboratory
DFAD- Design For ADaptability
ELECTRE- ELimination Et Choix Traduisant la REalité (ELimination and Choice Expressing REality)
EM- Entropy Method
EP- Exploitation Procedure
ESG- Environment, Social, Governance
EU- Expected Utility
FDR- Fuzzy Dominance Relation
GA- Genetic Algorithm
GAIA- Geometrical Analysis for Interactive Aid
LMS- Lean Manufacturing System
LP- Linear Programming
MADM- Multi-Attribute Decision Making
MAUT- Multi-Attribute Utility Theory
MARSAN- M´ethode d'Analyse, de Recherche, et de S´election d'Activit´es Nouvelles
MCAP- Multiple Criteria Aggregation Procedure
MCDM- Multi-Criteria Decision-Making
MDGs- Millennium Development Goals
MILP- Mixed Integer Linear Programming
MCA- Multi-Criteria Analysis
MSC- Multi-Sustainable Criteria
MODM- Multi-Objective Decision-Making
MOLP- Multi-Objective Linear Programming
TBL- Triple Bottom Line
TMS- Traditional Manufacturing System
PRI- Principles for Responsible Investment
PROMETHEE- Preference Ranking Organization Method for Enrichment Evaluation
SAW- Simple Additive Weightings
SMART- Simple Multi-Attribute Rating Technique
SME- Small and Medium Enterprises
SDM- Supra Decision Making
TOPSIS- Technique for Order Preference by Similarity to an Ideal Solution
US EPA- United State Environment Protection Agency
WMI- Water Missions International
WPM-Weighted Product Model
WSM- Weighted Sum Model
ZOGP- Zero One Goal Programming

CHAPTER 1

INTRODUCTION

1.1 Background

Non-financial factors such as Environmental, Social and Governance (ESG) have direct effect on industrial income. These factors represent a broad set of intrinsic concerns that may ultimately affect estimation of equity, fixed-income, real estate, and infrastructure investments (CFA Institute Centre). Industrial investors consider evaluation of ESG risk as a part of their investment process. They believe that considering ESG criteria in their business decisions is fundamental to making monetary value and developing a sustainable long term strategy for their portfolio company.

On the other hand, heavy industries, with high safety requirements and large number of consumers such as aerospace, automotive components and, oil & gas companies, have to deal with more internal and external uncertainties in order to obtain precise sustainability assessments to identify measures that will improve sustainability and enable them to remain in global competition.

Multi-Criteria Decision Making (MCDM) methods such as Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), ELimination Et Choix Traduisant la REalite (ELECTRE), Preference Ranking Organisation Method for Enrichment Evaluations (PROMETHEE), etc. are popularly reported in literature for sustainability assessment. Since, the sustainability decision making process involves comparing entities in pairs to determine the preferred entity, outranking methods are often used. In this thesis, we are considering two widely employed outranking based decision-aid methods namely ELECTRE and PROMETHEE for sustainability assessment of industrial organizations. The decision making in industrial organizations is characterized by the following features:

(1) The number of Decision Makers (DMs) is large (typically more than 8);
(2) The possibility to obtain preference information from the DMs is generally limited to the weighting of the criteria and;
(3) The number and type of the criteria is different (Salminen et al., 1998).

ELECTRE is a preference-based model which considers the concordance and discordance indices in order to make preference between each pair-wise comparison. In addition, in a real world where perfect knowledge is rare, imperfect knowledge could be taken into account in ELECTRE methods through the use of probabilistic distributions and expected utility criterion (EU) (Figueira et al., 2005). ELECTRE III method seems to be complicated for new users but it considers different aspects of criteria on sustainability such as imprecision, indetermination and uncertainty (Giannoulis et al., 2010) and is therefore chosen for our study.

PROMETHEE method generates partial ranking results based on higher ‘positive outranking flow’ and lower ‘negative outranking flow’ (Schwartz et al., 2009). Since PROMETHEE I provides partial ranking, we have considered PROMETHEE II for its ability to generate full rankings (Macharis et al., 2004). PROMETHEE II method is more compatible with human judgments and is relatively easy for decision makers to understand (Gilliams et al., 2005).

In order to ensure selection of right method for sustainability assessment, the problem should be well-understood and analysed by the decision makers. For example, the feasible alternatives, different outcomes, conflicts between the criteria and the level of uncertainty of the data should have been evaluated before describing different decision making ways. Besides, the ranking results of ELECTRE III and PROMETHEE I, II, may be different resulting in more difficulty for companies to choose the best method.

1.2 Research Objective

1.2.1 Overall Goal

Since different MCDM methods are available and not all techniques are adequate to solve a specific problem (Al-Shemmeri et al., 1997), a particular method may be inappropriately selected. There are four consequences of this kind of mismatch:

Firstly, the solution can be misleading or unsatisfactory.

Secondly, useful techniques may be judged inappropriate.

Thirdly, mismatches may result in wrong decisions, incurring losses in time, energy and money.

Finally, potential users may be discouraged from applying MCDM techniques to real world problems (Gilliams et al., 2005).

The overall goal of this research is to compare the performance of two outranking based decision making methodologies specially, ELECTRE and PROMETHEE for sustainability assessment of industrial organizations and perform a comparative evaluation.

1.2.2 Research Tasks

Two tasks were identified to address the main goal of this research.

Task 1

The motivation of this task is to address the need of sustainability assessment by taking into consideration multi-criteria decision making perspective. This task will apply ELECTRE III and PROMETHEE II methodologies to consider the ranking and selection based on Environmental, Social and Governance (ESG) issues which are involved in uncertainties.

Task 2

This task is motivated by the need in the industry and involves methodology selection by comparing various multi-criteria methods and assessing their performance.

1.3 Scope and Limitations

The scope of this research is limited to multi-criteria decision making techniques. Outranking methods ELECTRE and PROMETHEE are considered and only ELECTRE III and PROMETHEE II are executed. The data for our case studies is taken from Sustainalytics, a Global Platform Company. Three industries namely aerospace, oil & gas and automotive components are studied.

1.4 Research Significance

This research makes the following contributions:

- A literature review on application of ELECTRE and PROMETHEE methods in sustainability decision making;
- Application of ELECTRE III, PROMETHEE I and II for sustainability assessment of industrial organizations. Three industries namely aerospace, oil & gas and automotive components are considered;
- Comparing the performance of PROMETHEE I, II and ELECTRE III using a numerical case study, model verification, robustness, sensitivity and validation analysis.

1.5 Organization of the Thesis

This thesis is presented in six chapters as follows:

Chapter 1 defines the problem and presents the objectives of the research and structure of the thesis.

Chapter 2 contains literature review on ELECTRE and PROMETHEE techniques and their applications in sustainability planning.

Chapter 3 presents the details of outranking approaches ELECTRE and PROMETHEE used in our study.

Chapter 4 presents the comparative evaluation of ELECTRE and PROMETHEE methodologies through a case study on sustainability assessment of industrial organizations and performs model verification, robustness, sensitivity and validation analysis.

Chapter 5 presents the conclusions, lessons learnt and recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, we will present the literature review under following categories:

- Review on DM methods;
- Review on MCDM problems;
- Review on outranking methods;
- Review on sustainable industry;
- Review on the application of MCDM in sustainable industry;
- Review on ELECTRE method in sustainable industry;
- Review on PROMETHE method in sustainable industry.

2.2 Review on Decision Making Methods (DM)

Harris (1998) defines “decision making as the process of sufficiently reducing uncertainty and doubt about alternatives to allow a reasonable choice to be made from among them.” Fulop (2005) also accepted Harris (1998) definition “to choose the one that best fits with our goals, objectives, desires, values, and so on” and considered decision making as a challenge. He divided decision making in 5 subsets as shown in Figure 1. The details of these subsets are presented as follows:

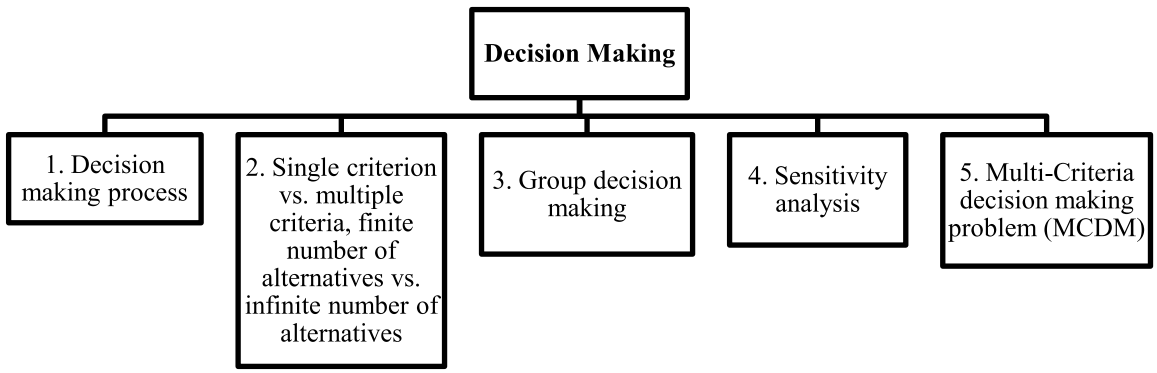

Figure 1. Decision Making Subsets

2.2.1 Decision Making Process

Baker et al. (2001) divided DM process in 8 steps which are briefly described as follows:

(1) Define the problem: The goal is to express problem statement by identifying root causes, finding limitations and stakeholder issues;

(2) Determine requirements: It shows any tolerable solution that problem must meet;

(3) Establish goals: This part defines the minimum essential must have's (i.e. requirements), wants and desires;

(4) Identify alternatives: The infeasible alternatives must be deleted and potential alternatives that meet the desired condition be identified;

(5) Define criteria: The goals are determined in the form of criteria and every goal should meet one criterion. Several criteria need to be defined in

problems with complex goals. The group of criteria and sub-criteria can be shown in a tree-structure (UK DTLR, 2001). The criteria should meet all goals, be non-redundant (Keeney et al., 2001), distinguish among the alternatives and be performant;

(6) Select a decision making tool: The DM method selection is not easy, especially in complex decision problems and therefore decision making tool needs to be identified;

(7) Evaluate alternatives against criteria: The evaluation depends on type of assessment. It can be objective (factual) and/or subjective (judgmental);

(8) Validate solutions against problem statement: The solution from the decision making model should be validated against other approaches using real data to ensure it addresses the problem in right way.

2.2.2 Single Criterion against Multiple Criteria and finite number of alternatives against infinite number of alternatives

In case of a decision problem with a single criterion or a single aggregate measure, objective function is the single criterion; the constraints are the requirements on the alternatives. Techniques that can be used to address these problems are linear programming, nonlinear programming, discrete optimization, etc. (Nemhauser et al. 1989). On the other hand, multiple criteria optimization is used in case of a finite number of criteria with feasible number of alternatives (Steuer, 1986).

When decision making problems involve a number of criteria and finite number of alternatives, the problem goals should be defined clearly. Problems of this type are called Multi-Attribute Decision Making (MADM) problems (Fulop, 2010).

2.2.3 Group Decision Making

In a group decision making, we have multiple decision makers with different skills, experience and knowledge (Fulop, 2010). In this situation, we apply consensus rules to determine voting powers which is called Supra Decision Making (SDM) (Keeney et al., 1976).

Several Multi-Attribute Decision Making approaches are considered in case of group decision such as Multi-Attribute Utility Theory (MAUT) that was examined by Bose et al. (1997). Two years before Bose, Csaki et al. (1995) applied WINGDSS software for group decision making and formulated group weights, qualification and utility by applying tree-structure. The highest group utility is the best alternative. Keeney (1976) defined the best group utility function for cardinal ranking.

In 1992, Dyer et al. applied Analytic Hierarchy Process (AHP) for group decision making and Lai et al. (2002) extended it by using AHP in software selection. The main challenge in applying AHP is how to synthesize the individual pair-wise comparison of group members. Aczel et al. (1983) submitted the procedure for synthesizing ratio judgments as a solution, which means the only synthesizing function is the geometric mean. A few years later, Gass et al. (1998) improved the application of AHP on synthesizing group decision.

From 1998 until now, scholars have worked on outranking methods for group decision making. For example Macharis et al. (1998) and Leyva-Lopez et al. (2003) applied outranking methods such as PROMETHEE and ELECTRE for group decision making, respectively.

2.2.4 Sensitivity Analysis

Since Multi-Attribute Decision Making (MADM) models are often subjective therefore, the weights and the scoring values of the alternatives are involved in uncertainties and there is sensitivity to change input parameters.

In 2001, Forman et al. presented graphical tools to show sensitivity analysis to a user where in case of different criteria weights, the stability intervals should be determined (Mareschal, 1988).

In 1995, Wolters et al. (1995) studied a linear programming model to perform minimum modification of the weights. Triantaphyllou et al. (1997) worked on complex sensitivity analysis where they changed the scores of the alternatives versus the criteria. Meszaros et al. (1996) proposed simultaneous change in the weights and the scores of the alternatives within given intervals and it was extended for more general decision functions by Ekart et al. (2005).

2.3 Multi-Criteria Decision Making Problems (MCDM)

Multi-criteria decision making (MCDM) was developed by Brans (1982) and extended by Vincke and Brans (1985). As a general view, MCDM includes two parts:

Multi-Objective Decision Making (MODM) and Multi-Attribute Decision Making (MADM) (Figure 2).

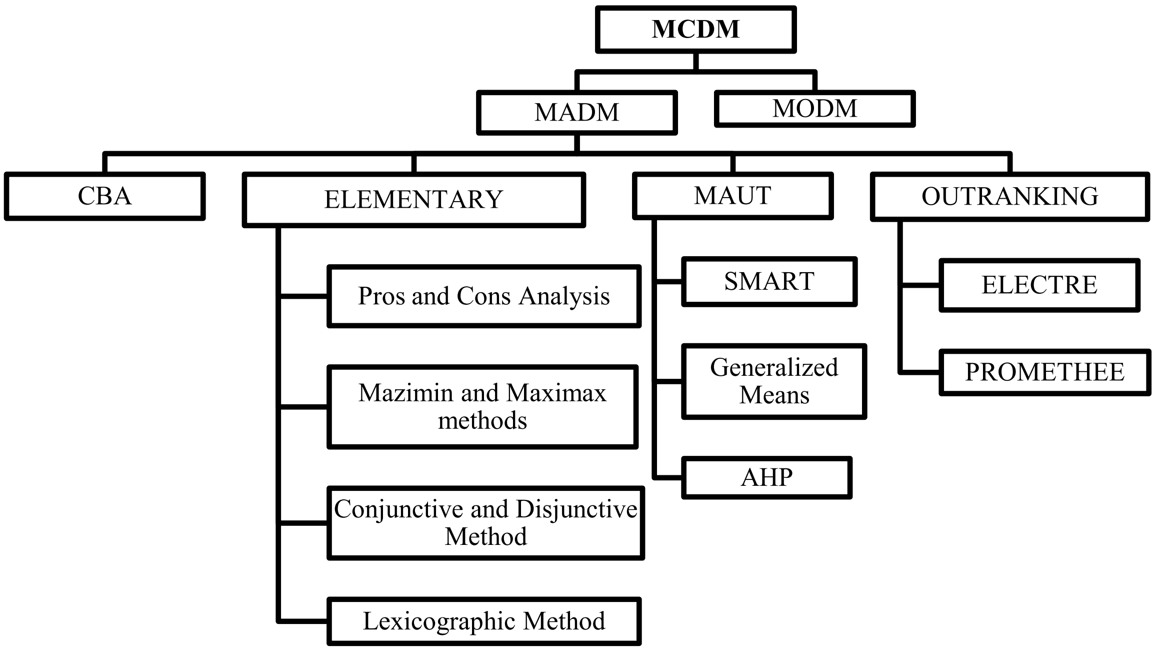

Figure 2. MCDM Hierarchy

2.3.1 Multi-Objective Decision Making (MODM)

In Multi-Objective Decision-Making (MODM), the objective should be measurable. Thus, if it is qualitative such as yes/no or present/absent, it should be converted from nominal scales to numerical scales (quantitative). The objective outcomes facilitate the comparison of the alternatives for the decision makers. Therefore, MODM is an appropriate method for ranking or selecting even in case of conflicting objectives.

Several methods are used in MODM but there is still the problem of selecting the best method for a given situation. Ustinovichius et al. (2007) divided MODM in following groups:

(1) The methods of rank correlation were introduced by psychologist Spearman (1904 and 1910) and extended by Kendall (1948). Bardauskiene (2007), Turskis et al. (2006) and Zavadskas et al. (2006) used MODM method for construction of problems solution, as well;
(2) Preference based where the alternatives are compared based on quantitative measurements such as ELECTRE and PROMETHEE;
(3) Initial qualitative assessment based such as AHP, game theory and fuzzy sets methods (Peldschus et al., 2005; Zavadskas et al., 2007, 2008a, 2008b);
(4) Reference point or goal based such as TOPSIS (Hwang et al, 1981; Zavadskas et al. 2006; Jakimavicius et al. 2007; Kaplinski et al. 2006) VIKOR (Opricovic et al. 2004; Ginevicius et al. 2006)

Thiel (2006) extended MODM groups by applying ELECTRE III method for public transport expansion and in 2005, Nowak used the PROMETHEE method to evaluate investment projects.

2.3.2 Multi-Attribute Decision Making (MADM)

MADM methods require inter- attribute and intra-attribute information in order to arrive at a choice (Rasa, 2012). Few important MADM methods are presented as follows:

2.3.2.1 Cost-Benefit Analysis (CBA)

Cost-benefit analysis (CBA) is a technique to evaluate the costs and benefits of the alternatives on monetary basis. Munda (1996) showed that CBA can be integrated into complex methods of environmental assessment and United State Environment Protection Agency (US EPA) (2000) used CBA for guideline on economic analysis.

2.3.2.2 Elementary Methods

These methods are used in case of problems with a single decision maker and few alternatives and criteria. The characteristic of elementary methods is that they are simple and do not need computational support (Linkov et al., 2004). The elementary methods include:

EL 1 Pros and Cons Analysis

It is a qualitative comparison method. The good things (pros) and bad things (cons) should be identified for each alternative and consequently, the alternative with the strongest pros and weakest cons is selected (Baker et al., 2001).

EL 2 Maximin and Maximax Methods

The maximin method is used to prevent the worst performance and the maximax method is used to choose the best performing of alternatives. The maximin method has limitations when the criteria are incomparable (Linkov et al., 2004).

EL 3 Conjunctive and Disjunctive Methods

The alternatives in conjunctive and disjunctive methods should meet a minimal performance threshold for all criteria and exceed the given threshold for at least one criterion. Alternatives that cannot meet the conjunctive and disjunctive methods should be deleted (Linkov et al., 2004).

EL 4 Lexicographic Method

In this method, criteria are ranked based on their importance and alternative with the most important criterion is selected. In case of tie among alternatives, they are compared on the next most important criterion (Linkov et al., 2004).

2.3.2.3 Multi-Attribute Utility Theory (MAUT)

MAUT is a type of MCDM technique based on utility theory (Goicoechea et al., 1982). In MAUT the weights of criteria have direct effect on ranking of alternatives. The different criteria are aggregated into a function in order to be maximized (Keeney et al, 1976). MAUT evaluates the alternatives and assigns weights with the purpose of trade-off between attributes (Von Winterfeldt et al., 1986).

The practical application of each MAUT method is different but the important procedures as defined by von Winterfeldt et al. (1986) are:

(1) Evaluate alternatives

(2) Assign weights

(3) Aggregate the weights of attributes and alternative scores

(4) Perform sensitivity analyses and make recommendations.

There are different models in MAUT where the weights associated with the criteria vary between the interval [0, 1] or [0, 100] in both factual (objective, quantitative) and judgmental (subjective, qualitative) criteria (Fulop, 2005). The models include:

(1) Simple Attribute Rating Technique (SMART): alternatives are ranked in order of importance on a 10 point scale (Edwards, 1977);

(2) Generalized means: define the vector $x=(x_1, \ldots, x_n)$ and aggregate the performance scores after multiplying every criterion with respective weight (Mészáros et al., 1996);

(3) Analytic Hierarchy Process (AHP): alternatives ranks are based on pair-wise comparison on a nine point scale (Saaty, 1990).

2.3.2.4 Outranking or Decision Aid Methods

The outranking methods require specifying alternatives, criteria and use of the data of the decision table, namely the a_{ij}'s and w_i's. Here, we explain the two most popular families of the outranking methods namely the ELECTRE and the PROMETHEE methods as follows:

2.3.2.4.1 Review on ELECTRE and its applications

I History of ELECTRE

The use of ELECTRE method as a decision aid started in 1965 at the European consultancy company SEMA where their research team worked on decision making problems on the development of new activities in firms. SEMA used a general multiple criteria method called MARSAN (M´ethode d'Analyse, de Recherche, et de S´election d'Activit´es Nouvelles) (Laffy, 1966). But MARSAN had serious drawbacks and Roy (1966) suggested ELECTRE method to overcome the limitations of MARSAN.

The ELECTRE method is used to select the best action(s) among a set of actions. The acronym ELECTRE stands for (Benayoun et al., 1966; Roy, 1985): ELimination Et Choix Traduisant la REalit´e (ELimination and Choice Expressing the REality), and it was established for commercial reasons. The ELECTRE methods have developed over the last three decades and are used in different engineering areas.

II Methodology of ELECTRE

ELECTRE is a preference-based model. For example, if we assume alternatives *(a)* and *(b),* ELECTRE method compares them to find whether *(a)* or *(b)* is strictly preferred to each other, or there is no difference between them, or they are incomparable. In addition, ELECTRE is based on the concordance and discordance indices. The concordance index lies between 0 and 1 and the sum of the weights of all criteria equals to 1.

In addition, in a world where perfect knowledge is rare, imperfect knowledge only could be considered in ELECTRE methods through the use of probabilistic distributions and expected utility criterion (EU).

Two important concepts in the ELECTRE approach are thresholds and outranking. The traditional preference modeling of ELECTRE assumes three types of relations between alternatives *(a, b)*:

aPb (*a* is preferred to *b*) $g_j(a) > g_j(b)$;

aIb (*a* is indifferent to *b*) $g_j(a) = g_j(b)$;

aRb (*a* is incomparable to *b*).

On the other hand, Buchanan et al. (1999) redefined them as bellows:

aPb (*a* is preferred to *b*) → $g_j(a) > g_j(b) + q_j$;

aIb (*a* is indifferent to *b*) → $|g_j(a) - g_j(b)| \leq q_j$;

aRb (a is incomparable to b) → remains.

While:

$q_j(\cdot)$ is the indifference threshold of criterion g_j.

The concept of veto threshold, $v_j(.)$, shows the possibility of the criterion g_j to impose its veto power. The voting power as defined by Water Missions International (WMI) Corporation (2010) is: "the total number of votes entitled to be cast on the issue at the time the determination of voting power is made, excluding a vote which is contingent upon the happening of a condition or event which has not occurred at the time."

The ELECTRE method comprises of two main procedures:

Multiple Criteria Aggregation Procedure (MCAP): makes use of one or several outranking relations for comparison. It is modeled by credibility index which combines concordance and disconcordance.

Exploitation Procedure (EP): is used to derive recommendations from results.

Table 1 demonstrates the main features of ELECTRE methods.

Table 1. Main Feature of ELECTRE

Main Features of ELECTRE	
The context in which they are relevant to following characteristics (Roy et al., 1991;1993):	There are at least three criteria in the model.
	Alternatives are evaluated on an ordinal scale or on a weekly interval scale (Roberts, 1979)
	There is heterogeneity of criteria.
	DM cannot compensate the loss criterion by another.

Main Features of ELECTRE	
	Small differences of evaluations are not significant while the accumulation of several small differences may become significant (Figueira et al., 2010)
Modelling with an outranking relation	Modelled Preferences are in binary outranking relations, *S*, which means “at least as good as” by considering two alternatives ‘*a*’ and ‘*b*’.
	The construction of outranking relations is based on: • Concordance: a majority of criteria meet the assertion; • Disconcordance: a minority of criteria meet the assertion.
Structure of ELECTRE (Mousseau, 1995; Roy et al., 90; 91; 93)	Two main procedures: MCAP and EP.
	Defined the nature of the recommendations by the problem types: 1. Choosing, 2. Ranking 3. Sorting. (Vanderpooten, 1990) (See Figure 3)
The role of criteria (Figueira et al., 2002; Rogers et al., 1998; Roy et al., 1996; Vansnick et al., 1986)	Defined by two parameters: • The importance coefficients: inherent “weights”. • Veto thresholds: voting power when the difference of the evaluation between $g_j(b)$ and $g_j(a)$ is greater than threshold.
How to take into account imperfect knowledge (Bouyssou et al., 1987)	Discriminated between thresholds due to a pseudo-criteria: • Preference thresholds, $p_j(.)$; • Indifference thresholds, $q_j(.)$.

III ELECTRE Applications

According to Bana (1992;1996), ELECTRE methods are used to formulate three different problem types namely choice, sorting and ranking as shown in Figure 3.

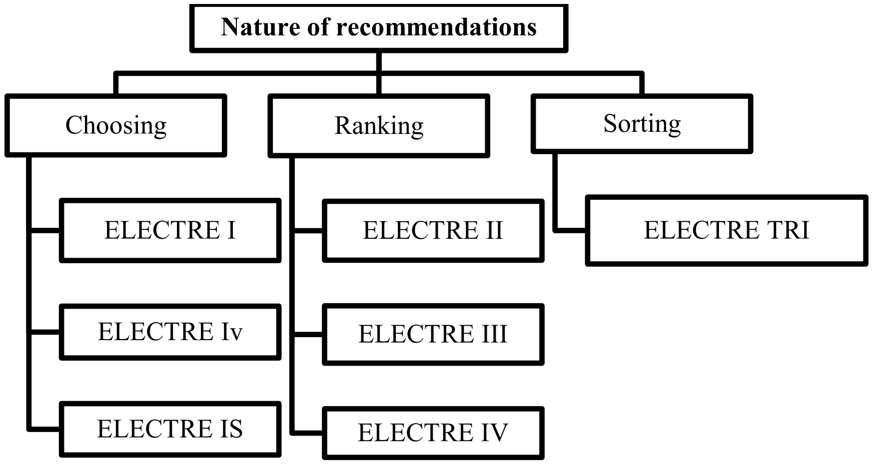

Figure 3. Nature of recommendations

ELEC App.1 Choice Problematic

The choice problem involves selecting restricted numbers or as small as possible potential actions from a list of actions and elimination of all others (Figure 4). Three primary ELECTRE methods are used in choice problematics: ELECTRE I, Iv and IS.

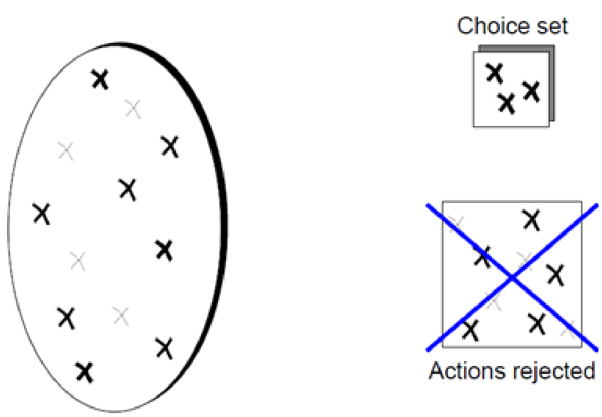

Figure 4. The concept of choice problematic

ELECTRE I (electre one)

ELECTRE I (electre one) was presented by Roy (July, 1965) at a conference (les journ´ees d’´etudes sur les m´ethodes de calcul dans les sciences de l’homme), in Rome

(Italy) and reported in Note de Travail 49 de la SEMA by Bebayoun et al. (1966) and in RIRO (la Revue d'Informatique et de Recherche Op´erationnelle) by Roy (1968).

The ELECTRE I method is used to select a set of alternatives using the concordance index C_{jk} and disconcordance index d_{jk} which are calculated as follows:

Concordance index:

$$C\ (aSb) = \sum_{g_j(a) \geq g_j(b)} w_j$$

Disconcordance index:

$$d\ (aSb) = max_{g_j(a) < g_j(b)}\{g_j(b) - g_j(a)\}$$

Concordance index indicates that a majority of criteria meet the assertion.

Disconcordance index indicates that a minority of criteria meet the assertion.

The problem of ELECTRE I is that it performs partial ranking and considers all actions as indifferent, therefore ELECTRE IS was suggested to overcome these limitations by Roy in 1984. ELECTRE I has been successfully applied in a vast range of fields (Buffet et al., 1967)

ELECTRE Iv (electre one vee)

ELECTRE Iv contains ELECTRE I with veto threshold. The veto threshold is related to the preference differences between $g_j\ (a)$ and $g_j\ (b)$ (Maystre et al., 1994). The purpose of using this method is to overcome the difficulties related to the heterogeneity of scales.

The differences between ELECTRE I to ELECTRE Iv is the discordance condition also called the no veto condition and may be stated as follows (Figueira et al., 2005):

$$g_j\ (a) + v_j\ (g_j(a)) \geq g_j\ (b)$$

ELECTRE IS (electre one esse)

ELECTRE IS was introduced by Roy (1984) for data which are imperfect. In fact, ELECTRE IS uses pseudo-criteria instead of true-criteria thus, concordance and no veto condition will change as follows:

Concordance condition:

$$C\ (aSb) = \sum w_j + \varphi_j\ w_j \geq s$$

Where,

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

No veto condition:

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

Where,

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

ELEC App.2 Ranking Problematic

In this problem type, a set of actions are used to rank the alternatives from the best to the worst (Figure 5). The ELECTRE methods used in ranking problematic are ELECTRE II, III and IV.

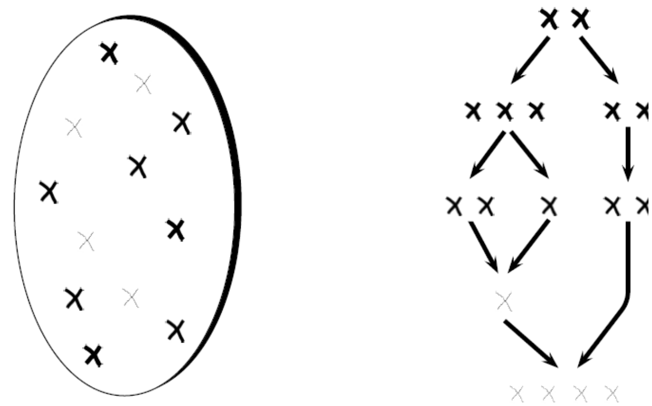

Figure 5. The concept of ranking problematic

ELECTRE II (electre two)

In 1971, Abgueguen established ELECTRE II with the purpose of ranking periodicals alternatives such as magazines and newspapers. The construction procedure of ELECTRE II is close to ELECTRE Iv which means that these are true-criteria based with the same no veto condition and different concordance condition. The exploiting procedure has four-step algorithm in ELECTRE II including: portioning the set A, building complete pre-orders based on ascending ordering, determining a complete pre-order based on descending ordering and defining the partial pre-order.

ELECTRE III (electre three)

ELECTRE III is applied for uncertain, imprecise and ill-determined data (Roy, 1978) and established to represent an outranking credibility between two alternatives. It is defined to improve ELECTRE II functions with respect to inaccurate, imprecise, uncertain or ill-determined data. ELECTRE III is based on pseudo-criteria instead of true-criteria which means the outranking relation can be interpreted as a fuzzy relation.

Concordance index is determined in same way as ELECTRE IS and the disconcordance index comes from the difference $g_j(b) - g_j(a)$ (Figueira et al., 2005).

$$d_j(a, b) = \begin{cases} 1 & if\ g_j(b) - g_j(a) \geq v_j \\ \frac{g_j(b) - g_j(a) - p_j}{v_j - p_j} & ,otherwise \\ 0 & if g_j(b) - g_j(a) \leq p_j \end{cases}$$

The exploitation procedure is used in the second stage by deriving from the fuzzy relation two complete pre-orders Z_1 and Z_2 in ELECTRE II. ELECTRE III was extended by Roy et al. (1993); Georgopoulou et al. (1997); Figueira et al. (2005).

C. ELECTRE IV (electre four)

Figueira et al. (2005) defined procedure of ELECTRE IV as: "based on the construction of a set of embedded outranking relations" and the exploiting procedure is the same as in ELECTRE III. ELECTRE IV has been applied to solve real-world problems related to the Paris subway network (Gargaillo et al., 1982; Hugonnard et al., 1982; Roy et al., 1982).

ELEC App.3 Sorting Problematic

In sorting problematic, a set of categories must be defined a priori (Roy et al. 1982) and the categories are ordered from the worst to the best (Figure 6). This includes the method ELECTRE TRI.

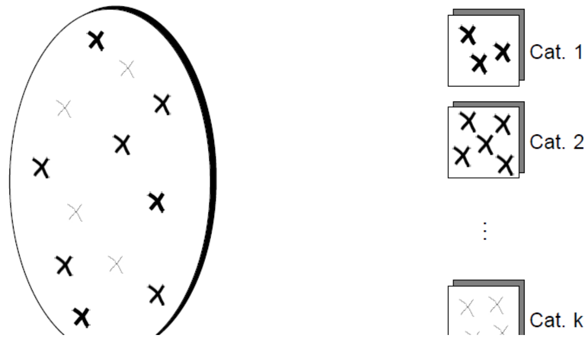

Figure 6. The concept of sorting problematic

ELECTRE TRI (electre tree)

ELECTRE TRI is a method of sorting problematic that Yu (1992a) built to prove the validation and invalidation of assertion *aSb* which means “a is at least as good as b_h”. ELECTRE TRI was used for pseudo-criteria by Roy et al. (1984) while preferences were restricted to the significance axis of each criterion. Mousseau et al. (1997) extended ELECTRE TRI by deriving weights for this method from some experimental results.

In ELECTRE TRI method, categories are ordered from the worst to the best based on two procedures namely pessimistic and optimistic rule.

ELEC App.4 Recent Developments and Application Areas

Recently, ELECTRE methods have gone further development in four categories: Methodological, New approaches, Axiomatic and meaningfulness analysis, other aspects (Figueria et al., 2010). Tables 2-3 demonstrate the summary of ELECTRE-Recent Developments and Application Areas by different authors from 2000 until 2010.

Table 2. ELECTRE-Recent Developments

Description	Author, year
Methodological Category	
1.Pure inference	
Inferring only the weights	Mousseau et al, 2001
Inferring veto	Mousseau and Dias, 2006
Inferring category bounds	Ngo The and Mousseau, 2002
Some manageable disaggregation procedures for valued outranking relations	Mouuseau and Dias, 2006
Inconsistent judgements or an inadequate preference model	Mousseau et al., 2006; Mousseau et al., 2006; Figueira, 2009
2. Inference-robustness	
The inference-robustness based approach for inferring weights and derive robust conclusions in sorting problems. Software: IRIS.	Dias et al., 2002
3.Pseudo-robustness	
The pseudo-robustness based approach dealing with simulation methods mainly for ranking and sorting problems. Software: SMAA-III, SMAA-TRI.	Tervonen et al., 2008, 2009
4.New robustness analysis concepts	
These papers are more general, but some techniques can be applied to ELECTRE methods.	Aissi and Roy, 2009; Roy, 2009
New approaches Category	
1.Bi-polar outranking	
Bi-polar outranking relations implemented in RUBIS software	Bisdorff et al., 2007, 2008
2.Weights of the interaction coefficients	
The weights of the interaction coefficients and the modifications in the concordance index	Figueira et al., 2009
3. Reinforced preference and the counter-veto effects	

Description	Author, year
Handling with the reinforced preference and the counter-veto effects	Roy and Słowi ´nski, 2009
4. ELECTRE TRI-C, TRIN, NC	Almeida-Dias et al., 2010a, 2010b
5. Possible and the necessary approach for ELECTRE	
The possible and the necessary approach for ELECTRE methods (ELECTRE-GKMS)	Greco et al., 2009, 2010
Axiomatic and meaningfulness analysis Category	
Axiomatic analysis of ELECTRE I method by using conjoint measurement theory	Greco et al., 2001
Representing preferences through conjoint measure and the decision rule approach	Greco et al., 2002
An axiomatic analysis based on a general conjoint measure framework with application to a variant of ELECTRE TRI	Bouyssou and Marchant, 2007a,b
An axiomatic analysis of the concordance-discordance relations	Bouyssou and Pirlot, 2009
Representing preferences by decision rules	Greco et al., 2002
The meaningfulness of ELECTRE methods	Martel and Roy, 2006
Other aspects	
The relative importance of criteria	Figueira and Roy, 2002
Concordant outranking with criteria of ordinal significance	Bisdorff, 2004
Evolutionary approaches	Leyva-López et al., 2008; Doumpos et al., 2009
The EPISSURE method for the assessment of non-financial performances	André and Roy, 2007; André, 2009
Group decision aiding	Damart et al., 2007; Greco et al., 2009, 2010

Table 3. Application Areas of ELECTRE

Application Areas of ELECTRE	
Description	**Author, year**
Sorting cropping systems	Arondel and Girardin, 2000
Land-use suitability assessment	Joerin et al., 2001
Greenhouse gases emission reduction	Georgopoulou, 2003
Risk zoning of an area subject to mining-inducing hazards	Merad et al., 2004
Participatory decision-making on the localization of waste-treatment plants	Norese, 2006
Material selection of bipolar plates for polymer electrolyte membrane fuel cell	Shanian and Savadogo, 2008
Assisted reproductive technology	Matias, 2008
Promotion of social and economic development	Autran-Gomes et al., 2009
Sustainable demolition waste management strategy	Roussat et al., 2009
Assessing the risk of nano-materials	Tervonen et al., 2009

2.3.2.4.2 Review on PROMETHEE Methodologies and Applications

I History of PROMETHEE

The PROMETHEE I and II were developed by Brans in 1982 and presented at a conference organized by Nadeau and Landry at the University Laval, Quebec, Canada (Brans, 1982). PROMETHEE I and PROMETHEE II are used for partial and complete ranking of alternatives, respectively. In 1992, Brans with Mareschal extended PROMETHEE family methods with PROMETHEE III, IV and V for interval, complete or partial ranking of the alternatives when the set of viable solutions is continuous and for problems with segmentation constraints (Brans and Mareschal, 1992). In 1995, Brans et al. presented the PROMETHEE VI for the human brain representation (Brans and

Mareschal, 1995) and Macharis et al. (1998) applied PROMETHEE GDSS for group decision making (Macharis et al., 1998). Figueira et al. (2004) proposed PROMETHEE TRI and PROMETHEE CLUSTER for sorting problems and nominal classification, respectively.

II Methodology of PROMETHEE

PROMETHEE II generates complete ranking for a finite set of alternatives. It is based on pair-wise comparisons of alternatives. The weight and preference function are two main parts of implementing PROMETHEE II. Macharis et al., (2004) applied PROMETHEE II to weight criteria when the number of criteria is not too large.

The step-wise procedure of PROMETHEE II starts by determining deviations based on pair-wise comparisons. The next step involves the calculation of preference function evaluation and relative weight. Then, we calculate global preference index which is used to calculate positive and negative outranking flows and in the final step, we calculate the net out ranking flow.

III PROMETHEE Applications

Behzadian et al. (2010) categorized PROMETHEE application areas into nine areas: Environment Management, Hydrology and Water Management, Business and Financial Management, Chemistry, Logistics and Transportation, Manufacturing and Assembly, Energy Management, Social, and Other Topics. Most of these areas have a direct effect on sustainability of manufacturers especially in case of ESG (Environment, Social and Governance) criteria. Table 4 presents the most recent papers that have applied PROMETHEE methodology (Behzadian M. et al., 2010).

Table 4. Applied PROMETHEE method papers

Specific area	Author(s)	Other tools/ methodologies used
	Environment Management	
Ranking and selecting environmental projects	Al-Rashdan et al. (1999)	The Nominal Group Technique
Ranking motor vehicles based on exhaust emissions	Beynon and Wells (2008)	Uncertainty analysis
Ranking various soil types /wastewater treatment systems	Carroll et al. (2004)	Principal Component Analysis (PCA)
Environmental assessment for sinter plants	Geldermann and Rentz (2001)	Trapezoidal fuzzy intervals
Decision-making in environmental projects	Kiker et al. (2005)	A review paper on MCDA methods including PROMETHEE
Decisions for sustainable development	Klauer et al. (2006)	Decisions under uncertainty
Ranking contaminated sediment management technologies	Linkov et al. (2006a)	A review on MCDA for sediment management
Environmental risk assessment and decision-making strategies/the New York/New Jersey arbor	Linkov et al. (2006b)	A review on MCDA applications for contaminated site management
Land-use suitability assessment	Marinoni (2006)	-
To analyze four different real applications to environment problems in Finland	Salminen et al. (1998)	-
Ranking waste management facilities	Vaillancourt and Waaub (2002)	Mixed integer linear programming
Ranking solid waste management alternatives	Vego et al. (2008)	-
	Hydrology and Water Management	
Ranking the quality of the water bodies	Ayoko et al. (2007)	PCA/PLS
Six water resource management decision problems	Hajkowicz and Higgins (2008)	-
Ranking river management alternatives	Hermans et al. (2007)	Conjoint analysis
To facilitate decision making at the watershed scale	Hermans and Erickson (2007)	A review of MCDA techniques
Sustainable water resource development problem	Hyde and Maier (2006)	Stochastic uncertainty analysis and distance-based uncertainty analysis
Ranking alternative strategies of water network to reduce leakage	Morais and De Almeida (2007)	-
To select the best alternative in irrigation development strategies	Raju and Pillai (1999)	Taguchi experimental method/Stochastic PROMETHEE
To select the suitable irrigation planning alternatives	Raju and Kumar (2006)	Data Envelopment Analysis (DEA)/Spearman rank

Specific area	Author(s)	Other tools/ methodologies used
		correlation/ EXPROM
Business and Financial Management		
Financial classification problems/business failure risk	Araz and Ozkarahan (2005)	PROMSORT
To measure the performance of the Web sites of Turkish hospitals	Bilsel et al. (2006)	Fuzzy PROMETHEE
Credit risk assessment based on 12 financial ratios	Doumpos and Zopounidis (2004)	A linear programming approach
To select investment projects	Halouani et al. (2009)	PROMETHEE- Multi Decision maker 2-Tuple-I and II
Ranking the financial performance of agri-food firms	Kalogeras et al. (2005)	PCA
The selection of firms applying for financial support from public funds	Mavrotas et al. (2006)	Multi-objective integer programming
Investment projects selection problem	Nowak (2005)	Stochastic dominance
Web service selection problem	Seo et al. (2005)	-
The problem of the optimal choice of investments	Vranegl et al. (1996)	Expert system/DSS/fuzzy sets
Selecting and ranking projects Superiority and inferiority ranking	Xu (2001)	-
Chemistry		
Ranking the sites and particle sizes from best to worst in terms of heavy metal pollution	Herngren et al. (2006)	Chemometrics methods: PCA
Ranking the cars based on the emission factors powered by liquefied petroleum gas and unleaded petrol	Lim et al. (2006)	Chemometrics methods: PCA
Ranking 10 different calibration models in food samples	Ni et al. (2004)	Chemometrics methods: PCA/ANN
Ranking spectral objects based on NIR (rapid near infrared) information	Purcell et al. (2007)	Chemometrics methods: PCA/PLS
Selecting the best alternative for improvement of process safety and reliability	Ramazan and Witt (2007)	Extended Hazop methodology
Logistics and Transportation		
Strategic sourcing in new product development/ranking suppliers	Araz and Ozkarahan (2007)	PROMSORT (PROMETHEE sorting)
To select the strategic partners/outsourcing manufacturers	Araz et al. (2007)	Fuzzy goal programming
Outsourcing in the field of public road and rail transportation/ranking suppliers	Dulmin and Mininno (2003)	-
To select the most suitable underground ore transport system	Elevli and Demirci (2004)	-
To rank and select distribution centers for a firm	Fernández-Castro and Jiménez (2005)	F-PROMETHEE/fuzzy integer linear programming
To analyze the traffic service of Pan-European corridor within market	Jugovic´ et al. (2006)	-

Specific area	Author(s)	Other tools/ methodologies used
conditions		
A location problem/ranking locations Graphic display method	Raveh (2000)	-
Ranking candidate information systems outsourcing	Wang and Yang (2007)	-
Manufacturing and Assembly		
Selecting lean manufacturing systems (LMS)	Anand and Kodali (2008)	-
To rank and select appropriate dispatching rules for a Dual-Resource Constrained (DRC) manufacturing system	Araz (2005)	-
The planning for preventive maintenance, by controlling failures in the specific context of equipment breakdown	Cavalcante et al. (2007)	Bayesian methodology to address uncertainties during equipment failures
Selecting the best equipment milling machines	Dagdeviren (2008)	-
To determine the best strategy for scheduling nonpreemptable jobs	Duvivier et al. (2007)	Classical hill-climber meta-heuristic
To choose the final optimal solution/an inverse electromagnetic scattering problem	Parreiras et al. (2006)	-
Ranking several scheduling strategies	Roux et al. (2008)	PlanOrdo framework/lexicographical sort
The tactical choice of a predictive maintenance program for an automotive paint shop	Waeyenbergh et al. (2004)	-
Decision analysis in energy and environmental modeling	Zhou et al. (2006)	A review paper on decision analysis methods including PROMETHEE
Energy Management		
To evaluate twelve nuclear dump sites	Chabchoub and Martel (2004)	-
To evaluate four scenarios for the development of the power generation sector	Diakoulaki and Karangelis (2007)	Cost-Benefit analysis
Ranking the various renewable energy technologies for the development of a wind park	Polatidis and Haralambopoulos (2007)	-
Social		
The fire protection management system	Buzolic´ et al. (2000)	GIS/0–1 programming
Rank neighborhoods under the housing choice	Johnson (2005)	Voucher Program Spatial decision support system
A car selection problem	Raveh (2000)	Graphic display technique
Other Topics		
Government Formulating national	Albadvi (2004)	Cluster analysis

Specific area	Author(s)	Other tools/ methodologies used
information technology strategies		
Design Ranking the individuals of the evolutionary algorithms at each generation/optimizing mechanical components during the first stage of the design process	Coelho and Bouillard (2005)	Evolutionary algorithms
Vendor selection	Wang et al. (2006)	-

2.4 Review on sustainable industry

Environmental, social and corporate governance (ESG) refer to the three main areas of concern in non-financial factors in measuring the sustainability. Those criteria are considered as ethical impact of an investment in a business. Climate change, hazardous waste, nuclear energy and sustainability are sample concerns in environmental. Social concerns are including human rights, consumer protection, diversity, etc. Governance concerns are such as management structure, employee relations, etc.

The 1992 Rio Summit defined sustainability as an integration of three “pillars” - environmental, social and economic - often referred to as triple bottom line (TBL).To achieve triple bottom line (also known as people, planet, profit) for sustainability, Millennium Development Goals (MDGs) were defined by the UN in 2000 in eight sectors: poverty eradication, primary education, gender equality, child mortality, maternal health, combating diseases, ensuring environmental sustainability, and global partnership for development (UN 2009). The MDG are generally focused on achieving national and international development. The recent Rio + 20 summit (2012) focussed on city sustainability.

Pope et al. (2004) worked on the assessment of sustainability based on Triple Bottom Line (TBL) concept and principles-based approaches. Szekely and Knirsch

(2005) studied the economic, environmental and social metrics involved in the achievement of sustainability goals and concluded that there is a large difference in measuring and reporting the sustainability performance. Krajnc and Glavic (2005) proposed sustainable index model for comparing the sustainability performance of companies. In 2007, Kasarda et al. designed a new methodology called DFAD (Design for adaptability) for sustainable design and modelled the product for a dynamic acceptable system and controllable system with feedback to allow it to adapt to different product performance criteria.

Kirton and Trebilcock (2004) explained the standards of Global Trade, Environmental, social and governance in their book and associated issues. Himick (2011) worked on the ESG challenges in investment field.

In 2006, United Nations in partnership with 'UNEP Finance Initiative' claimed that the 'Principles for Responsible Investment' (PRI) which is a voluntary framework, aims to incorporate issues of ESG in choosing portfolios for investment.

2.5 Review on the applications of MCDM in sustainable industry

Various multi-criteria methods such as Weighted Sum Model (WSM), Weighted Product Model (WPM), Analytical Hierarchy Process (AHP), PROMETHEE, ELECTRE, TOPSIS, CP and MAUT, and multi-objective optimization have been used for sustainability assessment. Pohekar and Ramachandran (2004) presented a well-documented synopsis of these methods. Furthermore, some other methods such as: Entropy Method (EM), CRITIC Method (CM) and Simple Additive Weightings (SAW) (Yilmaz and Harmancioglu, 2010) have also been reported.

Out of the seventy papers reviewed by Poheker and Ramachandran (2004), the highest number of papers (22) used straightforward multi-objective methods, and WSM was the most commonly used method.

Tsai and Chou (2009) proposed a management system that combines the method of Decision Making Trial and Evaluation Laboratory (DEMATEL), Analytic Network Process (ANP), Zero–One Goal Programming (ZOGP) for sustainable development in Small and Medium Enterprises (SME). Zhou et al. (2009) used another method that integrates the Artificial Neural Network (ANN) with Genetic Algorithm (GA) to optimise the objectives of material selection based on the environmental, cost, product and process factors.

2.6 Review on ELECTRE method in sustainable industry

Shanian (2008) used a new application of ELECTRE III and revised Simos' procedure for group material selection under weighting uncertainty. Group decision making happens due to separations in design preferences while there are uncertainties in each designer's mind with regards to expressing his/her preferences over design criteria (Shaniana et al., 2008). In 2011, Kaya et al. applied an integrated fuzzy AHP–ELECTRE methodology for environmental impact assessment of six different industrial districts to predict the shape of future industrial structure of Istanbul metropolitan area. Finally, a fuzzy dominance relation (FDR) methodology is used to rank the alternatives from the most risky to the least.

Infantea (2013) proposed ELECTRE III for triple bottom line analysis in oil and gas industry. It was concluded that sustainable strategies allied to the Triple Bottom Line are a corporate and operational differential.

Merad (2013) used outranking approach (ELECTRE) and a mono-criterion synthesis approach (MAUT approaches based on the Choquet integral) to implement sustainable development principles within an organization.

2.7 Review on PROMETHEE method in sustainable industry

The PROMETHEE family of outranking methods, including the PROMETHEE I for partial ranking of alternatives and the PROMETHEE II for complete ranking of alternatives, were developed by Brans (1982). After developing PROMETHEE, different versions of PROMETHEE were used to support complicated decision-making problems (Brans and Mareschal, 2005) such as; the PROMETHEE III for ranking based on interval, the PROMETHEE IV for complete or partial ranking of the alternatives when the set of viable solutions is continuous, the PROMETHEE V for problems with segmentation constraints (Brans and Mareschal, 1992), the PROMETHEE VI for the human brain representation (Brans and Mareschal, 1995), the PROMETHEE GDSS for group decision- making (Macharis et al., 1998), and the visual interactive module GAIA (Geometrical Analysis for Interactive Aid) for graphical representation (Mareschal & Brans, 1988; Brans and Mareschal, 1994). Furthermore, Figueira et al. (2004) extended two approaches on PROMETHEE, called as the PROMETHEE TRI for dealing with sorting problems and the PROMETHEE CLUSTER for nominal classification. It is clear that the PROMETHEE methods are more useful due to mathematical properties and particular friendliness of use (Brans and Mareschal, 2005).

Gurumurthy and Kodali (2008) used PROMETHEE for the selection of manufacturing concepts among Computer Integrated Manufacturing Systems (CIMS), Traditional Manufacturing System (TMS) and Lean Manufacturing System (LMS) and selected LMS as the best concept to implement in the case organisation. Kolli and Presasi (1992) ranked the alternatives based on multiple criteria for the implementation of advanced manufacturing technology by using PROMETHEE II. Vinodh and Girubha (2012) applied PROMETHEE II for sustainable concept selection. They considered three sustainability orientations including production methodology, material and product design and concluded that change of material attains a high preference rather than the design modification and alternate manufacturing process.

CHAPTER 3

ELECTRE AND PROMETHEE METHODOLOGIES

3.1 Introduction

There are two key elements in decision aiding situations: The Analyst and the Decision Maker (DM). Decision maker should consider three fundamental pillars for any decision aiding activity: the actions; the consequences; the modeling of a preference system: indifference, preference, or incomparable. Some scholars mentioned the fourth performance situation which is the hesitation, weak performance:

$I \rightarrow$ Indifference;

$P \rightarrow$ Strict Preference;

$Q \rightarrow$ Hesitation, Weak Preference;

$R \rightarrow$ Incomparability.

In addition, a pseudo-criterion is a function g_j associated with two threshold functions ($q_j\ (\cdot)$ and $p_j\ (\cdot)$) and also there are two fundamental concepts called veto thresholds and pseudo-criteria.

We will now present the detailed description of ELECTRE III and PROMETHEE II methodologies considering their definitions.

3.2 ELECTRE III (electre tree)

ELECTRE III relies upon the construction and exploitation of outranking relations. It involves two main different phases (Figure 7):

(1) **Construction of the outranking relation**: Alternatives are in pair-wise comparison *(a, b)*. Each pair-wise comparison shows the type of outranking relation. "Alternative '*a*' outranks alternative '*b*' means that "*a* is at least as good as *b*". Therefore, three outranking relations exists: '*a*' is "indifferent", "weakly preferred" or "strictly preferred" to '*b*' depending on the difference between the performance of the alternatives and the thresholds given by the user. (See section 3.2.1)

(2) **Exploitation of the outranking relation**: Two pre-orders are then constructed with two opponent procedures (ascending and descending distillation). A final partial pre-order *Z* is then built as the intersection of the two complete pre-orders, Z_1 and Z_2. (See Section 3.2.2)

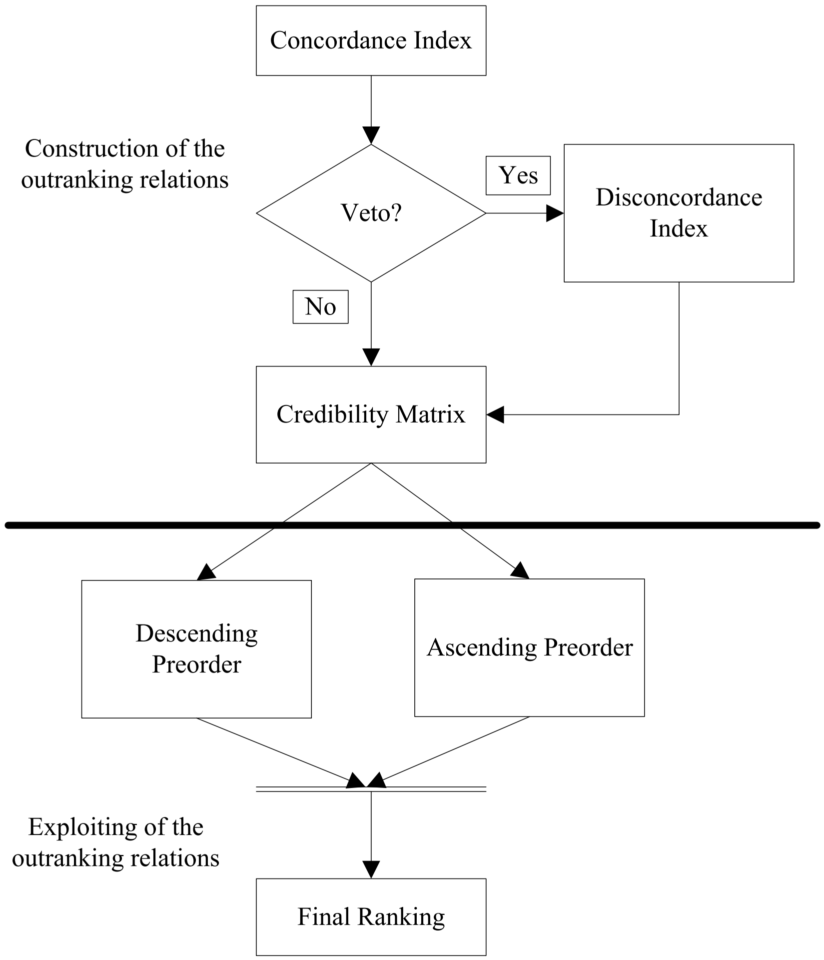

Figure 7. The two distinct phases of ELECTRE III

3.2.1 Building the Outranking Relations

ELECTRE III establishes an outranking credibility between two alternatives and is able to deal with inaccurate, imprecise, uncertain or ill-determined data. The construction of this relation requires the definition of a credibility index which is defined using both the concordance index (as determined in ELECTRE IS), *C (aSb)*, and a discordance index for each criterion g_j in *F* (coherent family of criteria, with $n > 3$), that is, $d_j(aSb)$.

A. Pseudo-Criteria

The innovation of ELECTRE III method lies in using pseudo-criteria instead of true-criteria which means the outranking relation can be interpreted as a fuzzy relation (Figueira et al., 2005). In this method, there are uncertain, indeterminate and imprecise data, which are described as follows:

- Imprecise criteria: arbitrary selection different criteria definitions;
- Indeterminate criteria: difficult to determine them;
- Uncertain criteria: criteria values vary over time (Giannoulis et al., 2010).

ELECTRE III has been applied in various ranking problems, such as problem in ranking the stocks in investment selection (Huck et al., 2009), for choosing a sustainable demolition waste management strategy (Roussat et al., 2009), for the selection of energy systems (Papadopoulos et al., 2008), for ranking urban storm water drainage (Martin et al., 2007) or for housing evaluation (Natividade-Jesus et al., 2007), however has not yet been used for ranking companies based on sustainability criteria (ESG).

In order to consider imprecision, uncertainty and indetermination in complex decision making, pseudo-criteria are used. The indifference 'q_j (.)' and preference 'p_j (.)' thresholds allow the construction of a pseudo-criterion (Giannoulis et al., 2010). Thus, three relations between alternatives '*a*' and '*b*' can should be considered:

$$aPb \text{ if } g_j(a) > g_j(b) + p_j \tag{1}$$

$$aQb \text{ if } g_j(b) + p_j \geq g_j(a) > g_j(b) + q_j \tag{2}$$

$$aIb \text{ if } g_j(b) + q_j \geq g_j(a) \quad \text{and} \quad g_j(a) + q_j \geq g_j(b) \tag{3}$$

B. Concordance Index

The concordance index is calculated by Eq. (4) which proves the assertion "*a* outranks *b*" *(aSb)* (Roy 1978). *C=1* shows the validity of the assertion and *C=0* shows that the assertion is false. g_j

$$C\ (a,\ b) = \frac{\sum w_j\, c_j\,(a,b)}{W} \tag{4}$$

Where $W=\sum w_j\ c_j\ (a,\ b)$

$$c_j\ (a,\ b)= \begin{cases} 1 & if\ g_j(a) +\ q_j > g_j(b) \\ \frac{p_j\ +\ g_j(a) -\ g_j(b)}{p_j - q_j} & ,otherwise \\ 0 & if\ g_j(a) +\ p_j\ \leq g_j(b) \end{cases} \tag{5}$$

Here,

w_j: weight of the criterion *j*;

n: number of criteria;

$g_j\ (a)$: performance of the alternative *'a'* as regards to the criterion *j*;

$q_j\ (.)$: indifference threshold for the criterion *j*;

$p_j\ (.)$: preference threshold of the alternative on the criterion *j*.

C. Discordance Index

To calculate discordance, veto threshold is defined. The veto threshold, $v_j\ (.)$, allows for the possibility of *aSb* to be refused totally if, for any one criterion *j*, $g_j(b)>g_j(a)+v_j$. The discordance index for each criterion *j*, $d_j\ (a,\ b)$ is computed using Eq. (6):

$$d_j(a,b) = \begin{cases} 1 & if\ g_j(b) - g_j(a) \geq v_j \\ \frac{g_j(b) - g_j(a) - p_j}{v_j - p_j} & , otherwise \\ 0 & if\ g_j(b) - g_j(a) \leq p_j \end{cases} \quad (6)$$

Here,

v_j: veto threshold for the criterion *j*.

D. Degree of Credibility

The final step in the building phase is to combine these two measures to produce a measure of the degree of outranking; that is a credibility matrix which assesses the strength of the assertion that *"a is at least as good as b"*. Eq. (7) is used to define the credibility degree for each pair *(a, b)* in *'a'*:

$$S(a,b) = \begin{cases} C(a,b) & if\ \ d_j(a,b) \leq C(a,b) \\ C(a,b).\prod \frac{1-\ d_j\ (a,b)}{1-C(a.b)} & where\ \ d_j(a,b) >\ C(a,b) \end{cases} \quad (7)$$

This formula assumes that if the strength of the concordance exceeds that of the discordance, then the concordance value does not need to be modified. Otherwise, we have to modify *C (a, b)* with respect to assertion *aSb* according to the above equation. If the discordance is 1 for any $(a, b) \epsilon A$ and any criterion *j*, then we have no confidence that *aSb*; therefore, *S (a, b) =0*.

3.2.2 Distillation Procedures

An automated procedure, named distillation, must be used to rank the alternatives. The name distillation comes from the analogy with alchemists, who distill mixtures of liquid to extract a magic ingredient (Giannoulis et al., 2010). The algorithm for ranking all alternatives is done using two pre-orders. These are:

(1) Descending distillation (pre-order Z_1);

(2) Ascending distillation (pre-order Z_2);

(3) Combined two pre-orders ($Z = Z_1 \cap Z_2$).

The first pre-order is obtained with a descending distillation, selecting the best-rated alternatives initially and finishing with the worst. Firstly, the maximum value of the credibility index should be determined using $\lambda_{max} = max\ S\ (a, b)$. Secondly, calculate $\lambda = \lambda_{max} - (0.3 - 0.15\ \lambda_{max})$ where -0.15 and 0.3 are the preset up values of distillation coefficients, α and β. Thirdly, for each alternative determines its *λ-strength*, i.e. the number of alternatives b with $S\ (a, b) > \lambda$. Fourthly, for each alternative determines its λ-weakness, i.e. the number of alternatives with $(1-(0.3-0.15\lambda))*S\ (a, b)>S\ (b, a)$.

Then, define the matrix T using:

$$T\ (a, b) = \begin{cases} 1, & if\ S(a,b) > \lambda - s(\lambda) \\ 0, & otherwise \end{cases} \tag{8}$$

Further, define the qualification of each alternative - $Q\ (a)$ - as the number of alternatives that are outranked by 'Alternative 1' minus the number of alternatives which outrank 'Alternative 1'. $Q\ (a)$ is calculated by subtracting the row sum to the column sum of the matrix T. The largest qualification is the first distillate of $D1$ and so on. If $D1$ has more than one alternative, repeat the process on the set $D1$ until all alternatives have been classified. If there is a single alternative, than this is the most preferred one. This process should continue with subtracting the original set of alternatives to the set *D1*, and it should repeat until all alternatives are classified (Brans et al., 1986).

The second pre-order is ascending distillation which is done in the same way as the descending distillation but the set of alternatives having the lowest qualification forms the first distillate.

E. Final Ranking

To obtain the final ranking, the two pre-orders are combined together and in case of comparison between the two alternatives having the same score, the decision is made between an indifferent or incomparable relation (Giannoulis et al., 2010).

3.3 PROMETHEE I, II

This section focuses on PROMETHEE as a rapid, flexible and progressive method for pair-wise comparison in MCDM. PROMETHEE method is similar to the ELECTRE method, but the concept is different. This method considers the outranking flows for evaluating alternatives. The concept is built on pair-wise comparison between alternatives, and calculates two outranking flows for each alternative, namely positive and negative outranking flows.

The positive outranking flow gives a measure of how the alternative outranks all the others, while the negative outranking flow gives a measure of how the alternative is outranked by all the others (Figueira et al., 2005). This concept has been shown in Figure 8. The higher $\varphi^+(a)$ is the better alternative where $\varphi^+(a)$ represents the power of *'a'*. On the other hand, the smaller $\varphi^-(a)$ is the better alternative when $\varphi^-(a)$ represents the weakness of *'a'*.

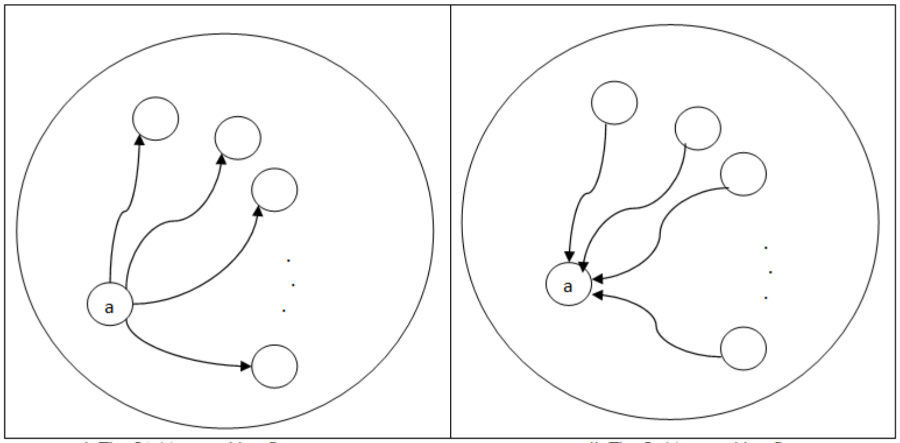

Figure 8. The PROMETHEE outranking flows

PROMETHEE allows the user to directly exploit the data (alternatives a_j, criteria g_j) of the problem in a simple evaluative multi-criteria table (Performance Matrix), where $a_1, a_2, \ldots, a_i$ are "*i* potential alternatives" and $g_1, g_2, \ldots, g_j$ are "*j* evaluation criteria". Each evaluation $g_j(a_i)$ must be a real number.

A multi-criteria preference index $\pi(a, b)$ of a_i over g_j can then be defined considering all the criteria:

$$\pi(a, b) = \sum P_j(a, b)w_j, \qquad \text{with } w_j \text{ in } [0,1] \tag{9}$$

Then the positive and negative outranking flows are calculated by Equations (10) and (11) (Kolli et al., 1992).

$$\varphi^+(a) = \frac{\sum \pi(a,b)}{(n-1)} \tag{10}$$

$$\varphi^-(a) = \frac{\sum \pi(b,a)}{(n-1)} \tag{11}$$

And the net outranking flow is calculated by using equation (12) (Gurumurthy et al., 2008).

$$\varphi = \varphi^{+}(a) - \varphi^{-}(a) \tag{12}$$

3.3.1 Computational Steps

The computational steps are described as follows subsection:

A. Deviation Calculation

The deviation between each pairs is calculated by Eq. (13) (Gurumurthy et al., 2008).

$$D_j(a, b) = g_j(a) - g_j(b) \tag{13}$$

For minimize criterion: if $d_j < 0$, the respective value will be taken as d_j, else $d_j = 0$.

For maximize criterion: if $d_j > 0$, the respective value will be taken as d_j, else $d_j = 0$.

B. Preference Function Evaluation and Relative Weight Calculation

Eq. (14) helps to evaluate the preference function.

$$P_j(a, b) = F_j[d_j(a, b)] \tag{14}$$

Where $P_j(a, b)$ indicates the preference of alternative '*a*' with regard to alternative '*b*' on each criterion, as a function of $D_j(a, b)$. The preference is calculated using the respective preference function formula for the elements (Howarth et al., 2006).

To have a common scale of values, the non-commensurable criteria should be converted into dimensionless criteria (Vinodh and Girubha, 2012).

In order to normalise the weights of the criterion, the relative weight has to be obtained using Eq. (15) and the sum of the relative weights of the criteria will be equal to one.

$$W_j = \frac{w_j}{\sum w_j} \tag{15}$$

Where w_j is the weight of the j^{th} criterion; $\sum w_j$ is the sum of weights of all the criteria.

C. Global Preference Index Calculation

The preference index is defined by Eq. (9) where π *(a, b)* of *'a'* over '*b'* (from zero to one) is defined as the weighted sum of P_j *(a, b)* for each criterion, and w_j, the weight associated with j^{th} criterion (Brans et al., 1985).

D. Computation of Positive and Negative Outranking Flows

By calculating π *(a, b)* value for all pair-wise comparisons, the partial outranking flows are calculated using Eqs. (10) and (11). Where, $\varphi^+ (a)$ and $\varphi^- (a)$ denote the positive and the negative outranking flow for each alternative, respectively (Kolli and Persasi, 1992).

E. Computation of Net Out Flow

The net flow is calculated for every pair-wise comparison using Eq. (12).

3.4 Differences between ELECTRE III and PROMETHEE I, II

ELECTRE III and PROMETHEE I, II have some differences in the procedure, in particular, in the following three phases:

(1) Constructing the criterion model;

(2) Building the valued relations between the alternatives;

(3) The ranking procedure.

A substantial difference comes from the information on the measured criteria values which are translated differently in each method in order to describe valued relations between the alternatives (Lertprapai, 2013).

3.4.1 The Criterion Models

It is assumed that $v_j\ (.) > p_j\ (.) > q_j(.) \geq 0$. The credibility degree $c_j\ (a, b) \in [0, 1]$ describes the strength of the positive arguments of criterion '*j*' supporting the assertion that *'a is at least as good as b' (aSb)* in ELECTRE III (Figueira et al., 2005). Thus, the credibility degree is defined as follows:

$$c_j\ (a, b) = 0 \quad \text{when} \quad g_j\ (b) - g_j\ (a) \geq p_j, \tag{16}$$

$$c_j\ (a, b) = 1 \quad \text{when} \quad g_j\ (b) - g_j\ (a) \leq q_j, \tag{17}$$

$$0 \leq c_j\ (a, b) \leq 1 \quad \text{when} \quad q_j < g_j\ (b) - g_j\ (a) < p_j, \tag{18}$$

The p_j and q_j values column indicate the strong and indifference parameters, respectively and these may be constant or proportional. A linear dependency is defined as follows:

$$c_j\ (a, b) = \frac{(\ p_j - (g_j(b) - g_j(a))\ )}{(p_j - q_j)} \tag{19}$$

Furthermore, a discordance index for each criterion can be defined in the same way as c_j *(a,b)*'s. The veto thresholds are defined to limit the compensation between the criteria.

In PROMETHEE the deviation value is calculated by $D_j\ (a, b) = g_j\ (a) - g_j\ (b)$ while the preference function $P_j\ (a, b) \in [0, 1]$ is describing the positive arguments of criterion '*j*' that the credibility degree meets the assumption that *'a is better than b'* similar to ELECTRE III:

$$P_j\ (a, b) = 0, \quad \text{when} \quad D_j\ (a, b) < q_j, \tag{20}$$

$$P_j\ (a, b) = 1, \quad \text{when} \quad D_j\ (a, b) > p_j, \tag{21}$$

$$0 < P_j\ (a, b) < 1, \quad \text{when} \quad q_j < D_j\ (a, b) < p_j, \tag{22}$$

Where q_j and p_j are constant. Therefore, a linear dependency can be defined in same as ELECTRE III:

$$P_j\ (a, b) = \frac{(g_j(a) - g_j(b) - q_j\ )}{(p_j - q_j)} \tag{23}$$

3.4.2 Comparing the Valued Outranking Relations

We assume that the DMs assign a set of weights, $W = (w_1, w_2, ..., w_n)$, to the criteria. The concordance index *C (a,b)* of ELECTRE III describes the preference between alternatives '*a*' and '*b*':

$$C\ (a, b) = \frac{\sum w_j\ .c_j(a,b)}{\sum w_j} \tag{24}$$

In PROMETHEE an outranking degree for all criteria is calculated as:

$$\pi\ (a,\ b) = \frac{\sum w_j\ .P_j(a,b)}{\sum w_j} \tag{25}$$

As we can see, the concordance index of ELECTRE III and the outranking degrees of PROMETHEE do not differ much from each other. The only difference so far comes from the definitions of $c_j\ (a,b)$ and $P_j(a,b)$. From the point of view of the DMs, the weights have similar meaning in each of these methods.

In PROMETHEE, positive and negative flows are defined as:

$$\varphi^+\ (a) = \frac{\sum \pi\ (a,b)}{(n-1)} \tag{26}$$

$$\varphi^-\ (a) = \frac{\sum \pi\ (b,a)}{(n-1)} \tag{27}$$

The net flows for each alternative are the differences between the positive and negative flows:

$$\varphi = \varphi^+\ (a) - \varphi^-\ (a) \tag{28}$$

From Eqs. (10)- (13),

$$\varphi\ (a) = \frac{\sum\sum(w_j\left(P_j(a,b)-P_j(b,a)\right))}{(\sum w_j\ (n-1))} \tag{29}$$

We assume that threshold values are $q_j= 0$ and $p_j> max\ (|g_j\ (a)-g_j\ (b)|)$ and using the 5th form for $P_j\ (a,\ b)$, the PROMETHEE credibility degrees become:

$$P_j\ (a,\ b) = max\ \{\frac{D_j(a,b)}{P_j}, 0\} \tag{30}$$

Substituting (30) into (29);

$$\varphi\ (a) = \frac{\sum\sum(w_j\left(max\left\{\frac{D_j(a,b)}{P_j},0\right\}-max\{\frac{D_j(b,a)}{P_j},0\}\right)}{(\sum w_j\ (n-1))}$$

$$\varphi\ (a) = \frac{\sum\sum(w_j\frac{D_j(a,b)}{P_j})}{(\sum w_j\ (n-1))}$$

$$\varphi\ (a) = \frac{\sum\sum(w_j\frac{gj(a)}{P_j})}{(\sum w_j)} + K$$

Where *K* is an alternative-independent constant (Salminen, 1998).

There is no flow concept in ELECTRE III, but a similar net flow concept for each alternative which could be computed from the concordance indices (Giannoulis and Ishizaka, 2010) as follows:

$$C\ (a) = \frac{\sum(C(a,b)-C(b,a))}{(n-1)} \tag{31}$$

From (24) and (16)-(19);

$$C\ (a) = \frac{\sum\sum(w_j(c_j(a,b)-c_j(b,a)))}{(\sum w_j\ (n-1))} \tag{32}$$

By comparing (29) and (32), we see that the terms *(P_j (a, b)-P_j (b, a))* are identical to *(c_j (a, b) - c_j (b, a))* for each *'a', 'b'* and *'j'*.

3.4.3 The Ranking Procedure

It is obvious that the ranking procedures of the two methods are different. PROMETHEE I, II are additive and ELECTRE III ranks the qualification of alternatives according to distillation. The basic principles of ELECTRE III are as follows (Maystre et al., 1994);

(1) Construction of a complete pre-order Z_1;

(2) Construction of a complete pre-order Z_2;

(3) Construction of the partial pre-order $Z = Z_1 \cap Z_2$.

The construction of Z_1 and Z_2 are performed through a descending and ascending distillation, respectively. In this procedure $s(\lambda)$ threshold and value $\lambda = max\ S(a,b)$ is to be determined. The value close to λ is considered in the T-matrix of the outranking degrees.

PROMETHEE I leads to partial ranking of the alternatives based on the intersection of two positive and negative outranking flows. On the other hand, PROMETHEE II ranks the alternatives based on their net flow and makes a complete order.

3.5 Conclusion

Based on our theoretical review, the choice between ELECTRE III and PROMETHEE I, II should be based on the following conditions.

ELECTRE III can be used when:

- Differences in criteria values are not well considered. It does not matter how much a criterion value is better than another criterion (Salminen et al., 1998);
- Uncertainty is dealt with thresholds (these may be constant or proportional);

- It is possible to define the veto thresholds in disconcordance for some criterion in order to decrease *c(a,b)* values;
- Distillation is used for outranking degrees *S(a,b)*, or ‘min’ procedure;
- *S(λ)* in distillation may influence the ranking;
- Behaviour close to linear value functions is observed without discordance;
- Any terrible criterion with the veto threshold needs to be revealed;
- Alternatives are indifferent and incomparable;
- A very large number of alternatives need to be compared (the limitation is given by the physical storage of data and not from ELECTRE III).

PROMETHEE can be used when (Salminen et al., 1998):

- Differences in criteria values are not taken into account totally; it does not matter, how much the preference threshold is exceeded;
- Uncertainty is dealt with thresholds (these are constant);
- The credibility degree $P_j(a,b)$ is based on additive model;
- Behaviour close to linear value functions is to be observed;
- Partial orders (I) or complete orders (II) are required.

The limitation of both methods is rank reversal. In ELECTRE III, rank reversal occurs with distillation, generally partial order.

CHAPTER 4

COMPARATIVE EVALUATION OF PROMETHEE AND ELECTRE METHODOLOGIES

4.1 Introduction

In this chapter, we perform comparative evaluation of ELECTRE III and PROMETHEE I, II methodologies. This chapter is divided in two parts:

- The first part is dedicated to numerical case study on sustainability assessment of industrial organizations (Aerospace & Defense, Auto Components and Oil & Gas Refining, Marketing, Storage & Transportation). The data for case study is obtained from Sustainalytics, a Global Platform company.
- In the second part, we perform model verification, robustness, sensitivity and validation analysis.

4.2 Case Study (Part 1)

Our case problem involves sustainability assessment of 10 firms from three significant industry sectors (Aerospace & Defense, Auto Components and Oil & Gas Refining, Marketing, Storage & Transportation). The input data for the case problem has obtained from Sustainalytics, a global platform company and is shown in Tables 5-7. Table 5 shows the 11 criteria and presents their brief description. Table 6 shows the criteria weights and their normalized values. The sum of weights of all criteria should be equal to 1. Table 7 presents the classification of criterion which has to be maximised, type of preference function, weight value and threshold values for each criterion.

Table 5. Criterion with description

No.	Evaluation criteria	Explanation about the criteria
1	Business Ethics (BE)	Ability to commit in non-economic values such as ethics codes
2	Corporate Governance (CG)	Ability to control internal and external corporate structures and mitigating risks
3	Public Policy (PP)	Ability to meet the domestic policy and global governance
4	Employees (EM)	The degree of employees' positive or negative reflex in terms of their job
5	Contractors & Supply Chain-So (CSS)	Capability to improve the overall performance of the global Contractor supply chain
6	Customers (CU)	Measurable degree of customers satisfaction
7	Society & Community (SC)	The size of sharing common values in the national and international community
8	Philanthropy (PY)	Act of making direct contributions to a charity or cause, in the form of grants or donations
9	Operations (OP)	Capability to continuous operation and meet the present and future needs
10	Contractors & Supply Chain-En (CSE)	Creating safe supply chain via the trade contractors
11	Products & Services (PS)	Act of providing a product-service system which is product-use-result oriented

Table 6. Normalized Weights

		Evaluation criteria	Aerospace &		Auto Components			Oil & Gas Refining, Marketing,					Weight
			Co.1	Co.2	Co.3	Co.4	Co.5	Co.6	Co.7	Co.8	Co.9	Co.10	wj
Governance	26%	BE	0.13	0.13	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.106
		CG	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.118
		PP	0.06	0.06	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.036
Social	39%	EM	0.19	0.19	0.22	0.2	0.22	0.2	0.22	0.2	0.2	0.22	0.206
		CSS	0.05	0.05	0.08	0.07	0.08	0.07	0.07	0.07	0.07	0.07	0.068
		CU	0.06	0.06	0.06	0.06	0.06	0.03	0.03	0.03	0.03	0.03	0.045
		SC	0.02	0.02	0.04	0.04	0.04	0.07	0.08	0.07	0.07	0.08	0.053
		PY	0.03	0.03	0	0.03	0	0.03	0	0.03	0.03	0	0.018
Environment	35%	OP	0.22	0.22	0.22	0.22	0.22	0.26	0.26	0.26	0.26	0.26	0.24
		CSE	0.07	0.07	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.054
		PS	0.06	0.06	0.08	0.08	0.08	0.04	0.04	0.04	0.04	0.04	0.056
	100%												**1**

Table 7. Criterion Characteristics

										Aerospace & Defense		Auto Components			Oil & Gas Refining				
Criteria	Direction	Type	Name of the preference function	Types of preference function	Units	wj	qj	pj	vj	Co.1	Co.2	Co.3	Co.4	Co.5	Co.6	Co.7	Co.8	Co.9	Co.10
BE	max	Qnt.	Linear	V	Percent	0.106	12.3	30.91	61.82	69.23	50	80	73	45	95.5	55	78	73	55
CG	max	Qnt.	Linear	V	Percent	0.118	6.7	17.09	34.18	79.54	62.72	59.89	64.58	59.89	83.75	77.08	69.58	75.41	77.08
PP	max	Qnt.	V-shape	III	Percent	0.036	0	37.97	75.94	56.25	75	100	75	100	56.25	100	81.25	56.25	100
EM	max	Qnt.	Linear	V	Percent	0.206	12.3	27.36	54.72	87.63	48.94	40.9	58	45.45	68.25	47.27	47.5	57.75	58.63
CSS	max	Qnt.	Linear	V	Percent	0.068	21.7	46.44	92.88	100	40	37.5	75	37.5	46.42	42.85	46.42	89.28	42.85
CU	max	Qnt.	V-shape	III	Percent	0.045	0	43.74	87.48	37.5	62.5	75	75	100	100	100	100	100	100
SC	max	Qlt.	Level	IV		0.053	1.91	3.34	6.68	9	9	9	9	9	5	9	9	5	9
PY	max	Qlt.	Level	IV		0.018	1.35	3.13	6.26	5	3	1	3	1	5	1	3	3	1
OP	max	Qnt.	Linear	V	Percent	0.24	12.8	28.18	56.36	86.36	50.9	41.45	61.63	62.5	36.05	51.34	48.84	48.07	45.48
CSE	max	Qlt.	Level	IV		0.054	1.71	2.91	5.82	7	3	7	9	7	7	7	7	7	7
PS	max	Qlt.	Level	IV		0.056	1.07	1.87	3.74	7	5	3	5	5	5	5	5	5	5

The p_j *(.)*, q_j *(.)* and v_j *(.)* value columns indicates the strong, indifference parameters and veto threshold, respectively.

Strong preference parameter: It is the lowest value below which there is strict preference.

Indifference parameter: It is the lowest value below which there is indifference between the alternatives.

The concept of veto threshold, v_j *(.)*, gives the possibility to the criterion g_j to impose its veto power. It means that g_j *(b)* is so much better than g_j *(a),* that it is not possible to allow aSb (Figueira et al., 2005). The value of the veto preference threshold is double the value of the preference threshold, which is double the value of the indifference threshold (Giannoulis et al., 2010). We assume veto thresholds for each criterion: q_j *(.)*< p_j *(.)*< v_j (.).

The preference function transforms the difference between the scores, achieved by the alternatives of a special criterion, into a preference degree ranging from 0 to 1

(Macharis et al. 2004). Preference function classification is presented as follows (Brans et al., 1982) (Figure 9):

Type I (usual criterion): It is the basic type without any threshold and no parameter has to be determined. It is useful for qualitative criteria with small number of levels (e.g. yes/no criteria or up to 5-point scale).

Type II (U-shape - quasi criterion): It is best suited for qualitative criteria and uses a single indifference threshold.

Type III (V-shape criterion): It is appropriate for quantitative criteria (e.g. prices, costs, power, etc.). The choice will depend on whether an indifference threshold is introduced or not.

Type IV (level criterion): It is always used for qualitative criteria and uses an additional indifference.

Type V (V-shape criterion): Criterion with indifference and linear preference is considered. It is a special case of the linear.

Type VI (Gaussian criterion): This preference function is less often used due to difficulty in parameters (the 's' threshold value is somewhere between the q_j indifference threshold and the p_j preference threshold) and it follows normal distribution.

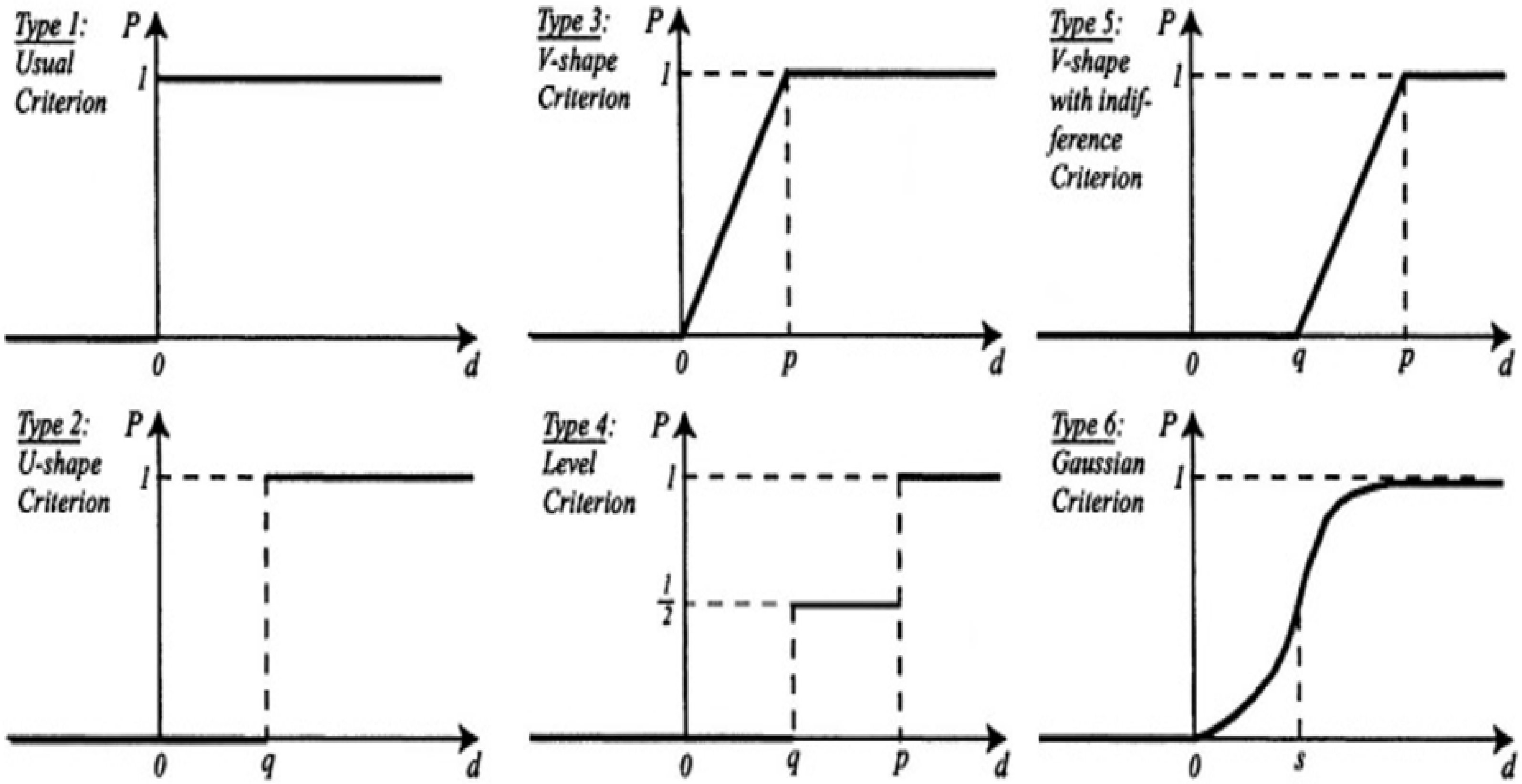

Figure 9. Types of preference function

4.2.1 Application of ELECTRE III

4.2.1.1 Building the Outranking Relations

A. Pseudo-Criteria

In our case study, we are involved in multiple criteria (ESG) which can be uncertain, indeterminate and imprecise. These are explained as follows:

- Imprecise criteria: when there is arbitrary selection of criteria between different possible definitions. For example, determining a reasonable ratio between part-time and full-time employees;
- Indeterminate criteria: difficult to determine. For example, Business Ethics (BE) is the ability to commit in non-economic values such as ethics codes in a company but no judgments can be made without a common reference to other companies (Bowden et al., 2000);
- Uncertain criteria: measures values that can vary over time (Giannoulis et al., 2010). For example "Employability" of a company depends on the economic situation.

B. Concordance Index

The concordance index is calculated using Eq. (4-5). Table 8 provides the results for concordance index. Table 106.A. presents the details of concordance index calculation used in pair-wise comparison. (Appendix A)

Table 8. Concordance Index

C (a, b)	Co.1	Co.2	Co.3	Co.4	Co.5	Co.6	Co.7	Co.8	Co.9	Co.10
Co.1	1	0.94	0.93	0.93	0.92	0.88	0.92	0.93	0.96	0.92
Co.2	0.22	1	0.84	0.70	0.88	0.58	0.80	0.81	0.71	0.80
Co.3	0.29	0.94	1	0.70	0.79	0.56	0.80	0.88	0.68	0.73
Co.4	0.44	1.00	0.98	1	0.95	0.79	0.88	0.97	0.93	0.88
Co.5	0.36	0.99	0.89	0.84	1	0.61	0.88	0.85	0.74	0.87
Co.6	0.49	0.90	0.91	0.70	0.70	1	0.87	0.92	0.94	0.91
Co.7	0.40	0.99	0.93	0.92	1.00	0.76	1	0.93	0.89	1.00
Co.8	0.39	1.00	0.98	0.97	0.97	0.76	0.97	1	0.94	0.97
Co.9	0.45	0.93	0.91	0.90	0.89	0.92	0.91	0.92	1	0.91
Co.10	0.40	0.99	0.94	0.87	0.93	0.88	1.00	0.93	0.89	1

C. Discordance Index

Disconcordance index is calculated using Eq. (6). A discordance matrix is produced for each criterion. Unlike concordance, no aggregation over criteria takes place; one disconcordance criterion is sufficient to discard outranking. Thus in our case study, we considered contractors & supply chain (CSS) because it has highest veto threshold (92.88). The disconcordance index results are shown in Table 9. (See Appendix A, Table 107.A for details of calculation)

Table 9. Disconcordance Index

dcss (a, b)	Co.1	Co.2	Co.3	Co.4	Co.5	Co.6	Co.7	Co.8	Co.9	Co.10
Co.1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Co.2	0.29	0	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00
Co.3	0.35	0.00	0	0.00	0.00	0.00	0.00	0.00	0.11	0.00
Co.4	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00
Co.5	0.35	0.00	0.00	0.00	0	0.00	0.00	0.00	0.11	0.00
Co.6	0.15	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00
Co.7	0.23	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00
Co.8	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00
Co.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00
Co.10	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0

D. Degree of Credibility

Using Eq. (7) we built the credibility matrix which is shown in Table 10. This is the last step of first stage of ELECTRE III (building the outranking relations)

Table 10. The credibility matrix

S (a, b)	Co.1	Co.2	Co.3	Co.4	Co.5	Co.6	Co.7	Co.8	Co.9	Co.10
Co.1	1	0.94	0.93	0.93	0.92	0.88	0.92	0.93	0.96	0.92
Co.2	0.19	1	0.84	0.70	0.88	0.58	0.80	0.81	0.71	0.80
Co.3	0.27	0.94	1	0.70	0.79	0.56	0.80	0.88	0.68	0.73
Co.4	0.44	1.00	0.98	1	0.95	0.79	0.88	0.97	0.93	0.88
Co.5	0.36	0.99	0.89	0.84	1	0.61	0.88	0.85	0.74	0.87
Co.6	0.49	0.90	0.91	0.70	0.70	1	0.87	0.92	0.94	0.91
Co.7	0.40	0.99	0.93	0.92	1.00	0.76	1	0.93	0.89	1.00
Co.8	0.39	1.00	0.98	0.97	0.97	0.76	0.97	1	0.94	0.97
Co.9	0.45	0.93	0.91	0.90	0.89	0.92	0.91	0.92	1	0.91
Co.10	0.40	0.99	0.94	0.87	0.93	0.88	1.00	0.93	0.89	1

4.2.1.2 Distillation Procedures

T-Matrix is built by following Tables 11-12 for descending and ascending distillation procedures. The qualification of each company - *Q (a)* - is calculated by subtracting the row sum to the column sum of the matrix T.

Table 11. The descending T-Matrix

T-descending	Co.1	Co.2	Co.3	Co.4	Co.5	Co.6	Co.7	Co.8	Co.9	Co.10	Strength
Co.1	0	1	1	1	1	1	1	1	1	1	9
Co.2	0	0	0	0	1	0	0	0	0	0	1
Co.3	0	1	0	0	0	0	0	1	0	0	2
Co.4	0	1	1	0	1	0	1	1	1	1	7
Co.5	0	1	1	0	0	0	1	1	0	1	5
Co.6	0	1	1	0	0	0	1	1	1	1	6
Co.7	0	1	1	1	1	0	0	1	1	1	7
Co.8	0	1	1	1	1	0	1	0	1	1	7
Co.9	0	1	1	1	1	1	1	1	0	1	8
Co.10	0	1	1	1	1	1	1	1	1	0	8
Weakness	0	9	8	5	7	3	7	8	6	7	
Qualification	9	-8	-6	2	-2	3	0	-1	2	1	

Table 12. The ascending T-Matrix

T-Ascending	Co.1	Co.2	Co.3	Co.4	Co.5	Co.6	Co.7	Co.8	Co.9	Co.10	Strength
Co.1	0	0	0	0	0	0	0	0	0	0	0
Co.2	1	0	1	1	0	1	1	1	1	1	8
Co.3	1	0	0	1	1	1	1	0	1	1	7
Co.4	1	0	0	0	0	1	0	0	0	0	2
Co.5	1	0	0	1	0	1	0	0	1	0	4
Co.6	1	0	0	1	1	0	0	0	0	0	3
Co.7	1	0	0	0	0	1	0	0	0	0	2
Co.8	1	0	0	0	0	1	0	0	0	0	2
Co.9	1	0	0	0	0	0	0	0	0	0	1
Co.10	1	0	0	0	0	0	0	0	0	0	1
Weakness	9	0	1	4	2	6	2	1	3	2	
Qualification	-9	8	6	-2	2	-3	0	1	-2	-1	

Tables 13-14 show the descending and ascending distillation pre-orders of companies.

Table 13. The descending distillation pre-orders

Descending pre-order	
1	Co.1
2	Co.6
3	Co.4
3	Co.9
4	Co.10
5	Co.7
6	Co.8
7	Co.5
8	Co.3
9	Co.2

Table 14. The ascending distillation pre-orders

Ascending pre-order	
1	Co.1
2	Co.6
3	Co.4
3	Co.9
4	Co.10
5	Co.7
6	Co.8
7	Co.5
8	Co.3
9	Co.2

E. Final Ranking

The final ranking is obtained by combination of the two pre-orders from Tables 13-14, where we can see there is strict preference for ranking between the various companies. Table 15 shows the final ranking of ELECTRE III. It can be seen that Co.1 is ranked the highest and Co. 2 has the lowest rank. Co. 4 and Co. 9 have the same ranking scores which means they can serve as resource recovery for each other.

Table 15. The final ranking

ELECTRE III	
1	Co.1
2	Co.6
3	Co.4
3	Co.9
4	Co.10
5	Co.7
6	Co.8
7	Co.5
8	Co.3
9	Co.2

4.2.2 Application of PROMETHEE

In this study, PROMETHEE I and II are used to perform sustainability assessment of firms in three significant industry sectors (Aerospace & Defense, Auto Components and Oil & Gas Refining, Marketing, Storage & Transportation). PROMETHEE II is preferred over PROMETHEE I because it performs complete ranking.

4.2.2.1 Computational Steps

A. Deviation Calculation

The deviation between each pair of companies i.e. (Co.1, Co.2), ..., (Co.10, Co.10) is calculated using Eq. (13) considering the minimize and maximize criterion rules. For example the deviation between company 1 and company 2 is presented in Table 16. (See Table 108.B: all deviation calculation)

Table 16. Deviation calculation

Criteria	Direction	|dj (L1, L2)|	Co.1	Co.2	|dj (L2, L1)|
Business Ethics	max	19.23	69.23	50	0
Corporate Governance	max	16.82	79.54	62.72	0
Public Policy	max	0	56.25	75	18.75
Employees	max	38.69	87.63	48.94	0
Contractors & Supply Chain	max	60	100	40	0
Customers	max	0	37.5	62.5	25
Society & Community	max	0	9	9	0
Philanthropy	max	2	5	3	0
Operations Score	max	35.46	86.36	50.9	0
Contractors & Supply Chain	max	4	7	3	0
Products & Services	max	2	7	5	0

B. Preference Function Evaluation and Relative Weight Calculation

The calculated preference function value and weight of each criterion between Co.1 and Co.2 is shown in Table 17. (See Table 109.B: all computation of preference function)

Table 17. Computation of preference function and preference index

Criteria	π (L1, L2)	Pj (L1, L2)	wj	Pj (L2, L1)	π (L2, L1)
Business Ethics	0.04	0.37	0.11	0.00	0.00
Corporate Governance	0.11	0.97	0.12	0.00	0.00
Public Policy	0.00	0.00	0.04	0.49	0.02
Employees	0.21	1.00	0.21	0.00	0.00
Contractors & Supply Chain	0.07	1.00	0.07	0.00	0.00
Customers	0.00	0.00	0.05	0.57	0.03
Society & Community	0.00	0.00	0.05	0.00	0.00
Philanthropy	0.01	0.50	0.02	0.00	0.00
Operations Score	0.24	1.00	0.24	0.00	0.00
Contractors & Supply Chain	0.05	1.00	0.05	0.00	0.00
Products & Services	0.06	1.00	0.06	0.00	0.00

C. Global Preference Index Calculation

The preference index is obtained using Eq. (9) and the value of the calculated preference index is shown in Table 17. (See Table 110.B: all computation of preference index)

D. Computation of Positive and Negative Outranking Flows

Tables 18-19 are built using Eqs. (10) and (11) which show the positive and negative outranking flows. The final rankings of companies from PROMETHEE I is shown in Table 20 and Figure 10.

Table 18. Calculation of positive and negative outranking flow

	Co.1	Co.2	Co.3	Co.4	Co.5	Co.6	Co.7	Co.8	Co.9	Co.10	φ + (a)
Co.1	0	0.79	0.71	0.56	0.71	0.51	0.60	0.62	0.56	0.60	0.63
Co.2	0.04	0	0.09	0.00	0.04	0.10	0.04	0.00	0.07	0.04	0.05
Co.3	0.07	0.19	0	0.02	0.11	0.09	0.07	0.02	0.09	0.07	0.08
Co.4	0.08	0.16	0.32	0	0.17	0.32	0.10	0.05	0.11	0.15	0.16
Co.5	0.08	0.12	0.21	0.05	0	0.30	0.00	0.03	0.11	0.07	0.11
Co.6	0.12	0.42	0.44	0.21	0.39	0	0.24	0.24	0.09	0.18	0.26
Co.7	0.08	0.20	0.20	0.12	0.12	0.13	0	0.03	0.09	0.00	0.11
Co.8	0.07	0.19	0.12	0.03	0.16	0.08	0.07	0	0.08	0.07	0.10
Co.9	0.05	0.29	0.32	0.07	0.27	0.06	0.11	0.06	0	0.11	0.15
Co.10	0.08	0.20	0.27	0.12	0.13	0.09	0.00	0.03	0.09	0	0.11
φ - (a)	0.08	0.29	0.30	0.13	0.23	0.19	0.14	0.12	0.14	0.14	

Table 19. The higher 'positive outranking flow' and the lower 'negative outranking flow'

PROMETHEE I: φ +		PROMETHEE I: φ -	
1	Co.1	1	Co.1
2	Co.6	2	Co.8
3	Co.4	3	Co.4
4	Co.9	4	Co.7
5	Co.10	5	Co.10
6	Co.5	6	Co.9
7	Co.7	7	Co.6
8	Co.8	8	Co.5
9	Co.3	9	Co.2
10	Co.2	10	Co.3

Table 20. Final PROMETHEE I ranking

Rank	PROMETHEE I
1	Co.1
2	Co.6, Co, 8
3	Co.4
4	Co.9, Co. 7
5	Co.10
6	Co.5
7	Co.2
8	Co.3

E. Computation of Net Outranking Flow

Table 21 shows the calculations for net outranking flow. Table 22 and Figure 11 show the ranking results from PROMETHEE II.

Table 21. Net outranking calculation

	Positive Outranking	Negative Outranking	Net outranking flow	PROMETHEE II
	φ + (a)	φ - (a)	φ (a)	
Co.1	0.63	0.08	0.55	1
Co.2	0.05	0.29	-0.24	10
Co.3	0.08	0.30	-0.22	9
Co.4	0.16	0.13	0.03	3
Co.5	0.11	0.23	-0.12	8
Co.6	0.26	0.19	0.07	2
Co.7	0.11	0.14	-0.03	6
Co.8	0.10	0.12	-0.02	5
Co.9	0.15	0.14	0.00	4
Co.10	0.11	0.14	-0.03	7

Table 22. PROMETHEE II ranking

Rank	PROMETHEE II
1	Co.1
2	Co.6
3	Co.4
4	Co.9
5	Co.8
6	Co.7
7	Co.10
8	Co.5
9	Co.3
10	Co.2

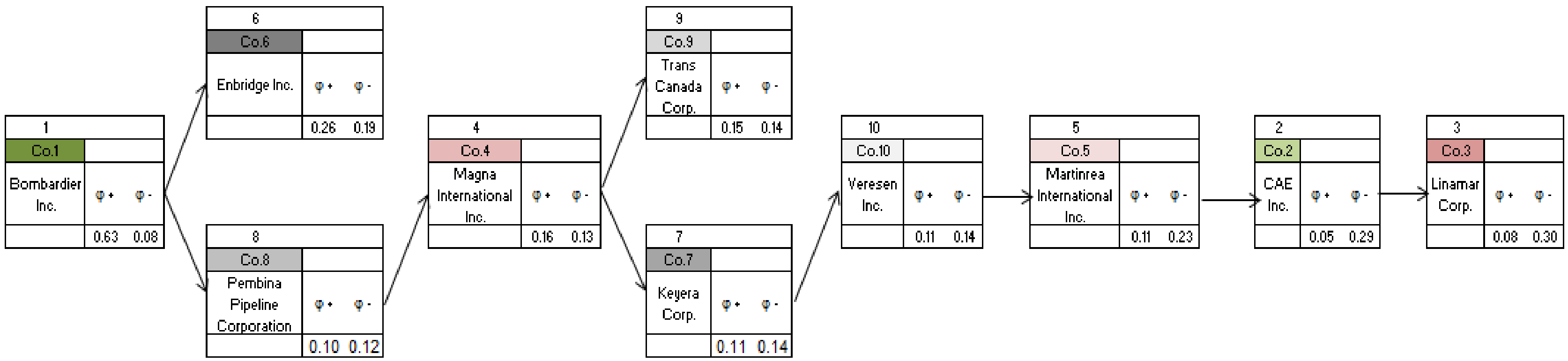

Figure 10. PROMETHEE I ranking

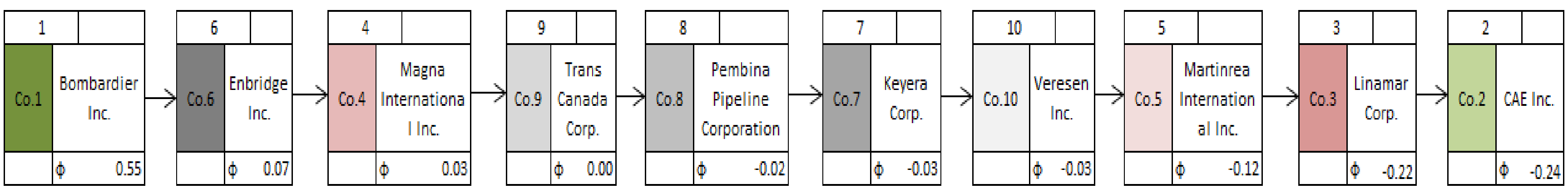

Figure 11. PROMETHEE II ranking

4.2.3 Comparing the results for ELECTRE III and PROMETHEE I, II

Table 23 presents the ranking results for the 10 companies obtained using ELECTRE III and PROMETHEE I, II methods.

It can be seen in Table 23 that Co.1, 6 and 4 are the first three highest ranked companies for sustainability performance based on PROMETHEE I, II and ELECTRE III. For the remaining companies, the rankings do not match, exactly.

Table 23. The ranking of alternatives sustainability in Canada

Ranking	PROMETHEE I	PROMETHEE II	ELECTRE III
1	Co.1	Co.1	Co.1
2	Co.6, Co, 8	Co.6	Co.6
3	Co.4	Co.4	Co.4, Co.9
4	Co.9, Co. 7	Co.9	Co.10
5	Co.10	Co.8	Co.7
6	Co.5	Co.7	Co.8
7	Co.2	Co.10	Co.5
8	Co.3	Co.5	Co.3
9		Co.3	Co.2
10		Co.2	

4.2.3.1 Reasons for Different Rankings

4.2.3.1.1 The Criterion Models

By comparing the results of Eq. (19) and Eq. (23) for linear dependency of ELECTRE III *(c_j (a, b))* and linear dependency of PROMETHEE I and II *(P_j (a, b))*, we can see that the concordance index of ELECTRE III is greater than the preference function of PROMETHEE I, II which means that ELECTRE III is more appropriate than PROMETHEE methods because it differentiates more between each pair-wise comparison and therefore companies have better outranking results. Tables 24-25 present a sample of this comparison for companies Co.1 and Co.2 based on BE criteria, $c_j\,(a, b) = 1 > P_j\,(a, b) = 0.37$. (See Table 98.A. and Table 101.B: all comparisons)

Table 24. The concordance index

	Co.1--Co.2	Co.1--Co.3	Co.1--Co.4	Co.1--Co.5	Co.1--Co.6	Co.1--Co.7	Co.1--Co.8	Co.1--Co.9	Co.1--Co.10
	Cj (a, b)	Cj (a, b)	Cj (a, b)	Cj (a, b)	Cj (a, b)	Cj (a, b)	Cj (a, b)	Cj (a, b)	Cj (a, b)
BE	1	1	1	1	0.249328318	1	1	1	1
CG	1	1	1	1	1	1	1	1	1
PP	0.506189097	0	0.506189097	0	1	0	0.341585462	1	0
EM	1	1	1	1	1	1	1	1	1
CSS	1	1	1	1	1	1	1	1	1
CU	0	0.14266118	0.14266118	0	0	0	0	0	0
SC	1	1	1	1	1	1	1	1	1
PY	1	1	1	1	1	1	1	1	1
OP	1	1	1	1	1	1	1	1	1
CSE	1	1	0.758333333	1	1	1	1	1	1
PS	1	1	1	1	1	1	1	1	1

Table 25. The Preference Function

	Co.1--Co.2	Co.1--Co.3	Co.1--Co.4	Co.1--Co.5	Co.1--Co.6	Co.1--Co.7	Co.1--Co.8	Co.1--Co.9	Co.1--Co.10
	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)
BE	0.372380441	0	0	0.641053197	0	0.103707684	0	0	0.103707684
CG	0.974013474	1	0.794995188	1	0	0	0.313763234	0	0
PP	0	0	0	0	0	0	0	0	0
EM	1	1	1	1	0.469414894	1	1	1	1
CSS	1	1	0.134087237	1	1	1	1	0	1
CU	0	0	0	0	0	0	0	0	0
SC	0	0	0	0	1	0	0	1	0
PY	0.5	1	0.5	1	0	1	0.5	0.5	1
OP	1	1	0.77553676	0.718932986	1	1	1	1	1
CSE	1	0	0	0	0	0	0	0	0
PS	1	1	1	1	1	1	1	1	1

4.2.3.1.2 Comparing the Valued Outranking Relations

From Eqs. (29) and (32), we can conclude that the terms $(P_j\ (a,b)\text{-}P_j\ (b,a))$ are identical to *(cj (a, b) – cj (b, a))* for each *'a', 'b'* and *'j'*. We examine the different cases and observe that identical values are obtained:

When $D_j\ (a, b) \geq p_j$:

$$c_j\ (a, b) - c_j\ (b, a) = 1 - 0 = 1,$$

$$P_j\ (a, b) - P_j\ (b, a) = 1 - 0 = 1.$$

When $q_j < D_j\ (a, b) < p_j$:

$$c_j\ (a, b) - c_j(b, a)$$

$$= 1 - \frac{(pj - (gj(a) - gj(b)))}{(pj - qi)} = P_j\ (a, b) - P_j\ (b, a)$$

$$= \frac{((gj(a) - gj(b)) - qj)}{(pj - qj)} - 0.$$

When $-q_j < D_j\ (a, b) < q_j$:

$$c_j\ (a, b) - c_j(b, a) = 1 - 1 = 0,$$

$$P_j\ (a, b) - P_j\ (b, a) = 0 - 0 = 0.$$

When $-p_j < D_j\ (a, b) < -\ q_j$:

$$c_j\ (a, b) - c_j\ (b, a)$$

$$= \frac{(Pj - (gj(b) - gj(a)))}{(pj - qj)} - 1 = P_j\ (a, b) - P_j\ (b, a)$$

$$= 0 - \frac{((gj(b) - gj(a)) - qj)}{(pj - qj)}.$$

When $D_j (a, b) < -p_j$:

$$c_j (a, b) - c_j (b, a) = 0 - 1 = - 1,$$

$$P_j (a, b) - P_j (b, a) = 0 - 1 = - 1$$

Therefore, we can observe from above that the net flows are identical between ELECTRE III and PROMETHEE which leads to the same ranking of alternatives. Besides, the additive procedure in PROMETHEE makes use of $C (a, b)$ and $\pi (a, b)$ matrices in generating alternative rankings.

4.2.3.1.3 The Ranking Procedure

ELECTRE III and PROMETHEE I, II have different ranking procedures. In PROMETHEE I, II, the ranks are additive whereas ELECTRE III ranks are based on ascending and descending ordering, which means ELECTRE III gives DMs more accurate results than PROMETHEE due to clearer resource recovery. Table 23 illustrates these types of differences among the alternatives. For example there is identical outranking to select the company 1 as the most sustainable company while there are two types of differences among others companies:

(1) Some companies have little difference between the criteria values such as Co. 4 and Co. 9 in ELECTRE III which means as a general view, Co. 4 is preferred over Co. 9 (combined).

(2) Some companies have big difference between the criteria values of alternatives such as Co. 6 and Co. 8 in PROMETHEE I. In spite of identicality between Co. 6 and Co. 8 in PROMETHEE I, Co. 4 is

recommended because of resource recovery based on results of three outranking methods.

4.2.4 Conclusion- Part 1

Based on the comparative evaluation of ranking results of ELECTRE III and PROMETHEE II for the numerical case study, we find that ELECTRE III generates more obvious results in spite of being complicated. ELECTRE III ranks companies with greater concordance index than preference function which means that decision maker can make a better decision between two companies. In other words, ELECTRE III gives the decision maker a chance to find better resource recovery and resource to improve sustainability.

4.3 Model Verification, Robustness, Sensitivity and Validation Analysis (Part 2)

In this part, we will apply several analyses to compare further the abilities of ELECTRE and PROMETHEE. Following analyses are conducted:

4.3.1 Model Verification and Robustness;

4.3.2 Model Sensitivity Analysis:

- **4.3.2.1** Sensitivity to Change in number of Alternatives;
- **4.3.2.2** Sensitivity to Change in number of Decision Makers;
- **4.3.2.3** Sensitivity to Change in number of Criteria;
- **4.3.2.4** Sensitivity to Change in type of Criteria.

4.3.3 Model Validation.

4.3.1 Model Verification and Robustness Analysis

The model verification is concerned with building the **model rightly**. For this purpose, we conduct different experiments and compare results of ELECTRE III and PROMETHEE II to ensure that the model is implemented correctly and the alternatives and logical structure of the model correctly represent different data and data variations. Furthermore, we will conduct robustness analysis of our model to identify potential robust characteristics and evaluate the vulnerabilities of our model to extreme values and trade-off.

Therefore, for these analyses we generated the weights and normalized them (Table 26) for common data set (5 criteria and 6 alternatives). The details of the various experiments are presented as follows:

- Two alternatives with **same criteria** values (Table 27);
- One alternative with **max values** for all criteria (Table 28);
- One alternative with **min values** for all criteria (Table 29);
- One alternative with **criteria values as zero** (Table 30);
- Alternatives with **random values** for all criteria (Table 31);
- Three alternatives with **zero values** for two different criteria (Table 32).

Table 26. Normalized weights of two alternatives with same criteria values

	Weights	**Normalized weights**
C1	0.33	0.16
C2	0.12	0.06
C3	0.60	0.30
C4	0.26	0.13
C5	0.72	0.36

Weights	Normalized weights
2.02	**1**

Table 27. Two alternatives with same criteria values

	SAME					
	A1	A2	A3	A4	A5	A6
C1	1	1	0	0	8	8
C2	10	10	6	10	7	0
C3	1	1	5	0	9	10
C4	1	1	8	9	9	2
C5	8	8	1	8	2	6

Table 28. One alternative with max values for all criteria

	MAX					
	A1	**A2**	**A3**	**A4**	**A5**	**A6**
C1	10	6	9	7	10	6
C2	10	7	0	2	10	5
C3	10	2	0	8	6	8
C4	10	6	9	2	5	1
C5	10	7	2	4	0	6

Table 29. One alternative with min values for all criteria

	MIN					
	A1	**A2**	**A3**	**A4**	**A5**	**A6**
C1	1	1	6	0	5	1
C2	1	5	1	7	4	0
C3	1	1	9	1	3	4
C4	1	0	2	4	0	6
C5	1	10	9	3	0	10

Table 30. One alternative with criteria values zero

	ZERO					
	A1	**A2**	**A3**	**A4**	**A5**	**A6**
C1	0	2	8	8	8	0
C2	0	7	10	6	4	5
C3	0	5	5	3	8	8
C4	0	0	0	4	9	8
C5	0	6	3	0	10	10

Table 31. Alternatives with random values for all criteria

RANDOM						
	A1	**A2**	**A3**	**A4**	**A5**	**A6**
C1	8	1	4	4	5	2
C2	4	3	10	10	0	9
C3	1	5	8	1	0	4
C4	2	0	9	1	3	3
C5	7	7	0	4	9	2

Table 32. Three alternatives with given zero values for two different criteria

TWO ZERO						
	A1	**A2**	**A3**	**A4**	**A5**	**A6**
C1	0	7	2	0	2	0
C2	0	10	2	5	1	4
C3	1	10	2	0	5	10
C4	0	1	7	0	3	0
C5	7	3	8	4	8	0

Tables 33-35 present the results for the above experiments after applying ELECTRE III and PROMETHEE II. The interpretations of these results are presented as follows.

4.3.1.1 Two alternatives with same criteria values (Case I)

In this case, we consider two alternatives with same criteria values and therefore their rankings should be the same to ensure correctness of our model. For two alternatives with same criteria values, we are considering different preference functions in terms of types of criteria (Qualitative and Quantitative). Table 33 presents the results of PROMETHEE II and ELECTRE III. It can be seen that the ranking is same for alternatives A1 and A2.

To verify the correctness of PROMETHEE II, we compared the model results (observed) with the expected results (Table 34). It can be seen in Table 34, for alternatives A1 and A2, the expected results are same as observed results. Table 35 presents the verification results for ELECTRE III. It can be seen that the observed and expected results are same for alternatives A1 and A2.

Table 33. Results of two alternatives with same criteria values

	PROMETHEE II	ELECTRE III
A1	2	4
A2	2	4
A3	5	6
A4	4	1
A5	6	3
A6	1	2

Table 34. PROMETHEE II results (Case I)

PROMETHEE II	Observed	Expected
A1	2	4
A2	2	4
A3	5	5
A4	4	4
A5	6	6
A6	1	1

Table 35. ELECTRE III results (Case I)

ELECTRE III	Observed	Expected
A1	4	4
A2	4	4
A3	6	6
A4	1	1
A5	3	2
A6	2	3

4.3.1.2 One alternative with max values for all criteria (Case II)

In this case, we test our model by considering one alternative (A1) with the max value. The expected result from PROMETHEE II and ELECTRE III should therefore give us the highest rank for this alternative.

Tables 36-38 demonstrate that both PROMETHEE II and ELECTRE III rank alternative A1 as first and the observed and expected ranking results are same for both of them, thereby verification of model results for this case.

Table 36. Results of alternative A1 with max values for all criteria

	PROMETHEE II	ELECTRE III
A1	1	1
A2	4	6
A3	5	5
A4	6	4
A5	3	2
A6	2	2

Table 37. PROMETHEE II results (Case II)

PROMETHEE II	Observed	Expected
A1	1	1
A2	4	5
A3	5	4
A4	6	6
A5	3	3
A6	2	2

Table 38. ELECTRE III results (Case II)

ELECTRE III	Observed	Expected
A1	1	1
A2	6	5
A3	5	6
A4	4	3
A5	2	2
A6	2	3

4.3.1.3 One alternative with min values for all criteria (Case III)

In this case, we allocate minimum values for all criteria to alternative A1. The expected results from ELECTRE III and PROMETHEE II are that alternative A1 should be given the lowest ranking. Tables 39- 41 present the results for ELECTRE III and

PROMETHEE II. It can be seen that in all the three tables, alternative A1 received rank 6 (lowest), and therefore our model results for ELECTRE III and PROMETHEE II are verified for case III.

Table 39. Results of one alternative with min values for all criteria

	PROMETHEE II	ELECTRE III
A1	6	6
A2	2	2
A3	1	1
A4	5	5
A5	4	4
A6	3	3

Table 40. PROMETHEE II results (Case III)

PROMETHEE II	Observed	Expected
A1	6	6
A2	2	2
A3	1	1
A4	5	4
A5	4	5
A6	3	3

Table 41. ELECTRE III results (Case III)

ELECTRE III	Observed	Expected
A1	6	6
A2	2	2
A3	1	1
A4	5	5
A5	4	4
A6	3	3

4.3.1.4 One alternative with criteria value zero (case IV)

In this case, we allocate zero value for all criteria to alternative A1. The expected results from ELECTRE III and PROMETHEE II are that alternative A1 should be given the lowest ranking, having received minimum (equal to zero) value on all criteria. Tables

42- 44 present the results for ELECTRE III and PROMETHEE II. It can be seen that in all the three tables, alternative A1 received rank 6 (lowest), and therefore our model results for ELECTRE III and PROMETHEE II are verified for case IV.

Table 42. Results of one alternative with criteria value zero

	PROMETHEE II	ELECTRE III
A1	6	6
A2	1	4
A3	3	1
A4	2	1
A5	5	4
A6	4	3

Table 43. PROMETHEE II results (Case IV)

PROMETHEE II	Observed	Expected
A1	6	6
A2	1	2
A3	3	3
A4	2	1
A5	5	4
A6	4	5

Table 44. ELECTRE III results (Case IV)

ELECTRE III	Observed	Expected
A1	6	6
A2	4	4
A3	1	1
A4	1	1
A5	4	3
A6	3	4

4.3.1.5 Alternatives with random values for all criteria (case V)

In this case, we allocate random values for all the criteria to the alternatives and compare the similarity of ranking results between ELECTRE III and PROMETHEE II. Tables 45-47 present the results for ELECTRE III and PROMETHEE II. It can be seen in

Table 45, that alternatives A4 and A5 receive the same ranking by the two methods. For PROMETHEE II (Table 46), the expected and the observed results are same for all alternatives except A2 and A6 whereas for ELECTRE III (Table 47), the results differ only for alternative A3. Therefore, we can say that for this case, ELECTRE III seems to perform better over PROMETHEE II having less number of mismatches between observed and expected rankings.

Table 45. Results of alternatives with random values for all criteria

	PROMETHEE II	**ELECTRE III**
A1	6	5
A2	2	1
A3	1	4
A4	3	3
A5	5	5
A6	4	2

Table 46. PROMETHEE II results (case V)

PROMETHEE II	**Observed**	**Expected**
A1	6	6
A2	2	4
A3	1	1
A4	3	3
A5	5	5
A6	4	2

Table 47. ELECTRE III results (case V)

ELECTRE III	**Observed**	**Expected**
A1	5	5
A2	1	1
A3	4	3
A4	3	3
A5	5	5
A6	2	2

4.3.1.6 Three alternatives with zero values for two different criteria (case VI)

In this case, we are considering an exceptional situation where three alternatives (A1, A4 and A6) are given zero values for two different criteria for testing the robustness of our model. The expected results are that these three alternatives should not receive the top ranks, i.e. 1, 2 and 3. Tables 48-50 presents the results for this case. It can be seen from these tables, that alternatives A1, A4 and A6 receive ranks between 4-6 by both ELECTRE III and PROMETHEE II although the results of the two are not exactly the same. This is in agreement with the expected results and therefore, our model results for this case are verified.

Table 48. Results of three alternatives with zero values for two different criteria

	PROMETHEE II	ELECTRE III
A1	4	6
A2	1	2
A3	2	1
A4	6	4
A5	3	3
A6	5	4

Table 49. PROMETHEE II results (case VI)

PROMETHEE II	Observed	Expected
A1	4	6
A2	1	1
A3	2	2
A4	6	5
A5	3	3
A6	5	4

Table 50. ELECTRE III results (case VI)

ELECTRE III	Observed	Expected
A1	6	6
A2	2	1

ELECTRE III	Observed	Expected
A3	1	2
A4	4	4
A5	3	3
A6	4	4

Based on the results of experiments, we found that ELECTRE and PROMETHEE were able to handle variations in criteria values, alternative values, zero values, infeasible values, random values and are therefore robust enough to handle variations in model parameters and don not generate absurd results.

4.3.2 Sensitivity Analysis

Sensitivity analysis is applied for:

- Checking the strengths of the results of a model or system with uncertainty;
- Finding relationship between input and output variables;
- Finding errors;
- Simplifying the model.

Actually, the modellers need the sensitivity analysis:

- To find the strength of parameters and reduce output uncertainty;
- To find unimportant parameters and delete them;
- To find correlation between inputs and outputs;
- To find the most correlated parameter with output;

We applied sensitivity analysis to check what will happen to the ranking results of ELECTRE III and PROMETHEE I, II when following changes take place:

- Number of Alternatives is varied;
- Number of Decision Makers is varied;
- Number of Criteria is changed;
- Change in types of Criteria.

4.3.2.1 Sensitivity to Change in number of Alternatives

In this case, we change the number of alternatives from 3 to 6, 9, 12 and 15 step by step and observed the variation in results. The number of criteria remains equal to 3 in all cases. Table 51 presents the data for criteria weights. Table 52 shows the alternative values and Table 53 presents the ranking results by PROMETHEE I, II and ELECTRE III for the three alternatives case. It can be seen in Table 53 that alternative A2 is ranked best by both PROMETHEE and ELECTRE III.

Table 51. Normalized weights of A1 to A3

	Weights	Normalized weights
C1	0.17	0.14
C2	0.58	0.46
C3	0.49	0.40
	1.25	**1**

Table 52. Criteria values for A1 to A3

	A1	A2	A3
C1	9	1	8
C2	10	2	0
C3	6	9	8

Table 53. The results of A1 to A3

	ELECTRE III	PROMETHEE I +	PROMETHEE I -	PROMETHEE II
A1	2	3	3	3
A2	1	1	1	1
A3	3	2	2	2

Table 55 presents the results for the case when the number of alternatives is changed to 6. Table 54 presents the criteria data for the six alternatives. It can be seen from the results of Table 55 that:

- All PROMETHEE techniques have the same results in spite of changing alternatives which means that PROMETHEE is not sensitive to the change in number of alternatives and also retains A2 as the highest ranking alternative.
- The ranking of A2 and A3 has changed dramatically from 1 to 2 and from 3 to 6 which means that ELECTRE III is sensitive to change in number of alternatives.

Table 54. Criteria values for A1 to A6

	A1	**A2**	**A3**	**A4**	**A5**	**A6**
C1	9	1	8	10	1	1
C2	10	2	0	6	2	6
C3	6	9	8	2	8	9

Table 55. The results of A1 to A6

	ELECTRE III	**PROMETHEE I +**	**PROMETHEE I -**	**PROMETHEE II**
A1	2	5	5	5
A2	2	1	1	1
A3	6	3	3	3
A4	5	6	6	6
A5	4	4	4	4
A6	1	2	2	2

We continue this process for 9, 12 and 15 alternatives as shown in Tables 56-61. As we can see, the interpretation is the same which means PROMETHEE is not sensitive to change in number of alternatives and keeps the same result. On the other hand, ELECTRE III shows variation in results which means it is sensitive to change in the number of alternatives.

Table 56. Criteria values for A1 to A9

	A1	A2	A3	A4	A5	A6	A7	A8	A9
C1	9	1	8	10	1	1	3	10	7
C2	10	2	0	6	2	6	0	7	3
C3	6	9	8	2	8	9	3	7	5

Table 57. The results of A1 to A9

	ELECTRE III	PROMETHEE I +	PROMETHEE I -	PROMETHEE II
A1	1	6	6	6
A2	5	1	1	1
A3	3	3	3	3
A4	6	9	9	9
A5	6	4	4	4
A6	3	2	2	2
A7	9	8	8	8
A8	1	5	5	5
A9	6	7	7	7

Table 58. Criteria values for A1 to A12

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
C1	9	1	8	10	1	1	3	10	7	7	8	10
C2	10	2	0	6	2	6	0	7	3	8	7	7
C3	6	9	8	2	8	9	3	7	5	2	9	5

Table 59. The results of A1 to A12

	ELECTRE III	PROMETHEE I +	PROMETHEE I -	PROMETHEE II
A1	2	7	9	7
A2	7	1	1	1
A3	4	4	4	4
A4	9	11	11	11
A5	9	5	5	5
A6	5	2	2	2
A7	12	9	10	10
A8	3	6	6	6
A9	11	8	7	8
A10	8	12	12	12

	ELECTRE III	PROMETHEE I +	PROMETHEE I -	PROMETHEE II
A11	1	3	3	3
A12	5	10	8	9

Table 60. Criteria values for A1 to A15

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
C1	9	1	8	10	1	1	3	10	7	7	8	10	9	0	7
C2	10	2	0	6	2	6	0	7	3	8	7	7	0	1	0
C3	6	9	8	2	8	9	3	7	5	2	9	5	1	7	5

Table 61. The results of A1 to A15

	ELECTRE III	PROMETHEE I +	PROMETHEE I -	PROMETHEE II
A1	2	8	9	9
A2	7	1	1	1
A3	4	4	2	4
A4	8	14	4	13
A5	8	5	5	5
A6	6	2	3	2
A7	15	11	12	12
A8	2	7	7	7
A9	11	10	10	10
A10	8	15	15	15
A11	1	3	4	3
A12	5	12	11	11
A13	13	13	13	14
A14	13	6	6	6
A15	12	9	8	8

As a conclusion, we can say that ELECTRE III is much more sensitive to change in number of alternatives than PROMETHEE I, II for the following reasons:

- ELECTRE III doesn't consider differences in criteria values;
- ELECTRE III defines the veto thresholds in disconcordance of criterion.

4.3.2.2 Sensitivity to Change in number of Decision Makers

In this section, we change the number of decision makers from 1 to 9 in steps of 1, 3, 5, 7, 9 to observe the change in ranking results of PROMETHEE and ELECTRE. Tables 62, 66, 69, 72 and 75 present the criteria values provided by the decision makers for different cases and Tables 63, 67, 70, 73 and 76 present the normalized criteria weights for the same values. The alternative values for the three alternatives are presented in Table 64.

Tables 65, 68, 71, 74 and 77 present the ranking results for the three alternatives using ELECTRE III and PROMETHEE. It can be seen that although the ranking results of ELECTRE III and PROMETHEE are not the same, yet for their individual cases, the results remain the same despite the change in number of decision makers. The reason is the linear dependency of methods which are the same.

Table 62. The criterion weights of D1

	D1
C1	4
C2	4
C3	3

Table 63. Normalized weights of D1

	Weights	Normalized Weights
C1	4	0.36
C2	4	0.36
C3	3	0.27
	11	**1**

Table 64. The values of A1 to A3

	A1	A2	A3
C1	2	0	3
C2	8	5	1
C3	2	7	5

Table 65. The results of D1

	ELECTRE	PROMETHEE I +	PROMETHEE I -	PROMETHEE II
A1	1	3	3	3
A2	3	2	2	2
A3	2	1	1	1

Table 66. The criterion weight of D1 to D3

	D1	D2	D3
C1	4	6	8
C2	4	3	10
C3	3	9	1

Table 67. Normalized weights of D1 to D3

	Weights	Normalized Weights
C1	6.00	0.38
C2	5.67	0.35
C3	4.33	0.27
	16.00	**1.00**

Table 68. Results of D1 to D3

	ELECTRE	PROMETHEE I +	PROMETHEE I -	PROMETHEE II
A1	1	3	3	3
A2	3	2	2	2
A3	2	1	1	1

Table 69. The criterion weight of D1 to D5

	D1	D2	D3	D4	D5
C1	4	6	8	6	0
C2	4	3	10	9	1
C3	3	9	1	3	6

Table 70. Normalized weights of D1 to D5

	Weights	Normalized Weights
C1	4.80	0.33
C2	5.40	0.37
C3	4.40	0.30
	14.60	**1.00**

Table 71. The results of D1 to D5

	ELECTRE	PROMETHEE I +	PROMETHEE I -	PROMETHEE II
A1	1	3	3	3
A2	3	2	2	2
A3	2	1	1	1

Table 72. The criterion weight of D1 to D7

	D1	D2	D3	D4	D5	D6	D7
C1	4	6	8	6	0	2	0
C2	4	3	10	9	1	9	4
C3	3	9	1	3	6	8	10

Table 73. Normalized weights of D1 to D7

	Weights	Normalized Weights
C1	3.71	0.25
C2	5.71	0.38
C3	5.71	0.38
	15.14	**1.00**

Table 74. The results of D1 to D7

	ELECTRE	PROMETHEE I +	PROMETHEE I -	PROMETHEE II
A1	1	3	3	3
A2	3	2	2	2
A3	2	1	1	1

Table 75. The criterion weight of D1 to D9

	D1	D2	D3	D4	D5	D6	D7	D8	D9
C1	4	6	8	6	0	2	0	1	6
C2	4	3	10	9	1	9	4	1	0
C3	3	9	1	3	6	8	10	6	2

Table 76. Normalized weights of D1 to D9

	Weights	Normalized Weights
C1	3.67	0.27
C2	4.56	0.34
C3	5.33	0.39
	13.56	**1.00**

Table 77. The results of D1 to D9

	ELECTRE	PROMETHEE I +	PROMETHEE I -	PROMETHEE II
A1	1	3	3	3
A2	3	2	2	2
A3	2	1	1	1

4.3.2.3 Sensitivity to Change in number of Criteria

In this section, we investigate the influence of change in number of criteria on alternative rankings. We consider 3 alternatives and change the number of criteria from 3 to 15 in steps of 3, 6, 9, 12 and 15. The criteria weights and their normalized values for the various cases are presented in Tables 78, 81, 84, 87 and 90. The alternative values for the various criteria are demonstrated in Tables 79, 82, 85, 88 and 91. The ranking results from ELECTRE III and PROMETHEE II for the various cases are presented in Tables 80, 83, 86, 89 and 92.

It can be seen from the ranking results that ELECTRE III is not sensitive in case of small number of criteria while it is more sensitive with increasing number of criteria and the results are reasonable. On the other hand, PROMETHEE results are the same which means PROMETHEE is not sensitive to change in number of criteria.

The reason for sensitivity of ELECTRE III to the change in number of criteria is the degree of credibility which assesses the strength of the assertion that *"a is at least as good as b"* by overcoming concordance index than disconcordance index.

The reason for same results (or insensitivity to change in number of criteria) in PROMETHEE is due to the nature of criteria which remains the same (despite change in numbers) and therefore keeps the same results.

Table 78. Normalized weights of C1 to C3

	Weights	**Normalized**
C1	3	0.15
C2	7	0.35
C3	10	0.50
	20	**1**

Table 79. The values of C1 to C3

	A1	**A2**	**A3**
C1	10	7	1
C2	5	2	4
C3	6	7	7

Table 80. The results of C1 to C3

	ELECTRE III	**PROMETHEE I +**	**PROMETHEE I -**	**PROMETHEE II**
A1	1	1	3	2
A2	1	3	2	3
A3	1	2	1	1

Table 81. Normalized weights of C1 to C6

	Weights	**Normalized**
C1	3	0.08
C2	7	0.18
C3	10	0.26
C4	5	0.13
C5	6	0.16
C6	7	0.18
	38	**1**

Table 82. The values of C1 to C6

	A1	**A2**	**A3**
C1	10	7	1
C2	5	2	4
C3	6	7	7
C4	5	4	4
C5	4	0	9
C6	3	1	7

Table 83. The results of C1 to C6

	ELECTRE III	PROMETHEE I +	PROMETHEE I -	PROMETHEE II
A1	1	2	2	2
A2	1	3	3	3
A3	1	1	1	1

Table 84. Normalized weights of C1 to C9

	Weights	normalized
C1	3	0.05
C2	7	0.13
C3	10	0.18
C4	5	0.09
C5	6	0.11
C6	7	0.13
C7	7	0.13
C8	10	0.18
C9	0	0.00
	55	**1**

Table 85. The values of C1 to C9

	A1	A2	A3
C1	10	7	1
C2	5	2	4
C3	6	7	7
C4	5	4	4
C5	4	0	9
C6	3	1	7
C7	7	2	2
C8	3	3	5
C9	4	9	8

Table 86. The results of C1 to C9

	ELECTRE III	PROMETHEE I +	PROMETHEE I -	PROMETHEE II
A1	1	2	2	2
A2	1	3	3	3
A3	1	1	1	1

Table 87. Normalized weights of C1 to C12

	Weights	**normalized**
C1	3	0.04
C2	7	0.10
C3	10	0.14
C4	5	0.07
C5	6	0.08
C6	7	0.10
C7	7	0.10
C8	10	0.14
C9	0	0.00
C10	3	0.04
C11	6	0.08
C12	8	0.11
	72	**1**

Table 88. The values of C1 to C12

	A1	**A2**	**A3**
C1	10	7	1
C2	5	2	4
C3	6	7	7
C4	5	4	4
C5	4	0	9
C6	3	1	7
C7	7	2	2
C8	3	3	5
C9	4	9	8
C10	2	1	7
C11	7	1	5
C12	0	5	6

Table 89. The results of C1 to C12

	ELECTRE III	**PROMETHEE I +**	**PROMETHEE I -**	**PROMETHEE II**
A1	1	2	2	2
A2	1	3	3	3
A3	1	1	1	1

Table 90. Normalized weights of C1 to C15

	Weights	normalized
C1	3	0.03
C2	7	0.07
C3	10	0.11
C4	5	0.05
C5	6	0.06
C6	7	0.07
C7	7	0.07
C8	10	0.11
C9	0	0.00
C10	3	0.03
C11	6	0.06
C12	8	0.09
C13	8	0.09
C14	6	0.06
C15	8	0.09
	94	**1**

Table 91. The values of C1 to C15

	A1	A2	A3
C1	10	7	1
C2	5	2	4
C3	6	7	7
C4	5	4	4
C5	4	0	9
C6	3	1	7
C7	7	2	2
C8	3	3	5
C9	4	9	8
C10	2	1	7
C11	7	1	5
C12	0	5	6
C13	1	6	5
C14	5	1	2
C15	0	4	1

Table 92. The results of C1 to C15

	ELECTRE III	PROMETHEE I +	PROMETHEE I -	PROMETHEE II
A1	2	2	3	2

	ELECTRE III	PROMETHEE I +	PROMETHEE I -	PROMETHEE II
A2	3	3	2	3
A3	1	1	1	1

4.3.2.4 Sensitivity to Change in type of Criteria

In this section, we investigate the influence of change in type of criteria on ranking results. Table 93 shows the normalized weights for a set of criteria in Table 94. We considered three criteria including two types of criteria (qualitative and quantitative criteria) with two directions (maximize and minimize) and different types of preference functions such as linear, v-shape and level type (Tables 95-7). As shown applying ELECTRE III and PROMETHEE II, we found different results in Tables 98-100.

Table 93. Normalised weights of criteria

	Weights	Normalized weights
C1	4	0.36
C2	4	0.36
C3	3	0.27
	11	**1**

Table 94. Values of three alternatives

	A1	A2	A3
C1	2	0	3
C2	8	5	1
C3	2	7	5

Table 95. Change in the type of criteria (Case I)

	Direction	Type	Preference Function		wj	qj	pj	vj=pj*2
C1	max	Quant.	Linear	V	0.36	0.50	1.00	2.00
C2	min	Quant.	V-shape	III	0.36	0	3.00	6.00
C3	max	Qualt.	Level	IV	0.27	1.00	2.00	4.00

Table 96. Change in the type of criteria (Case II)

	Direction	Type	Preference Function		wj	qj	pj	vj=pj*2
C1	min	Quant.	V-shape	III	0.36	0.00	3.00	6.00

	Direction	Type	Preference Function		wj	qj	pj	vj=pj*2
C2	max	Quant.	Linear	V	0.36	0.5	1.00	2.00
C3	max	Qualt.	Level	IV	0.27	1.00	2.00	4.00

Table 97. Change the type of criteria (Case III)

	Direction	Type	Preference Function		wj	qj	pj	vj=pj*2
C1	max	Qualt.	Level	IV	0.36	1.00	2.00	4.00
C2	max	Quant.	Linear	V	0.36	0.50	1.00	2.00
C3	min	Quant.	V-shape	III	0.27	0	3.00	6.00

Table 98. Results of Case I

	ELECTRE III	PROMETEE I +	PROMETEE I -	PROMETEE II
A1	1	3	3	3
A2	3	2	2	2
A3	2	1	1	1

Table 99. Results of Case II

	ELECTRE III	PROMETEE I +	PROMETEE I -	PROMETEE II
A1	1	2	2	2
A2	3	1	1	1
A3	2	3	3	3

Table 100. Results of Case III

	ELECTRE III	PROMETEE I +	PROMETEE I -	PROMETEE II
A1	1	1	1	1
A2	3	3	3	3
A3	2	2	2	2

We used different types of criteria (Qualitative and quantitative) in our calculations and two directions for them (maximize, minimize). According to results of Tables 98-100, we bound that PROMETHEE is sensitive but ELECTRE III is not sensitive to change in type of criteria.

(1) Electre is not sensitive to type of criteria because:

- The criteria are evaluated based on concordance, disconcordance and thresholds, which have been proved by Roy et al. (1986-2005).

- ELECTRE uses the quantitative criteria (as it is one of the limitations of ELECTRE III).

(2) PROMETHEE is **sensitive** to change in the type of criteria because:

- We have to apply maximize and minimize rules in PROMETHEE which will affect the deviation which will be greater than zero (maximize) or less than zero (minimize).
- PROMETHEE considers six types of preference functions for different types of criteria (qualitative and quantitative) which affect the calculations.

4.3.3 Model Validation

Model validation is concerned with building the **right model**. To validate our model results, we applied ELECTRE and PROMETHEE methodologies for common dataset and compared the results with other MCDM techniques such as TOPSIS and VIKOR. We are using Tzeng et al. (2005) work for model validation.

Tzeng et al. (2005) applied TOPSIS and VIKOR for addressing energy problem in public transportation. Table 101 demonstrates the criteria weights based on Tzeng's paper. The criteria have been normalized in Table 102. Table 103 presents the alternatives and their abbreviations. The alternative values for the various criteria are shown in Table 104.

Table 101. Criteria weights

Criterion	Manufacture	Academic institute	Research organization	Bus operator	Average
1 Energy supply	0.0357	0.0314	0.0340	0.0249	0.0313
2 Energy efficiency	0.1040	0.0943	0.1020	0.0748	0.0938
3 Air pollution	0.1355	0.2090	0.1595	0.1605	0.1661
4 Noise pollution	0.0452	0.0697	0.0532	0.0535	0.0554
5 Industrial relationship	0.0923	0.0357	0.0480	0.0757	0.0629
6 Employment cost	0.0900	0.0680	0.0343	0.1393	0.0829
7 Maintenance cost	0.0300	0.0227	0.0114	0.0464	0.0276
8 Vehicle capability	0.1373	0.0953	0.1827	0.0803	0.1239
9 Road facility	0.0827	0.0590	0.1520	0.0283	0.0805
10 Speed of traffic flow	0.1520	0.2420	0.1400	0.2637	0.1994
11 Sense of comfort	0.0957	0.0730	0.0833	0.0523	0.0761

Table 102. Normalized weights of Tzeng

	Criteria	Average	Normalized weight
C1	Energy supply	0.03	0.03
C2	Energy efficiency	0.09	0.09
C3	Air pollution	0.17	0.17
C4	Noise pollution	0.06	0.06
C5	Industrial relations	0.06	0.06
C6	Employment cost	0.08	0.08
C7	Maintenance cost	0.03	0.03
C8	Capability vehicle	0.12	0.12
C9	Road facility	0.08	0.08
C10	Speed of traffic	0.20	0.20
C11	Sense of comfort	0.08	0.08
		0.9999	1

Table 103. Alternatives Abbreviation

Alternative	Abbr.
Conventional diesel engine	CDE
Compress natural gas (CNG)	CNG
Liquid propane gas (LPG)	LPG
Fuel cell (hydrogen)	FC
Methanol	M
Electric bus—opportunity charging	EB-OC
Electric bus—direct charging	EB-DC
Electric bus—exchangeable battery	EB-EB
Hybrid electric bus—gasoline engine	HEB-GE
Hybrid electric bus—diesel engine	HEB-DE

Alternative	Abbr.
Hybrid electric bus with CNG	HEB-CNG
Hybrid electric bus with LPG	HEB-LPG

Table 104. Criteria values for the various alternatives

Alternatives	Energy supply	Energy efficiency	Air pollution	Noise pollution	Industrial relations	Employment cost	Maintenance cost	Capability vehicle	Road facility	Speed of traffic	Sense of comfort
1. Diesel bus	0.82	0.59	0.18	0.42	0.58	0.36	0.49	0.79	0.81	0.82	0.56
2. CNG bus	0.77	0.70	0.73	0.55	0.55	0.52	0.53	0.73	0.78	0.66	0.67
3. LPG bus	0.79	0.70	0.73	0.55	0.55	0.52	0.53	0.73	0.78	0.66	0.67
4. Hydrogen	0.36	0.63	0.86	0.58	0.51	0.59	0.74	0.56	0.63	0.53	0.70
5. Methanol	0.40	0.54	0.69	0.58	0.51	0.52	0.68	0.52	0.63	0.60	0.70
6. Charging	0.69	0.76	0.89	0.60	0.72	0.80	0.72	0.54	0.35	0.79	0.73
7. Electric dir.	0.77	0.79	0.89	0.59	0.73	0.80	0.72	0.47	0.44	0.87	0.75
8. Electric bat	0.77	0.79	0.89	0.59	0.73	0.80	0.72	0.51	0.48	0.87	0.75
9. Hybrid-gas.	0.77	0.63	0.63	0.52	0.66	0.63	0.65	0.67	0.70	0.80	0.74
10. Hyb-diesel	0.77	0.63	0.51	0.58	0.66	0.63	0.65	0.67	0.70	0.80	0.74
11. Hyb.-CNG	0.77	0.73	0.80	0.48	0.63	0.66	0.65	0.67	0.71	0.62	0.78
12. Hyb.-LPG	0.77	0.73	0.80	0.48	0.63	0.66	0.65	0.67	0.71	0.62	0.78

The normalized weights and alternatives data (Tables 101-104) are subject to ELECTRE III and PROMETHEE I and II. The results for TOPSIS and VIKOR obtained from Tzeng et al (2005) are present in the last columns of Table 105.

Table 105. Model validation results

	Author's Ranking				Tzeng G. et al. Ranking (2005)		
						TOPSIS	
	PROMETHEE I +	**PROMETHEE I -**	**PROMETHEE II**	**ELECTRE III**	**VIKOR**	**I Rank**	**II Rank**
CDE	1	9	5	8	10	12	12
CNG	5	1	1	8	7	10	7
LPG	4	4	4	8	6	11	8
FC	6	7	6	11	12	8	6
M	7	8	9	12	11	9	10
EB-OC	10	10	10	3	3	2	3
EB-DC	11	11	11	2	4	3	2
EB-EB	11	11	11	1	2	1	1
HEB-GE	8	5	7	4	1	4	9
HEB-DE	8	5	7	4	5	7	11
HEB-CNG	2	2	2	6	8	5	4
HEB-LPG	2	2	2	6	9	6	5

In Table 105, we can see that most of the ELECTRE III rankings are in agreement with Tzeng's ranking (TOPSIS and VIKOR) which support it as the **right model** for sustainability assessment of industrial organizations. The alternatives CNG, FC, M, HEB-DE and HEB-CNG in ELECTRE III have very close ranking with TOPSIS and VIKOR (bold borders). There are same ranking results between ELECTRE III, TOPSIS and VIKOR for alternatives LPG, EB-OC, EB-DC, EB-EB, HEB-GE and HEB-LPG.

On the other hand, PROMETHEE I and II have the lowest agreement in ranking with Tzeng's rankings for alternatives FC, M and HEB-DE. Ranking of alternatives EB-OC, EB-DC and EB-EB by PROMETHEE I and II explain one of the PROMETHEE limitations which is the compensation between the criteria values, therefore the results of PROMETHEE are not reliable for the mentioned alternatives which have been rated as the most important alternatives by other ranking methods. This problem in PROMETHEE comes from not defining the veto thresholds and no existence of distillation ranking to rank the alternatives in terms of value of the credibility index (λ).

As an extra analysis, we can see that ELECTRE III result is even better than TOPSIS and VIKOR , because we can use the alternatives with the same rankings as a backup source for each other (resource recovery) for example, CNG and LPG or HEB-GE and HEB-DE or HEB-CNG or HEB-LPG together. Another reason is the ranking of the three most promising alternatives including: EB-OC, EB-DC and EB-EB. The definitions of these alternatives prove the claim by Tzeng et al. (2005) which is presented as follows:

- **Electric vehicle—opportunity charging (EB-OC):** The source of power for the opportunity charging electric vehicle (OCEV) is the combination of a loaded battery and fast opportunity charging during the time the bus is idle when stopped. Whenever the bus starts from the depot, its loaded battery will be fully charged. During the 10–20 s when the bus is stopped, the power reception sensor on the electric bus (installed under the bus) will be lowered to the charging supply plate installed in front of the bus stop to charge the battery. Within 10 s of a stop, the battery is charged with 0.15kWh power (depending on the design of power supply facility), and the power supplied is adequate for it to move to the next bus stop.

- **Direct electric charging (EB-DC):** This type of electric bus is in the prototype design stage. The power for this vehicle comes mainly from the loaded battery. Once the battery power is insufficient, the vehicle will have to return to the plant to conduct recharging. The development of a suitable battery is critical for this mode of vehicle. If a greater amount of electricity can be stored in the battery, the cruising distance by this vehicle will increase.
- **Electric bus with exchangeable batteries (EB-EB):** The objective of an electric bus with an exchangeable battery is to perform a fast battery charge and to achieve a longer cruising distance. The bus is modified to create more on-board battery space and the number of on board batteries is adjusted to meet the needs of different routes. The fast exchanging facility has to be ready to conduct a rapid battery exchange so that the vehicle mobility can be maintained.

Therefore, as we can see: EB-EB alternative has the highest rank and preference because the two other alternatives need to load battery which can be provided by EB-EB.

In addition, EB-DC has more preference than EB-OC because greater amount of electricity can be stored in the battery.

4.3.4 Conclusion- Part 2

In this chapter, we conducted a numerical case study and performed model verification, validation, robustness and sensitivity analysis to perform comparative evaluation of ELECTRE III and PROMETHEE II methodologies. The validation of our model was done by comparing the results of ELECTRE III and PROMETHEE II with the existing results from Tzeng et al. (2005) paper for a common test problem. Tzeng et al. (2005) applied TOPSIS and VIKOR to rank the alternatives and from model validation results, we found that the results of ELECTRE III are in conformance with Tzeng et al. (2005) thereby we can conclude that we chose the right model in our study.

For robustness and verification analysis, we conducted several test cases and checked the agreement between expected and observed results for ELECTRE III and PROMETHEE II. Following results were found:

- Case I (two alternatives with **same criteria** values) → the same results;
- Case II (one alternative with **max values** for all criteria) → the highest rank;
- Case III (one alternative with **min values** for all criteria) → the lowest rank;
- Case IV (one alternative with **criteria value zero**) → the lowest rank;
- Case V (alternatives with random values for all criteria) → close results;
- Case VI (three alternatives with given zero for two different criteria) → the lowest rank in A1.

Furthermore, we checked our methods by sensitivity analysis and found that:

- Sensitivity to change in number of Alternatives → ELECTRE III is sensitive;
- Sensitivity to change in number of Decision Makers → both techniques are not sensitive;
- Sensitivity to change in number of Criteria → ELECTRE III is sensitive to increase in the number of criteria;
- Sensitivity to change in type of criteria → PROMETHEE is sensitive.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this thesis, our goal was to perform comparative evaluation of outranking based MCDM methods namely ELECTRE III and PROMETHEE I, II with application to sustainability assessment. The ELECTRE III and PROMETHEE I, II were chosen because of their ability to deal with uncertainty, imprecision and ill-determined data, and generation of rankings based on pair-wise comparison.

ELECTRE III considers pseudo-criteria and was chosen as an appropriate method for our problem because of its ability:

(1) To consider the real data because it takes into account the qualitative nature of criteria;

(2) To deal with heterogeneous criteria. Every procedure can be run by preserving the original performances of the alternatives;

(3) To decrease the compensation between the criteria values by veto threshold;

(4) To consider imperfect data and arbitrariness through the indifference and preference thresholds;

(5) To reveal any terrible criterion with the veto threshold;

(6) To mark the difference between indifferent and incomparable alternatives and;

(7) To compare large number of alternatives (the limitation is given by the physical storage of data and not from ELECTRE III).

On the other hand, PROMETHEE I, II are other suitable methods comparable to ELECTRE but the concept is different. PROMETHEE I, II methods allow us:

(1) To support group-level decision making;
(2) To deal with qualitative and quantitative criteria;
(3) To express criteria scores in their units with uncertain and fuzzy information;
(4) To make partial ranking by PROMETHEE I;
(5) To make complete ranking by PROMETHEE II.

After applying ELECTRE III and PROMETHEE I, II, we found some differences in final ranking of alternatives which can be confusing to DM. Therefore, to select the best method, we evaluated each phases of the two methods comprising of the criterion models; the valued relations between the alternatives; and the ranking procedure. We selected ELECTRE III because it has more features than PROMETHEE method. ELECTRE III gives apparent results in spite of being complicated for users. Actually, ELECTRE III ranks and selects companies by greater concordance index than preference function that gives a chance to DM to find better resource recovery and the resources can be combined to improve sustainability. Another preference of ELECTRE III over PROMETHEE methods lies in its procedure, that is, the ELECTRE method uses ascending and descending ranking for each pre-order but PROMETHEE ranks by just descending distillation. In ELECTRE III, the veto thresholds cause decrease in the compensation between criteria and as a result, it leads to completely different rankings than PROMETHEE I, II.

5.2 Lessons Learnt and Recommendations for Future Research

We used two outranking methods ELECTRE III and PROMETHEE I, II in this study. Although they have individual advantages, there were some limitations on their applications.

In ELECTRE III, we have to:

(1) Assign score for each criterion. The scoring model is recommended;
(2) Apply in transitivity;
(3) Provide formal guideline for weighting. There is just AHP weighting approach which was applied by Macharis et al (2004). Neural Network (NN) is recommended.

In PROMETHEE, we have to:

(1) Address the rank reversal when a new alternative is introduced. Because it is based on net flow;
(2) Provide clear view of the problem and evaluate the results;
(3) Provide formal guideline for weighting. AHP is applied before and Neural Network (NN) is recommended;
(4) Provide proportional thresholds.

Considering the above mentioned limitations of ELECTRE III and PROMETHEE I, II, we recommended the following future studies to extend the current work:

(1) ELECTRE III method is a complicated method for new user therefore development of user-friendly software is recommended. (our calculations are excel-based tool);

(2) Investigation of the impact of thresholds on the final ranking of alternatives;

(3) Comparison of ELECTRE and PROMETHEE methods using different weighting methods such as AHP and Neural Network (NN);

(4) Investigation of ways in which the shortcomings of PROMETHEE can be addressed. The PROMETHEE methods are different from ELECTRE due to compensation, but it cannot be always called bad in cases where the number of criteria is not large;

(5) Comparison of ELECTRE III performance with aggregate weighting (AHP, SAW) and aspiration based methods (TOPSIS, VIKOR) for common datasets.

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APPENDIX A

Table 106. A. Concordance index calculation

	Co.1--Co.2		**Co.1--Co.3**		**Co.1--Co.4**		**Co.1--Co.5**		**Co.1--Co.6**		**Co.1--Co.7**		**Co.1--Co.8**		**Co.1--Co.9**		**Co.1--Co.10**	
	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)
BE	1	0.106	1	0.106	1	0.106	1	0.106	0.2493283	0.0264288	1	0.106	1	0.106	1	0.106	1	0.106
CG	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118
PP	0.5061891	0.0182228	0	0	0.5061891	0.0182228	0	0	1	0.036	0	0	0.3415855	0.0122971	1	0.036	0	0
EM	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206
CSS	1	0.068	1	0.068	1	0.068	1	0.068	1	0.068	1	0.068	1	0.068	1	0.068	1	0.068
CU	0	0	0.1426612	0.0064198	0.1426612	0.0064198	0	0	0	0	0	0	0	0	0	0	0	0
SC	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053
PY	1	0.018	1	0.018	1	0.018	1	0.018	1	0.018	1	0.018	1	0.018	1	0.018	1	0.018
OP	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24
CSE	1	0.054	1	0.054	0.7583333	0.04095	1	0.054	1	0.054	1	0.054	1	0.054	1	0.054	1	0.054
PS	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056
		0.9372228		0.9254198		0.9305926		0.919		0.8754288		0.919		0.9312971		0.955		0.919

	Co.2--Co.1		**Co.2--Co.3**		**Co.2--Co.4**		**Co.2--Co.5**		**Co.2--Co.6**		**Co.2--Co.7**		**Co.2--Co.8**		**Co.2--Co.9**		**Co.2--Co.10**	
	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)
BE	0.6276196	0.0665277	0.0488984	0.0051832	0.4250403	0.0450543	1	0.106	0	0	1	0.106	0.1563675	0.016575	0.4250403	0.0450543	1	0.106
CG	0.0259865	0.0030664	1	0.118	1	0.118	1	0.118	0	0	0.2627526	0.0310048	0.9846006	0.1161829	0.4234841	0.0499711	0.2627526	0.0310048
PP	1	0.036	0.3415855	0.0122971	1	0.036	0.3415855	0.0122971	1	0.036	0.3415855	0.0122971	0.8353964	0.0300743	1	0.036	0.3415855	0.0122971
EM	0	0	1	0.206	1	0.206	1	0.206	0.5352394	0.1102593	1	0.206	1	0.206	1	0.206	1	0.206
CSS	0	0	1	0.068	0.4620355	0.0314184	1	0.068	1	0.068	1	0.068	1	0.068	0	0	1	0.068
CU	1	0.045	0.7142204	0.0321399	0.7142204	0.0321399	0.1426612	0.0064198	0.1426612	0.0064198	0.1426612	0.0064198	0.1426612	0.0064198	0.1426612	0.0064198	0.1426612	0.0064198
SC	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053
PY	0.6348315	0.011427	2.8820225	0.0518764	1	0.018	1	0.018	0.6348315	0.011427	1	0.018	1	0.018	1	0.018	1	0.018
OP	0	0	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24
CSE	0	0	0	0	-2.575	-0.13905	0	0	0	0	0	0	0	0	0	0	0	0
PS	0	0	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056
		0.215021		0.8424966		0.6965626		0.8837168		0.581106		0.7967216		0.8102519		0.7104452		0.7967216

Table 106. A. Concordance index Calculation -Cont.

	Co.3--Co.1		Co.3--Co.2		Co.3--Co.4		Co.3--Co.5		Co.3--Co.6		Co.3--Co.7		Co.3--Co.8		Co.3--Co.9		Co.3--Co.10	
	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)
BE	1	0.106	1	0.106	1	0.106	1	0.106	0.8280494	0.0877732	1	0.106	1	0.106	1	0.106	1	0.106
CG	0	0	1	0.118	1	0.118	1	0.118	0	0	0	0	0.7122233	0.0840423	0.1511068	0.0178306	0	0
PP	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036
EM	0	0	1	0.206	0.6821809	0.1405293	1	0.206	0	0	1	0.206	1	0.206	0.6988032	0.1439535	0.6402926	0.1319003
CSS	0	0	1	0.068	0.3610662	0.0245525	1	0.068	1	0.068	1	0.068	1	0.068	0	0	1	0.068
CU	1	0.045	1	0.045	1	0.045	0.4284408	0.0192798	0.4284408	0.0192798	0.4284408	0.0192798	0.4284408	0.0192798	0.4284408	0.0192798	0.4284408	0.0192798
SC	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053
PY	0	0	0.6348315	0.011427	0.6348315	0.011427	1	0.018	0	0	1	0.018	0.6348315	0.011427	0.6348315	0.011427	1	0.018
OP	0	0	1	0.24	0.5204945	0.1249187	0.4638907	0.1113338	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24
CSE	1	0.054	1	0.054	0.7583333	0.04095	1	0.054	1	0.054	1	0.054	1	0.054	1	0.054	1	0.054
PS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		0.294		0.937427		0.7003774		0.7896136		0.5580531		0.8002798		0.8777492		0.6814909		0.7261801

	Co.4--Co.1		Co.4--Co.2		Co.4--Co.3		Co.4--Co.5		Co.4--Co.6		Co.4--Co.7		Co.4--Co.8		Co.4--Co.9		Co.4--Co.10	
	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)
BE	1	0.106	1	0.106	1	0.106	1	0.106	0.4519076	0.0479022	1	0.106	1	0.106	1	0.106	1	0.106
CG	0.2050048	0.0241906	1	0.118	1	0.118	1	0.118	0	0	0.4417709	0.052129	1	0.118	0.6025024	0.0710953	0.4417709	0.052129
PP	1	0.036	1	0.036	0.3415855	0.0122971	0.3415855	0.0122971	1	0.036	0.3415855	0.0122971	0.8353964	0.0300743	1	0.036	0.3415855	0.0122971
EM	0	0	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206
CSS	0.8659128	0.0588821	1	0.068	1	0.068	1	0.068	1	0.068	1	0.068	1	0.068	1	0.068	1	0.068
CU	1	0.045	1	0.045	1	0.045	0.4284408	0.0192798	0.4284408	0.0192798	0.4284408	0.0192798	0.4284408	0.0192798	0.4284408	0.0192798	0.4284408	0.0192798
SC	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053
PY	0.6348315	0.011427	1	0.018	1	0.018	1	0.018	0.6348315	0.011427	1	0.018	1	0.018	1	0.018	1	0.018
OP	0.2244632	0.0538712	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24
CSE	1	0.054	1	0.054	1	0.054	1	0.054	1	0.054	1	0.054	1	0.054	1	0.054	1	0.054
PS	0	0	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056
		0.4423708		1		0.9762971		0.9505769		0.791609		0.8847059		0.9683541		0.9273751		0.8847059

Table 106. A. Concordance index Calculation -Cont.

	Co.5--Co.1		Co.5--Co.2		Co.5--Co.3		Co.5--Co.4		Co.5--Co.6		Co.5--Co.7		Co.5--Co.8		Co.5--Co.9		Co.5--Co.10	
	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)
BE	0.3589468	0.0380484	1	0.106	0	0	0.1563675	0.016575	0	0	1	0.106	0	0	0.1563675	0.016575	1	0.106
CG	0	0	1	0.118	1	0.118	1	0.118	0	0	0	0	0.7122233	0.0840423	0.1511068	0.0178306	0	0
PP	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036
EM	0	0	1	0.206	1	0.206	0.9847074	0.2028497	0.3031915	0.0624574	1	0.206	1	0.206	1	0.206	0.9428191	0.1942207
CSS	0	0	1	0.068	1	0.068	0.3610662	0.0245525	1	0.068	1	0.068	1	0.068	0	0	1	0.068
CU	2.428898	0.1093004	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045
SC	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053
PY	0	0	0.6348315	0.011427	1	0.018	0.6348315	0.011427	0	0	1	0.018	0.6348315	0.011427	0.6348315	0.011427	1	0.018
OP	0.281067	0.0674561	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24
CSE	1	0.054	1	0.054	1	0.054	0.7583333	0.04095	1	0.054	1	0.054	1	0.054	1	0.054	1	0.054
PS	0	0	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056
		0.3578049		0.993427		0.894		0.8443542		0.6144574		0.882		0.8534693		0.7358325		0.8702207
	Co.6--Co.1		**Co.6--Co.2**		**Co.6--Co.3**		**Co.6--Co.4**		**Co.6--Co.5**		**Co.6--Co.7**		**Co.6--Co.8**		**Co.6--Co.9**		**Co.6--Co.10**	
	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)
BE	1	0.106	1	0.106	1	0.106	1	0.106	1	0.106	1	0.106	1	0.106	1	0.106	1	0.106
CG	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118
PP	1	0.036	0.5061891	0.0182228	0	0	0.5061891	0.0182228	0	0	0	0	0.3415855	0.0122971	1	0.036	0	0
EM	0.5305851	0.1093005	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206
CSS	0	0	1	0.068	1	0.068	0.7213247	0.0490501	1	0.068	1	0.068	1	0.068	0.144588	0.009832	1	0.068
CU	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045
SC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.053	0	0
PY	1	0.018	1	0.018	1	0.018	1	0.018	1	0.018	1	0.018	1	0.018	1	0.018	1	0.018
OP	0	0	0.8672739	0.2081457	1	0.24	0.1691607	0.0405986	0.1125569	0.0270137	0.8386467	0.2012752	1	0.24	1	0.24	1	0.24
CSE	1	0.054	1	0.054	1	0.054	0.7583333	0.04095	1	0.054	1	0.054	1	0.054	1	0.054	1	0.054
PS	0	0	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056
		0.4863005		0.8973685		0.911		0.6978215		0.6980137		0.8722752		0.9232971		0.941832		0.911

Table 106. A. Concordance index Calculation -Cont.

	Co.7--Co.1		**Co.7--Co.2**		**Co.7--Co.3**		**Co.7--Co.4**		**Co.7--Co.5**		**Co.7--Co.6**		**Co.7--Co.8**		**Co.7--Co.9**		**Co.7--Co.10**	
	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)
BE	0.8962923	0.095007	1	0.106	0.3175712	0.0336625	0.6937131	0.0735336	1	0.106	0	0	0.4250403	0.0450543	0.6937131	0.0735336	1	0.106
CG	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118
PP	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036
EM	0	0	1	0.206	1	0.206	1	0.206	1	0.206	0.4242021	0.0873856	1	0.206	1	0.206	1	0.206
CSS	0	0	1	0.068	1	0.068	0.5771405	0.0392456	1	0.068	1	0.068	1	0.068	0	0	1	0.068
CU	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045
SC	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053
PY	0	0	0.6348315	0.011427	1	0.018	0.6348315	0.011427	1	0.018	0	0	0.6348315	0.011427	0.6348315	0.011427	1	0.018
OP	0	0	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24	1	0.24
CSE	1	0.054	1	0.054	1	0.054	0.7583333	0.04095	1	0.054	1	0.054	1	0.054	1	0.054	1	0.054
PS	0	0	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056
		0.401007		0.993427		0.9276625		0.9191561		1		0.7573856		0.9324812		0.8929606		1

	Co.8--Co.1		**Co.8--Co.2**		**Co.8--Co.3**		**Co.8--Co.4**		**Co.8--Co.5**		**Co.8--Co.6**		**Co.8--Co.7**		**Co.8--Co.9**		**Co.8--Co.10**	
	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)
BE	1	0.106	1	0.106	1	0.106	1	0.106	1	0.106	0.7205803	0.0763815	1	0.106	1	0.106	1	0.106
CG	0.6862368	0.0809759	1	0.118	1	0.118	1	0.118	1	0.118	0.2810395	0.0331627	0.9230029	0.1089143	1	0.118	0.9230029	0.1089143
PP	1	0.036	1	0.036	0.5061891	0.0182228	1	0.036	0.5061891	0.0182228	1	0.036	0.5061891	0.0182228	1	0.036	0.5061891	0.0182228
EM	0	0	1	0.206	1	0.206	1	0.206	1	0.206	0.4394947	0.0905359	1	0.206	1	0.206	1	0.206
CSS	0	0	1	0.068	1	0.068	0.7213247	0.0490501	1	0.068	1	0.068	1	0.068	0.144588	0.009832	1	0.068
CU	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045
SC	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053
PY	0.6348315	0.011427	1	0.018	1	0.018	1	0.018	1	0.018	0.6348315	0.011427	1	0.018	1	0.018	1	0.018
OP	0	0	1	0.24	1	0.24	1	0.24	0.9446975	0.2267274	1	0.24	1	0.24	1	0.24	1	0.24
CSE	1	0.054	1	0.054	1	0.054	0.7583333	0.04095	1	0.054	1	0.054	1	0.054	1	0.054	1	0.054
PS	0	0	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056
		0.3864029		1		0.9822228		0.9680001		0.9689502		0.763507		0.9731371		0.941832		0.9731371

Table 106. A. Concordance index Calculation -Cont.

	Co.9--Co.1		**Co.9--Co.2**		**Co.9--Co.3**		**Co.9--Co.4**		**Co.9--Co.5**		**Co.9--Co.6**		**Co.9--Co.7**		**Co.9--Co.8**		**Co.9--Co.10**	
	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)
BE	1	0.106	1	0.106	1	0.106	1	0.106	1	0.106	0.4519076	0.0479022	1	0.106	1	0.106	1	0.106
CG	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	0.8421559	0.0993744	1	0.118	1	0.118	1	0.118
PP	1	0.036	0.5061891	0.0182228	0	0	0.5061891	0.0182228	0	0	1	0.036	0	0	0.3415855	0.0122971	0	0
EM	0	0	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206
CSS	1	0.068	1	0.068	1	0.068	1	0.068	1	0.068	1	0.068	1	0.068	1	0.068	1	0.068
CU	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045
SC	0	0	0	0	0	0	0	0	0	0	1	0.053	0	0	0	0	0	0
PY	1	0.018	1	0.018	1	0.018	1	0.018	1	0.018	0.6348315	0.011427	1	0.018	1	0.018	1	0.018
OP	0	0	1	0.24	1	0.24	0.9512036	0.2282889	0.8945999	0.214704	1	0.24	1	0.24	1	0.24	1	0.24
CSE	1	0.054	1	0.054	1	0.054	0.7583333	0.04095	1	0.054	1	0.054	1	0.054	1	0.054	1	0.054
PS	0	0	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056
		0.445		0.9292228		0.911		0.9044617		0.885704		0.9167036		0.911		0.9232971		0.911

	Co.10--Co.1		**Co.10--Co.2**		**Co.10--Co.3**		**Co.10--Co.4**		**Co.10--Co.5**		**Co.10--Co.6**		**Co.10--Co.7**		**Co.10--Co.8**		**Co.10--Co.9**	
	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)	Cj (a, b)	wj*Cj(a,b)
BE	0.8962923	0.095007	1	0.106	0.3175712	0.0336625	0.6937131	0.0735336	1	0.106	0	0	1	0.106	0.4250403	0.0450543	0.6937131	0.0735336
CG	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118	1	0.118
PP	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036	1	0.036
EM	0	0	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206	1	0.206
CSS	0	0	1	0.068	1	0.068	0.5771405	0.0392456	1	0.068	1	0.068	1	0.068	1	0.068	0	0
CU	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045	1	0.045
SC	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053	1	0.053
PY	0	0	0.6348315	0.011427	1.758427	0.0316517	0.6348315	0.011427	1	0.018	0	0	1	0.018	0.6348315	0.011427	0.6348315	0.011427
OP	0	0	1	0.24	1	0.24	0.7826936	0.1878465	0.7260898	0.1742615	1	0.24	1	0.24	1	0.24	1	0.24
CSE	1	0.054	1	0.054	1	0.054	0.7583333	0.04095	1	0.054	1	0.054	1	0.054	1	0.054	1	0.054
PS	0	0	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056	1	0.056
		0.401007		0.993427		0.9413142		0.8670026		0.9342615		0.876		1		0.9324812		0.8929606

Table 107. A. Disconcordance Index (SCC)

Co.1--Co.2			Co.1--Co.3			Co.1--Co.4			Co.1--Co.5			Co.1--Co.6		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
192.88	146.44	-2.2919897	192.88	146.44	-2.3458226	192.88	146.44	-1.538329	192.88	146.44	-2.3458226	192.88	146.44	-2.1537468
	0			0			0			0			0	
Co.2--Co.1			Co.2--Co.3			Co.2--Co.4			Co.2--Co.5			Co.2--Co.6		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
132.88	86.44	0.2919897	132.88	86.44	-1.0538329	132.88	86.44	-0.2463394	132.88	86.44	-1.0538329	132.88	86.44	-0.8617571
		0.2919897		0			0			0			0	
Co.3-Co.1			Co.3-Co.2			Co.3-Co.4			Co.3-Co.5			Co.3-Co.6		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
130.38	83.94	0.3458226	130.38	83.94	-0.9461671	130.38	83.94	-0.1925065	130.38	83.94	-1	130.38	83.94	-0.8079242
		0.3458226		0			0			0			0	
Co.4-Co.1			Co.4-Co.2			Co.4-Co.3			Co.4-Co.5			Co.4-Co.6		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
167.88	121.44	-0.461671	167.88	121.44	-1.7536606	167.88	121.44	-1.8074935	167.88	121.44	-1.8074935	167.88	121.44	-1.6154177
	0			0			0			0			0	
Co.5-Co.1			Co.5-Co.2			Co.5-Co.3			Co.5-Co.4			Co.5-Co.6		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
130.38	83.94	0.3458226	130.38	83.94	-0.9461671	130.38	83.94	-1	130.38	83.94	-0.1925065	130.38	83.94	-0.8079242
		0.3458226		0			0			0			0	
Co.6--Co.1			Co.6--Co.2			Co.6--Co.3			Co.6--Co.4			Co.6--Co.5		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
139.3	92.86	0.1537468	139.3	92.86	-1.1382429	139.3	92.86	-1.1920758	139.3	92.86	-0.3845823	139.3	92.86	-1.1920758
		0.1537468		0			0			0			0	
Co.7--Co.1			Co.7--Co.2			Co.7--Co.3			Co.7--Co.4			Co.7--Co.5		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
135.73	89.29	0.2306202	135.73	89.29	-1.0613695	135.73	89.29	-1.1152024	135.73	89.29	-0.3077089	135.73	89.29	-1.1152024
		0.2306202		0			0			0			0	
Co.8--Co.1			Co.8--Co.2			Co.8--Co.3			Co.8--Co.4			Co.8--Co.5		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
139.3	92.86	0.1537468	139.3	92.86	-1.1382429	139.3	92.86	-1.1920758	139.3	92.86	-0.3845823	139.3	92.86	-1.1920758
		0.1537468		0			0			0			0	
Co.9--Co.1			Co.9--Co.2			Co.9--Co.3			Co.9--Co.4			Co.9--Co.5		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
182.16	135.72	-0.7691645	182.16	135.72	-2.0611542	182.16	135.72	-2.1149871	182.16	135.72	-1.3074935	182.16	135.72	-2.1149871
	0			0			0			0			0	
Co.10--Co.1			Co.10--Co.2			Co.10--Co.3			Co.10--Co.4			Co.10--Co.5		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
135.73	89.29	0.2306202	135.73	89.29	-1.0613695	135.73	89.29	-1.1152024	135.73	89.29	-0.3077089	135.73	89.29	-1.1152024
		0.2306202		0			0			0			0	

Table 107. A. Disconcordance Index (SCC)-Cont.

Co.1--Co.7			Co.1--Co.8			Co.1--Co.9			Co.1--Co.10		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
192.88	146.44	-2.2306202	192.88	146.44	-2.1537468	192.88	146.44	-1.2308355	192.88	146.44	-2.2306202
	0			0			0			0	
Co.2--Co.7			Co.2--Co.8			Co.2--Co.9			Co.2--Co.10		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
132.88	86.44	-0.9386305	132.88	86.44	-0.8617571	132.88	86.44	0.0611542	132.88	86.44	-0.9386305
	0			0				0.0611542		0	
Co.3-Co.7			Co.3-Co.8			Co.3-Co.9			Co.3-Co.10		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
130.38	83.94	-0.8847976	130.38	83.94	-0.8079242	130.38	83.94	0.1149871	130.38	83.94	-0.8847976
	0			0				0.1149871		0	
Co.4-Co.7			Co.4-Co.8			Co.4-Co.9			Co.4-Co.10		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
167.88	121.44	-1.6922911	167.88	121.44	-1.6154177	167.88	121.44	-0.6925065	167.88	121.44	-1.6922911
	0			0			0			0	
Co.5-Co.7			Co.5-Co.8			Co.5-Co.9			Co.5-Co.10		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
130.38	83.94	-0.8847976	130.38	83.94	-0.8079242	130.38	83.94	0.1149871	130.38	83.94	-0.8847976
	0			0				0.1149871		0	
Co.6--Co.7			Co.6--Co.8			Co.6--Co.9			Co.6--Co.10		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
139.3	92.86	-1.0768734	139.3	92.86	-1	139.3	92.86	-0.0770887	139.3	92.86	-1.0768734
	0			0			0			0	
Co.7--Co.6			Co.7--Co.8			Co.7--Co.9			Co.7--Co.10		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
135.73	89.29	-0.9231266	135.73	89.29	-0.9231266	135.73	89.29	-0.0002153	135.73	89.29	-1
	0			0			0			0	
Co.8--Co.6			Co.8--Co.7			Co.8--Co.9			Co.8--Co.10		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
139.3	92.86	-1	139.3	92.86	-1.0768734	139.3	92.86	-0.0770887	139.3	92.86	-1.0768734
	0			0			0			0	
Co.9--Co.6			Co.9--Co.7			Co.9--Co.8			Co.9--Co.10		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
182.16	135.72	-1.9229113	182.16	135.72	-1.9997847	182.16	135.72	-1.9229113	182.16	135.72	-1.9997847
	0			0			0			0	
Co.10--Co.6			Co.10--Co.7			Co.10--Co.8			Co.10--Co.9		
1	0	otherwise	1	0	otherwise	1	0	otherwise	1	0	otherwise
135.73	89.29	-0.9231266	135.73	89.29	-1	135.73	89.29	-0.9231266	135.73	89.29	-0.0002153
	0			0			0			0	

APPENDIX B

Table 108. B. Deviation Calculation

	Co.1--Co.2	Co.1--Co.3	Co.1--Co.4	Co.1--Co.5	Co.1--Co.6	Co.1--Co.7	Co.1--Co.8	Co.1--Co.9	Co.1--Co.10
	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I
BE	19.23	0	0	24.23	0	14.23	0	0	14.23
CG	16.82	19.65	14.96	19.65	0	2.46	9.96	4.13	2.46
PP	0	0	0	0	0	0	0	0	0
EM	38.69	46.73	29.63	42.18	19.38	40.36	40.13	29.88	29
CSS	60	62.5	25	62.5	53.58	57.15	53.58	10.72	57.15
CU	0	0	0	0	0	0	0	0	0
SC	0	0	0	0	4	0	0	4	0
PY	2	4	2	4	0	4	2	2	4
OP	35.46	44.91	24.73	23.86	50.31	35.02	37.52	38.29	40.88
CSE	4	0	0	0	0	0	0	0	0
PS	2	4	2	2	2	2	2	2	2

	Co.2--Co.1	Co.2--Co.3	Co.2--Co.4	Co.2--Co.5	Co.2--Co.6	Co.2--Co.7	Co.2--Co.8	Co.2--Co.9	Co.2--Co.10
	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I
BE	0	0	0	5	0	0	0	0	0
CG	0	2.83	0	2.83	0	0	0	0	0
PP	18.75	0	0	0	18.75	0	0	18.75	0
EM	0	8.04	0	3.49	0	1.67	1.44	0	0
CSS	0	2.5	0	2.5	0	0	0	0	0
CU	25	0	0	0	0	0	0	0	0
SC	0	0	0	0	4	0	0	4	0
PY	0	2	0	2	0	2	0	0	2
OP	0	9.45	0	0	14.85	0	2.06	2.83	5.42
CSE	0	0	0	0	0	0	0	0	0
PS	0	2	0	0	0	0	0	0	0

Table 108. B. Deviation Calculation-Cont.

	Co.3--Co.1	Co.3--Co.2	Co.3--Co.4	Co.3--Co.5	Co.3--Co.6	Co.3--Co.7	Co.3--Co.8	Co.3--Co.9	Co.3--Co.10
	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I
BE	10.77	30	7	35	0	25	2	7	25
CG	0	0	0	0	0	0	0	0	0
PP	43.75	25	25	0	43.75	0	18.75	43.75	0
EM	0	0	0	0	0	0	0	0	0
CSS	0	0	0	0	0	0	0	0	0
CU	37.5	12.5	0	0	0	0	0	0	0
SC	0	0	0	0	4	0	0	4	0
PY	0	0	0	0	0	0	0	0	0
OP	0	0	0	0	5.4	0	0	0	0
CSE	0	4	0	0	0	0	0	0	0
PS	0	0	0	0	0	0	0	0	0
	Co.4--Co.1	Co.4--Co.2	Co.4--Co.3	Co.4--Co.5	Co.4--Co.6	Co.4--Co.7	Co.4--Co.8	Co.4--Co.9	Co.4--Co.10
	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I
BE	3.77	23	0	28	0	18	0	0	18
CG	0	1.86	4.69	4.69	0	0	0	0	0
PP	18.75	0	0	0	18.75	0	0	18.75	0
EM	0	9.06	17.1	12.55	0	10.73	10.5	0.25	0
CSS	0	35	37.5	37.5	28.58	32.15	28.58	0	32.15
CU	37.5	12.5	0	0	0	0	0	0	0
SC	0	0	0	0	4	0	0	4	0
PY	0	0	2	2	0	2	0	0	2
OP	0	10.73	20.18	0	25.58	10.29	12.79	13.56	16.15
CSE	2	6	2	2	2	2	2	2	2
PS	0	0	2	0	0	0	0	0	0

Table 108. B. Deviation Calculation-Cont.

	Co.5--Co.1	Co.5--Co.2	Co.5--Co.3	Co.5--Co.4	Co.5--Co.6	Co.5--Co.7	Co.5--Co.8	Co.5--Co.9	Co.5--Co.10
	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I
BE	0	0	0	0	0	0	0	0	0
CG	0	0	0	0	0	0	0	0	0
PP	43.75	25	0	25	43.75	0	18.75	43.75	0
EM	0	0	4.55	0	0	0	0	0	0
CSS	0	0	0	0	0	0	0	0	0
CU	62.5	37.5	25	25	0	0	0	0	0
SC	0	0	0	0	4	0	0	4	0
PY	0	0	0	0	0	0	0	0	0
OP	0	11.6	21.05	0.87	26.45	11.16	13.66	14.43	17.02
CSE	0	4	0	0	0	0	0	0	0
PS	0	0	2	0	0	0	0	0	0
	Co.6--Co.1	Co.6--Co.2	Co.6--Co.3	Co.6--Co.4	Co.6--Co.5	Co.6--Co.7	Co.6--Co.8	Co.6--Co.9	Co.6--Co.10
	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I
BE	26.27	45.5	15.5	22.5	50.5	40.5	17.5	22.5	40.5
CG	4.21	21.03	23.86	19.17	23.86	6.67	14.17	8.34	6.67
PP	0	0	0	0	0	0	0	0	0
EM	0	19.31	27.35	10.25	22.8	20.98	20.75	10.5	9.62
CSS	0	6.42	8.92	0	8.92	3.57	0	0	3.57
CU	62.5	37.5	25	25	0	0	0	0	0
SC	0	0	0	0	0	0	0	0	0
PY	0	2	4	2	4	4	2	2	4
OP	0	0	0	0	0	0	0	0	0
CSE	0	4	0	0	0	0	0	0	0
PS	0	0	2	0	0	0	0	0	0

Table 108. B. Deviation Calculation-Cont.

	Co.7--Co.1	Co.7--Co.2	Co.7--Co.3	Co.7--Co.4	Co.7--Co.5	Co.7--Co.6	Co.7--Co.8	Co.7--Co.9	Co.7--Co.10
	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I
BE	0	5	0	0	10	0	0	0	0
CG	0	14.36	17.19	12.5	17.19	0	7.5	1.67	0
PP	43.75	25	0	25	0	43.75	18.75	43.75	0
EM	0	0	6.37	0	1.82	0	0	0	0
CSS	0	2.85	5.35	0	5.35	0	0	0	0
CU	62.5	37.5	25	25	0	0	0	0	0
SC	0	0	0	0	0	4	0	4	0
PY	0	0	0	0	0	0	0	0	0
OP	0	0.44	9.89	0	0	15.29	2.5	3.27	5.86
CSE	0	4	0	0	0	0	0	0	0
PS	0	0	2	0	0	0	0	0	0
	Co.8--Co.1	Co.8--Co.2	Co.8--Co.3	Co.8--Co.4	Co.8--Co.5	Co.8--Co.6	Co.8--Co.7	Co.8--Co.9	Co.8--Co.10
	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I
BE	8.77	28	0	5	33	0	23	5	23
CG	0	6.86	9.69	5	9.69	0	0	0	0
PP	25	6.25	0	6.25	0	25	0	25	0
EM	0	0	6.6	0	2.05	0	0.23	0	0
CSS	0	6.42	8.92	0	8.92	0	3.57	0	3.57
CU	62.5	37.5	25	25	0	0	0	0	0
SC	0	0	0	0	0	4	0	4	0
PY	0	0	2	0	2	0	2	0	2
OP	0	0	7.39	0	0	12.79	0	0.77	3.36
CSE	0	4	0	0	0	0	0	0	0
PS	0	0	2	0	0	0	0	0	0

Table 108. B. Deviation Calculation-Cont.

	Co.9--Co.1	Co.9--Co.2	Co.9--Co.3	Co.9--Co.4	Co.9--Co.5	Co.9--Co.6	Co.9--Co.7	Co.9--Co.8	Co.9--Co.10
	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I
BE	3.77	23	0	0	28	0	18	0	18
CG	0	12.69	15.52	10.83	15.52	0	0	5.83	0
PP	0	0	0	0	0	0	0	0	0
EM	0	8.81	16.85	0	12.3	0	10.48	10.25	0
CSS	0	49.28	51.78	14.28	51.78	42.86	46.43	42.86	46.43
CU	62.5	37.5	25	25	0	0	0	0	0
SC	0	0	0	0	0	0	0	0	0
PY	0	0	2	0	2	0	2	0	2
OP	0	0	6.62	0	0	12.02	0	0	2.59
CSE	0	4	0	0	0	0	0	0	0
PS	0	0	2	0	0	0	0	0	0
	Co.10--Co.1	Co.10--Co.2	Co.10--Co.3	Co.10--Co.4	Co.10--Co.5	Co.10--Co.6	Co.10--Co.7	Co.10--Co.8	Co.10--Co.9
	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I	I dj (La, Lb) I
BE	0	5	0	0	10	0	0	0	0
CG	0	14.36	17.19	12.5	17.19	0	0	7.5	1.67
PP	43.75	25	0	25	0	43.75	0	18.75	43.75
EM	0	9.69	17.73	0.63	13.18	0	11.36	11.13	0.88
CSS	0	2.85	5.35	0	5.35	0	0	0	0
CU	62.5	37.5	25	25	0	0	0	0	0
SC	0	0	0	0	0	4	0	0	4
PY	0	0	0	0	0	0	0	0	0
OP	0	0	4.03	0	0	9.43	0	0	0
CSE	0	4	0	0	0	0	0	0	0
PS	0	0	2	0	0	0	0	0	0

Table 109. B. Computation of preference function

	Co.1--Co.2	Co.1--Co.3	Co.1--Co.4	Co.1--Co.5	Co.1--Co.6	Co.1--Co.7	Co.1--Co.8	Co.1--Co.9	Co.1--Co.10
	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)
BE	0.372380441	0	0	0.641053197	0	0.103707684	0	0	0.103707684
CG	0.974013474	1	0.794995188	1	0	0	0.313763234	0	0
PP	0	0	0	0	0	0	0	0	0
EM	1	1	1	1	0.469414894	1	1	1	1
CSS	1	1	0.134087237	1	1	1	1	0	1
CU	0	0	0	0	0	0	0	0	0
SC	0	0	0	0	1	0	0	1	0
PY	0.5	1	0.5	1	0	1	0.5	0.5	1
OP	1	1	0.77553676	0.718932986	1	1	1	1	1
CSE	1	0	0	0	0	0	0	0	0
PS	1	1	1	1	1	1	1	1	1
	Co.2--Co.1	Co.2--Co.3	Co.2--Co.4	Co.2--Co.5	Co.2--Co.6	Co.2--Co.7	Co.2--Co.8	Co.2--Co.9	Co.2--Co.10
	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)
BE	0	0	0	0	0	0	0	0	0
CG	0	0	0	0	0	0	0	0	0
PP	0.493810903	0	0	0	0.493810903	0	0	0.493810903	0
EM	0	0	0	0	0	0	0	0	0
CSS	0	0	0	0	0	0	0	0	0
CU	0.571559214	0	0	0	0	0	0	0	0
SC	0	0	0	0	1	0	0	1	0
PY	0	2	0	2	0	2	0	0	2
OP	0	0	0	0	0.13272609	0	0	0	0
CSE	0	0	0	0	0	0	0	0	0
PS	0	1	0	0	0	0	0	0	0

Table 109. B. Computation of Preference function-Cont.

	Co.3--Co.1	Co.3--Co.2	Co.3--Co.4	Co.3--Co.5	Co.3--Co.6	Co.3--Co.7	Co.3--Co.8	Co.3--Co.9	Co.3--Co.10
	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)
BE	0	0.951101558	0	1	0	0.682428802	0	0	0.682428802
CG	0	0	0	0	0	0	0	0	0
PP	1	0.658414538	0.658414538	0	1	0	0.493810903	1	0
EM	0	0	0	0	0	0	0	0	0
CSS	0	0	0	0	0	0	0	0	0
CU	0.85733882	0.285779607	0	0	0	0	0	0	0
SC	0	0	0	0	1	0	0	1	0
PY	0	0	0	0	0	0	0	0	0
OP	0	0	0	0	0	0	0	0	0
CSE	0	1	0	0	0	0	0	0	0
PS	0	0	0	0	0	0	0	0	0
	Co.4--Co.1	Co.4--Co.2	Co.4--Co.3	Co.4--Co.5	Co.4--Co.6	Co.4--Co.7	Co.4--Co.8	Co.4--Co.9	Co.4--Co.10
	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)
BE	0	0.574959699	0	0.843632456	0	0.306286943	0	0	0.306286943
CG	0	0	0	0	0	0	0	0	0
PP	0.493810903	0	0	0	0.493810903	0	0	0.493810903	0
EM	0	0	0.317819149	0.015292553	0	0	0	0	0
CSS	0	0.537964459	0.638933764	0.638933764	0.278675283	0.422859451	0.278675283	0	0.422859451
CU	0.85733882	0.285779607	0	0	0	0	0	0	0
SC	0	0	0	0	1	0	0	1	0
PY	0	0	0.5	0.5	0	0.5	0	0	0.5
OP	0	0	0.47950553	0	0.830839297	0	0	0.048796357	0.217306441
CSE	0.5	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5
PS	0	0	1	0	0	0	0	0	0

Table 109. B. Computation of Preference function-Cont.

	Co.5--Co.1	Co.5--Co.2	Co.5--Co.3	Co.5--Co.4	Co.5--Co.6	Co.5--Co.7	Co.5--Co.8	Co.5--Co.9	Co.5--Co.10
	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)
BE	0	0	0	0	0	0	0	0	0
CG	0	0	0	0	0	0	0	0	0
PP	1	0.658414538	0	0.658414538	1	0	0.493810903	1	0
EM	0	0	0	0	0	0	0	0	0
CSS	0	0	0	0	0	0	0	0	0
CU	1	0.85733882	0.571559214	0.571559214	0	0	0	0	0
SC	0	0	0	0	1	0	0	1	0
PY	0	0	0	0	0	0	0	0	0
OP	0	0	0.536109304	0	0.887443071	0	0.055302537	0.10540013	0.273910215
CSE	0	1	0	0	0	0	0	0	0
PS	0	0	1	0	0	0	0	0	0
	Co.6--Co.1	Co.6--Co.2	Co.6--Co.3	Co.6--Co.4	Co.6--Co.5	Co.6--Co.7	Co.6--Co.8	Co.6--Co.9	Co.6--Co.10
	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)
BE	0.750671682	1	0.171950564	0.548092423	1	1	0.279419667	0.548092423	1.515314347
CG	0	1	1	1	1	0	0.718960539	0.157844081	0
PP	0	0	0	0	0	0	0	0	0
EM	0	0.464760638	0.999335106	0	0.696808511	0.575797872	0.560505319	0	0
CSS	0	0	0	0	0	0	0	0	0
CU	1	0.85733882	0.571559214	0.571559214	0	0	0	0	0
SC	0	0	0	0	0	0	0	0	0
PY	0	0.5	1	0.5	1	1	0.5	0.5	1
OP	0	0	0	0	0	0	0	0	0
CSE	0	1	0	0	0	0	0	0	0
PS	0	0	1	0	0	0	0	0	0

Table 109. B. Computation of Preference function-Cont.

	Co.7--Co.1	Co.7--Co.2	Co.7--Co.3	Co.7--Co.4	Co.7--Co.5	Co.7--Co.6	Co.7--Co.8	Co.7--Co.9	Co.7--Co.10
	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)
BE	0	0	0	0	0	0	0	0	0
CG	0	0.737247353	1	0.558229066	1	0	0.076997113	0	0
PP	1	0.658414538	0	0.658414538	0	1	0.493810903	1	0
EM	0	0	0	0	0	0	0	0	0
CSS	0	0	0	0	0	0	0	0	0
CU	1	0.85733882	0.571559214	0.571559214	0	0	0	0	0
SC	0	0	0	0	0	1	0	1	0
PY	0	0	0	0	0	0	0	0	0
OP	0	0	0	0	0	0.161353286	0	0	0
CSE	0	1	0	0	0	0	0	0	0
PS	0	0	1	0	0	0	0	0	0
	Co.8--Co.1	Co.8--Co.2	Co.8--Co.3	Co.8--Co.4	Co.8--Co.5	Co.8--Co.6	Co.8--Co.7	Co.8--Co.9	Co.8--Co.10
	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)
BE	0	0.843632456	0	0	1.112305212	0	0.574959699	0	0.574959699
CG	0	0.015399423	0.287776708	0	0.287776708	0	0	0	0
PP	0.658414538	0.164603634	0	0.164603634	0	0.658414538	0	0.658414538	0
EM	0	0	0	0	0	0	0	0	0
CSS	0	0	0	0	0	0	0	0	0
CU	1	0.85733882	0.571559214	0.571559214	0	0	0	0	0
SC	0	0	0	0	0	1	0	1	0
PY	0	0	0.5	0	0.5	0	0.5	0	0.5
OP	0	0	0	0	0	0	0	0	0
CSE	0	1	0	0	0	0	0	0	0
PS	0	0	1	0	0	0	0	0	0

Table 109. B. Computation of Preference function-Cont.

	Co.9--Co.1	Co.9--Co.2	Co.9--Co.3	Co.9--Co.4	Co.9--Co.5	Co.9--Co.6	Co.9--Co.7	Co.9--Co.8	Co.9--Co.10
	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)
BE	0	0.574959699	0	0	0.843632456	0	0.306286943	0	0.306286943
CG	0	0.576515881	0.848893167	0.397497594	0.848893167	0	0	0	0
PP	0	0	0	0	0	0	0	0	0
EM	0	0	0.301196809	0	0	0	0	0	0
CSS	0	1	1	0	1	0.855411955	0.999596123	0.855411955	0.999596123
CU	1	0.85733882	0.571559214	0.571559214	0	0	0	0	0
SC	0	0	0	0	0	0	0	0	0
PY	0	0	0.5	0	0.5	0	0.5	0	0.5
OP	0	0	0	0	0	0	0	0	0
CSE	0	1	0	0	0	0	0	0	0
PS	0	0	1	0	0	0	0	0	0
	Co.10--Co.1	Co.10--Co.2	Co.10--Co.3	Co.10--Co.4	Co.10--Co.5	Co.10--Co.6	Co.10--Co.7	Co.10--Co.8	Co.10--Co.9
	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)	Pj (La, Lb)
BE	0	0	0	0	0	0	0	0	0
CG	0	0.737247353	1	0.558229066	1	0	0	0.076997113	0
PP	1	0.658414538	0	0.658414538	0	1	0	0.493810903	1
EM	0	0	0.359707447	0	0.057180851	0	0	0	0
CSS	0	0	0	0	0	0	0	0	0
CU	1	0.85733882	0.571559214	0.571559214	0	0	0	0	0
SC	0	0	0	0	0	1	0	0	1
PY	0	0	0	0	0	0	0	0	0
OP	0	0	0	0	0	0	0	0	0
CSE	0	1	0	0	0	0	0	0	0
PS	0	0	1	0	0	0	0	0	0

Table 110. B. Computation of preference index.

	Co.1--Co.2	Co.1--Co.3	Co.1--Co.4	Co.1--Co.5	Co.1--Co.6	Co.1--Co.7	Co.1--Co.8	Co.1--Co.9	Co.1--Co.10
	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)
BE	0.039472327	0	0	0.067951639	0	0.010993015	0	0	0.010993015
CG	0.11493359	0.118	0.093809432	0.118	0	0	0.037024062	0	0
PP	0	0	0	0	0	0	0	0	0
EM	0.206	0.206	0.206	0.206	0.096699468	0.206	0.206	0.206	0.206
CSS	0.068	0.068	0.009117932	0.068	0.068	0.068	0.068	0	0.068
CU	0	0	0	0	0	0	0	0	0
SC	0	0	0	0	0.053	0	0	0.053	0
PY	0.009	0.018	0.009	0.018	0	0.018	0.009	0.009	0.018
OP	0.24	0.24	0.186128822	0.172543917	0.24	0.24	0.24	0.24	0.24
CSE	0.054	0	0	0	0	0	0	0	0
PS	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.056
	0.787405917	0.706	0.560056187	0.706495556	0.513699468	0.598993015	0.616024062	0.564	0.598993015
	Co.2--Co.1	Co.2--Co.3	Co.2--Co.4	Co.2--Co.5	Co.2--Co.6	Co.2--Co.7	Co.2--Co.8	Co.2--Co.9	Co.2--Co.10
	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)
BE	0	0	0	0	0	0	0	0	0
CG	0	0	0	0	0	0	0	0	0
PP	0.017777193	0	0	0	0.017777193	0	0	0.017777193	0
EM	0	0	0	0	0	0	0	0	0
CSS	0	0	0	0	0	0	0	0	0
CU	0.025720165	0	0	0	0	0	0	0	0
SC	0	0	0	0	0.053	0	0	0.053	0
PY	0	0.036	0	0.036	0	0.036	0	0	0.036
OP	0	0	0	0	0.031854262	0	0	0	0
CSE	0	0	0	0	0	0	0	0	0
PS	0	0.056	0	0	0	0	0	0	0
	0.043497357	0.092	0	0.036	0.102631454	0.036	0	0.070777193	0.036

Table 110. B. Computation of Preference Index-Cont.

	Co.3--Co.1	Co.3--Co.2	Co.3--Co.4	Co.3--Co.5	Co.3--Co.6	Co.3--Co.7	Co.3--Co.8	Co.3--Co.9	Co.3--Co.10
	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)
BE	0	0.100816765	0	0.106	0	0.072337453	0	0	0.072337453
CG	0	0	0	0	0	0	0	0	0
PP	0.036	0.023702923	0.023702923	0	0.036	0	0.017777193	0.036	0
EM	0	0	0	0	0	0	0	0	0
CSS	0	0	0	0	0	0	0	0	0
CU	0.038580247	0.012860082	0	0	0	0	0	0	0
SC	0	0	0	0	0.053	0	0	0.053	0
PY	0	0	0	0	0	0	0	0	0
OP	0	0	0	0	0	0	0	0	0
CSE	0	0.054	0	0	0	0	0	0	0
PS	0	0	0	0	0	0	0	0	0
	0.074580247	0.191379771	0.023702923	0.106	0.089	0.072337453	0.017777193	0.089	0.072337453
	Co.4--Co.1	Co.4--Co.2	Co.4--Co.3	Co.4--Co.5	Co.4--Co.6	Co.4--Co.7	Co.4--Co.8	Co.4--Co.9	Co.4--Co.10
	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)
BE	0	0.060945728	0	0.08942504	0	0.032466416	0	0	0.032466416
CG	0	0	0	0	0	0	0	0	0
PP	0.017777193	0	0	0	0.017777193	0	0	0.017777193	0
EM	0	0	0.065470745	0.003150266	0	0	0	0	0
CSS	0	0.036581583	0.043447496	0.043447496	0.018949919	0.028754443	0.018949919	0	0.028754443
CU	0.038580247	0.012860082	0	0	0	0	0	0	0
SC	0	0	0	0	0.053	0	0	0.053	0
PY	0	0	0.009	0.009	0	0.009	0	0	0.009
OP	0	0	0.115081327	0	0.199401431	0	0	0.011711126	0.052153546
CSE	0.027	0.054	0.027	0.027	0.027	0.027	0.027	0.027	0.027
PS	0	0	0.056	0	0	0	0	0	0
	0.083357439	0.164387394	0.315999568	0.172022802	0.316128543	0.097220859	0.045949919	0.109488318	0.149374404

Table 110. B. Computation of Preference Index-Cont.

	Co.5--Co.1	Co.5--Co.2	Co.5--Co.3	Co.5--Co.4	Co.5--Co.6	Co.5--Co.7	Co.5--Co.8	Co.5--Co.9	Co.5--Co.10
	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)
BE	0	0	0	0	0	0	0	0	0
CG	0	0	0	0	0	0	0	0	0
PP	0.036	0.023702923	0	0.023702923	0.036	0	0.017777193	0.036	0
EM	0	0	0	0	0	0	0	0	0
CSS	0	0	0	0	0	0	0	0	0
CU	0.045	0.038580247	0.025720165	0.025720165	0	0	0	0	0
SC	0	0	0	0	0.053	0	0	0.053	0
PY	0	0	0	0	0	0	0	0	0
OP	0	0	0.128666233	0	0.212986337	0	0.013272609	0.025296031	0.065738452
CSE	0	0.054	0	0	0	0	0	0	0
PS	0	0	0.056	0	0	0	0	0	0
	0.081	0.11628317	0.210386398	0.049423088	0.301986337	0	0.031049801	0.114296031	0.065738452
	Co.6--Co.1	Co.6--Co.2	Co.6--Co.3	Co.6--Co.4	Co.6--Co.5	Co.6--Co.7	Co.6--Co.8	Co.6--Co.9	Co.6--Co.10
	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)
BE	0.079571198	0.106	0.01822676	0.058097797	0.106	0.106	0.029618485	0.058097797	0.160623321
CG	0	0.118	0.118	0.118	0.118	0	0.084837344	0.018625602	0
PP	0	0	0	0	0	0	0	0	0
EM	0	0.095740691	0.205863032	0	0.143542553	0.118614362	0.115464096	0	0
CSS	0	0	0	0	0	0	0	0	0
CU	0.045	0.038580247	0.025720165	0.025720165	0	0	0	0	0
SC	0	0	0	0	0	0	0	0	0
PY	0	0.009	0.018	0.009	0.018	0.018	0.009	0.009	0.018
OP	0	0	0	0	0	0	0	0	0
CSE	0	0.054	0	0	0	0	0	0	0
PS	0	0	0.056	0	0	0	0	0	0
	0.124571198	0.421320938	0.441809956	0.210817961	0.385542553	0.242614362	0.238919924	0.085723398	0.178623321

Table 110. B. Computation of Preference Index-Cont.

	Co.7--Co.1	Co.7--Co.2	Co.7--Co.3	Co.7--Co.4	Co.7--Co.5	Co.7--Co.6	Co.7--Co.8	Co.7--Co.9	Co.7--Co.10
	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)
BE	0	0	0	0	0	0	0	0	0
CG	0	0.086995188	0.118	0.06587103	0.118	0	0.009085659	0	0
PP	0.036	0.023702923	0	0.023702923	0	0.036	0.017777193	0.036	0
EM	0	0	0	0	0	0	0	0	0
CSS	0	0	0	0	0	0	0	0	0
CU	0.045	0.038580247	0.025720165	0.025720165	0	0	0	0	0
SC	0	0	0	0	0	0.053	0	0.053	0
PY	0	0	0	0	0	0	0	0	0
OP	0	0	0	0	0	0.038724789	0	0	0
CSE	0	0.054	0	0	0	0	0	0	0
PS	0	0	0.056	0	0	0	0	0	0
	0.081	0.203278358	0.199720165	0.115294118	0.118	0.127724789	0.026862852	0.089	0

	Co.8--Co.1	Co.8--Co.2	Co.8--Co.3	Co.8--Co.4	Co.8--Co.5	Co.8--Co.6	Co.8--Co.7	Co.8--Co.9	Co.8--Co.10
	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)
BE	0	0.08942504	0	0	0.117904352	0	0.060945728	0	0.060945728
CG	0	0.001817132	0.033957652	0	0.033957652	0	0	0	0
PP	0.023702923	0.005925731	0	0.005925731	0	0.023702923	0	0.023702923	0
EM	0	0	0	0	0	0	0	0	0
CSS	0	0	0	0	0	0	0	0	0
CU	0.045	0.038580247	0.025720165	0.025720165	0	0	0	0	0
SC	0	0	0	0	0	0.053	0	0.053	0
PY	0	0	0.009	0	0.009	0	0.009	0	0.009
OP	0	0	0	0	0	0	0	0	0
CSE	0	0.054	0	0	0	0	0	0	0
PS	0	0	0.056	0	0	0	0	0	0
	0.068702923	0.18974815	0.124677816	0.031645895	0.160862004	0.076702923	0.069945728	0.076702923	0.069945728

Table 110. B. Computation of Preference Index-Cont.

	Co.9--Co.1	Co.9--Co.2	Co.9--Co.3	Co.9--Co.4	Co.9--Co.5	Co.9--Co.6	Co.9--Co.7	Co.9--Co.8	Co.9--Co.10
	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)
BE	0	0.060945728	0	0	0.08942504	0	0.032466416	0	0.032466416
CG	0	0.068028874	0.100169394	0.046904716	0.100169394	0	0	0	0
PP	0	0	0	0	0	0	0	0	0
EM	0	0	0.062046543	0	0	0	0	0	0
CSS	0	0.068	0.068	0	0.068	0.058168013	0.067972536	0.058168013	0.067972536
CU	0.045	0.038580247	0.025720165	0.025720165	0	0	0	0	0
SC	0	0	0	0	0	0	0	0	0
PY	0	0	0.009	0	0.009	0	0.009	0	0.009
OP	0	0	0	0	0	0	0	0	0
CSE	0	0.054	0	0	0	0	0	0	0
PS	0	0	0.056	0	0	0	0	0	0
	0.045	0.289554849	0.320936101	0.072624881	0.266594434	0.058168013	0.109438952	0.058168013	0.109438952
	Co.10--Co.1	Co.10--Co.2	Co.10--Co.3	Co.10--Co.4	Co.10--Co.5	Co.10--Co.6	Co.10--Co.7	Co.10--Co.8	Co.10--Co.9
	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)	π (La, Lb)
BE	0	0	0	0	0	0	0	0	0
CG	0	0.086995188	0.118	0.06587103	0.118	0	0	0.009085659	0
PP	0.036	0.023702923	0	0.023702923	0	0.036	0	0.017777193	0.036
EM	0	0	0.074099734	0	0.011779255	0	0	0	0
CSS	0	0	0	0	0	0	0	0	0
CU	0.045	0.038580247	0.025720165	0.025720165	0	0	0	0	0
SC	0	0	0	0	0	0.053	0	0	0.053
PY	0	0	0	0	0	0	0	0	0
OP	0	0	0	0	0	0	0	0	0
CSE	0	0.054	0	0	0	0	0	0	0
PS	0	0	0.056	0	0	0	0	0	0
	0.081	0.203278358	0.273819899	0.115294118	0.129779255	0.089	0	0.026862852	0.089