Decision Support

PROMETHEE: A comprehensive literature review on methodologies and applications

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A R T I C L E   I N F O

A B S T R A C T

In recent decades, several Multi-Criteria Decision Aid (MCDA) methods have been proposed to help in selecting the best compromise alternatives. In the meantime, the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) family of outranking methods and their applications has attracted much attention from academics and practitioners. In this paper, a classification scheme and a comprehensive literature review are presented in order to uncover, classify, and interpret the current research on PROMETHEE methodologies and applications. Based on the scheme, 217 scholarly papers from 100 journals are categorized into application areas and non-application papers. The application areas include the papers on the topics of Environment Management, Hydrology and Water Management, Business and Financial Management, Chemistry, Logistics and Transportation, Manufacturing and Assembly, Energy Management, Social, and Other Topics. The last area covers the papers published in several fields: Medicine, Agriculture, Education, Design, Government and Sports. The scholarly papers are also classified by (1) year of publication, (2) journal of publication, (3) authors' nationality, (4) PROMETHEE as applied with other MCDA methods, and (5) PROMETHEE as applied with GAIA (Geometrical Analysis for Interactive Aid) plane. It is hoped that the paper can meet the needs of researchers and practitioners for easy references of PROMETHEE methodologies and applications, and hence promote the future of PROMETHEE research.

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1. Introduction

The Multi-Criteria Decision Aid (MCDA) has been one of the very fast growing areas of Operational Research (OR) during the two last decades. The MCDA often deals with ranking of many concrete alternatives from the best to the worst ones based on multiple conflicting criteria. The MCDA is also concerned with theory and methodology that can treat complex problems encountered in management, business, engineering, science, and other areas of human activity.

In recent years, several MCDA methods have been proposed to help in selecting the best compromise alternatives. The development of MCDA methods has been motivated not only by a variety of real-life problems requiring the consideration of multiple criteria, but also by practitioners' desire to propose enhanced decision-making techniques using recent advancements in mathematical optimization, scientific computing, and computer technology (Wiecek et al., 2008).

The PROMETHEE method (Preference Ranking Organization Method for Enrichment Evaluations) is one of the most recent MCDA methods that was developed by Brans (1982) and further extended by Vincke and Brans (1985). PROMETHEE is an outranking method for a finite set of alternative actions to be ranked and selected among criteria, which are often conflicting. PROMETHEE is also a quite simple ranking method in conception and application compared with the other methods for multi-criteria analysis (Brans et al., 1986). Therefore, the number of practitioners who are applying the PROMETHEE method to practical multiple criteria decision problems, and researchers who are interested in sensitivity aspects of the PROMETHEE method, increases year by year as can be illustrated by increasing numbers of scholarly papers and conference presentations.

Regarding the rapid spreading of the PROMETHEE method to much academic research, this paper conducts a comprehensive literature review on PROMETHEE methodologies and applications. For this purpose, a reference bank has been established based on a classification scheme which includes 217 papers already published in 100 scholarly journals since 1985. Scholarly papers in the scheme are categorized into application areas and non-application papers, and are further distributed to year of publication, journal of publication, authors' nationality, PROMETHEE as applied with other MCDA, and PROMETHEE as applied with GAIA plane.

The rest of the paper is organized as follows: Section 2 briefly describes the history of the PROMETHEE method, the software

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packages, and the steps for implementation of the PROMETHEE II. Section 3 outlines research methodology under a scheme for classification of scholarly papers. Section 4 conducts a review of application papers, which is organized into nine application areas. Analysis of non-application papers is presented in Section 5. Section 6 distributes the reviewed papers to several categories. Finally, the conclusion of the paper is interpreted in Section 7.

2. A brief review of PROMETHEE

2.1. History

The PROMETHEE family of outranking methods, including the PROMETHEE I for partial ranking of the alternatives and the PROMETHEE II for complete ranking of the alternatives, were developed by Brans and presented for the first time in 1982 at a conference organized by Nadeau and Landry at the University Laval, Quebec, Canada (Brans, 1982).

A few years later, several versions of the PROMETHEE methods 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, 1994a) were developed to help in more complicated decision-making situations (Brans and Mareschal, 2005). Figueira et al. (2004) has recently proposed two extended approaches on PROMETHEE, called as the PROMETHEE TRI for dealing with sorting problems and the PROMETHEE CLUSTER for nominal classification.

The methods of PROMETHEE have successfully been applied in many fields and a number of researchers have used them in decision-making problems. The PROMETHEE methods have some requisites of an appropriate multi-criteria method and their success is basically due to their mathematical properties and to their particular friendliness of use (Brans and Mareschal, 2005).

2.2. PROMETHEE II stepwise procedure

This part of the paper briefly describes PROMETHEE II, which is intended to provide a complete ranking of a finite set of feasible alternatives from the best to the worst. This method is fundamental to implement the other PROMETHEE methods and the majority of researchers have referred to this version of the PROMETHEE methods. The basic principle of PROMETHEE II is based on a pairwise comparison of alternatives along each recognized criterion. Alternatives are evaluated according to different criteria, which have to be maximized or minimized. The implementation of the PROMETHEE II requires two additional types of information:

2.2.1. The weight
Determination of the weights is an important step in most multi-criteria methods. PROMETHEE II assumes that the decision-maker is able to weigh the criteria appropriately, at least when the number of criteria is not too large (Macharis et al., 2004).

2.2.2. The preference function
For each criterion, the preference function translates the difference between the evaluations obtained by two alternatives into a preference degree ranging from zero to one. In order to facilitate the selection of a specific preference function, Vincke and Brans (1985) proposed six basic types: (1) usual criterion, (2) *U*-shape criterion, (3) *V*-shape criterion, (4) level criterion, (5) *V*-shape with indifference criterion and (6) Gaussian criterion. These six types are particularly easy to define. For each criterion, the value of an indifference threshold, q; the value of a strict preference threshold, p; and the value of an intermediate value between p and q, s, has to
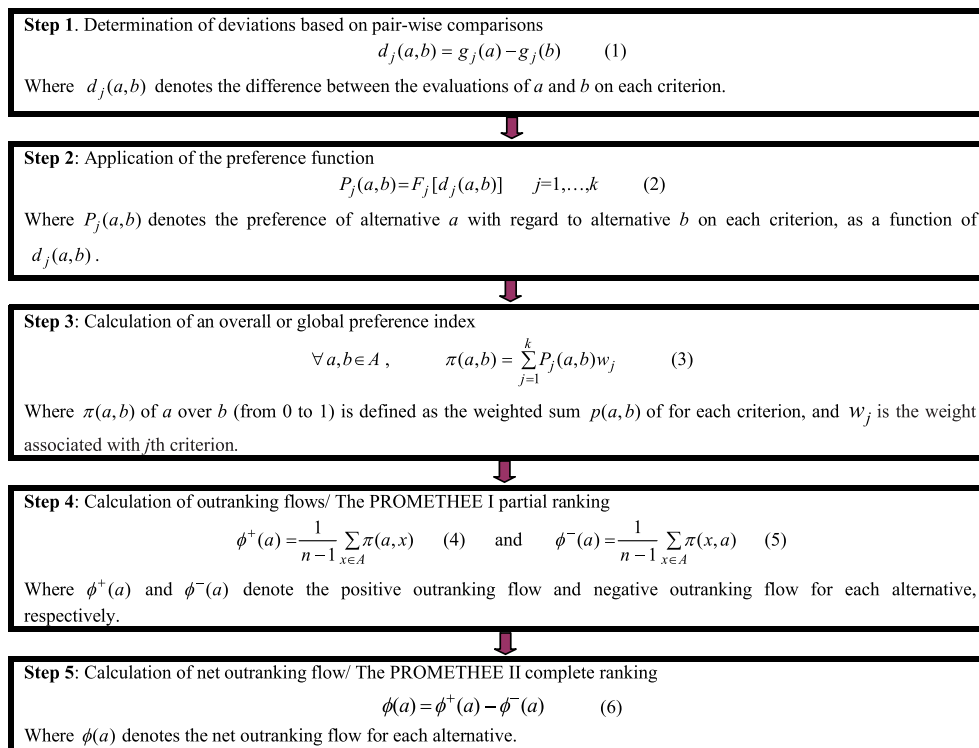

Step 1. Determination of deviations based on pair-wise comparisons
$$d_j(a,b) = g_j(a) - g_j(b) \qquad (1)$$
Where $d_j(a,b)$ denotes the difference between the evaluations of a and b on each criterion.

⬇

Step 2: Application of the preference function
$$P_j(a,b) = F_j[d_j(a,b)] \qquad j=1,\ldots,k \qquad (2)$$
Where $P_j(a,b)$ denotes the preference of alternative a with regard to alternative b on each criterion, as a function of $d_j(a,b)$.

⬇

Step 3: Calculation of an overall or global preference index
$$\forall\, a,b \in A, \qquad \pi(a,b) = \sum_{j=1}^{k} P_j(a,b) w_j \qquad (3)$$
Where $\pi(a,b)$ of a over b (from 0 to 1) is defined as the weighted sum $p(a,b)$ of for each criterion, and w_j is the weight associated with jth criterion.

⬇

Step 4: Calculation of outranking flows/ The PROMETHEE I partial ranking
$$\phi^+(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a,x) \qquad (4) \qquad \text{and} \qquad \phi^-(a) = \frac{1}{n-1} \sum_{x \in A} \pi(x,a) \qquad (5)$$
Where $\phi^+(a)$ and $\phi^-(a)$ denote the positive outranking flow and negative outranking flow for each alternative, respectively.

⬇

Step 5: Calculation of net outranking flow/ The PROMETHEE II complete ranking
$$\phi(a) = \phi^+(a) - \phi^-(a) \qquad (6)$$
Where $\phi(a)$ denotes the net outranking flow for each alternative.

Fig. 1. Stepwise procedure for PROMETHEE II.

be fixed (Brans and Mareschal, 1992). In each case, these parameters have a clear significance for the decision-maker.

Fig. 1 presents stepwise procedure for implementing PROMETHEE II. The procedure is started to determine deviations based on pair-wise comparisons. It is followed by using a relevant preference function for each criterion in Step 2, calculating global preference index in Step 3, and calculating positive and negative outranking flows for each alternative and partial ranking in Step 4.

The procedure is come to an end with the calculation of net outranking flow for each alternative and complete ranking.

2.3. The software packages

Two PROMETHEE software packages, including PROMCALC and DECISION LAB, have been developed to facilitate the PROMETHEE process.

PROMCALC was published by the authors of the method (Mareschal and Brans, 1986). It was provided for all types of multi-criteria problems, the PROMETHEE I, II, V, VI as well as the GAIA visual module. DECISION LAB, developed in collaboration with the Canadian company Visual Decision (Decision Lab, 2000, 1999), is the current software implementation of the PROMETHEE and GAIA methods. It replaces the PROMCALC software that the authors had previously developed. By using DECISION LAB, decision-makers can improve the quality and reliability of the decision-making processes, because of the structured procedure, accompanied by computational help, and the analytical aids (Geldermann and Zhang, 2001).

3. Research methodology

A literature review, based on a study of scholarly journals, was conducted as a research methodology to build a framework for PROMETHEE research. To identify those journal papers that describe methodologies and applications in PROMETHEE, an extensive search using library databases was carried out. The literature review was undertaken to identify the articles in high-ranking journals, which provide most valuable information to researchers and practitioners studying the PROMETHEE methods; hence conference proceeding papers, master's theses, doctoral dissertations, textbooks, and unpublished working papers were excluded from the literature review.

For the purpose of this review, 1985 was chosen as a starting date for search. It was the time that one of the first papers on the subject of PROMETHEE was published by the *Management Science* journal (Vincke and Brans (1985)). The authors believe, therefore, that this year may be considered the starting point of review. Based on the search in the library databases, 217 papers from 100 scholarly journals appeared on the subject of PROMETHEE. The PROMETHEE papers in scholarly journals were identified, analyzed, classified, coded, and recorded under a classification scheme, which is shown in Table 1. As each paper was reviewed, it was classified by several categories: year of publication, authors' nationality, application area, specific area, other tools/methodologies used,

PROMETHEE type, journal of publication, PROMETHEE as applied with other MCDA methods, and PROMETHEE as applied with GAIA plane.

Although this review cannot claim to be exhaustive, it covers a large portion of PROMETHEE publications on methodologies and applications, and hence is a useful source for PROMETHEE researchers and practitioners

4. Analysis of PROMETHEE application areas

One hundred and ninety-five papers out of the papers reviewed (89.9%), were considered applicable for the purposes of this review. The applications of PROMETHEE methods were many and varied; therefore it was so hard for the authors to find the relevant topics. After a detailed study on the applications in order to show similarities and differences, 195 papers were categorized 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. The last area covered the papers published in several fields: Medicine, Agriculture, Education, Design, Government, and Sports. In the next effort, application papers were distributed to the suitable topic. Although a scholarly paper may fall into two topics; the best possible topic was taken into account with the purpose of staying away of duplication.

The following sections review 195 scholarly papers based on the nine main application areas and various specific areas. First, a small number of the papers are briefly mentioned in each section, and then the whole of papers in each topic are summarized in the specific tables. In order to offer a brief overview on PROMETHEE applications published in each topic, the papers are arranged in alphabetical order by author. In the vast majority of application papers, a number of PROMETHEE extensions or modifications have been proposed to make PROMETHEE more representative and workable. Those are included in "other tools/methodologies used" column of each table.

4.1. Environment Management

Environment Management is considered as the most popular topic in PROMETHEE applications and a large amount of the papers are related to this topic. Environment Management has covered several specific areas such as waste management, Life Cycle Assessment (LCA), Environmental Impact Assessment (EIA), and land-use planning.

In the context of waste management, Briggs et al. (1990) employed PROMETHEE I and II, based on a small number of strongly conflicting criteria, to obtain a complete ordering of 27 actors: electricity companies, consumers, public bodies, and so on. Petras (1997) applied PROMETHEE II in order to rank the sites for radioactive waste disposal facilities in Croatia. The potential sites were chosen based on exclusionary criteria. Queiruga et al. (2008) used PROMETHEE, combined with a survey of experts, to rank Spanish municipalities according to their appropriateness for the installation of waste recycling plants.

Table 1
The classification scheme for the literature review on PROMETHEE.

S.N	Year of publication	Authors	Authors' nationality	Application area	Specific area	Other tools/ methodologies used	PROMETHEE type	Journal of publication	As applied with other MCDA	As applied with GAIA analysis
1										
2										
...										
217										

In the context of LCA, Le Téno and Mareschal (1998) developed a new version of PROMETHEE II, with interval criteria and fuzzy set theory, to evaluate the environmental quality of building products through LCA. Geldermann et al. (2000) proposed PROMETHEE, combined with fuzzy set theory, to rank sinter plants through LCA based on 12 impact factors. Geldermann and Rentz (2005) applied PROMETHEE I and II to rank scenarios for the coating of PVC parts for automobile production.

In other fields, in order to prioritize environmental projects in Jordan and to evaluate their environment impacts, Al-Rashdan et al. (1999) utilized PROMETHEE II and PROMETHEE V as decision tools and the Nominal Group Technique (NGT) as a structured group decision process. Application in this paper was undertaken to introduce financial, incomparability, and regional development constraints. Rogers et al. (2004) and Linkov et al. (2006a) employed PROMETHEE II, based on four criteria: cost, environmental quality, ecological habitat, and human habitat, to select technological alternatives for a sediment management project involving the Cocheco River. Huth et al. (2005) proposed a stochastic extension of the PROMETHEE method to evaluate 64 different tree-harvesting scenarios in an initially undisturbed dipterocarp lowland rain forest stand in Malaysia. Beynon and Wells (2008) developed an analysis of uncertainty on PROMETHEE II, based on constituents of exhaust emissions, to rank a small set of motor vehicles. In order to assess land-use suitability based on Geographic Information Systems (GIS) and PROMETHEE, Marinoni (2006) used an iterative approach. The research aimed at figuring out whether a specific area is suitable for residential housing construction. Drechsler (2004) applied PROMETHEE while considering uncertainties and goal conflicts in biological decision-making, and analyzed simple fictitious decision problem with four ecological objectives. Kapepula et al. (2007) proposed PROMETHEE II and III in order to rank nine areas of the city with respect to multiple criteria of nuisance. Palma et al. (2007) employed PROMETHEE II to evaluate integrated performance of silvoarable agroforestry on hypothetical farms.

In order to take into account the equity issues in the greenhouse gases emission rights allocation process, Vaillancourt and Waaub (2004) used PROMETHEE II to rank regions or countries, by considering their own characteristics, their perceptions of equity and the different economic, social, and environmental stakes countries. Diakoulaki et al. (2007) proposed PROMETHEE to identify priority countries and interesting investment opportunities in each priority country for the exploitation of the clean development mechanism. These opportunities were then evaluated through a conventional financial analysis, to assess their economic and environmental attractiveness. Table 2 presents a summary of the PROMETHEE papers addressed in the topic of Environment Management.

4.2. Hydrology and Water Management

Most of the papers on the topic of Hydrology and Water Management have been devoted to the sustainable water resources planning, water management strategies assessment, and irrigation planning. The publications on this topic are quite new in comparison with the other topics of PROMETHEE applications. The first paper on the topic of Hydrology and Water Management was presented by Abu-Taleb and Mareschal (1995) about water resources issues in the Middle East. The paper applied PROMETHEE II and V to evaluate and select from a variety of potentially feasible water resources development options, so that the allocation of limited funds to alternative development projects and programs can proceed in the most efficient manner.

In the context of water resources planning, Ozelkan and Duckstein (1996) used PROMETHEE I and II, based on 33 criteria, to rank 12 water resources projects designed at the Austrian part of Danube River. The projects included the construction of several hydro-power plants as well as a national park, and the criteria consisted of mainly three conflicting types of interest: economic, ecological, and sociological. Hyde and Maier (2006) applied PROMETHEE, coupled with stochastic uncertainty analysis approach and distance-based uncertainty analysis approach, to solve sustainable water resource development problems in the Northern Adelaide Plains, South Australia. The paper also introduced a program which enabled a decision-maker to examine the robustness of a solution obtained while using MCDA techniques.

In the field of water management strategies assessment, Simon et al. (2004, 2005, 2006) employed PROMETHEE I and II to evaluate water management strategies. Raju et al. (2000) presented PROMETHEE II, based on economic, environmental and social factors, to rank alternative strategies that could change the planning scenario of the irrigation system. The paper also used a group decision-making approach, compared to a single decision-maker approach.

In other fields, Khelifi et al. (2006a) developed PROMETHEE II, based on technical, economical, environmental, and social criteria, to assess and select groundwater remediation technologies. Opricovic and Tzeng (2007) proposed PROMETHEE as a tool, in comparison with three MCDA methods, to rank six alternative hydropower systems on the Driana River based on eight criteria. In order to plan actions in water supply systems, Morais and de Almeida (2006) employed a group decision-making on PROMETHEE. Raju and Pillai (1999a) proposed an extension of PROMETHEE in a distance-based environment to select the best reservoir configuration for river basins. Furthermore, in order to select the best alternative in irrigation development strategies, Raju and Pillai (1999b) applied PROMETHEE with the Taguchi experimental method and stochastic extension of PROMETHEE. Morais and De Almeida (2007) proposed a group decision-making model based on PROMETHEE GDSS procedure, which took into account the points of view of four stakeholders, and PROMETHEE V method, which selected feasible options under available budget constraints, to develop a leakage management strategy. A list of the papers on the topic of Hydrology and Water Management can be found in Table 3.

4.3. Business and Financial Management

The publications on the topic of Business and Financial Management are quite rich, focusing mainly on the key aspects of general management, performance measurement, portfolio management, and investment analysis.

In the contexts of investment analysis and portfolio management, Albadvi et al. (2007) applied PROMETHEE I and II as a decision-making tool to select the superior stocks for investment at Tehran Stock Exchange (TSE). With respect to selecting the superior stocks, 13 effective criteria in industry evaluation and 28 effective criteria in company evaluation were introduced according to a survey from the experts. Vranegl et al. (1996) applied PROMETHEE II, based on 15 criteria, to choose the optimal investments. Bouri et al. (2002) used PROMETHEE II and V to select attractive portfolios under the investor's constraints.

In the performance measurement context, Mareschal and Brans (1991) developed BANKADVISER, based on the PROMETHEE multi-criteria methodology, to provide evaluations of individual items such as firms, industries, companies, and industrial clients, within a set of similar ones. Babic and Plazibat (1998) ranked enterprises according to the achieved level of business efficiency, as a hybrid integration of Analytical Hierarchy Process (AHP) and PROMETHEE. Kalogeras et al. (2005) used PROMETHEE II to rank agri-food firms according to profitability ratios, solvency ratios, and managerial performance ratios. Bilsel et al. (2006) conducted a research based on PROMETHEE to measure the performance of the Web sites of Turkish hospitals

Table 2
The applied papers on the topic of "Environment Management".

Author(s)	Specific area	Other tools/methodologies used
Al-Rashdan et al. (1999)	Ranking and selecting environmental projects	The Nominal Group Technique
Ayoko et al. (2003)	Ranking organization compounds with fungicidal properties	–
Ayoko et al. (2004)	To select residential houses base on air quality criteria	–
Beynon and Wells (2008)	Ranking motor vehicles based on exhaust emissions	Uncertainty analysis
Briggs et al. (1990)	Nuclear waste management problem/ranking 27 actions	–
Carroll et al. (2004)	Ranking various soil types/wastewater treatment systems	Principal Component Analysis (PCA)
de Leeneer and Pastijn (2002)	To select land mine detection strategies	–
Delhaye et al. (1991)	Nuclear waste management problem	–
Diakoulaki et al. (2007)	To identify investment opportunities for the exploitation of the clean development mechanism	–
Drechsler (2004)	Major issues of conservation biology/analyzing simple fictitious	Uncertainty analysis and goal conflicts
Geldermann et al. (2000)	Ranking sinter plants through Life Cycle Assessment (LCA)	Fuzzy PROMETHEE
Geldermann and Rentz (2001)	Environmental assessment for sinter plants	Trapezoidal fuzzy intervals
Geldermann and Rentz (2005)	Ranking scenarios for the coating of PVC parts/LCA	–
Gilliams et al. (2005)	To choose among the afforestation strategies for a given class of agricultural land	Geographic Information System (GIS)/goal programming technique
Hokkanen and Salminen (1997)	The location problem of a waste treatment facility	–
Huth et al. (2005)	To evaluate tree-harvesting scenarios	Stochastic PROMETHEE
Kangas et al. (2001a)	Supporting strategic natural resources planning	Fuzzy method
Kangas et al. (2001b)	Ranking forestry strategies	–
Kapepula et al. (2007)	Household solid waste management/ranking nine areas	–
Kiker et al. (2005)	Decision-making in environmental projects	A review paper on MCDA methods including PROMETHEE
Klauer et al. (2006)	Decisions for sustainable development	Decisions under uncertainty
Le Téno and Mareschal (1998)	To evaluate the environmental quality of building products through LCA	A new version of PROMETHEE with interval criteria/fuzzy theory
Le Téno (1999)	LCA	PCA/non-parametric bootstrapping
Linkov et al. (2006a)	Ranking contaminated sediment management technologies	A review on MCDA for sediment management
Linkov et al. (2006b)	Environmental risk assessment and decision-making strategies/he New York/New Jersey arbor as a case study	A review on MCDA applications for contaminated site management
Margeta et al. (1990)	Ranking wastewater disposal alternatives	–
Marinoni (2006)	Land-use suitability assessment	An iterative approach/GIS
Martin et al. (1999)	Land-use planning and management	GIS
Martin et al. (2003)	The environmental impact assessment (EIA)/ranking sites to build bus station	Fuzzy PROMETHEE I and II
Mavrotas et al. (2006a)	To evaluate strategies for reducing atmospheric pollutants	–
Mergias et al. (2007)	To select the best scheme for End-of-Life Vehicles (ELVs)	–
Moffett and Sarkar (2006)	Biodiversity conservation planning	A taxonomy of MCDM methods including PROMETHEE
Palma et al. (2007)	To evaluate performance of silvoarable agroforestry	–
Petras (1997)	Ranking the sites for radioactive waste disposal facilities	–
Queiruga et al. (2008)	Ranking the alternatives location for installation of recycling plants (to recycle waste electrical and electronic equipment)	–
Rogers et al. (2004)	Ranking contaminated sediment management technologies	–
Rousis et al. (2008)	Ranking alternative management systems for the waste from electrical and electronic equipment constitutes	–
Salminen et al. (1998)	To analyze four different real applications to environment problems in Finland	–
Sarkis (2000)	The location problem of a waste treatment facility	–
Settle et al. (2007)	Ranking the combined North Lakes and Cabbage tree samples to determine the water quality behaviour	PCA/Partial Least Squares (PLS)
Spengler et al. (1998)	Ranking recycling measures in the iron and steel making industry/LCA	KOSIMEUS: a simulation and decision support system model
Vaillancourt and Waaub (2002)	Ranking waste management facilities	Mixed integer linear programming
Vaillancourt and Waaub (2004)	Ranking regions or countries in order to allocate the greenhouse gases emission rights	A dynamic multi-criterion model
Vego et al. (2008)	Ranking solid waste management alternatives	–
Vuk et al. (1991)	The location problem for disposal of communal waste	–
Walther et al. (2008)	To evaluate municipalities for the installation of recycling facilities	–
Yan et al. (2007)	Ranking municipal sewage treatment plant projects	–

In other fields, Baourakis et al. (2002) presented PROMETHEE II, based on financial characteristics, to assess the viability of Greek companies in the field of agricultural food-production and marketing. Hens et al. (1992) related PROMETHEE to the problem of determining fair burden sharing for the European budget. Mavrotas et al. (2006b) combined PROMETHEE II and V with multi-objective integer programming to select firms applying for financial support from public funds under policy restriction and budget constraints. Doumpos and Zopounidis (2004) used PROMETHEE and a linear programming approach for credit risk assessment, as an application to a financial decision-making problem. The PROMETHEE method was employed to perform the pair-wise comparisons and to develop an appropriate index for the classification of the alternatives. The linear programming approach was also proposed to

Table 3
The applied papers on the topic of "Hydrology and Water Management".

Author(s)	Specific area	Other tools/methodologies used
Abu-Taleb and Mareschal (1995)	To rank and select water resources development options	–
Al-Kloub and Abu-Taleb (1988)	To rank the co-riparians/water rights and water sharing	–
Al-Shemmeri et al. (1997)	Ranking of water development projects	–
Ayoko et al. (2007)	Ranking the quality of the water bodies	PCA/PLS
Chou et al. (2004)	To determine depression outlet location and flow direction in digital terrain model	A depression watershed method
Chou et al. (2007)	Ranking embankment types (ecotechnology models) located in Shihmen reservoir watershed	Fuzzy theory/GIS
Hajkowicz and Collins (2007)	Water resource management	A review of multiple criteria analysis
Hajkowicz and Higgins (2008)	Six water resource management decision problems	–
Hermans et al. (2007)	Ranking river management alternatives	Conjoint analysis
Hermans and Erickson (2007)	To facilitate decision making at the watershed scale	A review of MCDA techniques
Hyde and Maier (2006)	Sustainable water resource development problem	Stochastic uncertainty analysis and distance-based uncertainty analysis
Khelifi et al. (2006a)	To select groundwater remediation technologies	–
Mahmoud and Garcia (2000)	Evaluating alternatives for the operation of a diversion dam	–
Morais and de Almeida (2006)	The planning of actions in water supply systems	Group decision-making
Morais and De Almeida (2007)	Ranking alternative strategies of water network to reduce leakage	–
Opricovic and Tzeng (2007)	Ranking alternative hydropower systems on the river	–
Ozelkan and Duckstein (1996)	Ranking water resources projects (hydropower plants)	PCA
Pillai et al. (1996)	To select the best alternative plan in irrigation development strategies	–
Pudenz et al. (2002)	Evaluating strategies of sustainable water management	–
Raju and Pillai (1999a)	To select the best reservoir configuration for river basin	Spearman rank correlation
Raju and Pillai (1999b)	To select the best alternative in irrigation development strategies	Taguchi experimental method/Stochastic PROMETHEE
Raju and Kumar (1999)	To select the best compromise irrigation plan	Cluster analysis and Spearman rank correlation
Raju et al. (2000)	Ranking the alternative strategies of the irrigation system	Spearman rank correlation/group decision-making.
Raju and Kumar (2006)	To select the suitable irrigation planning alternatives	Data Envelopment Analysis (DEA)/Spearman rank correlation/EXPROM
Simon et al. (2004)	The evaluation of water management strategies	–
Simon et al. (2005)	The evaluation of water management strategies	–
Simon et al. (2006)	To evaluate eco-hydrological effects of water management strategies	–
Ulengin et al. (2001)	To select most suitable remedy for water-crossing problem	–

Table 4
The applied papers on the topic of "Business and Financial Management".

Author(s)	Specific area	Other tools/methodologies used
Albadvi et al. (2007)	To select the superior stocks for investment	–
Araz and Ozkarahan (2005)	Financial classification problems/business failure risk	PROMSORT
Babic and Plazibat (1998)	Ranking enterprises according to the achieved level of business efficiency	–
Baourakis et al. (2002)	To assess the viability of companies based upon the financial criteria	PCA
Bilsel et al. (2006)	To measure the performance of the Web sites of Turkish hospitals	Fuzzy PROMETHEE
Bouri et al. (2002)	To select attractive portfolio	–
Brans et al. (1986)	Selecting and ranking projects	–
de Smet and Guzman (2004)	Country risk problem and diagnosis of firms problem	An extension of k-means algorithm
Doumpos and Zopounidis (2004)	Credit risk assessment based on 12 financial ratios	A linear programming approach
Hababou and Martel (1998)	Selecting a portfolio manager	–
Halouani et al. (2009)	To select investment projects	PROMETHEE- Multi Decision maker 2-Tuple-I and II
Hens et al. (1992)	The problem of determining fair burden sharing for the European budget	–
Kalogeras et al. (2005)	Ranking the financial performance of agri-food firms	PCA
Kunsch and Brans (2004)	Ranking and selection of a strategy/strategic planning and control	System dynamics/control theory
Mareschal (1986)	Project evaluation by experts	Uncertainty analysis
Mareschal and Brans (1991)	To evaluate industrial clients	BANKADVISOR
Mareschal et al. (1992)	To position each bank with respect to used-defined reference market	–
Mavrotas et al. (2006b)	The selection of firms applying for financial support from public funds	Multi-objective integer programming
Mitková et al. (2007)	Ranking the private pension funds	Portfolio theory/Black–Littermann
Nowak (2005)	Investment projects selection problem	Stochastic dominance
Seo et al. (2005)	Web service selection problem	–
Vranegl et al. (1996)	The problem of the optimal choice of investments	Expert system/DSS/fuzzy sets
Wang et al. (2006)	Vendor selection	–
Xu (2001)	Selecting and ranking projects	Superiority and inferiority ranking
Zopounidis and Doumpos (2002)	Investment appraisal/performance portfolio assessment/Credit risk assessment	A review paper on MCDA methods including PROMETHEE

induce the parameters of the classification model, including the criteria weights and the criteria preference functions, from a given set of reference alternatives. Table 4 presents a list of the papers applied to the topic of Business and Financial Management.

4.4. Chemistry

Chemistry is a new and popular topic in PROMETHEE applications and a considerable number of publications have been devoted to this topic. The papers on the topic of Chemistry are often concerned with the evaluation and ranking of chemical material and samples in the experimental environments.

Most of the papers in this topic considered PROMETHEE II as a Chemometrics method to analyze the results of the experiments. For instance, Zhang et al. (2006) combined PROMETHEE and Chemometrics methods, based on physico-chemical properties, to rank 67 oil objects as a versatile indicator of quality performance of product. In order to rank the spectral objects, based on the Rapid Near Infrared (NIR) information. Purcell et al. (2007) conducted a research on PROMETHEE II in combination with Chemometrics methods. Herngren et al. (2006) used PROMETHEE II, based on eight heavy metal elements, to assess the relationships between heavy metals and Total Organic Carbon (TOC), and to rank residential, industrial, and commercial sites and five particle sizes.

Ni et al. (2002) employed PROMETHEE together with Chemometrics methods, to rank ten different calibration models in food samples. In a further attempt, Ni et al. (2007) applied PROMETHEE II to rank and compare the complex Huoxiang Zhengqi Tincture (HZT) profiles, and to obtain more information from the chromatograms. The results showed that with the PROMETHEE analysis, it was possible to match and discriminate correctly the batch samples from the three different manufacturers. Khalil et al. (2004) applied PROMETHEE I and II for the analysis of eight sampling sites and PROMETHEE II for the evaluation of 16 and 48 other sampling sites. In this regard, physico-chemical characteristics of soil were

the foundation for site suitability assessment for conventional on-site sewage treatment.

Lim et al. (2007a) used PROMETHEE II to rank the emission factors from the cars in terms of the types of the fuels, used to power the cars and the engine operating parameters. The complete ranking was performed on a matrix that consisted of the emission factors and 15 cars operated at modes 2 and 3. Lim et al. (2007b) also presented PROMETHEE II to investigate the effects of engine powers and sulfur contents in the diesel fuels on the emission factors for buses operated at modes 10 and 11. Table 5 gives a brief summary of scholarly papers on the topic of Chemistry.

4.5. Logistics and Transportation

Logistics and Transportation is also one of the earliest topics which can be found in the literature of PROMETHEE. The topic often discusses some specific areas such as location problems, outsourcing and selection of suppliers in the different fields, and transportation.

In the context of outsourcing, Wang and Yang (2007) conducted a research on information systems outsourcing. They employed a hybrid integration of PROMETHEE II and AHP to provide powerful tools for ranking of candidate information systems and analyzing of the relations between criteria. Araz and Ozkarahan (2007) developed a new multi-criteria sourcing method based on the PROMETHEE method, PROMSORT, to sort suppliers based on their preference relations and to select them for strategic partnership, supplier development programs, competitive partnership, and pruning. Dulmin and Mininno (2003) used PROMETHEE for an outsourcing research, applied for a mid-sized Italian firm operating in the field of public road and rail transportation, in order to choose the relevant suppliers.

In the context of location problems, Mladineo et al. (1987) presented PROMETHEE I and II to rank six alternative locations for the construction of small scale hydro plants. In order to select the best

Table 5
Applied papers on the topic of "Chemistry".

Author(s)	Specific area	Other tools/methodologies used
Carmody et al. (2005)	To study modified kaolinite surfaces.	Chemometrics methods: PCA/data pretreatment
Carmody et al. (2006)	To analyze the kaolinite surface infrared spectra	Chemometrics methods: PCA
Carmody et al. (2007)	To select a sorbent for an oil spill application	Chemometrics methods: PCA
Herngren et al. (2006)	Ranking the sites and particle sizes from best to worst in terms of heavy metal pollution	Chemometrics methods: PCA
Hendriks et al. (1992)	Optimization a coating process of fine granules	–
Khalil et al. (2004)	To evaluate and select suitable site for sewage effluent renovation	Chemometrics methods: PCA
Khalil et al. (2005)	To select hydrothermal conditions of waste sludge destruction	Chemometrics methods: PCA
Khelifi et al. (2006b)	To assess and rank oil regeneration technologies	–
Kokot et al. (1992a)	To select a suitable microwave digestion method	PCA
Kokot et al. (1992b)	To select a suitable microwave digestion method	PCA, SIMCA, and fuzzy clustering
Kumar et al. (2006)	Ranking the alternatives for biomass collection systems	–
Lerche et al. (2002)	Ranking 12 high production volume Chemical substances	–
Lewi et al. (1992)	Ranking experiments on the quality of treated polyester	Pareto optimal points
Lim et al. (2005)	Ranking the air samples and identifying the sources of the pollutants	Chemometrics methods: PCA
Lim et al. (2006)	Ranking the cars based on the emission factors powered by liquefied petroleum gas and unleaded petrol	Chemometrics methods: PCA
Lim et al. (2007a)	Ranking the emission factors from cars in terms of the types of the fuels	Chemometrics methods: PCA
Lim et al. (2007b)	Ranking the emission factors from buses in term of the diesel fuels	Chemometrics methods: PCA/PLS
Ni et al. (2002)	Ranking Chemometrics methods according to their performances in industrial electroplating	Classical Least Squares (CLS), Principal Component Regression (PCR), PLS, Artificial Neural Networks (ANN)
Ni et al. (2004)	Ranking 10 different calibration models in food samples	Chemometrics methods: PCA/ANN
Ni et al. (2007)	Ranking and comparing the complex HZT profiles	Chemometrics methods: PCA
Purcell et al. (2005)	Ranking the samples according to the gas chromatography data	Chemometrics methods: PCA/PLS
Purcell et al. (2007)	Ranking spectral objects based on NIR (rapid near infrared) information	Chemometrics methods: PCA/PLS
Ramazan and Witt (2007)	Selecting the best alternative for improvement of process safety and reliability	Extended Hazop methodology
Zhang et al. (2006)	Ranking oil objects as a versatile indicator of quality performance of products	Chemometrics methods: PCA/PLS/Radial Basis Function–Artificial Neural Networks (RBF–ANN)

location to build an electricity power plant somewhere in the European Union, Leyva-López and Fernández-González (2003) conducted a comparative study of PROMETHEE II for group decision with an extension of the ELECTRE III multi-criteria outranking methodology.

In the context of transportation, Radojevic and Petrovic (1997) combined PROMETHEE and fuzzy IF-THEN rules to rank alternative roads in Belgrade–Birmingham route problem, based on four criteria: distance, traveling time, traveling cost, and road quality. Brans and Mareschal (1994b) proposed PROMETHEE I and II to rank 12 potential alternative sites based on five criteria, and PROMETHEE V to select the suitable sites under six constraints. The research intended to enhance the network of distribution centers in Europe for a large North American distribution company. Fernández-Castro and Jiménez (2005) combined PROMETHEE II, III and V, based on fuzzy evaluations, to rank and select distribution centers for a firm in four areas of Belgium. PROMETHEE II in this research associated a crisp number to each action; PROMETHEE III associated an interval to each action; and PROMETHEE V applied integer linear programming, subject to a set of constraints, to select the subset of alternatives that maximizes the sum of PROMETHEE II scorings. Elevli and Demirci (2004) employed PROMETHEE I and II to select the most suitable underground ore transport system for a chromites mine in Turkey. The research included five possible ore transport systems and six criteria to evaluate them. Table 6 summarizes the papers on the topic of Logistic and Transportation.

4.6. Manufacturing and Assembly

Manufacturing and Assembly is also an important application area in the literature of the PROMETHEE methods that is mainly related to the aspects of manufacturing systems and planning, maintenance programming, and assembly line planning.

In the context of manufacturing system, Kolli et al. (1992) employed PROMETHEE II, based on six criteria: product quality, manufacturing flexibility, market response, costs, inventory, and lead-time, to rank six alternatives for investment in advanced manufacturing technology. Araz (2005) conducted a research by integrating a simulation model, Back-Propagation Neural Network (BPNN), and PROMETHEE II to rank and to select 27 appropriate dispatching

rules for a Dual-Resource Constrained (DRC) manufacturing system. Pandey and Kengpol (1995) proposed PROMETHEE I and II to rank the best possible automated inspection devices for use in a Flexible Manufacturing System (FMS) and PROMETHEE V to select them under technological and other constraints. In order to compare and to rank nine scheduling strategies based on a certain number of conflicting criteria, Roux et al. (2008) used a framework as a combination of a lexicographical sort and the PROMETHEE II multi-criteria method.

In the maintenance context, Petrovie et al. (1988) formulated integer programming, combined with PROMETHEE I and II, to choose the list of spare parts for maintenance purposes. Three objectives of the problem were: minimizing spare parts cost subject to a given mean logistics delay time, maximizing reliability subject to a constraint on spares cost, and minimizing spare cost subject to a given fill rate. Chareonsuk et al. (1997) incorporated a new model with two criteria, expected total costs per unit time and reliability of the production system, into PROMETHEE to determine optimal preventive–maintenance intervals for components in a production system. Waeyenbergh et al. (2004) employed PROMETHEE II to tactically choose a predictive maintenance program for an automotive paint shop.

In the field of assembly planning, Rekiek et al. (2002) used PROMETHEE II, combined with the multi-objective grouping genetic algorithm and the branch-and-cut method, to select the best equipment combination for each assembly station. In order to rank the new population in genetic algorithms, de Lit et al. (2001) and Rekiek et al. (2001) applied PROMETHEE II in the field of assembly line balancing. A list of PROMETHEE papers on the topic of Manufacturing and Assembly is presented in Table 7.

4.7. Energy Management

Various PROMETHEE applications are suggested for the topic of Energy Management. Most research in this topic have concentrated on selecting and evaluating energy generation or exploitation alternatives.

In the context of Energy Management, Tzeng et al. (1992) employed PROMETHEE to evaluate comprehensively the alternatives for new energy-system development. The paper evaluated energy

Table 6
The applied papers on the topic of "Logistic and Transportation".

Author(s)	Specific area	Other tools/methodologies used
Anagnostopoulos et al. (2003)	To evaluate priorities for land transportation infrastructure projects	–
Araz and Ozkarahan (2007)	Strategic sourcing in new product development/ranking suppliers	PROMSORT (PROMETHEE sorting)
Araz et al. (2007)	To select the strategic partners/outsourcing manufacturers	Fuzzy goal programming
Brans and Mareschal (1992)	The location choice of distribution centers	–
Brans and Mareschal (1994b)	Enhancing network of distribution centers in Europe/ranking and selecting potential sites	–
Dulmin and Mininno (2003)	Outsourcing in the field of public road and rail transportation/ranking suppliers	–
Elevli and Demirci (2004)	To select the most suitable underground ore transport system	–
Fernández-Castro and Jiménez (2005)	To rank and select distribution centers for a firm	F-PROMETHEE/fuzzy integer linear programming
Jugović et al. (2006)	To analyze the traffic service of Pan-European corridor within market conditions	–
Karkazis (1989)	The location choice of shops for a firm in order to enter a market	Linear programming/algorithm of allocating sites
Leyva-López and Fernández-González (2003)	To select the best location to build electricity power plant	Group decision/genetic algorithm for exploiting fuzzy relation
Marinoni (2005)	Ranking the large land parcels with respect to their suitability for residential housing construction.	Stochastic PROMETHEE/GIS
Mladineo et al. (1987)	Ranking the locations for the construction of small scale hydro plants	–
Mladineo et al. (1992)	Deciding on alternative solutions of the highway route according to DSS	–
Pavic and Babic (1991)	The location choice of a production system	–
Radojevic and Petrovic (1997)	Ranking alternative roads in Belgrade–Birmingham route problem	Fuzzy IF-THEN rules
Raveh (2000)	A location problem/ranking locations	Graphic display technique
Ribarovic and Mladineo (1987)	Ranking the locations of the ready-mixed concrete plants	–
Wang and Yang (2007)	Ranking candidate information systems/information system outsourcing	–

Table 7
The applied papers on the topic of "Manufacturing and Assembly".

Author(s)	Specific area	Other tools/methodologies used
Anand and Kodali (2008)	Selecting lean manufacturing systems (LMS)	–
Araz (2005)	To rank and select appropriate dispatching rules for a Dual-Resource Constrained (DRC) manufacturing system	–
Belz and Mertens (1996)	Scheduling in manufacturing/ranking the alternatives based on the completion times for one simulation round	SIMULEX: a prototype decision support system for scheduling
Cavalcante et al. (2007)	The planning for preventive maintenance, by controlling failures in the specific context of equipment breakdown	Bayesian methodology to address uncertainties during equipment failures
Chareonsuk et al. (1997)	Determining optimal preventive–maintenance intervals	Incorporating a new model with two criteria
Dagdeviren (2008)	Selecting the best equipment milling machines	–
de Lit et al. (2001)	Ranking the individuals in the population/assembly planning	Original ordering Genetic Algorithm (OGA)
Duvivier et al. (2007)	To determine the best strategy for scheduling nonpreemptable jobs	Classical hill-climber meta-heuristic
Keller et al. (1991)	To select an optimal formulation of a finishing product	PCA
Kolli et al. (1992)	Ranking alternatives for investment in advanced manufacturing technology	–
Martel and Aouni (1990)	The problems of production planning	Goal programming model
Pandey and Kengpol (1995)	To rank the best possible automated inspection devices for use in FMS and select them under technological and other constraints	–
Parsaei et al. (1993)	The justification of Computer Integrated Manufacturing (CIM) systems	–
Parreiras et al. (2006)	To choose the final optimal solution/an inverse electromagnetic scattering problem	–
Petrovie et al. (1988)	Choosing the list of spare parts for maintenance purposes	Spares cost minimization and reliability maximization integer programming
Rekiek et al. (2001)	Ranking the individuals in the population/assembly planning	Multi-objective grouping genetic algorithm
Rekiek et al. (2002)	To select the best equipment combination for each station/the hybrid assembly line design	Multi-objective grouping genetic algorithm/the branch-and-cut method
Roux et al. (2008)	Ranking several scheduling strategies	PlanOrdo framework/lexicographical sort
Waeyenbergh et al. (2004)	The tactical choice of a predictive maintenance program for an automotive paint shop	–

technology, environmental impacts, sociology, and economic factors, and then proposed development directions and strategy for future energy systems in Taiwan. Goumas and Lygerou (2000) conducted a research by fuzzy PROMETHEE II to evaluate and to rank alternative energy exploitation schemes of a low temperature geothermal field. The research introduced new information into the PROMETHEE II method resulting in a more realistic and reliable ranking, where the uncertainty of the input data needs taking into account. Diakoulaki and Karangelis (2007) presented PROMETHHE, based on eight economical, technical, and environmental criteria, to comparatively evaluate four scenarios for the development of the power generation sector in Greece. Doukas et al. (2006) applied PROMETHEE II to evaluate the sustainable technologies for electricity generation, according to the environmental, social, economical, and technological dimension of sustainable development.

In order to evaluate and to rank renewable energy projects according to a multi-criteria group decision-making action plan, Haralambopoulos and Polatidis (2003) conducted a research utilizing the PROMETHEE II method. Hyde et al. (2003) proposed an extension of the PROMETHEE method to evaluate six renewable energy scenarios. The proposed approach involved defining the uncertainty in the input values using probability distributions, performing a reliability analysis by Monte Carlo simulation, and undertaking a significance analysis using the Spearman rank correlation coefficient. In order to rank nine cooking energy alternatives for promoting a parabolic solar cooker in India, Pohekar and Ramachandran (2004b) employed PROMETHEE II according to 30 different criteria comprising of technical, economical, environmental, social, behavioral, and commercial issues. The papers on the topic of Energy Management are summarized in Table 8.

4.8. Social

In order to avoid the duplication in the proposed areas, a number of seven papers were just found on the topic of Social, which is not considerable in comparison with the seven previous topics.

In the Social topic, D'Avignon and Mareschal (1989) applied PROMETHEE I and II to determine specialization degrees for hospital services offered in the region of Quebec, Canada. The hospital services were ranked based on 11 criteria. Urli and Beaudry (1995) used modifications of the AHP and PROMETHEE methods to allocate funds for specific development programs in different administrative regions of Quebec, Canada. According to Buzolić et al. (2000), GIS and the PROMETHEE, together with 0–1 programming, represented a powerful and efficient tool in solving complex problems such as fire protection, detection, and intervention. The PROMETHEE analysis included vegetation characteristics and vegetation suitability for the fire dispersion and possibility to extinguish the fire. In order to choose neighborhoods and housing units that best suit their preferences and provide the greatest likelihood of beneficial outcomes, Johnson (2005) used PROMETHEE under the housing choice voucher program. Table 9 summarizes the papers on the topic of Social.

4.9. Other topics

The last category, which covered a fair number of publications, discusses other application aspects of the PROMETHEE methods including Agriculture, Design, Medicine, Education, Sports, and Government.

In the context of Agriculture, van Huylenbroeck (1995) developed a conflict analysis model combined with ELECTRE and PROMETHEE for the tractor choice problem. Kokot and Phuong (1999) used PROMETHEE to assess rice quality according to its properties. In the context of Design, Coelho et al. (2003) and Coelho and Bouillard (2005) applied PROMETHEE in the field of parametrical design optimization of mechanical structures, to rank the individuals of the evolutionary algorithms at each generation.

In other fields, Du Bois et al. (1989) developed an expert system for computer-aided diagnosis, using the PROMETHEE I, to select a list of possible diagnoses. In order to evaluate the candidates and to elect the best student's final work, Colson (2000) presented

Table 8
The applied papers on the topic of "Energy Management".

Author(s)	Specific area	Other tools/methodologies used
Chabchoub and Martel (2004)	To evaluate twelve nuclear dump sites	–
Diakoulaki and Karangelis (2007)	To evaluate four scenarios for the development of the power generation sector	Cost-Benefit analysis
Doukas et al. (2006)	To select the sustainable technologies for electricity generation	–
Georgopoulou et al. (1998)	Sustaining renewable energies exploitation	–
Goletsis et al. (2003)	Project ranking in the Armenian Energy Sector (by groups)	The Spearman rank correlation coefficient
Goumas and Lygerou (2000)	Ranking alternative geothermal energy exploitation schemes	Fuzzy PROMETHEE
Haralambopoulos and Polatidis (2003)	Ranking renewable energy projects	Group decision-making framework
Hyde et al. (2003)	The evaluation of six renewable energy scenarios	A reliability analysis by Monte Carlo simulation/ Spearman rank correlation
Madlener and Stagl (2005)	Ranking renewable energy technology bands	–
Madlener et al. (2007)	Ranking five renewable energy scenarios	–
Pohekar and Ramachandran (2004a)	Sustainable energy planning	A review paper on MCDA methods including PROMETHEE
Pohekar and Ramachandran (2004b)	Ranking cooking energy alternatives	–
Polatidis and Haralambopoulos (2007)	Ranking the various renewable energy technologies for the development of a wind park	–
Topcu and Ulengin (2004)	To select a suitable electricity generation alternative	–
Tzeng et al. (1992)	To evaluate alternatives for new energy-system development	–
Wolters and Mareschal (1995)	To make a decision on a heat exchanger network purely based on an economic evaluation of the alternatives	Sensitivity analysis for changes in weight and criteria scores
Zhou et al. (2006)	Decision analysis in energy and environmental modeling	A review paper on decision analysis methods including PROMETHEE

Table 9
The applied papers on the topic of "Social".

Author(s)	Specific area	Other tools/methodologies used
Brans et al. (1998)	The evolution of hypercomplex socio-economic systems	–
Buzolić et al. (2000)	The fire protection management system	GIS/0–1 programming
D'Avignon and Mareschal (1989)	Ranking specialization degrees for hospital services	PCA
Espinasse et al. (1997)	The development of Negotiation Support Systems (NSS)	Projection plans (group GAIA)
Johnson (2005)	Rank neighborhoods under the housing choice Voucher Program	Spatial decision support system
Raveh (2000)	A car selection problem	Graphic display technique
Urli and Beaudry (1995)	Allocation annual funds for development programs in health and welfare	–

PROMETHEE I, II and a Group Decision Support System (GDSS). Olson (2001) used PROMETHEE I and II to evaluate and to rank the abilities of eight baseball teams according to five criteria: hitting, power, speed, fielding, and pitching. Albadvi (2004) applied PROMETHEE II to formulate national information technology strategies. The research was carried out around a three-dimensional configuration of strategy development process: key technologies, socio-economic sectors, and applications. Table 10 shows a list of the PROMETHEE papers applied to other topics.

Table 11 shows the number of papers and percentage of total dealing with each area. As shown in the table, a considerable number of the PROMETHEE papers have been related to the topic of Environment Management. This is followed by the areas on Hydrology and Water Management, Business and Financial Man-

Table 10
The applied papers on the topic of "Other Topics".

Author(s)	Topic	Specific area	Other tools/methodologies used
Albadvi (2004)	Government	Formulating national information technology strategies	Cluster analysis
Coelho et al. (2003)	Design	Ranking the individuals of the population at each generation Parametrical design optimization of mechanical structures	Evolutionary algorithms
Coelho and Bouillard (2005)	Design	Ranking the individuals of the evolutionary algorithms at each generation/optimizing mechanical components during the first stage of the design process	Evolutionary algorithms
Colson (2000)	Education	To evaluate the candidates and to elect the best student's final work	–
Du Bois et al. (1989)	Medicine	A selection within a list of possible diagnoses	Trapezoidal evaluation function
Kokot and Phuong (1999)	Agriculture	To assess rice quality according to its properties	PCA
Olson (2001)	Sports	Evaluating and ranking the abilities of baseball teams	–
Ozerol and Karasakal (2008)	Education	Ranking top full-time (Master of Business Administration) MBA programs	Regret theory
van Huylenbroeck (1995)	Agriculture	Investment choice problem in agriculture/the tractor choice problem	Conflict analysis model

Table 11
Distribution of the papers by application areas.

Application areas	N	%
Environment Management	47	24.1
Business and Financial Management	25	12.8
Hydrology and Water Management	28	14.4
Chemistry	24	12.3
Logistics and Transportation	19	9.7
Energy Management	17	8.7
Manufacturing and Assembly	19	9.7
Social	7	3.6
Other Topics	9	4.6
Total	195	100

agement, and Chemistry. Only a small number of publications have been devoted to the topic of Social and Other Topics.

5. Analysis of non-application papers

The authors of 22 out of all reviewed papers (10.1%) could not find any application aspect or illustrative example. Some of these papers have incorporated an extensive mathematical contribution into the PROMETHEE method; the other papers have been related to general description of the PROMETHEE methods, the PROMETHEE software, and so on. In the following paragraphs, a review of 22 non-application papers is presented.

Parreiras and Vasconcelos (2007) introduced a multiplicative version of PROMETHEE and compared it with its original version, by applying them in the selection of the final solution of multi-objective optimization problems. Bouyssou (1996) used Generalized Strict Concordance (GSC) to investigate the existence of structural restrictions on concordance–discordance properties. Nemery and Lamboray (2008) developed a new multi-criteria sorting method, inspired by the PROMETHEE methodology, to completely ordered categories defined either by limiting profiles or by central profiles. Dias et al. (1998) presented an implementation of PROMETHEE, using the parallel processing approach compared with a sequential program, to reduce computer response time by the decision-makers. Bouyssou and Perny (1992) proposed a special method in terms of leaving and entering flows, to build a partial ranking based on a valued preference relation. Diakoulaki and Koumoutsos (1991) presented an extension of the PROMETHEE consisting of the differences existing among the performances of the actions examined, achieved through the notion of ideal and anti-ideal alternatives. Diaby and Martel (1997) developed a new goal programming approach combined with the PROMETHEE to model the decision-maker preferences. The preference structure of the decision-maker for each objective was modelled independently. Meier (1997) applied a simplified method for the PROMETHEE Preference ranking with additive weighting and general fuzzy values, compared to a method with individual fuzzy values, to reduce the set of alternatives at the lower computational effort and lower selectivity. According to Machant (1996), the Borda method and PROMETHEE were jointed together to aggregate a profile of crisp binary relations into a one-weak order. According to Mareschal (1988), an alternative approach was adapted to define stability intervals for the weights of different criteria.

Apart from the above-mentioned papers, there have been 12 non-application papers giving a description of the PROMETHEE methods, software packages, and novel concepts of decision-making. In the meantime, Vincke and Brans (1985) developed PROMETHEE I and II as a new outranking method among the alternatives. Mareschal and Brans (1988) and Brans and Mareschal (1994a) described the GAIA plane as an extension of the results of PROMETHEE, through a visual and interactive procedure. Brans

and Mareschal (1995) introduced the PROMETHEE VI sensitivity analysis procedure, when the decision-maker is not able or does not want to allocate precise weights to the criteria. Macharis et al. (1998) presented the PROMETHEE GDSS, based on the PROMETHEE II method, to provide decision aid to a group of decision-makers. Geldermann and Zhang (2001) provided useful information about the DECISION LAB software. De Keyser and Peeters (1996) described a short overview of some drawbacks of PROMETHEE methods that users must know and avoid. Guitouni and Martel (1998) developed a conceptual framework, based on tentative guidelines, to compare 29 MCDA methods including PROMETHEE and to help choosing an appropriate MCDA method. Macharis et al. (2004) discussed a comparison of strengths and weaknesses of PROMETHEE and AHP, and then recommended integration of PROMETHEE with a number of useful AHP features, regarding the design of the decision-making hierarchy and the determination of weights.

There have been two papers in this group presenting new concepts for decision-making. The first paper (Brans, 1996) sought for provision of additional information on soft or hard problems, according to the human brain and the space of freedom of the decision-maker. The second paper (Brans, 2002) was concerned with rationality, subjectivity, and ethics, as the three poles of influences in decision-making.

Finally, Brans and Macharis (1997) presented a teaching experiment including four chapters and three software packages, play preparation, and performance of the play, which is particularly motivating for students following an Operational Research course. The teaching experience included PROMETHEE, as a multi-criteria tool in chapter III, and PROMCALC, as a software, to handle multi-criteria problems with a finite number of alternatives and criteria.

6. Other classification results

In the two previous sections, 217 scholarly papers were classified into application and non-application categories according to the proposed scheme. This section of the paper analyzes the classification of 217 papers according to the following attributes: (1) year of publication, (2) journal of publication, (3) authors' nationality, (4) PROMETHEE as applied with other MCDA methods, and (5) PROMETHEE as applied with GAIA plane.

6.1. Distribution by year of publication

Table 12 gives the frequency distribution by year for PROMETHEE papers published in scholarly journals since 1985. As shown in the table, there has been a continuing growth over time in the number and percentage of papers published. Until 1990, only 11 papers were published in scholarly journals. The number of papers published increased during the period 1991–1993. Moreover, 17 papers (7.8%) were published during 1994–1996, 27 (12.4%) during 1997–1999, and 28 (12.9%) during 2000–2002. In recent years, the

Table 12
Frequency of papers by year.

Year	N	%
Prior to 1990	11	5.1
1991–1993	20	9.2
1994–1996	17	7.8
1997–1999	27	12.4
2000–2002	28	12.9
2003–2005	48	22.1
Since 2006	66	30.4
Total	217	100

number of papers published on PROMETHEE topics has grown significantly. More than 52.5% (114 papers) of the total number of papers have been published since 2003.

6.2. Distribution by journal of publication

Two hundred and seventeen papers are classified by journal of publication to develop a percentage of total papers. In this review, there have been 100 journals published at least one paper on the PROMETHEE topics. Sixty-five out of these 100 journals just contributed to one paper and 35 journals contributed to more than one paper. Table 13 provides a list of journals arranged by the number and percentage. The table indicates that the *European Journal of Operational Research* has published by far the most papers (53 papers, 24.4%) related to the PROMETHEE topics, since it has always had a special focus on the PROMETHEE methodologies and applications. There is a significant difference in the volume of the papers published between this journal and the other journals. The *Journal of Multi-Criteria Decision Analysis*, the *International Journal of Production Economics*, and the *Chemometrics and Intelligent Laboratory Systems* are the second, third, and fourth ones regarding the number and percentage of the total papers published, respectively.

6.3. Distribution by authors' nationality

Having developed more than 20 years development in Belgium, many countries in Europe, Asia, North and South America, Africa and Australia participated in the PROMETHEE publications. PROM-

ETHEE also continues to attract interest in other regions of the world.

Table 14 shows a geography distribution of the PROMETHEE papers, in number and percentage, published in different countries worldwide. Although most prolific authors are from Belgium, Australia, Germany, Greece, USA, and Canada, there have been 39 countries in the world that have contributed to at least one paper.

The value N in Table 14 stands for the total number of times authors from a country published paper/papers on the PROMETHEE topics. For instance, the Belgian authors contributed to 50 papers. In addition, the Australian, German, and Greek researchers contributed to 28, 21, and 19 papers, respectively. In this review, 180 papers out of 217 papers belong to one country, 32 papers to two different countries, and 5 papers to three different countries; Therefore, the total value of N was calculated 259 (180 * 1 + 32 * 2 + 5 * 3). Although the number of papers published in many countries is small, as shown in Table 14, it can clearly highlight the importance of the North and South American countries (N = 38), the Asian countries (N = 29), the African countries (N = 8), and Australia (N = 28), compared with the European countries (N = 156), in which PROMETHEE has had a worldwide interest.

6.4. PROMETHEE as applied with other MCDA methods

Forty-eight out of 217 papers reviewed, are integrated into or compared the performance of PROMETHEE methods with the other MCDA methods, such as AHP, ELECTRE ORESTE, SMARTS, Compro-

Table 13
Frequency of papers by journals.

Journal name	N	%
European Journal of Operational Research	53	24.4
Journal of Multi-Criteria Decision Analysis	9	4.1
International Journal of Production Economics	8	3.7
Chemometrics and Intelligent Laboratory Systems	6	2.8
Analytica Chimica Acta	5	2.3
Waste Management	4	1.8
Computers & Operations Research	3	1.3
Journal of Environmental Management	3	1.3
Lecture Notes in Computer Science	3	1.3
International Transaction in Operation Research	3	1.3
Decision Support Systems	3	1.3
Energy	3	1.3
Atmospheric Environment	3	1.3
Renewable Energy	3	1.3
Water Resources Management	3	1.3
Journal of Decision Systems	2	0.9
Journal of Hazardous Materials	2	0.9
Journal of Hydrology	2	0.9
Computers and Industrial Engineering	2	0.9
INFOR	2	0.9
International Journal of Production Research	2	0.9
Environmental Modelling & Software	2	0.9
Journal of the Operational Research Society	2	0.9
Fuzzy Sets and Systems	2	0.9
Talanta	2	0.9
International Journal of Geographical Information Science	2	0.9
International Journal of Intelligent Systems	2	0.9
Water International	2	0.9
Journal of Colloid and Interface Science	2	0.9
Ecological Economics	2	0.9
Renewable and Sustainable Energy Reviews	2	0.9
Journal of Quality in Maintenance Engineering	2	0.9
Annals of Operations Research	2	0.9
Journal of Intelligent Manufacturing	2	0.9
Energy Policy	2	0.9
Sixty-five other Journals	65	30
Total	217	100

Table 14
Frequency of papers by authors' nationality.

Country	N	%
Belgium	50	19.3
Australia	28	10.8
Germany	21	8.11
Greece	19	7.36
USA	17	6.56
Canada	15	5.79
Turkey	10	3.86
France	8	3.09
India	8	3.09
China	8	3.09
Yugoslavia	7	2.7
UK	7	2.7
Croatia	6	2.31
Tunisia	5	1.93
Netherlands	4	1.54
Finland	4	1.54
Taiwan	4	1.54
Brazil	4	1.54
Switzerland	3	1.16
Spain	3	1.16
Italy	3	1.16
Jordan	2	0.77
Iran	2	0.77
United Arab Emirates	2	0.77
Thailand	2	0.77
Portugal	2	0.77
Hungary	2	0.77
Israel	1	0.39
Egypt	1	0.39
Denmark	1	0.39
Mexico	1	0.39
Nigeria	1	0.39
Poland	1	0.39
Korea	1	0.39
Singapore	1	0.39
Papua New Guinea	1	0.39
Serbia and Montenegro	1	0.39
Slovakia	1	0.39
Colombia	1	0.39
Total	259	100

mise Planning (CP), and Multi-Attribute Utility Theory (MAUT). Table 15 shows an alphabetical order by author of the PROMETHEE papers applied with other MCDA methods.

The purpose of the comparative papers (33 papers) has been to define the differences of ranking between the PROMETHEE methods and other MCDA methods, and to enhance the popularity of the PROMETHEE methods. Most of these papers have demonstrated that PROMETHEE has some strengths in comparison with other MCDA methods. In the two following paragraphs, a small number of the comparative papers are illustrated.

Macharis et al. (2004) made a comparison between PROMETHEE and AHP, which showed PROMETHEE has some strengths of various approaches. Gilliams et al. (2005) revealed that PROMETHEE II is slightly preferable to bothELECTRE III and AHP, based on user friendliness, simplicity of the model strategy,variation of the solution, and implementation. In comparison with ELECTRE III, Al-Shemmeri et al. (1997) indicated that the PROMETHEE meth-

ods seem easier to be understood by the decision-maker and simpler to be managed by the analyst. Brans et al. (1986) also showed that PROMETHEE is more stable than ELECTRE.

In addition to the above-given comparisons, Salminen et al. (1998) compared the performance of the PROMETHEE, SMART, and ELECTRE III methods specifically because of their suitability in the context of environmental decision-making. The authors found little difference in performance between SMART and PROMETHEE, but felt that ELECTRE III had some extra functionality. Lerche et al. (2002) compared the PROMETHEE method with Utility Function Theory (UFT) and Hasse Diagram Technique (HDT) based on external input, i.e. on subjectivity and transparency. They considered HDT as the best performing, but placed PROMETHEE close to this method.

The purpose of the hybrid integration papers has been to utilize the PROMETHEE methods together with other MCDA methods. From the view-point of practical applications, developing hybrid

Table 15
Studies of PROMETHEE as applied with other MCDA methods.

Author(s)	As applied with another MCDA
Al-Shemmeri et al. (1997)	A comparison of PROMETHEE with ELECTRE III and MCDA techniques
Araz and Ozkarahan (2005)	A comparison of PROMSORT with PROMETHEE TRI and ELECTRE TRI
Araz and Ozkarahan (2007)	A comparison of PROMSORT with PROMETHEE TRI and ELECTRE TRI
Babic and Plazibat (1998)	A hybrid integration of AHP and PROMETHEE (PROMETHEE for final ranking and AHP to determine the importance of criteria)
Bilsel et al. (2006)	A hybrid integration of AHP and fuzzy PROMETHEE (Fuzzy PROMETHEE for final ranking and AHP for determination of the importance of criteria)
Brans et al. (1986)	A comparison of PROMETHEE and ELECTRE III
Chabchoub and Martel (2004)	Utilizing ELECTRE III and PROMETHEE
Colson (2000)	Application of ELECTRE I and PROMETHEE I, II, and III to the primary data
Dagdeviren (2008)	A hybrid integration of AHP and PROMETHEE/A comparison of PROMETHEE, AHP, TOPSIS, and ELECTRE results
de Leeneer and Pastijn (2002)	A comparison with ORESTE additive aggregation and PROMETHEE
Delhaye et al. (1991)	A comparison of PROMETHEE and ORESTE
Geldermann and Rentz (2005)	A comparison of the results by PROMETHEE, Multi-Attribute Utility Theory (MAUT), and AHP
Gilliams et al. (2005)	A comparison of PROMETHEE II, ELECTRE III, and AHP
Goletsis et al. (2003)	A hybrid integration of ELECTRE III and PROMETHEE methods
Guitouni and Martel (1998)	A comparison of 29 MCDA method including PROMETHEE based on seven guidelines
Hajkowicz and Higgins (2008)	A comparison of PROMETHEE II, Weighted summation, Range of value, Evamix, and Compromise Planning (CP)
Hendriks et al. (1992)	A comparison of the differences and similarities of PROMETHEE, Pareto optimality, Desirability functions, Overlay plots, Utility function
Hermans and Erickson (2007)	A comparison of PROMETHEE, MAUT and AHP
Hyde and Maier (2006)	Utilizing PROMETHEE and Weighted Sum Method (WSM)
Kangas et al. (2001a)	A comparison of the ELECTRE III and PROMETHEE II results with MAUT
Kangas et al. (2001b)	A comparison of the results by some MCDA techniques (PROMETHEE II, ELECTRE III, and Multi-Attribute ValueTheory (MAVT))
Keller et al. (1991)	A comparison of PROMETHEE, ELECTRE and Pareto optimality
Lerche et al. (2002)	A comparison of PROMETHEE, Utility Function Theory (UFT), and Hasse Diagram Technique (HDT)
Lewi (1992)	Applied with Pareto optimality
Leyva-López and Fernández-González (2003)	A comparison of ELECTRE III with PROMETHEE II for group decision-making
Macharis et al. (2004)	A comparison of strengths and weaknesses of PROMETHEE and AHP
Mahmoud and Garcia (2000)	A comparison of Weighted Average (WA), PROMETHEE II, CP, ELECTRE II, and AHP
Marinoni (2006)	A comparison of AHP and PROMETHEE
Olson (2001)	A comparison of SMART, PROMETHEE II, and Centroid method
Opricovic and Tzeng (2007)	A comparison of the extended VIKOR method with TOPSIS, PROMETHEE, and ELECTRE
Ozelkan and Duckstein (1996)	A Comparison of PROMETHEE, GAIA, Multi-Criterion Q Analysis (MCQA-I, II, III), CP, and Cooperative Game Theory (CGT)
Parreiras et al. (2006)	Utilizing SMARTS, PROMETHEE, and a fuzzy decision algorithm
Parsaei et al. (1993)	Discussing PROMETHEE, ELECTRE, and ORESTE
Pillai et al. (1996)	A comparison of ELECTRE-II, PROMETHEE-II, AHP, CP, and MCQA-II
Pudenz et al. (2002)	Using Concordance analysis, UFT, PROMETHEE, and AHP
Raju and Pillai (1999a)	A comparison of ELECTRE-II, PROMETHEE-II, AHP, CP and EXPROM-II (Extension of PROMETHEE II in distance based environment)
Raju and Pillai (1999b)	A comparison of MAUT and Stochastic extension of PROMETHEE-II (STOPROM-II)
Raju et al. (2000)	A comparison of ranking among PROMETHEE-II, EXPROM-II, ELECTRE-II and IV, and CP
Raju and Kumar (2006)	A comparison of DEA with discrete MCDM methods, PROMETHEE, and EXPROM
Salminen et al. (1998)	A comparison of ELECTRE II1, PROMETHEE I, II, and SMART decision-aids
Sarkis (2000)	A comparison of DEA with PROMETHEE I, PROMETHEE II, ELECTRE III, and SMART
Simon et al. (2004)	A comparison of PROMETHEE and HDT
Simon et al. (2005)	A comparison of METEOR (METhod of Evaluation by ORder) and PROMETHEE
Simon et al. (2006)	A comparison of METEOR and PROMETHEE results
Urli and Beaudry (1995)	Utilizing a modifications of the AHP and PROMETHEE methods
van Huylenbroeck (1995)	Combining the preference function approach of PROMETHEE and ELEETRE with the conflict analysis test of ORESTE
Wang et al. (2006)	A hybrid integration of AHP and PROMETHEE
Wang and Yang (2007)	A hybrid integration of AHP and PROMETHEE

Table 16
List of the papers with GAIA analysis.

Year	References	N
Prior to 1990	Briggs et al. (1990), D'Avignon and Mareschal (1989), and Mareschal and Brans (1988)	3
1991 to 1994	Brans and Mareschal (1994a), Brans and Mareschal (1994b),Hendriks et al. (1992), Hens et al. (1992), Keller et al. (1991), Kokot et al. (1992a), Kokot et al. (1992b), Mareschal et al. (1992), Mladineo et al. (1992), and Vuk et al. (1991)	10
1995 to 1999	Al-Rashdan et al. (1999), Espinasse et al. (1997), Hokkanen and Salminen (1997), Kokot and Phuong (1999), Le Téno (1999), Macharis et al. (1998), Martin et al. (1999), Ozelkan and Duckstein (1996), Pandey and Kengpol (1995), and Radojevic and Petrovic (1997)	10
2000 to 2004	Anagnostopoulos et al. (2003), Ayoko et al. (2003), Ayoko et al. (2004), Brans (2002), Carroll et al. (2004), Dulmin and Mininno (2003), Khalil et al. (2004), Ni et al. (2002), Ni et al. (2004), and Rogers et al. (2004)	10
Since 2005	Albadvi et al. (2007), Ayoko et al. (2007), Carmody et al. (2005), Carmody et al. (2006), Carmody et al. (2007), Dagdeviren (2008), Herngren et al. (2006), Jugović et al. (2006), Khalil et al. (2005), Lim et al. (2005), Lim et al. (2006), Lim et al. (2007a), Lim et al. (2007b), Linkov et al. (2006a), Ni et al. (2007), Purcell et al. (2005), Purcell et al. (2007), Settle et al. (2007), Vego et al. (2008), Wang et al. (2006), Wang and Yang (2007), and Zhang et al. (2006)	22
	% of the 217 papers	25.3%

methods has made a more realistic and promising decision than the stand-alone PROMETHEE. A number of papers in this regard combined PROMETHEE with AHP (Babic and Plazibat (1998); Wang et al. (2006); Bilsel et al. (2006); Wang and Yang (2007)). The final ranking of alternatives in this integration was done by PROMETHEE and the importance of criteria was determined by AHP. A hybrid integration of ELECTRE III and PROMETHEE methods has specially been developed and constituted the main part of a ranking methodology for groups by Goletsis et al. (2003).

6.5. PROMETHEE as applied with GAIA analysis

The GAIA plane, a descriptive tool, provides a powerful graphical representation of results obtained by the PROMETHEE method. This tool also provides valuable help in understanding the conflicts among criteria and in dealing with the problem of the weights related to them (Mareschal & Brans, 1988). The GAIA plane is the result of the Principal Component Analysis (PCA) for which as much information as possible is preserved after projection (Brans and Mareschal, 2005). The idea of the GAIA plane is based on the reduction of multi-dimensional problems to two-dimensional ones, such as allowing for direct presentation. The PCA provides a valuable tool for the decision-maker to discriminate the criteria expressing similar or conflicting preferences, as well as the quality of each alternative on the different criteria.

There have been 55 papers out of 217 papers reviewed (25.3%), focused on GAIA plane analysis and included it as a section of the paper. This percentage has not been stable over time and has grown in recent years (see Table 16). Most of the scholarly papers in this table have applied PROMCALC and DECISION LAB to analyze the results of decision-making; however recent publications on the PROMETHEE methods have been used DECISION LAB instead of PROMCALC, which was previously developed by the authors of PROMETHEE.

7. Conclusion

This paper has presented an extensive review of the literature on PROMETHEE methodologies and applications consisting of 217 papers from 100 scholarly journals. For this purpose, a classification scheme was developed to organize each paper into several categories. The PROMETHEE papers in the proposed scheme were categorized into application papers and non-application papers, and then were classified by year of publication, journal of publication, authors' nationality, PROMETHEE as applied with other MCDA methods, and PROMETHEE as applied with GAIA plane. Moreover, the papers under application areas were sub-classified into nine different topics.

The methodology that was used in this review has some limitations. The first limitation is that the findings are based on the data collected from scholarly journals, which do not include conference proceeding papers, master's theses, doctoral dissertations, textbooks, and unpublished working papers in the PROMETHEE literature. The second is that most of the findings were concentrated on English journals; hence the journals in the other languages were not concerned. Although this means that the review is not exhaustive, the authors believe that it provides a comprehensive review, and includes the majority of papers that were published by scholarly journals. Therefore, this paper would be able to provide useful insights into the anatomy of the PROMETHEE methods, and suggest academic researchers and practitioners a road map and framework for future attempts.

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