A hybrid Multi Criteria Approach for Performance Evaluation: The Case of a Holding Company

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KEYWORDS	ABSTRACT
Multiple criteria decision making, Performance evaluation, Fuzzy AHP, PROMETHEE, TOPSIS, Holding company.	*In today's competitive business situation, performance evaluation of firms is an extremely important concern of all the people who are typically stakeholders of the business game. In case of holding companies, this is a more important issue since the parent firm must permanently control the situation of its subsidiaries in their sectors to make appropriate investment decisions. This paper develops a multicriteria decision making (MCDM) approach for evaluating performance of firms considering financial and productivity criteria. We adopt a Fuzzy Analytic Hierarchy Process (FAHP) method to determine the relative importance of evaluation criteria, taking the vagueness and imprecision of human judgments into consideration. Then, we employ the Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE) for ranking of firms. Afterward, this paper enjoys benefit of using Technique of Order Preference by Similarity to Ideal Solution (TOPSIS) to assess the validity of the obtained ranking results. Our approach was applied to a holding company listed in Tehran Stock Exchange (TSE) as a real case. The analysis of ranking results revealed advantages of combining these MCDM methods.*

1. Introduction

In recent years, multiple criteria decision making paradigm has been one of the most important tools in the field of financial analysis. The diverse and conflicting nature of evaluation criteria and objectives which affects financial decisions, the convolution of financial, economic and business environments and ill-structured nature of the financial decisions are only some of unavoidable characteristics of financial

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decisions. These characteristics are in accordance with the MCDM modeling framework [1]. Performance evaluation of firms, banks and other financial or non-financial institutions is one of the main areas of financial decision making.

Performance evaluation of firms is really an imperative issue for their managers, shareholders, investors and policy makers. This evaluation assists the managers and shareholders to identify strengths and weaknesses of a firm and make appropriate decisions to conquer the existing problems. Furthermore, such an evaluation provides institutional and individual investors with

proper indications to make their investment choices, whereas it can help policy makers to discover the existing problems of business environment and take precautions to ensure the economic growth and social stability. Apparently, such an evaluation is multidimensional, as it is influenced by various factors each of which has different nature and should be manipulated on its own way. Integrating these criteria of various natures and obtaining a global evaluation score is a subjective procedure depending on the judgments and values assigned by decision makers. Such multidimensionality in the evaluation factors necessitates application of multicriteria decision making (MCDM) techniques in the assessment process [2].

In this paper, the proposed approach is to combine Fuzzy AHP and PROMETHEE to measure performance of firms. Fuzzy AHP has been utilized to determine the relative importance of evaluation criteria considering imprecision and vagueness of human judgments. Then, PROMETHEE has been used to obtain the final ranking of alternatives. Afterward, TOPSIS, as a prominent MCDM technique, has been adopted to assess the validity of the former ranking results. Furthermore, the proposed approach has been applied to a holding company listed in Tehran Stock Exchange to illustrate its applicability.

The rest parts of this paper have been organized as follows. Next, the problem description and an elaborate review of relevant studies have been presented. Then, our research approach has been explained. The utilized techniques namely Fuzzy AHP, PROMETHEE and TOPSIS have been presented in the fourth section. In the fifth section, an illustrative application of our approach has been presented and analyzed. The paper ends with some concluding remarks.

2. Problem Description and Review

Multiple attribute decision making (MADM), which constitutes a significant branch of MCDM paradigm, encompasses a number of successive steps leading to some global scores obtained through making a compromise between some different and even conflicting criteria. These global scores, each associated with one of the evaluated alternatives, are utilized to provide the final ranking of alternatives [3]. Performance evaluation of firms is an ordinary problem all over the world which is considerably in accordance with the above-mentioned characteristics of MADM paradigm. The assessment is particularly helpful for institutional and individual investors, since it can guide them in making appropriate investment decisions. Moreover, it can help policy makers to identify the existing problems of business environment and take precautions to guaranty the economic growth and social stability [2]. Therefore, a great number of studies have dealt with the problem of performance evaluation of firms, banks and other kinds of financial and non-financial institutions on the basis of MCDM paradigm. Moreover, large numbers of studies have proposed Multiple Criteria Decision Support Systems (MCDSSs) to support the investment or other decisions associated with performance of firms. This paper aims to propose a multicriteria approach to assess performance of firms regarding a number of financial and non-financial evaluation criteria. Thus, a review of studies concerning performance evaluation of firms through application of MCDM methods and also developing MCDSSs has been discussed below.

Albadvi et al. [4] developed a decision making model to select superior stocks in stock exchange. They applied PROMETHEE for ranking different industries and then ranking the firms related to the superior industries. Marasović and Babić [5] proposed a multi-criteria approach based on PROMETHEE II to select optimal portfolio of different industries. Babic and Plazibat [6] combined AHP and PROMETHEE to evaluate performance of enterprises according to the business efficiency. Kalogeras et al. [7] presented a new financial decision aid approach to evaluate performance of the agri-food firms through combining data analysis

techniques and PROMETHEE II multicriteria analysis method.

Mareschal and Brans [8] presented the BANKADVISER multicriteria industrial evaluation system based on PROMETHEE to provide evaluations of individual items such as firms, industries, companies, and industrial clients on the basis of financial data. Hu and Chen [9], exploiting both concordant and discordant relations, presented a classification method based on PROMETHEE for bankruptcy prediction. Kalogeras et al. [10] combined principal components analysis and PROMETHEE II to assess the financial success of agribusiness cooperatives based on financial ratios. Kilic et al. [11] utilized ANP and PROMETHEE to deal with the problem of ERP selection in Small Medium Enterprises (SMEs).

Kazan et al. [12] combined AHP and PROMETHEE to assess the financial performance of firms.

Doumpos and Zopounidis [13] employed PROMETHEE II to propose a decision support system for bank rating, considering both quantitative and qualitative criteria.

Ertuğrul and Karakaşoğlu [14] proposed an approach to assess performance of Turkish cement firms through combining Fuzzy AHP and TOPSIS, considering their financial ratios as the evaluation criteria. Seçme et al. [15] proposed a fuzzy multicriteria decision model to evaluate the performance of banks through integration of Fuzzy AHP and TOPSIS. Yalcin et al. [16], combined Fuzzy AHP, TOPSIS and VIKOR to evaluate financial performance of manufacturing industries. Moghimi and Anvari [17] utilized Fuzzy AHP and TOPSIS to assess the performance of Iranian cement firms.

Aydogan [18] combined Rough AHP and fuzzy TOPSIS to measure performance of aviation firms, considering both qualitative and quantitative criteria.

Zhang et al. [19] combined entropy method and TOPSIS to evaluate financial performance of electric power enterprises. Chang et al. [20], incorporating Minkowski and Mahalanobis distances, exploited

TOPSIS to evaluate the performance of mutual funds. Feng and Wang [21] applied TOPSIS to evaluate performance of airlines, taking financial ratios into consideration. The performance indicators were formed regarding both transportation and finance aspects. Hsu [22] combined factor analysis and an entropy-based TOPSIS to evaluate the financial performance of Taiwan's opto-electronic companies, considering financial ratios as well as risk-adjusted rate of return on capital as the evaluation criteria.

Hsu et al. [23] utilized grey relation analysis and an improved TOPSIS to construct a sustainable performance evaluation model for companies. The presented approach used the companies' financial, credit risk, environmental and social responsibility measures as the sustainable business performance evaluation criteria.

Wang et al. [24] utilized grey relation analysis as well as fuzzy TOPSIS to evaluate the financial performance of Taiwan container shipping companies. İÇ and Yurdakul [25] utilized fuzzy TOPSIS for developing a credibility scoring decision support system to enable banks to determine the credibility of manufacturing firms based on financial analysis. Kumar et al. [26] used fuzzy TOPSIS to evaluate the lean performance of firms.

Zopounidis et al. [27] proposed the FINEVA multicriteria knowledge-based DSS for the assessment of corporate performance and viability. The FINEVA system utilizes an expert system, a principal components analysis part as well as the UTASTAR multicriteria method to rank the firms. Table 1 elaborates an expressive list of articles dealing with performance evaluation of firms. These articles are classified according to their specific methodological approach.

The universe of discourse for each article is also provided. Next section provides description of our research approach.

Tab. 1. Application of MCDM Approaches and MCDSSs in The Evaluation of Firms' Performance

Methods	Studies	Topic
PROMETHEE	Mareschal and Mertens [28]	To situate each bank regarding the user-defined reference market
	Mareschal and Brans [8]	To assess firms, industries, companies and industrial clients on the basis of financial data
	Babic and Plazibat [6]	To rank enterprises based on the achieved level of business efficiency
	Baourakis et al. [29]	To assess the viability of agribusinesses based on financial data
	Kalogeras et al. [7]	To evaluate the financial performance of agri-food firms
	Albadvi et al. [4]	To select the superior stocks for investment
	Doumpos and Zopounidis [13]	An MCDSS for bank rating
	Hu and Chen [9]	A classification method for bankruptcy prediction of firms using concordance and discordance relations
	Marasović and Babić [5]	To select an optimal portfolio containing securities from different industries
	Kalogeras et al. [10]	To assess the financial success of Dutch agribusiness cooperatives
	Kilic et al. [11]	To select the best ERP system for SMEs
	Kazan et al. [12]	To evaluate financial performance of firms
TOPSIS	Kim et al. [30]	To measure performance of advanced manufacturing systems to identify new investment opportunities
	Feng and Wang [21]	To assess airlines with respect to financial ratios
	Chang et al. [31]	To evaluate performance of mutual funds
	Ertuğrul and Karakaşoğlu [14]	To evaluate financial performance of cement firms
	Seçme et al. [15]	To assess banking performance
	Wu et al. [32]	To assess banking performance based on Balanced Scorecard
	Chang et al. [20]	To evaluate performance of mutual funds
	Yu and Hu [33]	To evaluate performance of manufacturing plants
	İÇ and Yurdakul.[25]	To determine credibility scoring of manufacturing firms
	Aydogan [18]	To measure the performance of aviation firms
	Zhang et al. [19]	To evaluate financial performance of electric power enterprises
	Yalcin et al. [16]	To evaluate financial performance of manufacturing industries
	Hsu [22]	To evaluate the financial performance of Taiwan's opto-electronic companies
	Kumar et al. [26]	To evaluate the lean performance of firms
	Moghimi and Anvari [17]	To assess the performance of cement firms
	Wang [24]	To evaluate the financial performance of Taiwan shipping companies
	Hsu et al. [23]	To evaluate sustainable performance of companies
ELECTRE	Madlener et al. [34]	To evaluate performance of biogas plants
	Xidonas et al. [1]	To assess the corporate performance and to select the attractive equities based on financial analysis
MAUT	Diakoulaki et al. [35]	To evaluate the performance of pharmaceutical firms on the basis of financial analysis
	Yeh et al. [36]	To evaluate performance of bus companies
UTA	Zopounidis et al. [37]	To assess the performance and viability of companies
	Zopounidis et al. [38]	To evaluate banking performance based upon financial ratios
UTASTAR	Zopounidis et al. [27]	To evaluate the corporate performance and viability
	Matsatsinis et al. [39]	To present a methodology of knowledge acquisition and representation for developing FINEVA to assess the corporate performance and viability
UTADIS	Zopounidis and Doumpos [40]	A DSS to deal with financial classification problem
	Spathis et al. [41]	To assess profitability and efficiency of small and large banks
	Kosmidou et al. [42]	To assess performance of the UK domestic banks compared to the UK foreign banks

3.   Research Approach

This paper aims to evaluate performance of various firms each compared to those of its own activity sector (industry). In fact, the imperative, basic point of the evaluation process is that the firms associated with each activity sector are positioned through assessment of the overall corporate performance separately from the firms of other activity sectors. Therefore, it is essential that all parts of the assessment procedure be performed separately for each activity sector. The schematic representation of our evaluation procedure has been illustrated in Figure 1. A brief description of the research approach follows.
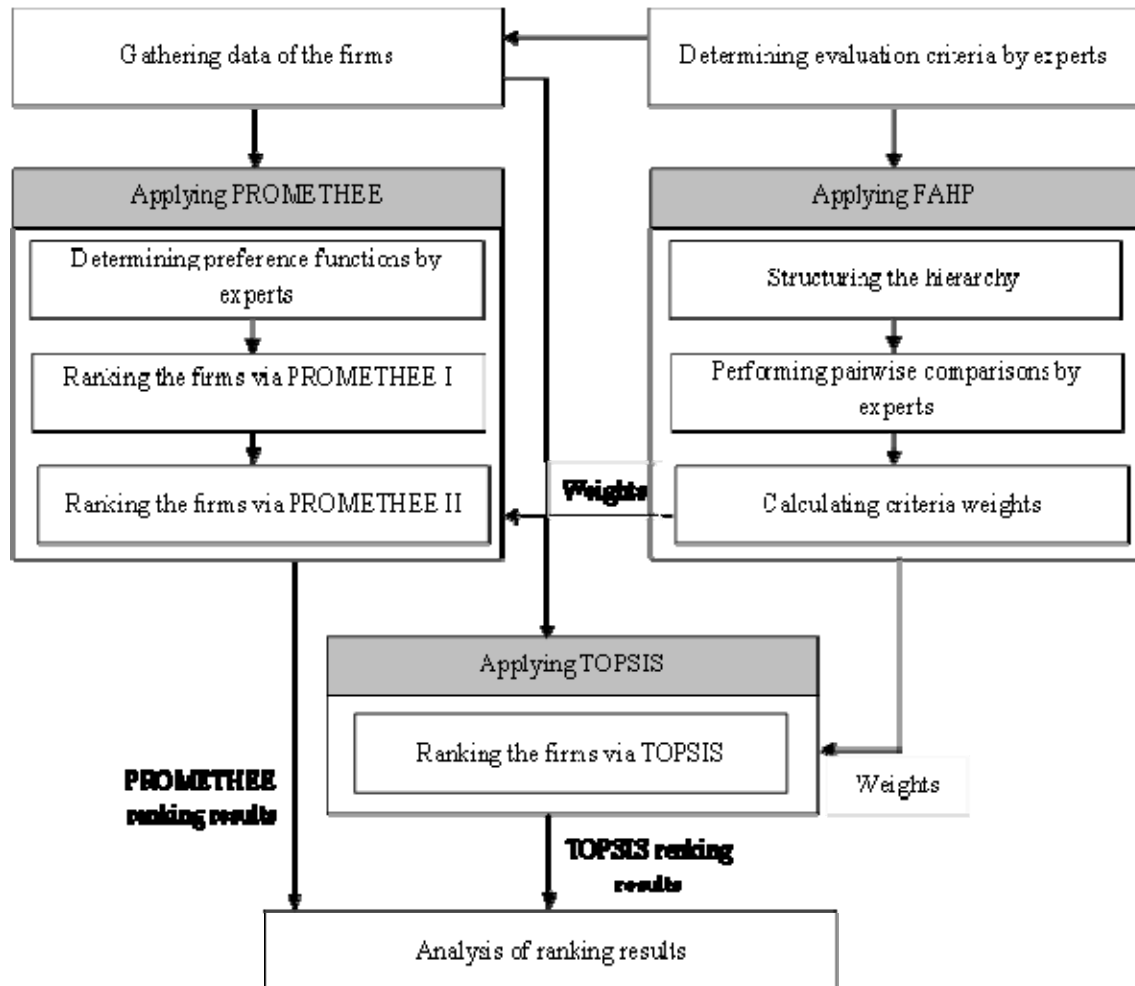

Fig. 1. Our Proposed Research Approach

3-1.   Determination of the Evaluation Criteria

The first important issue of the evaluation procedure is to choose the appropriate criteria for dealing with the assessment process. Appropriate evaluation criteria, as a main part of evaluation process, need to b-e well structured. Hence, this stage must be performed along with close collaboration of a panel of experts. Apparently, this procedure is partly dependent on the individuals who are asked to contribute in the determination of the evaluation criteria. Therefore, selecting a group of experts who are experienced, outstanding specialists in the field of financial analysis is a matter of particular importance.

3-2.   Weighting Evaluation Criteria Via Fuzzy AHP

The evaluation criteria, determined through collaboration with a group of experts, are not obviously of the same significances. It means that each criterion must contribute in the evaluation process in proportion to its importance. Hence, the relative importance, i.e. weights, of evaluation criteria should be determined prior to executing the evaluation process. In this paper, the extent FAHP [43] is adopted to determine relative importance of evaluation criteria. A general description of weighting steps through FAHP is described as follows.

3-2.1. Forming the Hierarchy of the Decision Problem

At the first step of FAHP, the hierarchy of the decision problem, composed of a goal, criteria, sub-criteria and alternatives, should be structured. In fact, a hierarchy is formed by the relationships between elements of one level with those of the immediate next level. Hence, each element of a hierarchy is linked to every element, at least in an indirect manner. To structure hierarchy of a decision problem, the goal or objective must be stood at the root of the hierarchy. The leaf nodes of the hierarchy are formed by the alternatives to be compared. The evaluation criteria and sub-criteria are placed in between these two levels. One of the main advantages of structuring the hierarchy is that a decision maker just needs to compare the elements of each level regarding their contributions to the upper level [44].

3-2.2.   Performing Pairwise Comparisons

After structuring the hierarchy, the decision makers are asked to compare the evaluation criteria in pairs according to the qualitative scale of AHP. These pairwise comparisons are made through utilizing some linguistic expressions namely equal, slightly strong, strong, very strong, and extremely strong. These expressions should be quantified through utilizing the integers between 1 and 9, each equivalent to a specific linguistic expression. Afterward, the quantified pairwise

comparisons are arranged in a square matrix. The element (i, j) states the preference of the ith criterion in comparison with the jth one. The more the preference of the ith criterion with respect to the jth one the higher the element (i, j).

3-2.3. Determining Weights of Evaluation Criteria

After forming pairwise comparison matrices, an FAHP approach [43] is utilized to determine relative importances of evaluation criteria. The above-mentioned approach uses triangular fuzzy numbers (TFNs) for the pairwise comparison scale. The pairwise comparison matrices of the same criteria, each associated with one expert's judgments, are transformed into a unique matrix whose entire elements are triangular fuzzy numbers. Furthermore, the extent analysis method is utilized for dealing with the synthetic extent values of the pairwise comparisons. The obtained weights have been used as inputs of PROMETHEE for ranking of firms.

3-3.   Ranking Firms Via Promethee

After obtaining relative importances of evaluation criteria, PROMETHEE is utilized to rank firms. PROMETHEE is an outranking method in multicriteria analysis, firstly proposed by Brans [45] and further developed by Vincke and Brans [46]. In fact, PROMETHEE is a simple, clear and stable outranking method in which the preferences are not necessarily expressed as linear relationships [47]. The above-mentioned features have made PROMETHEE an important method in the multicriteria decision making paradigm. To rank alternatives via PROMETHEE, the following steps must be pursued.

3-3.1. Defining Generalized Criteria and Providing Required Data

The first step of PROMETHEE is to define the appropriate generalized criterion for each evaluation criterion through collaboration with a panel of experts. Indeed, PROMETHEE utilizes the notion of generalized criteria to construct a valued

outranking relation. The generalized criterion is a preference function which determines preference of an alternative over another one based on a particular evaluation criterion. The generalized criterion associated with each evaluation criterion depends on its nature and decision makers' viewpoint [4]. There are six types of generalized criteria as follows: usual criterion, quasi criterion, criterion with linear preference, level criterion, criterion with linear preference and indifference area and Gaussian criterion [47].

In addition, the data gathering process is performed to provide information about the performance of alternatives over the selected evaluation criteria.

3-3.2. Providing Final Ranking of Alternatives via Promethee I and Promethee II

PROMETHEE requires three types of information to provide the ranking of alternatives. These types of information are as follows: information about relative importance of evaluation criteria, information about the preference function of decision makers on each criterion and information about the performance of alternatives on each criterion. All the required information has previously been provided and hence, PROMETHEE can be implemented to rank firms. Thus, Decision Lab software (Decision Lab website) is applied to provide the final ranking of alternatives via PROMETHEE I and PROMETHEE II. In PROMETHEE I, some alternatives may be incomparable and therefore, it provides a partial ranking of alternatives. Contrarily, PROMETHEE II provides a complete ranking of alternatives. Also, Decision Lab has a visual and powerful tool for sensitivity analysis called GAIA (Geometrical Analytic for Interactive Aid) plane [48]. Hence, the associated GAIA plane is analyzed to identify conflicts between criteria and to group the alternatives.

3-4. Ranking Firms Via TOPSIS

After ranking firms via PROMETHEE, an appropriate way for investigating the validity of ranking results is to evaluate the performance of firms through another prominent multicriteria decision making technique. Hence, TOPSIS, which is one of important multicriteria decision making techniques and firstly proposed by Hwang and Yoon [49], is applied. TOPSIS requires two types of information to provide the ranking of alternatives as follows: information about relative importance (i.e. weights) of evaluation criteria and information about the performance of alternatives on each criterion. Indeed, TOPSIS, unlike PROMETHEE, does not require any information about the preference function of decision makers on each criterion. Utilizing the information about performance of alternatives on each criterion, TOPSIS defines two virtual alternatives called positive and negative ideal solutions and determines the preference of alternatives according to their distances from these two solutions. After ranking firms through TOPSIS, the obtained results are compared and analyzed.

4.   Methodology of Applied MCDM Techniques

This section introduces the methodology of applied multi criteria decision making techniques utilized in the evaluation procedure namely FAHP and PROMETHEE. Also, the methodology of TOPSIS, adopted for evaluating PROMETHEE ranking results, is presented. Firstly, the methodology of FAHP is presented. As mentioned above, FAHP is utilized to determine the relative importance of evaluation criteria.

4-1.   Fuzzy Analytic Hierarchy Process (FAHP)

Analytic Hierarchy Process (AHP) is one of the most prominent multiple criteria decision making techniques and has been used almost in all the decision making applications [50]. The vast range of AHP applications may arise from its substantial advantages in comparison with other MCDM techniques. AHP can take the performance data into consideration for evaluating alternatives based on qualitative factors as well as quantitative ones. In

addition, AHP, in comparison with other multi attribute decision approaches, has a high degree of acceptability and confidence in its analysis. It also provides a systematic way for subjective decision process, serves sensitivity analysis, gives information about the implicit weights of evaluation criteria and makes a commitment to the selected alternative through providing better understanding and participation among members of the decision making group [51]. Perhaps the main advantage of AHP is the relative ease with which it can handle multiple criteria considering both qualitative and quantitative ones [52].

Although AHP, for its important advantages, is one of the most widely used MCDM techniques, it suffers from some shortcomings as reported below. Despite the fact that the aim of AHP is to capture experts' knowledge, the traditional AHP is incapable of reflecting the human thinking style [14, 53]. The traditional AHP is problematic in using an exact value for expressing the judgment of decision makers along the pairwise comparison process [54]. AHP method is often criticized, for using unbalanced scale of judgments and also inability of adequately handling the inherent uncertainty and imprecision of the pairwise comparison process [55].

Fuzzy Analytic Hierarchy Process (FAHP) is an extension to Analytic Hierarchy Process based on the concept of fuzzy set theory with which it is possible to combine fuzzy set theory and MCDM framework for several applications [31]. Indeed, Fuzzy AHP (FAHP) was developed to overcome all the above-mentioned drawbacks in solving hierarchical problems. In this paper, regarding the above-mentioned reasons, FAHP rather than AHP has been utilized to determine the weights of the entire evaluation criteria.

Van Laarhoven and Pedrcyz [56] were pioneer researchers who applied fuzzy logic concept to AHP. Chang [43] used triangular fuzzy numbers to propose a new FAHP methodology, while Buckley [57] used the concept of trapezoidal fuzzy numbers rather than the triangular ones. In this paper, the extent FAHP method [43] has been utilized to determine the weights of the evaluation criteria. The steps of the utilized FAHP are as follows:

Step 1: The values of fuzzy synthetic extent are calculated.

Let $X = \{x_1, x_2,..., x_n\}$ is an object set and $G = \{g_1, g_2,..., g_n\}$ is a goal set. According to the Chang's method, each object is analyzed for each goal and then there will be m extent analysis values for each object, represented by the following signs:

$$M^1_{g_i}, M^2_{g_i},..., M^m_{g_i} \qquad i = 1,2,..., n \qquad (1)$$

where, $M^j_{g_i}$ for j=1, 2,…, m are triangular fuzzy numbers.

Let $M^1_{g_i}, M^2_{g_i},..., M^m_{g_i}$ be the values of extent analysis of the ith object for m goals. The value of fuzzy synthetic extent with respect to the ith object is defined as:

$$S_i = \sum_{j=1}^{m} M^j_{g_i} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M^j_{g_i} \right]^{-1} \qquad (2)$$

where the components of S_i, as also indicated by Ertuğrul and Karakaşoğlu [14], are calculated by the following formulas:

$$\sum_{j=1}^{m} M^j_{g_i} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \qquad (3)$$

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M^j_{g_i} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \qquad (4)$$

Step 2: The degrees of possibility are calculated.

For two triangular fuzzy numbers $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$, the degree of possibility of $M_1 \geq M_2$ is defined as:

$$V(M_1 \geq M_2) = \sup_{x \geq y} \left[\min(\mu_{M_1}(x), \mu_{M_2}(y)) \right] \quad (5)$$

and can be expressed as follows:

$$V(M_1 \geq M_2) = hgt(M_1 \cap M_2) = \mu_{M_1}(d) \quad (6)$$

where, d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2}. The degree of possibility of $M_1 \geq M_2$ can be represented, in an expanded and more understandable way, as follows:

$$V(M_1 \geq M_2) = \begin{cases} 1, & if\ m_1 \geq m_2 \\ 0, & if\ l_2 \geq u_1 \\ \dfrac{l_2 - u_1}{(m_1 - u_1) - (m_2 - l_2)}, & otherwise \end{cases} \quad (7)$$

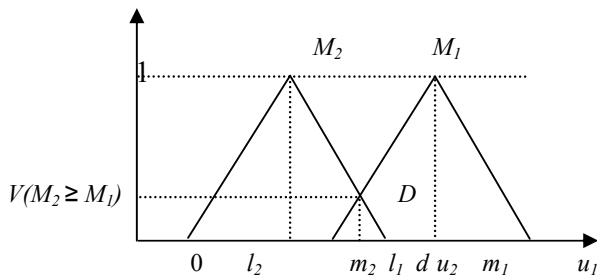Fig. 2 illustrates the intersection between the two triangular fuzzy numbers M_1 and M_2.

Fig. 2. The intersection between two TFNs
M_1 and M_2 [62]

Note that the value of $V(M_2 \geq M_1)$ must also be calculated for comparing of M_1 and M_2.
Step 3: The pairwise comparisons are provided between degrees of possibility of fuzzy numbers.

The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i ($i = 1, 2,\dots, k$) can be defined as:

$$V(M \geq M_1, M_2, \dots, M_k) = V \begin{bmatrix} (M \geq M_1)\ and\ (M \geq M_2)\ and.. \\ and\ (M \geq M_k) \end{bmatrix}$$
$$= \min V(M \geq M_i), \ i = 1, 2, \dots k. \quad (8)$$

Assuming that $d'(A_i) = min V(S_i \geq S_k)$ for k = 1, 2, …, n; $k \neq i$, the weight vector is given by:

$$W' = (d'(A_1), d'(A_2), \dots, d'(A_n))^T \quad (9)$$

where, A_i ($i = 1, 2, \dots, n$) are n elements.

Step 4: The weight vectors are normalized.

Via normalization, the normalized weight vectors are obtained as follows:

$$W = (d(A_1), d(A_2), \dots, d(A_n))^T \quad (10)$$

where, $d(A_i)$ ($i = 1, 2, \dots, n$) are crisp numbers.

4-2. Preference Ranking Organization METHod for Enrichment Evaluation PROMETHEE)
Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE) is one of prominent MCDM methods which was presented by Brans [45] and further developed by Vincke and Brans [46]. PROMETHEE is a simple, clear and stable outranking method [47] which is well adopted to problems where a finite set of alternatives are to be ranked considering several, sometimes conflicting criteria. The steps of PROMETHEE are as follows:
Step 1: The generalized criterion related to each evaluation criterion is defined using experts' judgments.
Let the following multicriteria problem:

$$Max\ \{ f_1(a), \dots, \ f_k(a) \mid a \in K \} \quad (11)$$

where K is a finite set of alternatives and f_i (i =1, 2,…, k) are k criteria to be maximized. For each alternative a, f_k is an evaluation of this alternative. When comparing two alternatives a and b, results of this comparison must be expressed in terms of preference. Thus, preference function P is defined as a real number between 0 and 1 which respectively express no preference and strict preference. In practice, this preference function will often be a function of difference

between two evaluations. The preference function of *a* over *b* has to be a non-decreasing function, equal to zero for negative values of $d = f(a) - f(b)$. The generalized criterion for each criterion *f* is defined by *f* and a corresponding preference function *P*. The generalized criteria utilized by PROMETHEE are of six types as follows: usual criterion, quasi criterion, criterion with linear preference, level criterion, criterion with linear preference and indifference area, and Gaussian criterion.

Step 2: The preference functions related to the entire alternatives are determined.

According to the generalized criteria defined by the decision maker(s) and using alternative evaluations on each criterion, alternatives are compared in pairs and the corresponding preference functions are calculated. Thus, for two alternatives *a* and *b*, both preference functions *a* over *b*, i.e. $P(a, b)$, and *b* over *a*, i.e. $P(b, a)$, must be determined.

Step 3: The multicriteria preference indices are calculated.

Let the decision maker has specified a preference function P_i and weight π_i for each criterion f_i (*i =1, 2,..., k*). For each pair of alternatives *a* and *b*, the weighted average of the corresponding preferences of *a* over *b* and *b* over *a*, are calculated regarding the entire evaluation criteria by Eq. (12).

$$\Pi(a,b) = \frac{\sum_{i=1}^{k} \pi_i P_i(a,b)}{\sum_{i=1}^{k} \pi_i} \quad (12)$$

Step 4: The entering and leaving flows are calculated for the entire alternatives.

For each alternative *a*, the corresponding leaving flow is defined as:

$$\Phi^+(a) = \sum_{b \in k} \Pi(a,b) \quad (13)$$

The corresponding entering flow is also defined as:

$$\Phi^-(a) = \sum_{b \in k} \Pi(b,a) \quad (14)$$

Step 5: The final ranking of alternatives is obtained.

According to PROMETHEE I, alternative *a* is superior to alternative *b* when $\Phi^+(a) > \Phi^+(b)$ and $\Phi^-(a) < \Phi^-(b)$. If the leaving flows (Φ^+) and the entering flows (Φ^-) for the two alternatives *a* and *b* are simultaneously equal, *a* and *b* are indifferent. Other conditions except for the two above-mentioned ones are considered incomparable. Thus, ranking alternatives by PTOMETHEE I is called partial ranking. To overcome this limitation, PROMETHEE II can be utilized for ranking alternatives. In PROMETHEE II, rather than separately calculating entering and leaving flows, the net flow of each alternative is calculated by subtracting the entering flow of the alternative from its leaving flow. The higher the net flow the better the alternative. Therefore, it can result in a complete ranking. In fact, PROMETHEE II in comparison with PROMETHEE I includes less realistic information. However, in the decision making process, this information could often be helpful in particular for incomparable situations.

4-3.   Technique of Order Preference by Similarity to Ideal Solution (TOPSIS)

As mentioned above, in this paper, TOPSIS is used to assess ranking results provided by PROMETHEE. Some advantages which make TOPSIS a major MCDM technique are conceptual simplicity, computational efficiency, large flexibility, having a scalar value that accounts for both the best and worst alternatives simultaneously and its acceptable degree of rank reversal in comparison with AHP, ELECTRE, PROMETHEE and many MCDM techniques [58-61].

The main concept of this technique is that the superior alternative must have the longest distance from the negative ideal solution, in addition to having the shortest distance from the positive ideal solution. The positive ideal solution is a solution that maximizes the benefit criteria and minimizes the cost criteria, while the negative ideal solution

maximizes the cost criteria and minimizes the benefit criteria. The methodology of TOPSIS is as follows:

For J alternative that must be evaluated according to n criteria, w_{ij} denotes the value of ith criterion for jth alternative. These values for $i=1,2,…,n$ and $j=1,2,…,J$ form the elements of the decision matrix. The methodology of TOPSIS comprises the following steps:

Step 1: The decision matrix is normalized. The normalized value r_{ij} is calculated by Eq. (15):

$$r_{ij} = \frac{w_{ij}}{\sqrt{\sum_{j=1}^{J} w_{ij}^2}} \ , \quad j = 1,2,...,J, \ i = 1,2,...,n \quad (15)$$

Step 2: The normalized decision matrix is weighted. The weighted normalized value v_{ij} is calculated by Eq. (16):

$$v_{ij} = w_i * r_{ij}, \quad j=1,2,...,J, i=1,2,3,...,n \quad (16)$$

Step 3: The positive and negative ideal solutions are calculated as follows:

$$A^* = \{v_1^*, v_2^*,...,v_n^*\} = \left\{ \left(\max_j v_{ij} \mid i \in C' \right), \left(\min_j v_{ij} \mid i \in C'' \right) \right\} \quad (17)$$

$$A^- = \{v_1^-, v_2^-,...,v_n^-\} = \left\{ \left(\min_j v_{ij} \mid i \in C' \right), \left(\max_j v_{ij} \mid i \in C'' \right) \right\} \quad (18)$$

where C' and C'' are related to benefit and cost criteria, respectively.

Step 4: The distance of each alternative from positive and negative ideal solutions is calculated:

$$d_j^+ = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^+)^2}, \quad j = 1,2,...,J \quad (19)$$

$$d_j^- = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^-)^2}, \quad j = 1,2,...,J \quad (20)$$

Step 5: The relative closeness of each alternative to the ideal solution is calculated:

$$CC_j = \frac{d_j^-}{d_j^- + d_j^+} \quad (21)$$

Step 6: The alternatives are ranked downwards according to their relative closeness coefficients.

5. Implementation of The Presented Approach: The Case of a Holding Company

As mentioned above, the purpose of this paper is to evaluate performance of some firms from various activity sectors each compared to those of its own activity sector (i.e., industry). Thus, a holding company listed in Tehran Stock Exchange, which holds shares of firms from various activity sectors, has been selected for implementing the presented approach. Such an evaluation can help the holding company to control performance of its subsidiaries and make appropriate rewarding or punishing decisions. These evaluations may also affect investment decisions of the holding company management. Three selected activity sectors for implementing the presented approach are as follows: mineral, cement, and financial sectors. The evaluation procedure has been implemented according to the steps illustrated in Figure. 1.

5-1. Determination of the Evaluation Criteria

First of all, the evaluation criteria have been determined through collaboration of a panel of financial experts working in the holding company as analysts. The analysts ought to regularly investigate conditions of both subsidiaries and the whole market to help management make appropriate rewarding, punishing and investment decisions. The firms have been divided into two main categories namely financial and non-financial firms. After comprehensive investigations and discussions, the hierarchy of the evaluation criteria has been structured based on 11 financial ratios for non-financial firms, 6 financial ratios for financial institutions, and 3 productivity criteria for non-financial firms. Table 2 illustrates the entire evaluation criteria for non-financial firms and financial institutions.

Tab. 2. The weights of the utilized evaluation criteria in this study

Main Criteria	Sub Criteria	Weights for non-financial firms	Weights for financial institutions
Liquidity Ratios	1. Current ratio	0.093	0.317
	2. Quick (acid-test) ratio	0.075	0
Leverage Ratios	3. Debt ratio	0.050	0.052
	4. Total debt to equity ratio	—	0.044
	5. Long-term debt to capital ratio	0.043	0.044
Activity Ratios	6. Inventory turnover ratio	0.109	0
	7. Total asset turnover ratio	0.108	0
Profitability Ratios	8. Net profit margin	0.063	0
	9. Operating profit margin	0.068	0
	10. Return on equity ratio	0.063	0.274
	11. Return on asset ratio	0.063	0.270
Productivity Criteria	12. Added value	0.092	0
	13. Personnel costs on added value ratio	0.08	0
	14. Net sales on number of work forces ratio	0.094	0

5-2. Weighting The Evaluation Criteria

As mentioned above, in this paper, FAHP has been utilized for determining the relative importance (i.e. weights) of evaluation criteria. Thus, firstly according to the hierarchy of evaluation criteria, pairwise comparison matrices for extracting experts' knowledge through Saaty's 9-point scale [64] have been devised. Then, the above-mentioned experts, working in the holding company, have assessed the importance of the evaluation criteria and sub criteria each in its related category. Afterwards, the weights of the evaluation criteria have been calculated via FAHP.

In this section, only the steps of weight computations for the main criteria in case of non-financial firms have been represented to demonstrate steps of Fuzzy AHP method. Correspondingly, for each activity sector, weights of entire main and sub criteria have been calculated.

After assessing the relative importance of evaluation criteria, independently by each expert, via Eq. (22), the pairwise comparison matrices have been transformed into a unique matrix, the elements of which are triangular fuzzy numbers instead of crisp ones. Table 3 illustrates the triangular fuzzy pairwise comparison matrix for the main criteria in case of non-financial firms.

$$(\tilde{x}_{ij}) = (a_{ij}, b_{ij}, c_{ij})$$

$$l_{ij} = \min_k \{a_{ijk}\}, \quad m_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ijk}, \quad u_{ij} = \max_k \{d_{ijk}\} \quad (22)$$

Tab. 3. Fuzzy pairwise comparison matrix for non-financial firms (main criteria)

	C_1	C_2	C_3	C_4	C_5
C_1	(1, 1, 1)	(0.333, 3.867, 6)	(0.143, 0.702, 2)	(0.125, 0.234, 0.5	(0.111, 0.323, 1)
C_2	(0.167, 0.807, 1)	(1, 1, 1)	(0.143, 0.275, 0.5)	(0.143, 0.18(0.25)	(0.125, 0.189, 0.333
C_3	(0.5, 3.9, 7)	(2, 4.8, 7)	(1, 1, 1)	(0.143, 0.409, 1)	(0.143, 0.407, 1)
C_4	(2, 5.4, 8)	(4, 5.8, 7)	(1, 4, 7)	(1, 1, 1)	(0.143, 1.479, 3)
C_5	(1, 6, 9)	(3, 6.2, 8)	(1, 4.2, 7)	(0.333, 2.533, 70	(1, 1, 1)

Then, Eq. (2) has been utilized to calculate synthesis values. From table 3, synthesis values of main criteria for non-financial firms have been computed as follows:

$$S_{C_1} = (1.71, 6.13, 10.5) \times (1/21.55, 1/56.70, 1/90.58) = (0.018903, 0.10802, 0.487203)$$

$$S_{C_2} = (1.58, 2.45, 5.08) \times (1/21.55, 1/56.70, 1/90.58) = (0.017414, 0.043228, 0.235868)$$

$$S_{C_3} = (3.79, 10.52, 17) \times (1/21.55, 1/56.70, 1/90.58) = (0.041793, 0.185449, 0.788805)$$

$$S_{C_4} = (8.14, 17.68, 26) \times (1/21.55, 1/56.70, 1/90.58) = (0.089894, 0.31177, 1.206408)$$

$$S_{C_5} = (6.33, 19.93, 32) \times (1/21.55, 1/56.70, 1/90.58) = (0.069917, 0.351533, 1.484809)$$

Afterward, synthesis values have been compared via Eq. (7) and the following values have been achieved:

$$V(S_{C_1} > S_{C_2}) = 1, V(S_{C_1} > S_{C_3}) = 0.85, V(S_{C_1} > S_{C_4}) = 0.66, V(S_{C_1} > S_{C_5}) = 0.63$$

$$V(S_{C_2} > S_{C_1}) = 0.77, V(S_{C_2} > S_{C_3}) = 0.58, V(S_{C_2} > S_{C_4}) = 0.35, V(S_{C_2} > S_{C_5}) = 0.35$$

$$V(S_{C_3} > S_{C_1}) = 1, V(S_{C_3} > S_{C_2}) = 1, V(S_{C_3} > S_{C_4}) = 0.85, V(S_{C_3} > S_{C_5}) = 0.81$$

$$V(S_{C_4} > S_{C_1}) = 1, V(S_{C_4} > S_{C_2}) = 1, V(S_{C_4} > S_{C_3}) = 1, V(S_{C_4} > S_{C_5}) = 0.97$$

$$V(S_{C_5} > S_{C_1}) = 1, V(S_{C_5} > S_{C_2}) = 1, V(S_{C_5} > S_{C_3}) = 1, V(S_{C_5} > S_{C_4}) = 1$$

Then, priority weights have been calculated via Eq. (8) as follows:

$$d_1' = \min (1, 0.85, 0.66, 0.63) = 0.63$$

$$d_2' = \min (0.77, 0.58, 0.35, 0.35) = 0.35$$

$$d_3' = \min (1, 1, 0.85, 0.81) = 0.81$$

$$d_4' = \min (1, 1, 1, 0.97) = 0.97$$

$$d_5' = \min (1, 1, 1, 1) = 1$$

Finally, the priority weight vector, i.e. (0.63, 0.35, 0.81, 0.97, 1), has been normalized to obtain final weights of main evaluation criteria for non-financial firms as follows:
W = (0.168, 0.093, 0.216, 0.257, 0.266)
Similarly, weights of other main and sub criteria have been calculated. The final weight of each evaluation criterion is calculated via multiplying the weight of each sub criterion and its underlying main criterion. These final weights have been shown in Table 2.

5-3. Ranking the Firms Via PROMETHEE

Using the weights calculated for the entire evaluation criteria, PROMETHEE has been utilized to provide the final ranking of firms of each activity sector independently. Hence, the appropriate generalized criterion associated with each evaluation criterion has been defined through collaboration with the above-mentioned panel of experts. Table 4 and Table 5 show the generalized criteria associated with non-financial firms and financial institutions respectively.

Tab. 4. Inputs for Applying the PROMEHTEE for Non-Financial Firms

Evaluation criteria	Generalized criteria	Parameters (cement firms)	Parameters (mineral firms)	Type	Weight
Current ratio		——	——	Max	0.093
Quick (acid-test) ratio		——	——	Max	0.075
Debt ratio		——	——	Min	0.050
Long-term debt to capital ratio		——	——	Min	0.043
Net profit margin		——	——	Max	0.063
Operating profit margin		——	——	Max	0.068
Return on equity ratio		——	——	Max	0.063
Return on asset ratio		——	——	Max	0.063
Inventory turnover ratio		$q = 0.5$	$q = 0.5$	Max	0.109
Total asset turnover ratio		$q = 0.05$	$q = 0.05$	Max	0.108
Added value		$p = 10^{11}$	$p = 0.3 \times 10^{12}$	Max	0.092
Personnel costs on added value ratio		$p = 0.1$	$p = 0.1$	Min	0.080
Net sales on number of work forces ratio		$p = 0.5 \times 10^{9}$	$p = 0.2 \times 10^{10}$	Max	0.094

Tab. 5. Inputs for applying the PROMEHTEE for financial institutions

Evaluation criteria	Generalized criteria	Type	Weight
Current ratio		M	0.317
Debt ratio		M	0.052
Total debt to equity ratio		M	0.044
Long-term debt to capital ratio		M	0.044
Return on equity ratio		M	0.274
Return on asset ratio		M	0.270

The required data for ranking process have been provided from financial statements of firms. These financial statements are obtained from the TSE website. Then the required raw data have been extracted from the provided financial statements. Finally, utilizing the extracted raw data, values of evaluation criteria for entire firms have been calculated. The weights, generalized criteria as well as values of evaluation criteria have been utilized as inputs for DECISION LAB software to obtain the final ranking of firms via PROMETHEE. Table 6 shows results of implementing PROMETHEE I and PROMETHEE II on firms of each activity sector.

5-4.   Ranking Firms Via TOPSIS
To assess the validity of ranking results via PROMETHEE, another prominent multicriteria decision making technique has been used. Here, TOPSIS, as one of the most

important multicriteria decision making techniques has been adopted. TOPSIS requires two types of information to provide the ranking of alternatives as follows: information about the relative importance (i.e. weights) of evaluation criteria and information about the performance of alternatives on each criterion. TOPSIS, unlike PROMETHEE, does not require any information about the preference function of decision makers on each criterion. Instead, TOPSIS utilizes the information about performance of alternatives on each criterion to define two virtual alternatives called positive and negative ideal solutions. Then, TOPSIS determines the preference of alternatives according to their distances from these two solutions. Table 6 shows results of implementing TOPSIS on firms of each activity sector.

Tab. 6. The outranked firms according to PROMETHEE and TOPSIS

Activity sector	Firms' name	Φ^+	Φ^-	Φ	TOPSIS score
Cement	Kordestan Cement Co.	0.63	0.23	0.40	0.59
	Hormozgan Cement Co.	0.60	0.27	0.33	0.66
	Khash Cement Co.	0.27	0.60	-0.33	0.38
	Bojnurd Cement Co.	0.28	0.68	-0.40	0.44
Mineral	Gol-e-Gohar Iron Ore Co.	0.69	0.27	0.42	0.51
	Chadormalu Mining Co.	0.27	0.69	-0.42	0.49
Financial	Bank Sepah Brokerage Co.	0.87	0.14	0.73	0.91
	Omid Exchange Co.	0.80	0.21	0.59	0.67
	Sepah Investment Co.	0.23	0.77	-0.54	0.26
	Omid Leasing Co.	0.12	0.88	-0.76	0.11

5-5.   Validation and analysis of ranking results
A comparative analysis of ranking results shows that results of implementing PROMETHEE and TOPSIS are in an almost strong concurrence with each other. More precisely, in case of entire firms of mineral and financial activity sectors, PROMETHEE I, PROMETHEE II and TOPSIS rankings have completely the same results. However, in case of cement firms, the results were not quite the same. In other words, the situation

of the 1st and 2nd ranked firms through implementing PROMETHEE namely Kordestan and Hormozgan cement firms is reversed when implementing TOPSIS. The occasion is resulted from the fact that the construction of preferences in PROMETHEE, unlike TOPSIS, is determined by the predefined generalized criteria. Thus, a small difference between results is unsurprisingly expected. The event is also occurred in case of the 3rd and 4th ranked firms namely Khash and Bojnurd cement firms which of course are incomparable according to PROMETHEE

I. But, in other cases, as mentioned above, results of TOPSIS and PROMETHEE are in a complete concurrence with each other.

Also, experts who were contributed in the entire stages of evaluation process were asked about the obtained results, as they regularly scrutinize the situation of the entire firms in comparison with their competitors and the whole market. As far as the panel of experts was concerned, its members confirmed the validity of PROMETHEE ranking results due to their experiences about the performance of firms within their activity sector and the whole market. Thus, PROMETHEE ranking results were confirmed by both quantitative and qualitative validation procedures.

The GAIA planes [68], associated with the ranking process of each activity sector, were also obtained via Decision Lab software. The GAIA plane shows situation of each alternative and criterion over each other using principal components analysis (PCA). Here, in case of cement firms, the 14-dimensional space of criteria has been projected onto a 2-dimensional plane through two linear combinations of evaluation criteria. According to the GAIA plane associated with cement firms, the Delta-parameter was equal to 88.31% which implies losing only 11.69% of the total information. The Delta-parameter is a measure of the quantity of information being preserved by the projection of the 14-dimentional space to a 2-dimentional space. In this case, since the Delta-parameter had a high value (more than 80%), the correlations between the entire evaluation criteria have been calculated. The Pearson correlation coefficient between the total debt to equity ratio and the debt ratio was 0.984 which was significant at the 0.05 level. This fact was confirmed by their similar directions in the GAIA plane. In addition, both of them belong to an identical category namely leverage ratios. Thus, to prevent the problem of double counting or weighing, the total debt to equity ratio was discarded from the list of the evaluation criteria for non-financial firms. After eliminating this criterion, the weights of the other criteria have been calculated again. Then, cement firms were ranked via

PROMETHEE and TOPSIS again and the Table 6 was modified regarding the newly obtained results. Furthermore, ranking results have also been obtained for firms of two other activity sectors again as shown in Table 6.

In financial and mineral sectors, firms were comparable via PROMETHEE I, however in cement sector, Khash and Bojnurd firms were not comparable via PROMETHEE I and therefore, PROMETHEE II has been applied. The incomparability between two alternatives *a* and *b* often occurs when *a* is strong on a set of criteria on which *b* is weak and vice versa [68]. Figure 3 and Figure 4 show results of ranking cement firms via PROMETHEE I and PROMETHEE II. In fact, eliminating the total debt to equity ratio did not have any effects on ranking results of PROMETHEE partial and complete rankings.
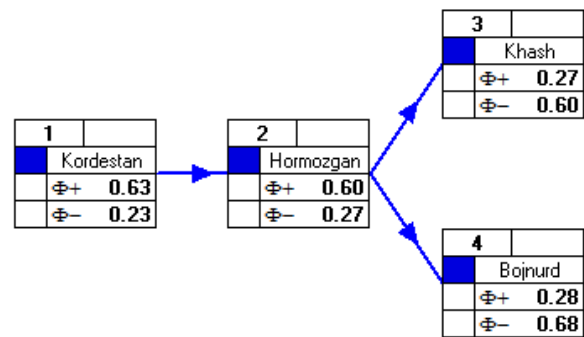

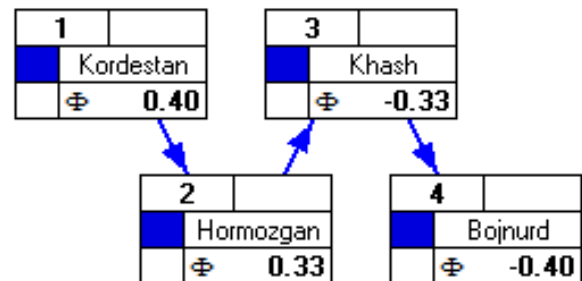**Fig. 3. Ranking of the cement firms through PROMETHEE I**

Fig. 4. Ranking of the cement firms through PROMETHEE II

Figure 5 shows the GAIA plane associated with the cement activity sector which has

been obtained after eliminating the total debt to equity ratio criterion. The GAIA plane has been resulted in a Delta-parameter of 88.02% which still has a high value meaning that only 11.98% of total information gets lost in applying the PCA method. Figure 5 also shows that the decision axis (*pi*) associated with the cement activity sector is extremely

long. Hence, superior firms are located in its direction. In this case, the decision axis is toward Kordestan and Hormozgan cement firms meaning that they are superior in comparison with the two other firms. This fact is in accordance with the results obtained from implementing PROMETHEE I and PROMETHEE II.
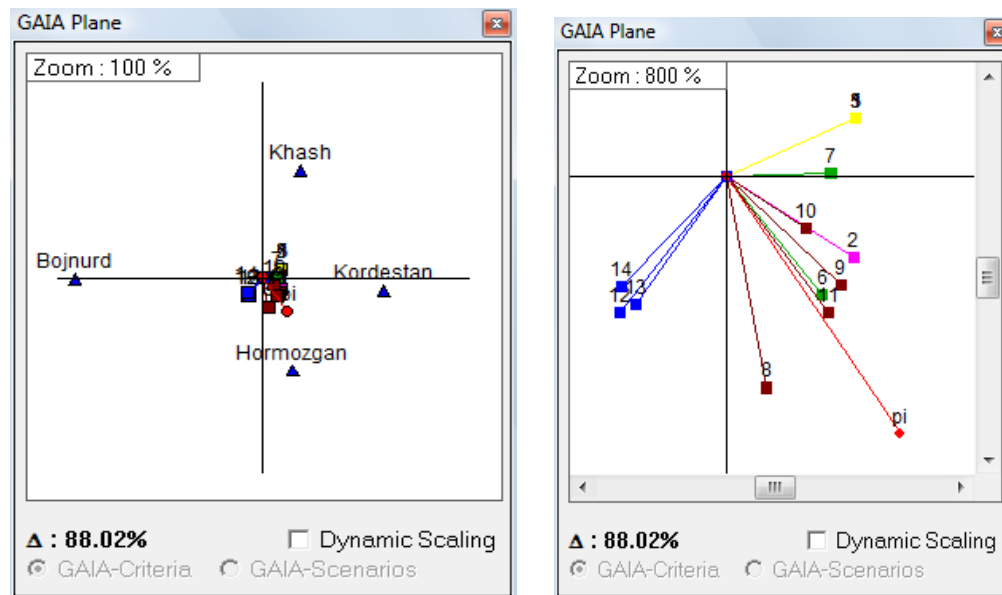
a) The original view of the GAIA plane   **b) A closer view of the GAIA plane**
Fig. 5. The GAIA plane for cement firms after eliminating the total debt to equity ratio criterion

Furthermore, GAIA plane has another capability which is differentiation power of criteria. The length of a criterion axis is a measure of differentiating alternatives. The longer the criterion axis, the more its corresponding criterion differentiates alternatives [68]. For example, Figure 5 shows that the 8th criterion (i.e., net profit margin) differentiates firms more than other criteria. Additionally, two criteria are similar when their corresponding axes are oriented approximately in an identical direction. Figure 5 shows that three productivity criteria are similar, since all of them have been oriented in an identical direction. In GAIA plane, independent criteria are also

represented by nearly orthogonal axes, while conflicting criteria are represented by axes having opposite directions. Therefore, the 9th criterion (i.e., operating profit margin) and the 12th one (i.e., added value) are nearly independent, while the 5th criterion (i.e., long-term debt to capital ratio) and the 14th criterion (i.e., net sales on number of work forces ratio) are nearly conflicting. These facts can help identify the status of each criterion in comparison with the other ones.
Figure 6, which includes profiles of cement firms, illustrates how a special cement firm is outranking or outranked by all other cement firms on each particular criterion.
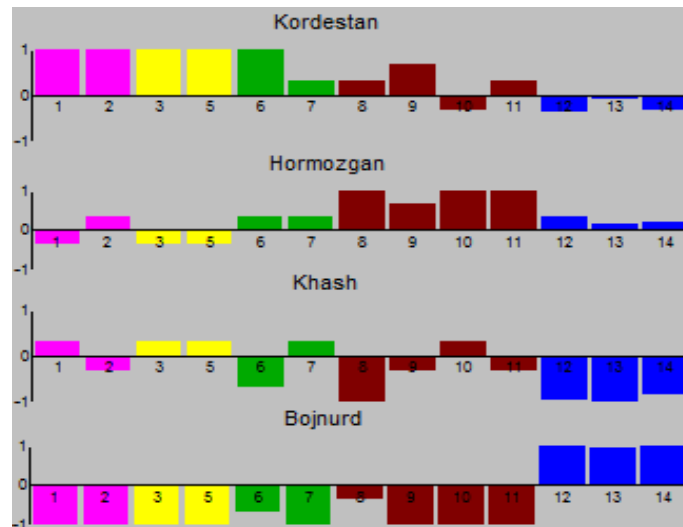
Fig. 6. The profiles of cement firms regarding the different criteria

For example, preferences of Kordestan and Bojnurd cement firms in proportion to the first criterion (i.e., current ratio), over the other cement firms are +1 and –1 respectively; while the preferences of Khash and Hormozgan cement firms in proportion to the first criterion over other cement firms are a positive number less than 1 (i.e., 0.333) and a negative number greater than –1 (i.e., –0.333) respectively. These figures show that Kordestan and Bojnurd cement firms are the best and the worst firms in proportion to the first criterion. Similar analyses can separately be performed for each criterion. According to Figure 6, Bojnurd firm is the best firm regarding to the entire productivity criteria, while it is the worst one regarding to the financial ratios. It confirms the necessity of utilizing productivity criteria as well as financial ratios, since it denotes that financial ratios are incapable of reflecting the all-purpose situation of a firm. Figure 6 also confirms the incomparability of Khash and Bojnurd firms, since Khash firm is good on some evaluation criteria which Bojnurd firm is bad on and vice versa.

Other analyses, e.g. Walking Weights, can be conducted via Decision Lab software by which the decision maker can assess results of evaluation process via changing weights of evaluation criteria.

6.   Conclusion

In this paper, an MCDM approach has been proposed for evaluating performance of firms which belong to various activity sectors. The proposed approach has utilized some of the most prominent multicriteria decision making techniques namely FAHP, PROMETHEE and TOPSIS to deal with such a problem. Firstly, evaluation criteria have been determined through collaboration of a panel of experts. Afterward, FAHP has been utilized to determine the relative importance of evaluation criteria. The required data have been extracted from financial statements of firms and values of evaluation criteria for entire firms have been calculated. Using calculated weights of evaluation criteria via FAHP, PROMETHEE has been utilized o obtain the final ranking of firms. Another prominent multicriteria decision making method namely TOPSIS has been adopted to evaluate the validity of formerly provided ranking results. Our proposed model has been implemented in a holding company listed in Tehran Stock Exchange as a real case. Analysis of PROMETHEE ranking results has also been conducted through GAIA plane. The concluding remarks are as follows:

•   After providing the ranking of firms via PROMETHEE, results have been validated

through implementing another important multicriteria decision making technique namely TOPSIS as well as the confirmation of the contributed experts due to their experiences about the performance of firms in their activity sector and the whole market.

•   The contribution of this paper is the simultaneous utilization of two outstanding multicriteria decision making techniques namely Fuzzy AHP and PROMETHEE in the evaluation process of firms. In fact, our proposed approach gains the advantages and avoids the disadvantages of these MCDM techniques. An important feature of PROMETHEE, which discriminates it from most of MCDM methods, is the ability of defining the appropriate generalized criterion associated with each evaluation criterion by the decision maker(s). Thus, PROMETHEE overcomes the influential limitation of numerous MCDM methods who assume that the relationship between the preferences of alternatives are linear. TOPSIS, as we applied it to assess the validity of our ranking results, has some important advantages such as considering both positive and negative ideal solutions as well as its acceptable degree of rank reversal in comparison with most of prominent MCDM techniques. Since PROMETHEE and TOPSIS do not provide any procedure for weighing the evaluation criteria, Fuzzy AHP has been utilized to overcome this limitation and enrich the ranking approach.

•   Analysis of the GAIA plane helped us identify and eliminate a redundant criterion (i.e., the total debt to equity ratio) from the list of evaluation criteria. This analysis also revealed the differentiating criterion which was the net profit margin as well as conflicting criteria which were a cluster of the current ratio and the long-term debt to capital ratio and a cluster of the three productivity

criteria. Furthermore, it could identify the independent criteria.

In spite of utilizing FAHP rather than AHP in the proposed methodology, the determined weights of evaluation criteria are still partly dependent to experts' judgments. Utilizing judgments of more experts can provide a greater degree of confidence. Furthermore, ranking results are partly dependent to types of generalized criteria determined by the decision maker(s). Hence, the precise determination of generalized criteria is a matter of particular importance.

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