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Inter-company comparison using modified TOPSIS with objective weights

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Abstract

Simultaneous consideration of multiple financial ratios is required to adequately evaluate and rank the relative performance of competing companies. This paper formulates the inter-company comparison process as a multi-criteria analysis model, and presents an effective approach by modifying TOPSIS for solving the problem. The modified TOPSIS approach can identify the relevance of the financial ratios to the evaluation result, and indicate the performance difference between companies on each financial ratio. To ensure that the evaluation result is not affected by the inter-dependence of the financial ratios, objective weights are used. As a result, the comparison process is conducted on a commonly accepted basis and is independent of subjective preferences of various stakeholders. An empirical study of a real case in China is conducted to illustrate how the approach is used for the inter-company comparison problem. The result shows that the approach can reflect the decision information emitted by the financial ratios used. The comparison of objective weighting methods suggests that, with the modified TOPSIS approach, the entropy measure compares favourably with other methods for the case study conducted.

Scope and purpose

The performance evaluation and ranking of modern enterprises is a complex process, in which multiple financial ratios are required to be considered simultaneously. The purpose of this paper is to apply the framework of multi-criteria analysis to the inter-company comparison problem. An effective approach based on the concept used by the technique for order preference by similarity to ideal solution (TOPSIS) is developed to rank competing companies in terms of their overall performance on multiple financial ratios. The approach modifies the TOPSIS method by using weighted Euclidean distances to ensure a meaningful interpretation of the evaluation result. The use of objective weights for financial ratios based on Shannon's entropy concept reflects the context-dependent concept of informational importance. This ensures that the evaluation result is not affected by the inter-dependency of criteria and inconsistency of subjective weights. This approach is particularly applicable for situations where reliable subjective weights cannot be obtained.

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With its simplicity in both concept and computation, the approach can readily be incorporated into a computer-based system.

Keywords: Multi-criteria analysis; Inter-company comparison; Objective weights

1. Introduction

The performance of a company during a stated period of time is usually reflected by various financial ratios summarized from its financial statements; such as the balance sheet, the income statement and the trading account. These ratios provide useful information to the stakeholders of the company, and reflect the company's performance from various perspectives [1]. For a specific company, these ratios do not always move in the same direction, and very often an improvement in one ratio can only be achieved at the expense of deterioration in another. The overall performance of competing companies cannot be properly evaluated or ranked without simultaneous consideration of all these conflicting ratios [2,3].

Two traditional approaches used for evaluating a company's performance are financial statement analysis based on the computation of financial ratios and multivariate analysis based on elaborate statistical models. These methods are no longer appropriate in today's dynamic business environment, due to their unrealistic assumptions and their dependency on a single performance measure [4].

Data envelopment analysis (DEA) [5] has recently attracted much attention for evaluating competing alternatives (companies) performing essentially the same task. For example, Charnes et al. [6] have successfully used DEA to evaluate the relative efficiency of large commercial banks with multiple inputs and outputs. Doyle and Green [7] have demonstrated that DEA can be effectively used to compare various products from multiple dimensions. Smith [8] suggests that the application of DEA to the analysis of the company's financial statements can be more informative in comparison with the ratio analysis method. However, the primary aim of DEA is not in general to rank or select one or more competing companies, the intention is rather to identify those companies that are not 'efficient' in some sense, and to assess where the inefficiencies arise [9]. In addition, the selection of inputs and outputs to be included in the evaluation process is often subject to some difficulty [10].

Alternatively, multi-criteria analysis (MA) or multiple criteria decision making (MCDM) is widely used in ranking or selecting one or more alternatives from a set of available alternatives with respect to multiple, usually conflicting criteria [11]. In line with the multi-dimensional characteristics of modern enterprises, MA provides an effective framework for inter-company comparison involving the evaluation of multiple financial ratios. It can rank competing companies compared in terms of their overall performance. This paper models the inter-company comparison problem as an MA problem, and presents a simple and effective approach to solving the problem.

2. The modified TOPSIS approach

A large number of methods have been developed for solving MA problems [11,12]. The methods developed along the lines of multi-attribute utility theory are suited for the inter-company comparison problem requiring a cardinal preference of the alternatives. In this paper, the concept of the approach used for solving the problem is based on the technique for order preference by similarity to ideal solution (TOPSIS) [11]. This is because (a) the concept is rational and comprehensible, (b) the computation involved is simple, (c) the concept is capable of depicting the pursuit of the best performance of a company's operation for each evaluation criterion in a simple mathematical form, and (d) the concept allows objective weights to be incorporated into the comparison process. The concept of TOPSIS is that the most preferred alternative should not only have the shortest distance from the positive ideal solution, but also have the longest distance from the negative ideal solution. This concept has also been pointed out by Zeleny [13], who refers to the positive and negative ideal solutions as the ideal and anti-ideal solutions, respectively.

In an inter-company comparison problem, a set of companies (*the alternatives*; $A = \{A_i,\ i = 1, 2, \ldots, n\}$) is to be compared with respect to a set of financial ratios (*the criteria*; $C = \{C_j,\ j = 1, 2, \ldots, m\}$). The performance rating of each company A_i for each criterion C_j is a crisp value, and can be calculated from the available financial data. Therefore, an $n \times m$ performance matrix (*the decision matrix*; X) for the problem can be obtained as

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix}, \tag{1}$$

where x_{ij} is a crisp value indicating the performance rating of each alternative A_i with regard to each criterion C_j. The criteria are assumed to be benefit criteria, as TOPSIS requires that the utility of each criterion be monotonic. This assumption does not cause any loss of generality as other types of criteria can easily be transformed into a beneficial one.

Criteria importance is a reflection of the DM's subjective preference as well as the objective characteristics of the criteria themselves [13]. The subjective preference is usually assigned by the DMs based on their own experiences, knowledge and perception of the problem via a preference elicitation technique such as the analytic hierarchy process (AHP) [14]. This process of assigning subjective preferences to the criteria is referred to as subjective weighting. A good review of various subjective weighting methods commonly used in MA is given by a number of authors based on various performance measures, such as Barron and Barrett [15], Hobbs [16], and Schoemaker and Waid [17]. The results of these studies show that no single method can guarantee a more accurate result, and the same DM may obtain different weights using different methods. This may mainly be due to the fact that the DM cannot always give consistent judgement under different weighting schemes and the weighting process itself is essentially context dependent.

The inconsistency problem in subjective weighting has been well addressed by some recent papers, reflecting the inherent difficulty of assigning reliable subjective weights. Fisher [18], Mareschal [19], and Triantaphyllou and Sanchez [20] use a sensitivity analysis approach to give DMs flexibility in assigning criteria weights and help them understand how criteria weights affect the decision outcome. Although this approach can reduce DMs' cognitive burden in determining precise weights, it may become tedious and difficult to manage as the number of the criteria increases. By recognizing the fact that criteria weights are context dependent and task specific, Ribeiro [21] presents an interactive run-time method which allows DMs to select the desirable preference elicitation technique. Yeh et al. [22] develop a task-oriented weighting approach which effectively links the criteria weights with the requirements of specific tasks for selecting the most suitable alternative. The approach greatly reduces the DM's burden in the subjective weighting process and achieves a rather consistent weighting outcome. However, when the problem involves a group of DMs with various interests, a consensus on the criteria weights may not always be achieved.

Inter-company comparison requires that it be conducted on a commonly accepted basis [23]. With the multiplicity of the problem under a specific environment, it is difficult for the stakeholders or DMs of various interests to reach an agreement on the relative importance of the financial ratios via a subjective weighting process. This difficulty is increased when suitable DMs are not available. In addition, the financial ratios used may not be totally independent as they are all linked and affected by the operation of the company to some extent. These problems can be overcome by using an objective weighting process, which is carried out independent of subjective preferences of various DMs. It is particularly applicable when reliable subjective weights are not obtainable.

Objective weights of criteria importance, measured by the average intrinsic information generated by a given set of alternatives through each criterion, reflect the nature of conflicting criteria and enable the incorporation of inter-dependent criteria [23]. In the application of inter-company comparison, objective weights of the financial ratios are determined by the contrast intensity of the companies' performance ratings with respect to each financial ratio. In other words, it is based on the context-dependent concept of informational importance [13]. Shannon's entropy concept [24] is well suited for measuring the relative contrast intensities of financial ratios to represent the average intrinsic information transmitted to the DM [13]. The entropy measure clearly indicates the amount of decision information that each financial ratio contains [11].

Entropy is a measure of uncertainty in the information formulated using probability theory. It indicates that a broad distribution represents more uncertainty than does a sharply peaked one. To determine objective weights by the entropy measure, the decision matrix in Eq. (1) needs to be normalized for each criterion C_j $(j = 1, 2, \ldots, m)$ as

$$p_{ij} = \frac{x_{ij}}{\sum_{p=1}^{n} x_{pj}}, \quad i = 1, 2, \ldots, n. \tag{2}$$

As a consequence, a normalized decision matrix representing the relative performance of the alternatives is obtained as

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1m} \\ p_{21} & p_{22} & \cdots & p_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ p_{n1} & p_{n2} & \cdots & p_{nm} \end{bmatrix}. \tag{3}$$

The amount of decision information contained in Eq. (3) and emitted from each criterion C_j $(j = 1, 2, \ldots, m)$ can thus be measured by the entropy value e_j as

$$e_j = -k \sum_{i=1}^{n} p_{ij} \ln p_{ij}, \tag{4}$$

where $k = 1/\ln n$ is a constant which guarantees $0 \leqslant e_j \leqslant 1$.

The degree of divergence (d_j) of the average intrinsic information contained by each criterion C_j ($j = 1, 2, \ldots, m$) can be calculated as

$$d_j = 1 - e_j. \tag{5}$$

d_j represents the inherent contrast intensity of the criterion C_j. The more divergent the performance ratings p_{ij} ($i = 1, 2, \ldots, n$) for the criterion C_j, the higher its corresponding d_j, and the more important the criterion C_j for the problem [13, p. 190]. This reflects that a criterion is less important for a specific problem if all alternatives have similar performance ratings for that criterion [25]. If all the performance ratings against a criterion are the same, the criterion can be eliminated for the given situation on which a decision is to be based, because it transmits no information to the DM [13].

The objective weight for each criterion C_j ($j = 1, 2, \ldots, m$) is thus given by

$$w_j = \frac{d_j}{\sum_{k=1}^{m} d_k}. \tag{6}$$

In addition to the entropy measure (EM), any other method of measuring the divergence in performance ratings could be used to determine the objective weights. Diakoulaki et al. [23] propose the CRiteria Importance Through Intercriteria Correlation (CRITIC) method. They also present two other methods for comparison. The standard deviation (S.D.) method calculates objective weights by $w_j = \sigma_j / \sum_{k=1}^{m} \sigma_k$, where σ_j is the standard deviation of the performance rating vector $p_j = (p_{1j}, p_{2j}, \ldots, p_{nj})$ in Eq. (3). The mean weight (MW) method gives objective weights by $w_j = 1/m$, where m is the number of the criteria. This is based on the assumption that all the criteria are of equal importance. All these four methods of determining objective weights will be used and compared in the case study to be presented in the next section.

After determining performance ratings of the alternatives and objective weights of the criteria, the next step is to aggregate them to produce an overall performance index for each alternative. This aggregation process is based on the positive ideal solution (A^+) and the negative ideal solution (A^-), which are defined, respectively, by

$$\begin{aligned} A^+ &= \left(\max_i (p_{i1}), \max_i (p_{i2}), \ldots, \max_i (p_{im})\right) = (p_1^+, p_2^+, \ldots, p_m^+), \\ A^- &= \left(\min_i (p_{i1}), \min_i (p_{i2}), \ldots, \min_i (p_{im})\right) = (p_1^-, p_2^-, \ldots, p_m^-). \end{aligned} \tag{7}$$

The overall performance index of an alternative is determined by its distance to A^+ and A^-. This distance is interrelated with the criteria weights [13] and should be incorporated in the distance measurement [25]. This is because all alternatives are compared with A^+ and A^-, rather than directly among themselves. In TOPSIS, the criteria weights mainly serve as a channel through which the criteria with different performances can be brought together. The decision matrix is weighted by multiplying each column of the matrix by its associated criteria weight. Thus, the resultant Euclidean distances are not weighted at all, and are often subject to an amorphous interpretation. To avoid this problem, we use the weighted Euclidean distances instead of the weighted decision matrix required by TOPSIS in the aggregation process.

From Eqs. (3) and (7), the weighted Euclidean distances, between A_i and A^+, and between A_i and A^-, are calculated, respectively, as

$$d_i^+ = \left[\sum_{j=1}^{m} w_j(d_{ij}^+)^2\right]^{1/2}, \quad d_i^- = \left[\sum_{j=1}^{m} w_j(d_{ij}^-)^2\right]^{1/2}, \quad i = 1, 2, \ldots, n, \tag{8}$$

where

$$d_{ij}^+ = p_j^+ - p_{ij}, \quad d_{ij}^- = p_{ij} - p_j^-, \quad i = 1, 2, \ldots, \; j = 1, \ldots, m. \tag{9}$$

An overall performance index for each alternative A_i ($i = 1, \ldots, n$) is thus computed by

$$P_i = \frac{d_i^-}{d_i^+ + d_i^-}. \tag{10}$$

The larger the index value, the better the performance of the alternative.

3. Numerical example

A case study of comparing seven companies ($A_1, A_2, \ldots, A_7$) in the textile industry at Wuhan, China was conducted to examine the applicability of the modified TOPSIS approach. Four financial ratios (profitability (C_1), productivity (C_2), market position (C_3), and debt ratio (C_4)) were identified as the evaluation criteria for the industry. By using the available financial data of these companies, the performance rating of each company with respect to each financial ratio was calculated. The ratings of the debt ratio were adjusted by taking the reversal of the original value so that it could be treated as a benefit criterion like other criteria. Table 1 shows the result and the corresponding rankings.

To apply the modified TOPSIS approach developed, the decision matrix contained in Table 1 needs to be normalized by Eq. (2). Table 2 shows the result.

The positive ideal solution and the negative ideal solution are then determined by Eq. (7) as

$$A^+ = (0.21, 0.19, 0.20, 0.18), \quad A^- = (0.05, 0.12, 0.08, 0.12).$$

Table 1
Performance ratings and rankings of companies

	Profitability (C_1)		Productivity (C_2)		Market position (C_3)		Debt ratio (C_4)	
	Ratio	Ranking	Ratio	Ranking	Ratio	Ranking	Ratio	Ranking
A_1	0.12	4	49 469	1	0.15	2	1.21	4
A_2	0.08	6	34 251	3	0.14	3	1.23	3
A_3	0.04	7	32 739	5	0.09	6	1.12	6
A_4	0.16	1	44 631	2	0.11	5	1.56	1
A_5	0.09	5	33 151	4	0.13	4	1.09	7
A_6	0.15	2	31 408	6	0.07	7	1.39	2
A_7	0.13	4	30 654	7	0.17	1	1.16	5

A comparison between the normalized performance ratings of each company A_i in Table 2 and A^+, and between that of A_i and A^- by Eq. (9) would indicate how the company is performing as compared with the best performance and the worst performance of all the companies with respect to each criterion. This would help individual companies identify the area to be improved most in order to best improve their rankings. Table 3 shows the result.

The entropy measure (EM) method and other methods (CTITIC, S.D., and MW) for determining objective weights were used by the case study in order to examine the effectiveness of the modified TOPSIS approach developed. Table 4 shows the objective weights derived from each method.

With the EM and S.D. methods, the profitability criterion has the highest degree of importance in assessing the company's overall performance. The productivity criterion and the debt ratio criterion have a relative low degree of importance for the companies considered. This is because all the companies compared have a relatively similar performance on these two criteria. This reflects the concept that a criterion does not contribute much towards the evaluation outcome, if all alternatives (companies) have similar performance ratings with respect to the criterion.

The result of Table 4 seems to suggest that objective weights derived by the EM method are more significantly different to each other. This reflects the capability of the EM method in reflecting the average intrinsic information generated by the performance of companies through multiple

Table 2
Normalised decision matrix

	Profitability (C_1)	Productivity (C_2)	Market position (C_3)	Debt ratio (C_4)
A_1	0.16	0.19	0.17	0.14
A_2	0.10	0.13	0.16	0.14
A_3	0.05	0.13	0.10	0.13
A_4	0.21	0.17	0.13	0.18
A_5	0.12	0.13	0.15	0.12
A_6	0.19	0.12	0.08	0.16
A_7	0.17	0.12	0.20	0.13

Table 3
Performance comparison of companies

	Profitability (C_1)		Productivity (C_2)		Market position (C_3)		Debt ratio (C_4)	
	d_{i1}^+	d_{i1}^-	d_{i2}^+	d_{i2}^-	d_{i3}^+	d_{i3}^-	d_{i4}^+	d_{i4}^-
A_1	0.05	0.10	0.00	0.07	0.02	0.09	0.04	0.01
A_2	0.10	0.05	0.06	0.01	0.03	0.08	0.04	0.02
A_3	0.16	0.00	0.07	0.01	0.09	0.02	0.05	0.00
A_4	0.00	0.16	0.02	0.05	0.07	0.05	0.00	0.05
A_5	0.09	0.06	0.06	0.01	0.05	0.07	0.05	0.00
A_6	0.01	0.14	0.07	0.00	0.12	0.00	0.02	0.03
A_7	0.04	0.12	0.07	0.00	0.00	0.12	0.05	0.01

financial ratios. This would help the DM identify the most important criterion (e.g. the profitability criterion in this case) on which the companies have the most divergent performance ratings.

With the data in Table 3 and each set of weights in Table 4, the overall performance index of each company evaluated can be calculated by Eqs. (8) and (10). Table 5 shows the performance index of each company and its corresponding ranking under different objective weighing methods.

To identify the relevance of criteria in assessing the overall performance of the companies, the Spearman's rank correlation coefficients [26] between the multi-criteria ranking and uni-criterion ranking were calculated. Table 6 shows the result. Based on the t-statistics, values of the Spearman's correlation coefficient greater than 0.11 indicate at 1% level of significance the existence of a positive relationship between the rankings examined. The positive relationship shown in Table 6 for the four financial ratios under various objective weighting methods suggests that the modified TOPSIS approach can reflect the decision information emitted by four financial ratios effectively.

The profitability ratio has the highest value, meaning that it contributes most to the relative performance of the company. This is in line with the real situation and the general perception of the management in the textile industry at Wuhan. It is noteworthy that the EM method has a higher coefficient value for the profitability criterion than other methods. This would help the DM give prominence to the most important criterion, while being able to incorporate the decision information emitted by all other criteria. In addition, the EM method produces more divergent coefficient values for all the criteria. We regard this phenomenon as favourable to the EM method as it can better resolve the inherent conflict between the criteria embedded in MA decision problems. This

Table 4
Objective weights of the evaluation criteria

Criteria	EM	CRITIC	S.D.	MW
Profitability (C_1)	0.54	0.31	0.38	0.25
Productivity (C_2)	0.13	0.18	0.20	0.25
Market position (C_3)	0.28	0.38	0.28	0.25
Debt ratio (C_4)	0.06	0.13	0.13	0.25

Table 5
Performance index and ranking of companies

	EM		CRITIC		S.D.		MW	
	Index	Ranking	Index	Ranking	Index	Ranking	Index	Ranking
A_1	0.70	3	0.71	1	0.70	2	0.69	2
A_2	0.41	6	0.46	5	0.43	6	0.43	5
A_3	0.09	7	0.12	7	0.10	7	0.11	7
A_4	0.76	1	0.69	3	0.73	1	0.71	1
A_5	0.44	5	0.46	6	0.44	5	0.42	6
A_6	0.61	4	0.51	4	0.56	4	0.52	4
A_7	0.72	2	0.70	3	0.68	3	0.64	3

Table 6
Spearman's rank correlation coefficients between multi-criteria and uni-criterion rankings

Method	Profitability (C_1)	Productivity (C_2)	Market position (C_3)	Debt ratio (C_4)
EM	0.89	0.14	0.32	0.50
CRITIC	0.64	0.25	0.57	0.43
SD	0.86	0.36	0.29	0.54
MW	0.82	0.39	0.32	0.68

result seems to suggest that the modified TOPSIS approach with objective weights obtained from the EM method is suitable for the inter-company comparison problem examined.

4. Conclusion

MA provides an effective framework for ranking competing companies in terms of their overall performance with respect to multiple financial ratios. In this paper, we have presented an effective MA approach for solving the inter-company comparison problem in a simple and straightforward manner. The approach modifies the TOPSIS method by using weighted Euclidean distances to ensure a meaningful interpretation of the comparison result. It can identify the relevance of the financial ratios to the result, and indicate the performance difference between companies for each financial ratio. To address the criteria inter-dependence problem, objective weights for the financial ratios are used. The evaluation result would be acceptable to various stakeholders of the companies, as it is independent of their subjective and often inconsistent preferences of the financial ratios. The empirical study of a real case in China demonstrates that the approach can effectively reflect the decision information emitted by the financial ratios, and provide meaningful rankings and useful information. The approach is computationally simple and its underlying concept is rational and comprehensible, thus facilitating its implementation in a computer-based system.

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