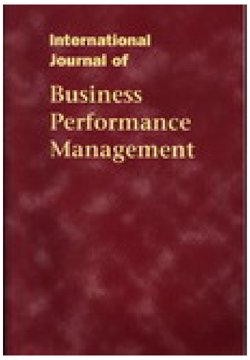

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Evaluating of suppliers selection in auto parts manufacturing company using DEMATEL and TOPSIS

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Abstract: Global competition in an environment which is permanently changing has led organisations to understand the importance of flexibility, present reasonable and in time reactions towards it. Management of supply chain is a strategy to carry out such a work in a way that customers can achieve reliable and fast services along with products having high quality with the least possible costs. The goal of the present research is to evaluate suppliers of Iranian Diesel Engine Manufacturing (IDEM) company using a decision making trial and evaluation laboratory (DEMATEL) and ranking them using technique for order of preference by similarity to ideal solution (TOPSIS). Results showed that planning has appropriated the highest weight. Ideal Motor Parts Factory (IMPF) with 0.8231 has appropriated the highest rank to itself compared with other options and this shows that based on SCOR model, the factory has had the best conditions compared with others.

Keywords: supply chain; suppliers' evaluation; outsourcing; DEMATEL; strategic alliances; TOPSIS; IDEM Company.

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1 Introduction

In the competitive world of the new era, organisations try very hard to grow and maintain consistency and utilise appropriate strategies to develop and survive. The surrounding environment for the organisations is changing rapidly and the diversity of demands along with customers' needs is among such changes. As the importance of purchase and facilities increases, decisions to buy have become more important and due to the fact that nowadays the organisations depend more on suppliers, the immediate and non-immediate outcomes of weak decision-makings seem to be more serious and harmful. In many cases, raw materials' cost and parts of products entail a great portion of product cost. In such a condition, the part dealing with purchases can have a great influence in efficiency and effectiveness of an organisation and it can immediately affect the costs' reduction, increasing profitability, also enhancing the flexibility in a company (Esmaeili et al., 2017).

In traditional supply chain management, members of the supply chain view each other competitively, and the overall concern is keeping costs down. However, if suppliers are selected based on cost alone, a hostile relationship is created between the supplier and buyer, negatively affecting product quality and service (Dyer, 1997). Therefore, companies must evaluate suppliers from multiple angles to protect each other's interests and create good and lasting partnerships (Chen et al., 2005; Sadeghi Asl et al., 2021). Suppliers play crucial roles in supply chain management, producing components, ensuring product quality, and indirectly managing and assisting with the operational costs of their partners (Wu et al., 2016). The quality level of their products determines the degree to which the quality of the final product can be guaranteed and the ability of all the members of the supply chain to control costs. For this reason, the selection of the right suppliers is vital for companies. Supplier selection is a decision-making process that involves a number of steps and several criteria – both quantitative and qualitative (Yang and Chen, 2019).

Evaluation of suppliers and selection of appropriate ones for procurement of needed materials can be an important activity for improvement and optimisation of processes in many companies (Parkouhi and Ghadikolaei, 2017). In supply chain management, selection of appropriate suppliers is a strategic decision that can affect the quality and price of the final product of a company (Dey et al., 2015; Razmi et al., 2016; Rostamzadeh et al., 2020). The current research focuses on the environmental aspects as a competitive advantage. Supplier evaluation and selection problem can be considered as a multi-criteria decision-making (MCDM) problem because it usually involves some alternatives that are evaluated with respect some criteria (Esmaeili et al., 2014).

The paper proceeds as follows. In Section 2, we review related literature on evaluating suppliers using decision-making trial and evaluation laboratory (DEMATEL) method and ranking them using technique for order of preference by similarity to ideal solution (TOPSIS) technique. In Section 3, we present research method and propose method for the evaluating supplier's selection with Dickson framework criteria for supplier selection. In Section 4, we also present the data collection tools process for research to operationalise and validate our proposed approach. In Section 5, we present the data analysis and results. In Section 6, we present conclusions of the study, future research and managerial suggestion.

2 Literature review

'Supply chain' is discussed in many articles and is known as the alignment of firms that present products or services to market (Lambert et al., 1998). Chopra and Meindl (2007) has claimed that "a supply chain is composed of all parties involved, directly or indirectly, in fulfilling a customer request. It entails all functions within receiving and filling a request of customer within each organization, such as a manufacturer." Felea and Albăstroiu (2013) dealt with identifying the concept of supply chain.

SCM has fast changed into the most critical management strategy within the world's top organisations. Significance of SCM has been deemed to very important in the 1990s, on the contrary that it was suggested in early 1980s for the first time (Oliver and Weber, 1982). It is considered as an approach for management to establish a strict relationship with suppliers and consumers to achieve a good status in the market and finally gain highest outcomes through the supply chain (Jüttnet et al., 2007). Loubna et al. (2020) recognised an implementation system using multi-agents for making-decision through supply chain management.

There exists a new term called 'the model entitled supply chain operations reference (SCOR)' which provides methodology, diagnostic and benchmarking tools that help organisations make dramatic and fast improvements in processes of supply chain. The most outstanding characteristic of chain management never stops advancing, and nor do supply chain experts and their related organisations. This is a pre-requisite for savvy operators, supervisors and leaders with the expertise and know-how on the global standards and tryouts that foster supply chain performance. Additionally, APICS is the industry authority that enhances supply chain talent and elevates performance of end-to-end supply chain. APICS identifies the industry standards, starting from education and certification, to benchmarking and best practices in the field.

Figure 1 House of SCM (see online version for colours)

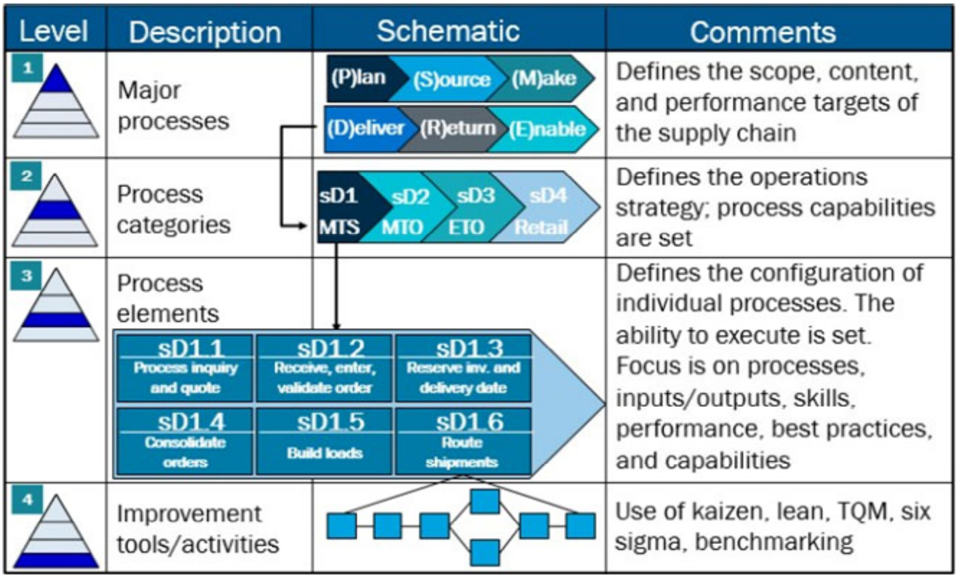
Source: Stadtler (2002)

As it can be observed in Figure 2, the model mentioned above is used to support supply chain analysis regarding multiple levels. APICS has been concentrated on three highest process levels, which are deemed to be industry neutral. SCOR resigns to try to predetermine how an organisation should run its business or tailor the related systems/information flow. Any organisation implementing enhancements for supply chain using SCOR, will be required to generalise the model, to Level-4 at least, using the following items: industry, organisation, and/or location- specific processes, systems and practices (APICS, 2017).

SCOR is a model oriented on process reference. The ending target of a model called process reference, or a framework of business process, is to explain process design in a way that aligns with fundamental business functions and targets. The design mentioned identifies the interaction and performance of processes, the configuration of these processes, and the pre-requisites (skills) on staff conducting the processes. The model of SCOR entails four main parts as follows:

- performance: measures to explain process performance and identify strategic goals
- processes: explanations of processes of management and process deals
- practices: traits that bring about outstanding better process performance
- people: identifications of skills needed to establish supply chain processes.

Figure 2 SCOR is a hierarchical process model (ver. 12.0) (see online version for colours)



Source: APICS (2017)

Suppliers have a critical role in management of supply chain, components' production, product quality ensure, and managing and assisting with the operational costs of their partners indirectly (Wu et al., 2016). It is their products' quality that identifies the quality amount of the final product as a warranty and how much all the members of the supply chain can control costs. Therefore, choosing the appropriate suppliers is deemed to be critical for companies. Choosing suppliers is a process of decision-making that entails several steps and different criteria involving both qualitative and quantitative criteria Cengiz et al., 2017). A favourable selection of supplier would cut down buying costs, make better profits, cut down product lead time, enhance the customer satisfaction and reinforce the competitiveness (Frej et al., 2017). Chen et al. (2019) investigated about the selection of supplier and the evaluation of performance for high-voltage power film capacitors within a fuzzy environment. Taherdoost and Barad (2019) dealt with studying the supplier selection process criteria and methods.

Based on research project carried out by Sollish and Semanik (2006), a process of supplier selection is one of the critical organisational activities controlled by the procurement department. Handfied et al. (2009) claimed that it can be a strong tryout needing a crucial commitment of resources. Additionally, Weele and Van (2014) suggested that the supplier choosing process is a constituent of the purchasing process began through a market research after identifying and clarifying the functional or the technical characteristics.

In some states, the available approved suppliers are not enough; thus, a comprehensive research on supply market should be carried out to find novel suppliers.

Furthermore, Handfied et al. (2009) suggested seven levels for the evaluation of supplier and process selection as follows:

a *Identifying the need to choose supplier:* The process can begin according to the forecast of an ongoing requirement for buying. In this case, the engineering staff might have some primary characteristics identification on the type of the needed materials, processes, or services. Meanwhile, the features have no specific details, but these specifications are satisfactory to start the process to find a potential supply source.

b *Determining the fundamental sourcing requirements:* Regarding the importance of the requirements fundamental for the purchaser, and these requirements might vary from an item to the next.

c *Identifying the sourcing strategy:* This contains items such as local versus international suppliers, unitary versus several supply sources, short-term versus long-term buying contracts.

d *Recognising the potential supply sources:* The stage depends on different information sources.

e *The suppliers' number reduction in selection pool:* Staff of purchase most of the time use an in-depth evaluation of all possible suppliers for the purpose of narrowing the number to a small list which will be used for an in-depth formal evaluation.

f *Supplier evaluation and selection method determination:* This technique will be utilised on the remained supplier following the first cut in the previous level. The process of evaluation and selection can be carried out through the use of several methods such as evaluating the suppliers' information, using a list of preferred suppliers, or doing a site visit.

The goal of choosing is to recognise highest potential suppliers to alleviate needs of the firm in a compatible way and using acceptable cost levels. On the whole, in decisions related to supplier selection, two things are critically important. First, what criteria should be utilised and then, which methods should be used to compare the suppliers. A specification of criteria related to decision-making besides the proper supplier choosing methods are the major factors identifying a firm's development and competitiveness, as a result, these issues are outstandingly important in the supplier choice. Since long times ago, the ancient method of supplier choosing to select suppliers simply was based on price. Meanwhile, companies have recognised that the sole emphasis on price, as the only basis for supplier selection, is not well-organised, they have shifted their focus on a more comprehensive approach entailing multi-criteria (Pal et al., 2013).

The very first research in the field was carried out by Dickson in 1962. He ranked 23 criteria to evaluate suppliers and categorised them according to their significance level and the outcomes are represented in Table 2.

Since 1994, new criteria have been proposed regarding the research projects dealing with the supplier selection and some of them are the development of Dickson's primary criteria while some others were suggested to develop management philosophy in a way that the two criteria of delivery and quality still are recognised as the most important ones and product design and development and flexibility are two criteria recently included in the literature due to supply chain management development.

Table 1 Recent studies on supplier selection in various subject and industry

Author and year	*Subject/industry*	*Methods used*	*Results*
Keshavarz Ghorabaee et al. (2017)	Environmental considerations	Interval type-2 fuzzy sets and evaluation based on distance from average solution (EDAS) method	The proposed model is efficient and applicable for real-world problems.
Taherdoost and Barad (2019)	Analysing the process of supplier selection criteria	Multiple criteria decision making (MCDM)	The application of a structured decision-making technique is vital, especially under the complex conditions that include both qualitative and quantitative criteria.
Yang and Chen (2019)	Supplier selection and performance evaluation	Fuzzy operations for supplier evaluation	Evaluation scores for each criterion for the linguistic labels are converted to triangular fuzzy numbers in order to reduce ambiguity.
Cheng et al. (2020)	Global supply chain	MCDM is employed to obtain the label of each supplier instead of the manual label; genetic programming (GP) is adopted to set three critical parameters of support vector regression (SVR)	The accuracy and robustness of proposed intelligent model are superior when compared with existing models.
Niaz et al. (2022)	Circular supplier selection in the construction Industry	MCDM framework, fuzzy analytical hierarchy process (FAHP), preference ranking organisation method for enrichment of evaluations II (PROMETHEE II)	This approach has been compared with another MCDM method, namely the weighted aggregated sum product assessment (WASPAS) method, which validated the accuracy and efficiency of the proposed approach.
Demiralay and Paksoy (2022)	Strategy development for supplier selection process	Using different fuzzy environments and different decision-making methods on smart and sustainable supplier selection	Best knowledge, strategy development for the smart and sustainable criteria-based supplier selection process is a pioneering work in this field as it has never been studied before in the literature.
Sonar et al. (2022)	Role of lean, agile, resilient, green and sustainable paradigm in supplier selection	Interpretive structural modelling (ISM)	The presented model can be assessed as a strategic tool to select a supplier who considers lean, agile, resilient, green, and sustainable criteria simultaneously to increase supply chain efficiency and effectiveness.

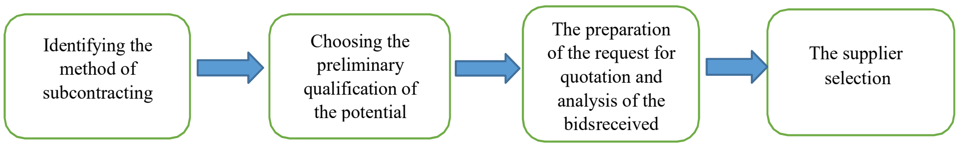
Table 2 Dickson criteria to supplier selection

Rank	*Criterion*
1	Quality (ability of each supplier to achieve qualitative features)
2	Delivery time (ability of supplier to achieve delivery timing)
3	Historical performance records
4	Warranty policies and compensation
5	Facilities and production capacity
6	Price
7	Technical ability (including facilities for R&D)
8	Firm's financial status
9	Compatibility with the purchasing processes (acceptance of approaches and purchase procedures by the supplier)
10	Communication system
11	Position in industry among the rivals
12	Tendency for transactions
13	Management and organisation
14	Operational controls (including reports, quality control, current control systems)
15	After sale services
16	The seller's treatment with the organisation
17	Our image of the seller
18	Packing ability (ability of each supplier to reach required packing for the product)
19	Previous experiences and work relations
20	Geographical position
21	Business experience
22	Teaching programmes (presence of training material for the product on the part of the supplier)
23	Reciprocal relationship

Source: Weber et al. (1991)

The issue of choosing supplier depends on several items such as multiple methods, because there does not exist any standard predetermined for such a process. Each method of supplier choosing resembles to be different from others, thus clearly the firms have multitude choices from among methods considering their product, expectations, criteria and the industry. Furthermore, the selected methods are deemed greatly important for the overall selection process and can create a considerable pressure on the results of the selection. Consequently, it is very important to know which method should be utilised in a different state. Many supplier selection methods are available that could be classified into main categories and sub-categories. This categorical method entails analytic hierarchy process (AHP), analytic network process (ANP), and TOPSIS, out-ranking method with elimination and choice expressing reality (ELECTREE) and preference ranking organisation method for enrichment evaluations (PROMOTHEE), but also the multi-attribute facilities theory (MAUT method). Furthermore, according to Pal et al. (2013), the linear programming, target programming and multi-objective linear programming are part of the mathematical programming method, with the data envelopment analysis as a prequalification for that. Additionally, the artificial intelligence technique covers the case-based reasoning and the artificial neural network. Along with the progressing enhancement of supplier selection, as posed above in the text, the combined approaches methods have been designed such as mathematical programming + TCO, AHP + linear programming, MAUT + LP, ANP + TOPSIS or fuzzy TOPSIS. Figure 3 represents a summary of the supplier selection methods and their categorisation.

Figure 3 Process of supplier selection (see online version for colours)



Source: Weele and Van (2014)

Weber et al. (1991) classified the quantitative approaches to select suppliers into three categories: linear weight models, mathematical planning models and statistical/probability approaches.

a Linear weight models

In these models, a weight (which is usually determined in abstract form) is appointed to each criterion with the highest weight that represents the highest importance. The rank for each criterion is multiplied by its weight and then to achieve a unified form for each supplier, the results are added together. Thus, the supplier with highest overall rank is selected. These methods include models such as multi-attribute facilities approach, ANP, and AHP.

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b Mathematical programming models

Mathematical programming models pave the way to regulate decision-making problems based on a mathematical target function for the decision makers. Based on the number of target functions, the process of supplier selection can be divided into two groups:

1 single-goal mathematical programming model
2 multiple-goal mathematical programming model.

c Statistical models

These models are utilised in random lack of assurance conditions. Most current statistical models only consider lack of assurance conditions related to one criterion each time. The option with the highest efficiency expected is selected. Most researchers utilise single target techniques such as linear or mixed integers for programming where a criterion – considered to be the goal function and other features are considered to pose limitations. Often unitary-target models are used to minimise total purchase costs, current costs and ordering costs. But in multiple-goal models, the researchers seek for concurrent achievement of several criteria in a way that some target functions is presented in maximisation or minimisation status.

3 Research method

Iranian Diesel Engine Manufacturing (IDEM) located in the West Tabriz Industrial Zone, East Azerbaijan Province of Iran that used to be wholly owned by Iran Khodro Diesel but has now been completely divested. The company was put into operation in 1971 with the partnership investment of Iran-National (70%) and Daimler-Benz of Germany (30%). The company's logo is also the Mercedes-Benz logo. The company annually produces more than 12,000 diesel engines. It produces and annually exports some of its products to other countries, including Germany, Turkey and the UAE. This company was selected in 2009 as the industrial model unit of province. The present research is applied regarding target because it seeks the way to the development of practical knowledge within a certain scope. Also, the researchers are responsive in answering the intended questions. This study is descriptive. A descriptive investigation entails a series of methods whose target is to explain the states or processes under investigations. On the other hand, the present research entails all the intended issues by the researcher without any limitations and interference. First, the administrative model of this research representing the steps fulfilled by the researcher has been presented and considering the research title, data collection process has been explained. Then, the mathematical model designing algorithm has been represented. Also, based on the relationships between the variables, the conceptual model has been identified using math. The tools to measure the optimal ranking pattern explained afterward.

3.1 Research question

What are the effects of criteria such as flexibility, job experience, technology, risk, time, quality, and logistic costs in evaluating suppliers using DEMATEL method and their ranking in IDEM Co. using TOPSIS technique?

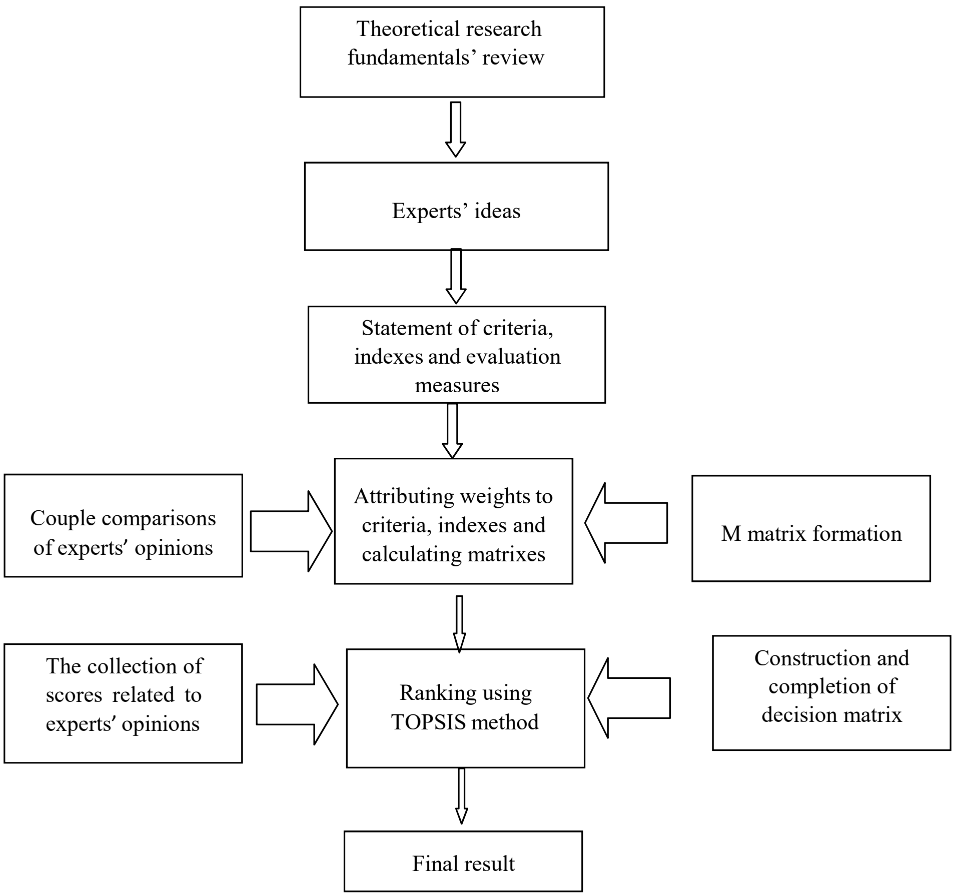
In this research and regarding the fact that multiple criteria of decision-making approaches have been utilised to investigate about evaluation of suppliers located in IDEM Co. using an integrative mode, we have not provided any hypotheses. Thus, the researcher does not propose any presupposition to be evaluated through research administration process using statistical tests. Therefore, the researcher has utilised several research questions as follows:

1. What effect does the flexibility of suppliers have on the evaluation of suppliers?
2. What effect does the work experience of suppliers have on the evaluation of suppliers?
3. What effect does supplier technology have on the evaluation of suppliers?
4. What effect does the risk of suppliers have on the evaluation of suppliers?
5. What effect does the time of suppliers have on the evaluation of suppliers?
6. What effect does the quality of suppliers have on the evaluation of suppliers?

7 What effect does the logistics cost of the suppliers have on the evaluation of the suppliers?

8 What effect does the assessment and ranking of suppliers using the DEMATEL/TOPSIS have on the improvement of the production process, productivity and product quality?

Figure 4 Research administration model



4 Data collection tools

In this research and regarding the nature of the issue, we have used questionnaires to collect data through field study and interviews with the experts. During the research period, we have used two questionnaires as follows: the first questionnaire was designed to carry out supplier evaluation after literature review of the criteria. Then, a researcher made questionnaire extracted effective or influential relationships using DEMATEL method. Also, the researcher proposed the second questionnaire to rank supplier's criteria through which the experts were asked to identify the amounts of each supplier evaluation ranking criteria using by TOPSISS method.

The statistical population of the present research entails industry experts' ideas such as manufacturing managers, manufacturing planning managers, and industry engineers working in industrial firms which include the main suppliers of the company. Based on Thomas Saaty idea, ten experts from the main suppliers were selected as sample and their opinion were collected through the questionnaire based on SCOR model. In data analysis, we have used DEMATEL technique to identify the effectiveness amount of suppliers' evaluation criteria and TOPSIS technique has been utilised to rank the suppliers. The software used to analyse the data were BT DEMATEL SOLVER and BT TOPSIS SOLVER package to evaluate suppliers. Table 3 shows the dimensions and structure of questionnaire using Dickson's criteria to select suppliers. From among the criteria identified through Dickson's model, ten criteria were selected by the experts through the scores appropriated for the criteria.

Table 3 Dickson's criteria for supplier selection

Rank	*Criterion*
1	Quality (ability of each supplier to achieve qualitative features)
2	Delivery time (ability of supplier to achieve delivery timing)
3	Historical performance records
4	Warranty policies and compensation
5	Facilities and production capacity
6	Price
7	Technical ability (including facilities for R&D)
8	Firm's financial status
9	Compatibility with the purchasing processes (acceptance of approaches and purchase procedures by the supplier)
10	Communication system
11	Position in industry among the rivals
12	Tendency for transactions
13	Management and organisation
14	Operational controls (including reports, quality control, current control systems)
15	After sale services
16	The seller's treatment with the organisation
17	Our image of the seller
18	Packing ability (ability of each supplier to reach required packing for the product)
19	Previous experiences and work relations
20	Geographical position
21	Business experience
22	Teaching programs (presence of training material for the product on the part of the supplier)
23	Reciprocal relationship

Source: Weber et al. (1991)

4.1 DEMATEL method

The Geneva Research Center of the Battelle Memorial Institute proposed DEMATEL technique for the first time to visually represent the form of complex causal relationships using matrixes or digraphs (Gabus and Fontela, 1972). Regarded to be a type of approach using structural modelling, it is specifically useful to analyse the cause-and-effect interactions among constituents of a system. The DEMATEL could be used to approve interdependence among factors and help in the generalisation of a map to reflect relative relationships within them and can be applied to investigate and solve complex and intertwined problems. Besides converting the interdependency relationships into a cause-and-effect group via matrixes, it finds the critical factors of a complex structure system using an impact relation diagram. Many stages are seen in DEMATEL and a brief scheme of it is given as follows:

Step 1 Form the average matrix.

Suppose that there are h experts and n factors. We entitled the scales, 0, 1, 2, 3 and 4, showing ‘no influence’, ‘little influence’, ‘medium influence’, ‘strong influence’ and ‘very strong influence’, respectively. The matrix of influence of the h^t respondent among total factor n is represented as:

$$Z_k = \left[Z_{ij}^k \right]_{n*n} \tag{1}$$

The sum of mean influenced value collected from all respondents considering the score from criteria a_i to a_j is given as:

$$Z_{ij} = \frac{\sum_{i=0}^{n} Z_{ij}^k}{K} \tag{2}$$

Step 2 The calculation of the initial direct-relation matrix normalised.

The initial direct-relation matrix normalised is measured through normalising the average matrix Z using the following equation:

$$N = \lambda.Z \tag{3}$$

$$\lambda = \text{Max}\left[\max_{0 \le i \le n} \sum_{j=1}^{n} Z_{ij}, \max_{1 \le j \le j} \sum_{j=1}^{n} Z_{ij} \right] \tag{4}$$

Step 3 The total relation matrix calculation.

The total relation matrix T can be achieved by using the following equation:

$$T = N(1 - N)^{-1} \tag{5}$$

If t_{ij} be the (i, j) element of matrix T; the total amount of the i^{th} row and the total amount of the j^{th} column, d_i and r_j, respectively, are gained as follows:

$$D_i = \sum_{j=1}^{n} t_{ij} \quad (i = 1, 2, \ldots, n) \tag{6}$$

$$R_i = \sum_{j=1}^{n} t_{ij} \quad (i = 1, 2, \ldots, n) \tag{7}$$

Step 4 A threshold value devising and obtaining the impact-relations map.

Necessarily, we should set a threshold value p to describe the structural relation between the factors to filter out the unsuitable effects in matrix T. At this time, decision makers or experts would select the threshold value.

4.2 TOPSIS method

First, it was suggested by Hwang and Yoon (1981) and it was utilised to recognise the ideal positive solution (A^*) and ideal negative solution (A^-) for decision-making. The fundamental characteristic of TOPSIS is to select an option which should have the least distance with positive ideal solution and the largest distance with negative ideal solution. The calculation approach could be represented as follows:

First step Normalised decision matrix calculation

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{8}$$

i is option index, j shows criterion selection, and x_{ij} is mean of the option i in the presence of criterion j.

Second step Harmonic decision matrix calculation (without a criterion)

The weights of criteria selection, $\omega = (\omega_1, \omega_2, \ldots, \omega_n)$, could be expressed through the multiplication of standard evaluation matrix in the form below:

$$v = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} = \begin{bmatrix} \omega_1 r_{11} & \omega_2 r_{12} & \cdots & \omega_n r_{1n} \\ \omega_1 r_{21} & \omega_2 r_{22} & \cdots & \omega_n r_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \omega_1 r_{m1} & \omega_1 r_{m2} & \cdots & \omega_n r_{mn} \end{bmatrix} \tag{9}$$

Third step Ideal positive solution and ideal negative solution recognition

$$\begin{aligned} A^* &= \{v_1^*, v_2^*, \ldots, v_j^*, \ldots, v_n^*\} = \{(\max v_{ij} \mid j \in J) \mid i = 1, \ldots, m\} \\ A^- &= \{v_1^-, v_2^-, \ldots, v_n^-\} = \{(\min v_{ij} \mid j \in J) \mid i = 1, \ldots, m\} \end{aligned} \tag{10}$$

Fourth step The size of distance calculation based on Euclid norm for each ideal positive solution (S_i^*) and ideal negative solution (S_j^-) for each option

$$\begin{aligned} S_i^* &= \sqrt{\sum_{i=1}^{m} (v_{ij} - v_i^*)^2} \quad i = 1, \ldots, m \\ S_j^- &= \sqrt{\sum_{i=1}^{m} (v_{ij} - v_i^*)^2} \quad i = 1, \ldots, m \end{aligned} \tag{11}$$

Fifth step Relative closeness calculation to ideal positive solution for each option

$$C_i^* = \frac{S_j^-}{S_i^* + S_j^-} \tag{12}$$

According to the formula is 3 and is farther than A^{-}. A^{*} is closer to A_i.

Sixth step Ranking based on C_i^* arrangement

C_i^* is the biggest index value and shows the best performance for the options.

5 Data analysis and results

In this part, supplier evaluation features were investigated and analysed using DEMATEL method. First, the viewpoints of experts such as the lecturers, manufacturing managers, manufacturing planning managers, and industry engineers working in industrial firms including companies from the main suppliers of IDEM Company are taken into consideration.

As the last step, to rank supplier evaluation, the ideas of experts such as the lecturers, managers, and technicians of firms above were collected through the questionnaire designed using BT TOPSIS Solver software with the help of TOPSIS method.

5.1 Findings resulted from DEMATEL

Step 1

Based on steps in DEMATEL method, the responses related to the amount of effectiveness and being affected resulted from the first type questionnaire in the form of average matrix of experts' ideas are represented in Table 4.

In Table 3, based on DEMATEL method alpha is equal to 0.357 (the inverse of the highest amount of the total raw based on experts' ideas) and this is the first factor regarding experts' ideas and it refers to the quality. The sum of line amounts of quality is higher than total sum of all other factors and alpha is equal to 1 divided by 28 which could reach 0.357.

Step 2 Normalisation or relative severity of direct relations

Below the relative severity of direct relations matrix has been represented in the form of Table 5. The numerical amount of alpha in constituents has been multiplied by each of the matrixes in Table 4 and the relative severity of the matrix of direct relations has been achieved.

Step 2.1 Possible severity matrix (reverse)

This step shows the calculation of possible severity matrix regarding direct and indirect relations and it is calculated in the form of reversed equation $I - M$ and the results are represented in Table 6.

This step shows the calculation of possible severity matrix regarding direct and indirect relations and it is calculated in the form of reversed equation $I - M$.

Table 4 Average matrix of experts' ideas

Matrix	*Quality*	*Delivery date*	*Warranty and compensation*	*Facilities and production capacity*	*Price*	*Financial condition of the company*	*Compatibility with the purchasing process*	*Operational controls*	*Pack ability*	*Educational programme*	*Total*
Quality	0	3.1	3.1	2.4	3.8	3.4	3.1	3.3	2.9	2.9	28
Delivery date	0.382	0	1.7	2.6	2.4	3	3.1	1.9	2.3	2.1	19.482
Warranty and compensation	0.424	0.733	0	2.8	3.3	2.6	3.1	2.9	2.5	2.2	20.557
Facilities and production capacity	0.507	0.491	0.358	0	2.7	3.3	2.3	2.3	2.4	2.6	16.956
Price	0.291	0.549	0.315	0.474	0	3.7	2.7	2.7	3.1	2.5	16.329
Financial condition of the company	0.298	0.357	0.482	0.315	0.274	0	2.8	2.1	3.2	3	12.826
Compatibility with the purchasing process	0.265	0.349	0.349	0.557	0.441	0.424	0	2.4	2.7	2.4	9.885
Operational controls	0.324	0.682	0.365	0.491	0.474	0.582	0.432	0	1.7	2.8	7.85
Pack ability	0.398	0.491	0.49	0.549	0.34	0.341	0.507	0.482	0	2.4	5.998
Educational programme	0.299	0.5	0.466	0.524	0.508	0.399	0.366	0.424	0.582	0	4.068

Note: Alpha is equal to 0.0357.

Table 5 Relative severity of direct relations matrix

Normal matrix (M)	*Quality*	*Delivery*	*Warranty and compensation*	*Facilities and production capacity*	*Price*	*Financial condition of the company*	*Compatibility with the purchasing process*	*Operational controls*	*Pack ability*	*Educational programme*
Quality	0	0.1107	0.1107	0.0857	0.1357	0.1214	0.1107	0.1179	0.1036	0.1036
Delivery	0.0136	0	0.0607	0.0929	0.0857	0.1071	0.1107	0.0679	0.0821	0.075
Warranty and compensation	0.0151	0.0262	0	0.1	0.1179	0.0929	0.1107	0.1036	0.0893	0.0786
Facilities and production capacity	0.0181	0.0175	0.0128	0	0.0964	0.1179	0.0821	0.0821	0.0857	0.0929
Price	0.0104	0.0196	0.0113	0.0169	0	0.1321	0.0964	0.0964	0.1107	0.0893
Financial condition of the company	0.0106	0.0128	0.0172	0.0113	0.0098	0	0.1	0.075	0.1143	0.1071
Compatibility with the purchasing process	0.0095	0.0125	0.0125	0.0199	0.0158	0.0151	0	0.0857	0.0964	0.0857
Operational controls	0.0116	0.0244	0.013	0.0175	0.0169	0.0208	0.0154	0	0.0607	0.1
Pack ability	0.0142	0.0175	0.0175	0.0196	0.0121	0.0122	0.0181	0.0172	0	0.0857
Educational programme	0.0107	0.0179	0.0166	0.0187	0.0181	0.0143	0.0131	0.0151	0.0208	0

Note: In this step, we multiply alpha and direct relations matrix.

Table 6 Possible severity matrix (reverse)

Reverse matrix	*Quality*	*Delivery date*	*Warranty and compensation*	*Facilities and production capacity*	*Price*	*Financial condition of the company*	*Compatibility with the purchasing process*	*Operational controls*	*Pack ability*	*Educational programme*
Quality	1.021	0.1417	0.1425	0.1374	0.1968	0.2084	0.2061	0.2158	0.2254	0.2388
Delivery date	0.0277	1.0231	0.0805	0.1215	0.1242	0.161	0.1706	0.1351	0.1648	0.1678
Warranty and compensation	0.0295	0.0496	1.0225	0.1267	0.1533	0.1497	0.1702	0.1694	0.1737	0.175
Facilities and production capacity	0.0291	0.0369	0.0314	1.0239	0.1202	0.1559	0.1291	0.1328	0.1517	0.1681
Price	0.0209	0.0366	0.0283	0.0385	1.0239	0.1581	0.1345	0.1384	0.1671	0.1588
Financial condition of the company	0.0187	0.0265	0.0301	0.0292	0.0295	1.0233	0.1223	0.1045	0.1509	0.1552
Compatibility with the purchasing process	0.016	0.0238	0.023	0.0338	0.0322	0.0358	1.0219	0.106	0.1238	0.1239
Operational controls	0.0169	0.0333	0.0228	0.0306	0.0324	0.0403	0.0367	1.0218	0.0856	0.1288
Pack ability	0.0183	0.0253	0.0254	0.0307	0.0265	0.0297	0.0362	0.0362	1.0232	0.1086
Education al programme	0.0139	0.0237	0.0227	0.0276	0.0296	0.0297	0.0293	0.0316	0.0404	1.0225

Table 7 Total relations matrix or severity of direct and indirect relations

Total relations matrix	*Quality*	*Delivery date*	*Warranty and compensation*	*Facilities and production capacity*	*Price*	*Financial condition of the company*	*Compatibility with the purchasing process*	*Operational controls*	*Pack ability*	*Educational programme*	*Raw (R)*
Quality	0.021	0.1417	0.1425	0.1374	0.1968	0.2084	0.2061	0.2158	0.2254	0.2388	1.7339
Delivery date	0.0277	0.0231	0.0805	0.1215	0.1242	0.161	0.1706	0.1351	0.1648	0.1678	1.1761
Warranty and compensation	0.0295	0.0496	0.0225	0.1267	0.1533	0.1497	0.1702	0.1694	0.1737	0.175	1.2197
Facilities and production capacity	0.0291	0.0369	0.0314	0.0239	0.1202	0.1559	0.1291	0.1328	0.1517	0.1681	0.9791
Price	0.0209	0.0366	0.0283	0.0385	0.0239	0.1581	0.1345	0.1384	0.1671	0.1588	0.9052
Financial condition of the company	0.0187	0.0265	0.0301	0.0292	0.0295	0.0233	0.1223	0.1045	0.1509	0.1552	0.6903
Compatibility with the purchasing process	0.016	0.0238	0.023	0.0338	0.0322	0.0358	0.0219	0.106	0.1238	0.1239	0.54
Operational controls	0.0169	0.0333	0.0228	0.0306	0.0324	0.0403	0.0367	0.0218	0.0856	0.1288	0.4491
Pack ability	0.0183	0.0253	0.0254	0.0307	0.0265	0.0297	0.0362	0.0362	0.0232	0.1086	0.3602
Educational programme	0.0139	0.0237	0.0227	0.0276	0.0296	0.0297	0.0293	0.0316	0.0404	0.0225	0.271
(J) line	0.2122	0.4205	0.4291	0.5997	0.7687	0.9919	1.0569	1.0917	1.3066	1.4474	

Table 8 Severity matrix of indirect relations

Indirect severity matrix	*Quality*	*Delivery date*	*Warranty and compensation*	*Facilities and production capacity*	*Price*	*Financial condition of the company*	*Compatibility with the purchasing process*	*Operational controls*	*Pack ability*	*Educational programme*
Quality	0.021	0.031	0.0318	0.0517	0.0611	0.0869	0.0954	0.0979	0.1219	0.1352
Delivery date	0.014	0.0231	0.0198	0.0286	0.0385	0.0538	0.0598	0.0672	0.0826	0.0928
Warranty and compensation	0.0144	0.0234	0.0225	0.0267	0.0354	0.0569	0.0595	0.0658	0.0844	0.0965
Facilities and production capacity	0.011	0.0193	0.0186	0.0239	0.0238	0.0381	0.0469	0.0507	0.066	0.0753
Price	0.0105	0.017	0.0171	0.0216	0.0239	0.026	0.038	0.042	0.0564	0.0695
Financial condition of the company	0.0081	0.0137	0.0129	0.018	0.0197	0.0233	0.0223	0.0295	0.0366	0.048
Compatibility with the purchasing process	0.0065	0.0113	0.0105	0.0139	0.0164	0.0207	0.0219	0.0203	0.0273	0.0382
Operational controls	0.0053	0.0089	0.0097	0.013	0.0155	0.0195	0.0213	0.0218	0.0249	0.0288
Pack ability	0.0041	0.0078	0.0079	0.0111	0.0143	0.0176	0.0181	0.019	0.0232	0.0229
Education al programme	0.0032	0.0058	0.006	0.0088	0.0114	0.0154	0.0163	0.0165	0.0197	0.0225

Step 3 Total relations matrix or severity of direct and indirect relations

This step calculates relative severity matrix through direct and indirect relations (total relations) and is achieved in the form of $M(I - M)$ and the results are represented in Table 7.

This step calculates relative severity matrix through direct and indirect relations (total relations) and is achieved in the form of $M(I - M)$.

Step 3.1 Severity matrix of indirect relations

This step regards with calculation of relative severity matrix using indirect relations represented in the form of $M^2(I - M)$ and the results are represented in Table 8.

This step regards with calculation of relative severity matrix using indirect relations represented in the form of $M^2(I - M)$.

Step 4 Setting a threshold amount and achieving effect relations map

During the administration in this stage, a group of scholars were asked to identify a threshold value of dimensions. The threshold value was 0.375, and it could represent that only values higher than this threshold was taken into consideration. For instance, capability with the purchasing process impact on quality, capability with the purchasing process, educational programme, pack ability, operational control, financial condition of the company, price, facilities and production capacity, deliver date and warranty and compensation with impact levels of 0.16, 0.219, 0.1239, 0.1238, 0.106, 0.0358, 0.0322, 0.0338 and 0.023, respectively. Biased on threshold 0.375, warranty and compensation, deliver date, facilities and production capacity, financial condition of the company, operational control, pack ability and educational programme are influenced by capability with the purchasing process.

Figure 5 The causal influence diagrams (see online version for colours)

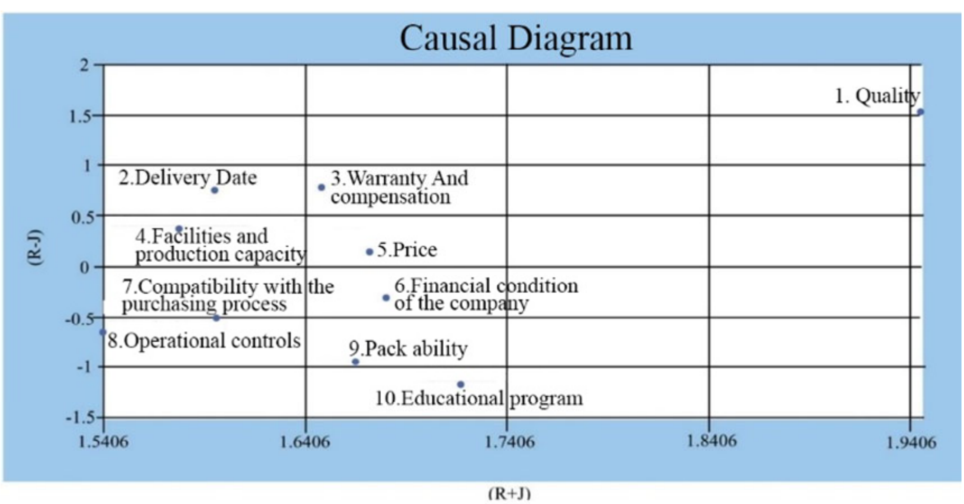


Table 9 Results matrix

Result	*R*	*J*	*R + J*	*R – J*
Quality	1.7339	0.2122	1.9461	1.5218
Delivery date	1.2197	0.4291	1.6488	0.7906
Warranty and compensation	1.1761	0.4205	1.5966	0.7556
Facilities and production capacity	0.9791	0.5997	1.5788	0.3794
Price	0.9052	0.7687	1.6739	0.1366
Financial condition of the company	0.6903	0.9919	1.6822	–0.3017
Compatibility with the purchasing process	0.54	1.0569	1.5968	–0.5169
Operational controls	0.4491	1.0917	1.5408	–0.6426
Pack ability	0.3602	1.3066	1.6668	–0.9464
Educational programme	0.271	1.4474	1.7185	–1.1764

In Table 8, the highest raw sum of R represents the indexes which strongly affect other elements (quality). Also, the highest amount of line sum of J represents the elements that are affected (educational programmes). Furthermore, the output of $R + J$ for each of the criteria under investigation has been calculated. The equation $R + J$ represents total influence of the factor mentioned in IDEM Company (quality). On the other hand, if we calculate $R - J$ for each criterion in isolation, when $R - J$ is positive, the criterion is effective (criteria 1, 2, 3, 4 and 5) and when the result is negative for the intended criterion, it is considered as a vulnerable criterion in IDEM Company (criteria 6, 7, 8, 9 and 10).

Based on DEMATEL, the results related to the amount of effectiveness and being affective regarding first type questionnaire in the form of average experts' ideas matrix, Table 3 represents the findings. The decision-making process regarding the presence or lack of a relationship is concluded like the structural-interpretative method through gaining the vote of the majority of the participants or the highest number of experts' votes. The numerical amounts were also calculated through average calculation of the scores given by the experts. Table 3 represents average experts' ideas matrix.

In second step known as normalisation or relative severity of direct relationships represented in Table 4, alpha based on DEMATEL is equal to 0.357 (the reverse of highest amount of total raw regarding experts' ideas). Relative severity matrix of direct relations has been reported in Table 4. The numerical amount of alpha in elements of each of the matrixes in Table 3 is multiplied and the amount has been calculated.

This step of calculating possible severity matrix is gained from direct and indirect relation represented in the form of $I - M$ and the results are included in Table 5.

Step 5 Total relations matrix or severity of direct and indirect relations

This step deals with calculating relative severity matrix through direct and indirect relations (total relations) shown as $M(I - M)$ and the results are shown in Table 6.

Step 5.1 Indirect relations severity matrix

This step involves calculating relative severity matrix through indirect relations represented as $M^2(I - M)$ and the results can be seen in Table 7.

Step 6 Achieving relations map of effects in Figure 5 and its results

In Table 8 result matrix, the highest amount of raw sum R represents the arrangement of indexes that strongly affect other elements (first factor, quality). Also, the highest amount of line sum J represents the arrangement of elements being affected (tenth factor, educational programmes). Furthermore, the output of $R + J$ for each of the factors has been investigated. $R + J$ shows total influence of the factor mentioned in company (first factor). On the other hand, if each factor is considered in isolation, $R – J$ is calculated. If $R – J$ is positive, the factor is effective (factors 1, 2, 3, 4 and 5) and of it is negative, company is being affected (factors 6, 7, 8, 9 and 10).

5.2 Findings resulted from TOPSIS

According to Saaty's idea, ten people were selected as industry experts and their ideas were ranked through the use of a questionnaire regarding ranking the suppliers based on SCOR model and the results were analysed using TOPSIS SOLVER software. It should be noted that the ten criteria in this project based on SCOR model were isolated according to Table 10 and the results were represented in Table 11.

Table 10 The selection of ten criteria based on SCOR model

No.	*Criterion*	*SCOR model element name*
1	Quality	Resource finding
2	Delivery date	Delivery
3	Warranty and compensation	Delivery
4	Facilities and production capacity	Construction
5	Price	Delivery
6	Financial condition of the company	Delivery
7	Compatibility with the purchasing process	Planning
8	Operational controls	Planning
9	Pack ability	Resource finding
10	Educational programme	Construction

First step: average experts' ideas table

Table 11 Experts' average ideas

Matrix	*Criterion 1 – planning*	*Criterion 2 – resource finding*	*Criterion 3 – construction*	*Criterion 4 – delivery*
A1 – Tabriz Machinery Manufacturing Co.	7.8	8.9	7	7
A2 – Tabriz Tractor Manufacturing Co.	7.8	6.7	6.2	6.4
A4 – Ideal Motor Part	8.4	8	7.4	7.6
A6 – Piston Iran Factory	7	8.8	7.4	7.4
Criterion type	Positive	Positive	Positive	Positive
Criterion weight	0.5	0.2	0.1	0.2

Second step: normalisation or de-indexing the matrix

In this step, de-index present indexes in the decision matrix. In this way, each of the amounts is divided by the size of the vector related to the same index.

Third step: giving weights to the normalised matrix

The decision matrix is in fact a parameter and it should be quantified. To do so, the decision maker identifies a weight for each index. The total amount of weights is multiplied by the normalised matrix.

Table 12 De-indexed matrix

De-indexed matrix	*Criterion 1 – planning*	*Criterion 2 – resource finding*	*Criterion 3 – construction*	*Criterion 4 – delivery*
A1 – Tabriz Machinery Manufacturing Co.	0.5022	0.5462	0.4988	0.4919
A2 – Tabriz Tractor Manufacturing Co.	0.5022	0.4112	0.4418	0.4498
A4 – Ideal Motor Part	0.5408	0.4909	0.5273	0.5341
A6 – Piston Iran Factory	0.4507	0.54	0. 5273	0.52

Table 13 Normal matrix

Weighed matrix/normalised	*Criterion 1 – planning*	*Criterion 2 – resource finding*	*Criterion 3 – construction*	*Criterion 4 – delivery*
A1 – Tabriz Machinery Manufacturing Co.	0.2511	0.1092	0.0499	0.0984
A2 – Tabriz Tractor Manufacturing Co.	0.2511	0.0822	0.0442	0.09
A4 – Ideal Motor Part	0.2704	0.0982	0.027	0.1068
A6 – Piston Iran Factory	0.2253	0.108	0.0527	0.014

Fourth step: the identification of positive ideal solution and negative ideal solution

The two virtual options created are in fact the worst and the best solutions.

Table 14 The identification of positive ideal solution and negative ideal solution

Optimal solution	*Criterion 1 – planning*	*Criterion 2 – resource finding*	*Criterion 3 – construction*	*Criterion 4 – delivery*
+	0.2704	0.1092	0.0527	0.1068
–	0.2253	0.0822	0.0442	0.09

Fifth step: the identification of distance size from the positive and negative ideal solution

The distance between each option is measured through a Euclid method. This means that the distance between options is found based on positive and negative ideal options.

Table 15 The identification of distance size from the positive and negative ideal solution

Distance size	+	–
A1 – Tabriz Machinery Manufacturing Co.	0.0213	0.0387
A2 – Tabriz Tractor Manufacturing Co.	0.0382	0.0258
A4 – Ideal Motor Part	0.011	0.0514
A6 – Piston Iran Factory	0.0452	0.036

Sixth step: calculating closeness to ideal positive and negative solution as well as ranking the options

As it can be observed in Table 15, A4 (Ideal Motor Parts) amounting to 0.8231 has the highest rank among the options present and it shows that based on SCOR model the above company has had the best conditions among other options for IDEM company. It should be noted that the ten criteria in this project based on SCOR model were isolated according to Table 9. After all, six steps of TOPSIS are carried out as the results are represented in Table 15, A4 (Ideal Motor Parts Company) amounting to 0.8231 has appropriated the highest rank among the present options and this shows that according to SCOR model the company above has had the best conditions among other alternatives for company. Tabriz Machinery Manufacturing Co. amounting to 0.6452 ranks second, Piston Iran Factory with an amount of 0.4037 ranks third and finally casting company with 0.4026 has appropriated the last rank for itself.

Table 16 Calculating closeness to ideal positive and negative solution as well as ranking the options

Result	*Closeness coefficient*
A4 – Ideal Motor Parts	0.8231
A1 – Tabriz Machinery Manufacturing Co.	0.6452
A6 – Piston Iran Factory	0.4037
A2 – Tabriz Tractor Manufacturing Co.	0.4026

Regarding the fact that quality has appropriated the highest amount of alpha due to the ideas of experts, it is suggested to value quality in supply chain management. Since Ideal Motor Parts Company has appropriated the highest rank with 0.8231 to itself among all other options and it shows that based on SCOR model the above-mentioned company has had the best conditions for company among all other alternatives, it could be suggested to have more fruitful relations with the company mentioned. Considering the results from the present research and comparing it regarding the evaluation and ranking suppliers there have been several works. Tavana et al. (2016) considered the evaluation and selection of suppliers as one of the major concerns in SCM and stated that data based on corresponding selections in real life are often indefinite or ambiguous. Accordingly, they proposed an integrated model of ANFIS-ANN to help managers in suppliers' evaluation processes. They first collected data through an AHP and then determined effective factors based on performance of suppliers through ANFIS. Then, multiple layer proportion (MLP) was utilised to predict and rank the suppliers' performance based on effective criteria. Lima-Junior et al. (2016) proposed a novel approach to alleviate lack of cooperation present in different methods suggested to evaluate suppliers and it has used

SCOR performance criteria in order to assess suppliers regarding costs and delivery performance. They suggested fuzzy TOPSIS to evaluate and classify suppliers into four groups depending on their performance evaluation and some procedures were suggested for practical programmes. Based on the integrative method, they designed and constructed a visual software based on a production background. They showed that the integration of SCOR method and fuzzy TOPSIS has several advantages compared with other methods and some these advantages are the merge of supplier performance evaluation processes and SC. This integration is able to do less comparisons compared with other methods of SC and fuzzy TOPSIS (which requires a quantitative judgment for parameter identification) and it helps agile decision-making processes. Also, a limited number of options could not evaluate the options concurrently. This does not create rank change problems if a new supplier is introduced in the evaluation process. Keshavarz Ghorabaee et al. (2017) studied the importance of efficiency of environment for the suppliers and the role of economic performance in suppliers' selection and then introduced a new unitary model to evaluate suppliers who consider environmental and economic factors. This research utilised EDAS method and type 2 fuzzy sets to evaluate suppliers regarding environmental criteria. Considering this evaluation, two parameters are identified for each supplier: positive score and negative score. These parameters are used along with other cost parameters to propose a multiple goal mathematical model to determine the order amount of each supplier. Their results showed that the proposed model would be efficient and applicable in real world issues.

6 Conclusions

Considering that the selection of a supplier is one of the most important pillars of the success of companies in the business world, so it is necessary to use an appropriate system to evaluate and select them. It is also possible to align production needs and warehouse inventory by making use of the capabilities of the information technology system, customer information, suppliers and production processes can be organised to send orders to customers in the shortest time having the best quality. On the other hand, by managing the costs that are more important in the production process, it is possible to reduce the total costs of the production process and select suppliers that are more in line with the criteria. It is suggested to reverend managers in company to form a data bank related to suppliers of the particles and machine parts required for the company and utilise up-to-date information in their decision-makings. Also utilisation of supplier companies of machine parts that have higher quality compared with other firms regarding production and service delivery. Further, to support supplier companies that observe their commitments regarding speed, precision, quality and other effective factors in order to manufacture highly qualified machine parts and provide rewards for such companies and establish a very close reciprocal relationship.

Considering the importance of suppliers for the companies and regarding that supplier are known as the critical factors in an organisation and can have great effects on the performance of the company. Since supply chain plays a fundamental role in permanent competitiveness of companies and institutions, the selection of appropriate suppliers is deemed to be highly important throughout supply chain. It could be suggested to recognise the novel dimensions affecting supply chain and supplier selection through new models and integrated models in future research projects.

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