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EVALUATION OF SUPPLIERS USING THE INTEGRATED APPROACH OF BWM AND GRAY TOPSIS (CASE STUDY: ROAD CONSTRUCTION EQUIPMENT ...)

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ABSTRACT

In today's global competitions, economic and production enterprises are focused on controlling the costs of raw materials, reliability of supply, reparability and support, as major factors influencing the total price directly and indirectly, in order to gain competitive advantage or advantages with the aim of gaining more market share. Therefore, suppliers play a key role in the efficiency and effectiveness of the organization in reducing costs, quality, profitability, flexibility, etc. With the increase of competition in the field of global trade, the method of supplying and selecting equipment in the supply chain is considered an important challenge for most organizations. Therefore, in the studied industry, according to the existing infrastructure of required equipment, having appropriate strategies for evaluating the quality level of suppliers based on supply risks in order to improve the competitive power and create a platform for the development of internal resources is necessary. In this research, the effective criteria on the evaluation of the suppliers' quality level were identified using the opinions and experiences of experts, the relationships between them were analyzed, and the criteria were ranked using the BWM method, and then suppliers (on a case-by-case basis) were evaluated using the GRAY TOPSIS approach. The results have shown that among the 16 strategic indicators introduced to the experts of the organization, four indicators of inward technology transfer, reliability, product reparability at the buyer's site, technical support and warranty in time were approved and in the evaluation method BWM weights of 0.61, 0.18, 0.14, and 0.05 were obtained, respectively, and finally, using the semi-ideal gray approach, 8 suppliers of the company were graded.

Keywords: *Equipment supply chain, Supply risk, BWM, GRAY TOPSIS.*

INTRODUCTION

The new approach that has dominated operations management in recent years is the supply chain management approach. A supply chain includes all the facilities, tasks, operations and activities that are involved in the production and delivery of a good or service, from suppliers (and their suppliers) to customers (and their customers). It includes planning and management of supply and demand, procurement of materials, production and scheduling of products or services, storage, inventory control and distribution, delivery and customer service. Supply chains exist in manufacturing and service organizations, although the complexity of the supply chain may change drastically from one industry to another and from one company to another (Ahmadi, 2018). Also, in the era of globalization and communication, organizations need to make correct and quick decisions so that they can be one step ahead in the tight competition, and that is why, at the same time as this need increases, thinkers have tried to help managers in making complex decisions (Wang, 2016). In many organizational decisions, it is necessary to prioritize several options based on a series of criteria or indicators (Cor, 2018). One of the solutions is to use decision-making models so that they can step by step observe different aspects of the complexity of the problem in the form of precise multi-indicator decision-making process (Shang, 2010). The choice of equipment supplier is one of these types of issues, which is considered one of the most important strategies of the company to achieve success in the business (Zhang, 2019). The strategic importance of this choice is so great that a large number of researchers in fields such as industrial engineering, production management, automation, etc. have devoted a large amount of their research to the issue of supplier selection and each of them has suggested different models for this choice (Tang, 2018). One of the most important reasons for the role of supplier selection being more and more meaningful for companies is a paradigm shift. While in the beginning, companies sought to increase their list of suppliers in order to increase their bargaining power on price, now they are trying to establish strategic alliances with a smaller number of suppliers that best meet their need (Nirmal, 2019). This increases the efficiency and effectiveness of the company and its value chain through the communication of partnerships and facilitation of communication, faster and better supply of items, high reliability of equipment, technical support and supply costs. In most industries, the cost of supplying equipment and supporting components comprises a major part of the total cost of the equipment. With the increase in the importance of purchasing and procurement activities, purchasing decisions have become more important, and since today organizations are more dependent on suppliers, the direct and indirect consequences of poor decision-making appear more serious (Hassan, 2019). In such a situation, the procurement department can play a key role in the efficiency and effectiveness of the organization and have a direct impact on reducing costs, profitability and flexibility of a company (Yazdani, 2018). In fact, choosing the right set of equipment suppliers to work with is very important and vital for the success of a company, and for many years, the selection of equipment suppliers has been emphasized. With the emergence of supply chain management, the attention of organizations from within (the internal process of the organization) was drawn to the analysis of the upper and lower members of the supply chain in such a way that various organizations inevitably use supply chain management in order to create and maintain their competitive position (Liu, 2016). The term "supply chain management" has been used for nearly twenty years and refers to a set of approaches used to integrate the efficiency of suppliers, manufacturers, warehouses and stores. So that the goods are supplied to the right equipment and supporting parts, to the right place and at the right time, so that the goals of the whole system are optimized. The supply chain is also a network of facilities that provide the necessary equipment (Rajesh, 2015). Considering the essential role of suppliers in determining the criteria of reliability, reparability, supply support, etc. in achieving the goals of the supply chain, one of the basic tasks of purchasing units in supply chain management is to evaluate, select and attract suitable and capable suppliers. It is to prepare and provide the needs of the organization (Chatterjee, 2018). The problem of evaluation and selection of potential suppliers is a group multi-criteria decision making problem in which the degree of uncertainty of the data, the number of decision makers and the nature of the criteria are among the issues that should be considered in these problems. Therefore, the selection of the best supplier requires the analysis of many factors, as a result of which organizations face a multi-criteria decision problem. On the other hand, BWM process technique and GRAY TOPSIS along with it can consider several goals in the order of priority of the decision maker due to the accuracy of their calculation evaluation. These two techniques can create a model that uses different organizational ideals in choosing the right supplier and consider various criteria at the same time.

LITERATURE REVIEW

With the momentum created in the processes of economic globalization, today's companies are exposed to intense competition. To attract more customers, many companies increase product quality and reduce the price (cost). In this process, the supplier of raw materials plays an important role. Therefore, companies should choose appropriate suppliers and establish good cooperative relations with them. When choosing suppliers, various criteria are influential and some of them conflict with each other, such as quality and cost. Therefore, supplier selection shows itself as a multi-criteria decision-making problem (Estrella, 2014 and Kane, 2015). To identify evaluation criteria, Dixon (1966) first conducted a survey and as a result proposed 23 different criteria, including quality, on-time delivery, price, performance history, warranty policies, technical ability and so on. Among these criteria, the first three ones are more common and are applied in many issues related to supplier selection (Chen, 2011 and Ifi, 2016). As a result, new evaluation criteria were introduced, such as reliability, reparability, technical support, technology transfer, etc. According to these criteria, various sub-criteria (Chen, 2011 and Wan, 2015) were presented and listed in **Table 1**.

Table 1. Main supplier selection criteria

Resource	Criteria	Sub-criteria
Yang (2011)	Quality	Quality performance; Quality control and feedback VDCS
	Price and conditions	Price; Conditions; responsiveness; Lead time, VMI/VOI cost arrangement
	Supply chain support	Reaction to the purchase order; Flexibility and capacity in support, VMI operations/delivery
	Technology	Technical support, design issues; ECN/PCN processes
Chen (2011)	Cost	Product price, distribution cost, tariff and customs duties
	Quality	Product return rate, increase in preparation time, quality assessment, solution for quality problems
	Service performance	Delivery schedule, service and technical support, response to changes; Easy communication
	Supplier profile	Financial condition, customer base, performance history; Production capacity and facilities
	Risk	Geographical location, political stability; Economy, terrorism

Lee (2015)	Capability perspective General management	Strategy and management; Financial situation; customer relations; curriculum; History; the fame; language, certificate; geographical location
	Capability perspective Production	Production capacity; product capability; Serviceability, security regulations; Environmental regulations, quality control; Production price
	Capability perspective Cooperation	After-sales service, trust delivery
	Agility perspective	Delivery speed; flexibility in delivery; creating flexibility; flexibility in resources; Agility in responding to the customer; Cooperation with partners, IT infrastructure

Regarding decision-making methods, more recent studies have adopted some classical methods to solve supplier selection problems with poor numerical evaluation information, such as AHP (Analytic Hierarchy Process) (Nidik, 1992), ANP (Analytic Network Process), (Tseng, 2009) and TOPSIS (the technique of determining priority by similarity to the ideal answer) (Lin, 2011). However, as the complexity of decision-making problems increases, decision-making information becomes more and more ambiguous. In this case, Pedriches (2015) suggested that linguistic variables (Mata, 2014) are suitable for describing information obtained from quantitative assessment. For example, when evaluating a supplier's reputation, terms like "poor," "good," and "very good" are commonly used. Many gray decision making methods are proposed by converting linguistic variables into gray numbers. To put it bluntly, these methods can be divided into two categories:

A) Individual methods

b) Hybrid methods

Common individual methods are fuzzy AHP (FAHP) (Rezaei, 2014), fuzzy ANP (FANP) (Vinoda, 2011) and fuzzy TOPSIS (FTOPSIS) Roshandel (2013). Hybrid methods are those that combine at least two individual methods. Generally, some individual methods are used to determine the weight of the criteria and the rest are used to rank the suppliers. For example, considering that the measures are independent of each other, Hashemian *et al.* (2014), and Lee *et al.* (Lee, 2015) extracted criteria weights with FAHP and then ranked the suppliers with fuzzy PROMETHEE (Priority Ranking Optimization Method for Enrichment Evaluation) and FTOPSIS, respectively. Considering the interaction between the criteria, Nguyen *et al.* (2014) used FANP to determine the weights of the criteria and applied COPRAS-G (Complex Relative Evaluation of Alternatives with Gray Relations) to rank the suppliers; Karsak and Dorsan (2014) used QFD (Quality Function Development) and extracted criteria weights and then used DEA (Data Envelopment Analysis) to rank suppliers. The mentioned methods show that most researchers solved supplier selection problems by transferring linguistic variables.

According to the results of the studies, the calculation results usually do not exactly match any of the linguistic themes, and an approximate process should be used to express the results in the primary expression domain, which simply leads to the loss of information and the lack of accuracy in the final results. To overcome these limitations, Herrera and Martinez (2000) introduced a linguistic representation model that consists of a linguistic sentence and a numerical value. The main advantage of this representation is its domain continuity. Therefore, it can express any number of information in the discourse world. Although past linguistic decision-making methods can solve some supplier selection problems, there are also some weaknesses:

(1) Fuzzy decision-making methods can lead to loss or deviation (Wan, 2016).

(2) Although integrative decision-making methods can overcome information loss, they cannot consider the interaction between criteria. Interaction phenomena between criteria often occur in decision making problems in the real world. For example, when evaluating a supplier, high quality leads to a good reputation, and a good reputation leads to high quality.

To compensate for the above weaknesses, this paper proposes a hybrid method to solve supplier selection problems by two-level criteria. The most important motivations of this article are expressed as follows:

As stated earlier, various criteria and sub-criteria are involved in supplier selection issues.

In multi-criteria decision making, it is very important to rationally determine the weight of the criteria. However, they did not discuss the methods of determining the weights of the criteria. As a result, this paper formulates supplier selection as a type of multi-criteria decision-making problem with two criteria. By combining the BWM method and G-TOPSIS, a new hybrid method is proposed to solve this type of problem.

RESEARCH METHODS

In the first part of this research, the best and worst components of supplier selection are evaluated using the approach, and in the second part, the suppliers are ranked using the TOPSIS gray method.

The best-worst method is introduced to solve the multi-criteria decision making problem. In a multi-criteria decision making problem, a number of alternatives are evaluated according to a number of criteria in order to select the best alternative. This method was proposed by Jafar Rezaei in 2015.

The statistical results show that the BWM method performs significantly better than the AHP method in terms of consistency rate and other performance criteria such as minimum error, total deviation and consistency. Among the prominent features of the proposed method compared to existing MCDM methods are:

- Needing less comparative data

- This method leads to a more stable and reliable comparison, which means that more reliable answers are obtained.

In this section, we describe the steps of the BWM method that can be used to obtain the weights of the criteria.

Step 1- Specifying the set of criteria:

In this step, we consider the criteria {C1,C2,...,Cn} that should be used in decision making.

Step 2- Determining the best (in other words, the most desirable and important) and worst (the most undesirable and unimportant) criteria. In this section, the decision maker generally specifies the best and worst criteria. No comparison is made in this section. For example, for a particular decision maker, price and shape may be the best and worst criteria, respectively.

Step 3- Determining the performance of the best criterion against other criteria using numbers between 1 and 9. The results of the best criterion compared to the rest of the criteria may be as follows:

(1)

AB= (aB1, aB2,...,aBn),

where a_{Bj} specifies the performance of the best criterion B compared to criterion j. Obviously, A_{bb}=1. For our example, this vector shows the performance of the price criterion compared to other criteria.

Step 4- Determining the performance of all criteria compared to the worst criterion using numbers 1 to 9. The vector of the comparison results of the criteria compared to the worst criterion can be as follows:

(2)

Aw = (a1w, a2w,...,anw)T,

where a_{jw} represents the performance of criterion j compared to the worst criterion W. Obviously, the value of a_{WW}=1. For our example, this vector represents the performance of all criteria compared to the appearance criterion.

Step 5- Finding optimal weights (w1*,w2*,...,wn*)

The optimal values for the criteria are unique, which I will have for each pair of W_B/W_j and W_j/W_w:

$W_B/w_j=a_{Bj}$ and $W_j/W_w=a_{jw}$. To satisfy these conditions for all js, we need to find a solution such that the absolute value of the maximum difference $|\frac{wB}{wj} - a_{Bj}|$ and $|\frac{wB}{wj} - a_{jw}|$ should be minimized. Considering that the weights are non-negative and summable, the following problem can be expressed as a non-linear model according to formula (3).

(3)

$$\min_j \max\{\left|\frac{wB}{wj} - a_{Bj}\right|, \left|\frac{wB}{wj} - a_{jw}\right|\}$$

s.t.

$\sum_j W_j = 1$

$W_j \geq 0$, for all j

The above problem can be expressed as formula (4):

(4)

Min ε

s.t.

$\left|\frac{WB}{Wj} - a_{Bj}\right| \leq \varepsilon$, for all j

$\left|\frac{Wj}{Ww} - a_{jw}\right| \leq \varepsilon$, for all j

$\sum_j W_j = 1$

$W_j \geq 0$, for all j

And this problem has been converted into a linear model in the form of formula (5), which has made its calculations easier:

(5)

$$\min_j \max\{|W_B - a_{Bj}W_j|, |W_j - a_{jw}W_w|\}$$

$\sum_j W_j = 1$

$W_j \geq 0$, for all j

The above problem can be expressed using formula (6) as follows:

(6)

Min ξ^L

s.t.

$|W_B - a_{Bj}W_j| \leq \xi^L$, for all j

$|W_j - a_{jw}W_w| \leq \xi^L$, for all j

$\sum_j W_j = 1$

$W_j \geq 0$, for all j

By solving the above relationship, the optimal values of weights ($W^*1, W^*2, \ldots, W^*3$) and $^*\varepsilon$ value will be obtained.

Then, using ε*, we introduce an adaptation rate. It will be clear that larger values for *ε will result in higher concordance rates and lower reliability of comparisons.

Ranking of suppliers by GARY TOPSIS method

In this section, according to the ranking results of the indicators, the evaluation of suppliers is done based on the gray TOPSIS approach.

Step 1: Determine the gray numbers

Table 2. Linguistic variable of gray numbers

Linguistic variable	Symbol	Gray number	
		L	U
Very poor	VP	0	1
Poor	P	1	3
Moderately poor	MP	3	4
Average	F	4	5
Moderately good	MG	5	6
Good	G	6	9
Very good	VG	9	10

In this step, normal gray numbers have been used to evaluate countermeasures, which will be calculated in the next step of the gray decision matrix.

Second step: building the gray decision matrix

In this step, according to the pairwise comparison matrix of experts in the field of effectiveness of each of the control measures in facing the identified risks, the gray decision matrix is compiled.

(7)

$$G_{ij} = \frac{1}{K}\left[G_{ij}^{1} + G_{ij}^{2} + \ldots + G_{ij}^{K}\right]$$

The third step: Normalizing the gray decision matrix

For profit criteria:

(8)

$$G^{*}_{ij} = \left[\frac{\underline{G}_{ij}}{G_j^{max}}, \frac{\overline{G}_{ij}}{G_j^{max}} \right] \text{ where } G_j^{max} = max_{1 \le j \le m} \left\{ \overline{G}_{ij} \right\}$$

For cost criteria:

(9)

$$G^{*}_{ij} = \left[\frac{G_j^{min}}{\overline{G}_{ij}}, \frac{G_j^{min}}{\underline{G}_{ij}} \right] \text{ where } G_j^{min} = min_{1 \le i \le m} \left\{ \underline{G}_{ij} \right\}$$

The fourth step: formation of the weighted normalized gray decision matrix:

(10)

$$D = \begin{bmatrix} V_{11} & V_{12} & \dots & V_{1n} \\ V_{21} & V_{22} & & V_{2n} \\ \vdots & & \ddots & \vdots \\ V_{m1} & V_{m2} & \dots & V_{mn} \end{bmatrix} \text{ where } V_{ij} = G^{*}_{ij} \times W_j$$

Fifth step: determining the ideal and non-ideal answer

(11)

$$S^{max} = \left\{ \left[max_{1 \le i \le m} \underline{V}_{i1}, max_{1 \le i \le m} \overline{V}_{i1} \right], \left[max_{1 \le i \le m} \underline{V}_{i2}, max_{1 \le i \le m} \overline{V}_{i2} \right], \dots, \left[max_{1 \le i \le m} \underline{V}_{in}, max_{1 \le i \le m} \overline{V}_{in} \right] \right\}$$

$$S^{min} = \left\{ \left[min_{1 \le i \le m} \underline{V}_{i1}, min_{1 \le i \le m} \overline{V}_{i1} \right], \left[min_{1 \le i \le m} \underline{V}_{i2}, min_{1 \le i \le m} \overline{V}_{i2} \right], \dots, \left[min_{1 \le i \le m} \underline{V}_{in}, min_{1 \le i \le m} \overline{V}_{in} \right] \right\}$$

The sixth step: calculating the degree of gray possibility between the compared options and ideal and non-ideal solutions.

Ideal answers:

(12)

$$P_1 = P\left\{ S_i \le S^{max} \right\} = \frac{1}{n} \sum_{j=1}^{n} P\left\{ V_{ij} \le G_j^{max} \right\}$$

Non-ideal answers:

(13)

$$P_2 = P\left\{ S_i \ge S^{min} \right\} = \frac{1}{n} \sum_{j=1}^{n} P\left\{ V_{ij} \le G_j^{min} \right\}$$

Seventh step: Determining the degree of closeness to the ideal and ranking the options

(14)

$$C_i = \frac{P_1}{P_2}$$

Therefore, according to the presented research methodology, in the next section, the presented method will be evaluated.

4. Research findings

According to the evaluation of the selection criteria among the experts of the relevant organization, among the 16 most important indicators in **Table 3**, which were evaluated and selected based on the library study, in this research, according to the information collected in the field and also using the Experts and experts, based on the Likert scale, "very low importance=1", "low importance=2", "moderate importance=3", "high importance=4", "very high importance=5" are the most important evaluation and selection indicators. Road construction equipment contractors were evaluated and selected at the macro level. Therefore, according to the average level of polling, the indicators that had a weight of more than 3 were selected.

Table 3. Identified indicators of evaluation and selection of suppliers

Number	Criterion description	Weight	confirmation
1	Product price	2.9	
2	Delivery location	2.6	
3	Inward technology transfer	4.2	*
4	Company's after sales support criteria	2.1	
5	Ability to customize	2.2	
6	Corrective/preventive measure systems	1.5	
7	Reliability	4.3	*
8	Inventory accessibility	2.9	
9	Product quality	2.85	
10	Ability to reduce costs	2.2	
11	Packaging	2.4	
12	Negotiability	1.5	

13	Product reparability on the buyer's site	4.5	*
14	Logistic cost	2.8	
15	Value added cost	2.2	
16	Ability to provide technical support and timely warranty	4.5	*

According to the selection of four main indicators by the experts of the studied company, in the next step, using the BWM approach, the indicators are evaluated and weighted.

Therefore, the implementation steps are as follows:

Step 1: Determining a set of decision criteria

Inward technology transfer (C1)

Reliability (C2)

Product reparability on the buyer's site (C3)

Ability to provide technical support and timely warranty (C4)

Step 2: Determining the best (most desirable, most important) and worst (least desirable, least important) criteria

In this section, according to the survey of organizational experts, the best indicator of inward technology transfer and the worst indicator of technical support capability and warranty were evaluated and introduced on time.

Step 3: Determining the importance of the best criterion over other criteria

Table 4. Pairwise comparison vector for the best criterion

The average weight of indicators based on the opinion of experts				
Type of criteria	**C1**	**C2**	**C3**	**C4**
Weight	W_1	W_2	W_3	W_4
C1	1	5/(6+2+7+5+3) =4.6	5/(6+5+8+5+4) =5.6	7.2 = 5/(6+6+7+9+8)

Step 4: Determining the importance of other criteria relative to the worst criterion

Table 5. Pairwise comparison vector for the best criterion

The average weight of indicators based on the opinion of experts				
Type of criteria	**C1**	**C2**	**C3**	**C4**
Weight	W_1	W_2	W_3	W_4

C4	4.6= 5/(4+2+6+6+5)	5/(6+5+7+8+8) =6.8	5/(3+5+2+2+4) =3.6	1

Step 5: Determining the optimal weights

The relationships between criteria based on model (6) are written as follows.

Min ε

s.t.

$|w1 - 4.6\ w2| \leq \varepsilon$

$|w1 - 5.6\ w3| \leq \varepsilon$

$|w1 - 7.2\ w4| \leq \varepsilon$

$|w2 - 6.8\ w4| \leq \varepsilon$

$|w3 - 3.6\ w4| \leq \varepsilon$

$w_1 + w_2 + w_3 + w_4 = 1$

$w_1, w_2, w_3, w_4 \geq 0$

The above model is implemented in Lingo mathematical programming software. After solving the above model, the optimal weight of the criteria is obtained as follows.

w^*_1=0.6167, w^*_2=0.1791, w^*_3=0.1471, w^*_4=0.0.056, ε^* = 0.20

Table 6. Calculated weight of research criteria

C_i	C_1	C_2	C_3	C_4
W_i	W_1	W_2	W_3	W_4
	0.6167	0.1791	0.1471	0.056

According to the analysis, the inconsistency rate of the opinions was acceptable and the weight of the indicators was confirmed. According to the weighting of the indicators based on the BWM method, in the next step, according to the selected companies in the field of road construction equipment supply, ranking will be done using the pseudo-ideal gray approach. According to the evaluation, eight main suppliers of road construction equipment were listed and ranked according to the semi-ideal gray method.

First step: building the gray decision matrix

In this step, according to the pairwise comparison matrix of experts about influence of each of the identified indicators in facing the supply of road construction equipment, the gray decision matrix is compiled, which is as follows.

Table 7. Gray decision Matrix

Criteria	C1	C2	C3	C4

Criteria Material	Positive		Positive		Positive		Positive	
Limits	L	U	L	U	L	U	L	U
Criteria weight	0.6167	0.6167	0.1791	0.1791	0.1417	0.1417	0.056	0.056
A1	3	4	4	5	3	4	4	5
A2	5	6	6	9	5	6	5	6
A3	4	5	6	9	5	6	4	5
A4	6	9	5	6	6	9	5	6
A5	9	10	5	6	4	5	5	6
A6	5	6	3	4	4	5	4	5
A7	3	4	3	4	5	6	4	5
A8	4	5	1	3	3	4	6	9

According to the above table, it has been shown that, for example, criterion A1 had an effect of [3 and 4] based on the technology transfer index, and these numbers were obtained from the opinions of experts.

Second step: Normalizing the gray decision matrix

According to the weight of each of the ranked suppliers' evaluation index the options in question are normalized based on relationship 8 and 9, the weight of the indicators is as described in **Table 8**:

Table 8. Normalizing gray decision matrix

Criteria	C1		C2		C3		C4	
Criteria Material	Positive		Positive		Positive		Positive	
Limits	L	U	L	U	L	U	L	U
Criteria weight	0.6167	0.6167	0.1791	0.1791	0.1417	0.1417	0.056	0.056
A1	0.3	0.4	0.4444	0.5556	0.3333	0.4444	0.4444	0.5556
A2	0.5	.06	0.6667	1	0.5556	0.6667	0.5556	0.6667
A3	0.4	0.5	0.6667	1	0.5556	0.6667	0.4444	0.5556
A4	0.6	0.9	0.5556	0.6667	0.6667	1	0.5556	0.6667
A5	0.9	1	0.5556	0.6667	0.4444	0.5556	0.5556	0.6667
A6	0.5	0.6	0.3333	0.4444	0.4444	0.5556	0.4444	0.5556
A7	0.3	0.4	0.3333	0.4444	0.5556	0.6667	0.4444	0.5556
A8	0.4	0.5	0.1111	0.3333	0.3333	0.4444	0.6667	1

In this section, according to the evaluation and opinions of experts, a normalized matrix of opinions is made to absorb the type of index, which was shown in the above table.

The third step: forming the weighted normalized gray decision matrix based on equation 10:

Table 9. Formation of the weighted normalized gray decision matrix

Criteria	C1		C2		C3		C4	
Criteria Material	Positive		Positive		Positive		Positive	
Limits	L	U	L	U	L	U	L	U
Criteria weight	0.6167	0.6167	0.1791	0.1791	0.0472	0.1417	0.056	0.056
A1	0.18501	0.24668	0.0796	0.0995	0.3333	0.063	0.0249	0.0311
A2	0.30835	0.37002	0.1194	0.1791	0.0787	0.0945	0.0311	0.0373
A3	0.24668	0.30835	0.1194	0.1791	0.0787	0.0945	0.0249	0.0311
A4	0.37002	0.55503	0.0995	0.1194	0.0945	0.1417	0.0311	0.0373
A5	0.55503	0.6167	0.0995	0.1194	0.063	0.0787	0.0311	0.0373
A6	0.30835	0.37002	0.0597	0.0796	0.063	0.0787	0.0249	0.0311
A7	0.18501	0.24668	0.0597	0.0796	0.0787	0.0945	0.0249	0.0311
A8	0.24668	0.30835	0.0199	0.0597	0.0472	0.063	0.0373	0.056

The fourth step: determining the ideal and non-ideal answer

In this section, according to the opinions of experts, ideal and non-ideal solutions have been obtained based on relations 12 and 13:

Table 10. Determining the ideal and non-ideal answer

Criteria	C1		C2		C3		C4	
Limits	L	U	L	U	L	U	L	U
Positive ideal answer	0.3084	0.37	0.1194	0.1791	0.0787	0.0945	0.0311	0.0373
Negative ideal answer	0.2468	0.3084	0.1194	0.1791	0.0787	0.0945	0.0249	0.0311

In this section, positive and negative ideal gray numbers are identified and introduced to evaluate the criteria.

The fifth step: calculating the degree of gray possibility between the compared options and ideal and non-ideal solutions

In this step, the gray level calculations of supplier companies are done based on the four indicators and based on equation 14.

Table 11. Positive and negative ideal gray numbers

Options	The degree of gray possibility between the options and the positive ideal answer (P1)	The degree of gray possibility between the options and the negative ideal answer (P2)
A1	1	0.652
A2	0.875	1
A3	0.875	0.875
A4	0.875	1
A5	0.875	1
A6	1	0.875
A7	1	0.75
A8	0.875	0.75

The sixth step: determining the degree of closeness to the ideal and ranking the options

Then, in the final step, while calculating the degree of improvement to the ideal answer, the rating of supplier companies has been done.

Table 12. Determining the degree of closeness to the ideal and ranking the options

Options	Index of the relative closeness of options to the ideal answer (Ci)	Ranking the options
A1	1.6	8
A2	0.875	1
A3	1	4
A4	0.875	1
A5	0.875	1
A6	0.142857143	5
A7	1.333333333	7
A8	1.166666667	6

Therefore, according to the evaluation, supplier companies A2, A4, A5 were introduced as top grade suppliers, and road construction equipment can be supplied from these three suppliers.

5. Conclusion and suggestions for further research

Assessing the quality level of suppliers is one of the important actions of reputable companies in the business environment. Companies that are looking for agility in a competitive environment, focus on quality from the early stages and the time the equipment is going to enter the company and follow and implement this approach in the process chain until the delivery of the project.

The strategy of any company can explain the general business method of the company/organization. In line with the macro strategies of every company, the different units of that organization should explain and implement the policies of their units, which are in line with the general strategies of the company. Undoubtedly, without having a written strategy and plan, no company will be successful in the commercial business environment and the opposite of this hardly happens. Therefore, in this research, the basic indicators in the field of road equipment supply were evaluated and based on the integrated approach of BWM and Khaksari's quasi-ideal equipment suppliers were ranked. In order to develop this research, it is suggested to evaluate the risks of international relations and the required equipment according to the needs of the organization under the quality framework (QFD) and to be involved in the evaluation of suppliers.

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