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Suitable computerized maintenance management system selection using grey group TOPSIS and fuzzy group VIKOR: A case study

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C H R O N I C L E

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A B S T R A C T

The purpose of this paper is developing a method to choose an appropriate Computerized Maintenance Management System (CMMS) using Multiple Criteria Decision Making (MADM) for a dairy company. Among different methods, the grey group TOPSIS and fuzzy group VIKOR methods were selected. TOPSIS is a Technique for order of Preference by Similarity to Ideal Solution and VIKOR technique is a method based on compromise programming. The data in this article were gathered using the interviews with the company's managers and elites in the field of maintenance. Then, out of five types of maintenance software, the best ones were selected using these two techniques and finally the results were compared with each other. In the selection process, 13 sub-criteria were introduced under 5 main criteria. These criteria were selected out of a huge number of criteria using the studies of others and by consulting with the company's managers and experts. We have tried to make the choices in a way that the majority of aspects could be considered. This paper helps the maintenance managers in decision-making related to choosing the CMMS software in uncertainty environment. Using two different fuzzy and grey approaches and comparing the results can lead to appropriate selection and improve the confidence in decision-making. Maintenance planning issues are among the important issues in industrial production systems. Maintenance systems have basically made remarkable progress in recent years. The increase of companies' competitive pressure on the one hand and the close relationship between maintenance activities and companies' core activities, on the other hand, have encouraged companies to use the software in order to manage their maintenance activities.

1. Introduction

Man has long been trying to increase his share of existing resources as much as possible using the means of production. Easy use of production means has always been the objective. Thus, the significance of proper maintenance of production means has been an issue for human beings for a long time (Sinkkonen et al., 2013). Technology was developed as a means of production and as the level of increase in production, the knowledge of maintenance personnel was extended as well, such that within a developed industrial culture the issue of maintenance has gone beyond the utilization of production

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means. It now includes such areas as the design of production machines, production technology, ease of maintenance, lowering the costs, increasing the reliability, etc.

After all, industrial units' requirements for being equipped and having a codified, effective, and dynamic maintenance system is increasingly growing due to the expansion and increase of their activities. It is therefore essential to have an equipped system of operation and information flow and a maintenance system so that it becomes possible to have a continuous control over and total awareness of the situation and the way different units perform.

1.1.Statement of the problem

Performance measurement is nowadays one of the best ways to elicit information in order to make decisions in the organizational context and plays a vital role in its success. Currently, the main challenges facing maintenance professionals are not limited to learning performance measurement techniques, but they include decision-making on the selection of the best alternative and the most effective maintenance techniques for their organizations. Experts and technical managers are faced with a huge amount of data in maintenance systems, and it is inevitable that they make an appropriate and timely use of these data in a bid to make comparisons, analyses, and decisions. This is why the use of CMMS (Stevens, 2009; Kackar, 1989) has attracted such considerable attention.

One of the biggest problems with CMMS is their choice. Given the huge number of computerized maintenance management systems in the market nowadays, organizations are often faced with problems in choosing the best system. Despite the heavy costs and the numerous advantages of these systems, their implementation poses plenty of problems and in most cases leads to failure. Choosing a software application with high costs and numerous features is not always appropriate for organizations, as it can also lead to a possible decrease in efficiency. Thus, introducing a method for choosing a CMMS which is appropriate for the organization's needs can make a good contribution to the implementation and execution of CMMS in that setting.

In management phase, managers are always faced with challenges, and they should take appropriate decisions to remove these barrels. It becomes even more difficult when various criteria are considered in a way that the decision totally influences various factors. In such case, multiple criteria decision making (MCDM) introduces certain techniques to facilitate the process. This study is mainly aimed at providing and using two methods to choose an appropriate CMMS. Important criteria for choosing the software were identified, and the selection was made using fuzzy group VIKOR and grey group TOPSIS methods in a bid to make appropriate decisions. The research data were acquired using the alternatives of a company's maintenance experts, and among the existing software applications, the best one was selected using the abovementioned methods.

2. Literature review

O'Donoghue et al. (2004) reviewed the results of implementing a CMMS in a textile manufacturing company in Ireland. Braglia et al. (2005) identified the required criteria in a CMMS and divided them into the five categories of costs, performance, implementation, data management, and auxiliary characteristics. Finally, they surveyed specialists to choose the most appropriate system. Carnero and Novés (2007) underlined the most well-known computerized maintenance management systems, and by identifying the important criteria, they illustrated a network tree. Finally, by surveying specialists, they showed which CMMS is appropriate for different companies. Spörk (2007) suggested that management success requires an improvement in all fields including the field of maintenance. Improvement of maintenance, which in turn requires a step-by-step evolution towards the excellent target. Labib (2008) referred to some of the benefits of using CMMS and highlighted the current situation of maintenance systems. Durán (2011) identified important criteria in choosing a maintenance software application, and in the next step, illustrated the network tree in three levels. Uysal and Tosun (2012) provided a structured methodology to permit the optimal selection of the best-suited CMMS software within maintenance information technologies. The analysis was carried out using TOPSIS method. Saharkhiz et al. (2012) addressed the application of CMMS in a refinery environment and analyzed and compared the performance of two types of software. Galar et al. (2012) proposed a combined data-mining-based methodology for condition-based maintenance (CBM) considering condition-monitoring (CM) data and Historical Maintenance Management data. Macchi and Fumagalli (2013) measured and checked the performance improvement level of a company's maintenance practices. Mazurkiewicz (2014) studied the reliability of the continuous availability of conveyor belt. The researcher focused on the most popular diagnostic systems used in the maintenance of internal transport conveyor systems. Also, a new method of computer-aided maintenance was presented. Chua et al. (2015) proposed an AHP-based decision-making framework for maintenance personnel to choose the most appropriate procurement method. The validation process was carried out through a structured interview with nine public universities selected. The proposed decision-making framework was a great help to maintenance department in making decisions on selecting the most appropriate methods. Rastegari and Mobin (2016) presented three different decision making techniques Which could be linked to CMMS. Their Methods included Decision Making Grid (DMG), TOPSIS and clustering techniques.

The current research used Grey Group TOPSIS and Fuzzy Group VIKOR to take into account decision uncertainties. Linguistic variables were used to facilitate the complete collection of data in order to identify and select the best alternative in the shortest possible time.

3. Research theory

Fig. 1 displays the procedure of the current study. In the present article, we first review the Fuzzy Group VIKOR and the Grey Group TOPSIS Methods. Then we examine a case study using the mention methods. Finally, we will compare the results from both methods.

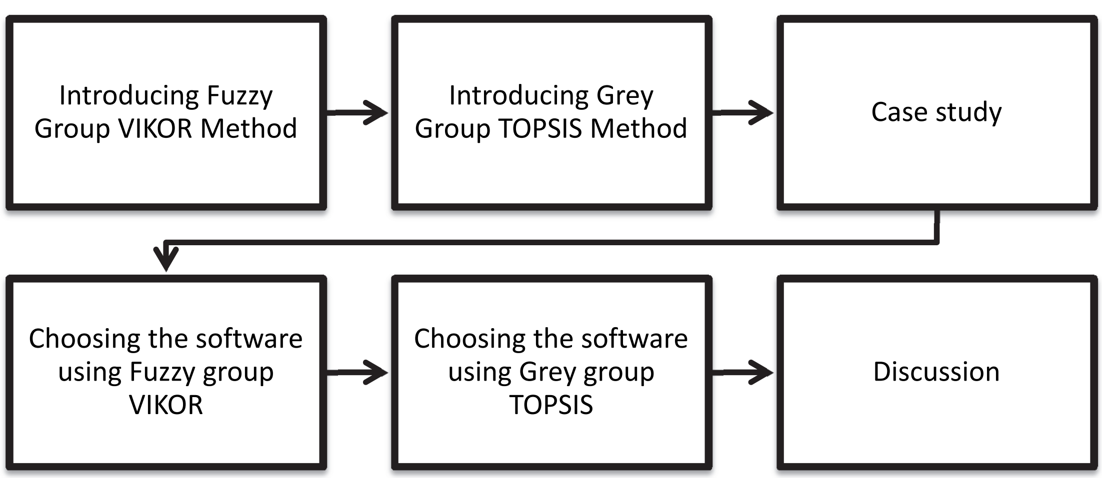

Fig. 1. Procedure of the current study

3.1. Fuzzy approach

In a decision-making process, decision-makers are often faced with uncertainties. In other words, the natural language for expressing one's feelings or judgments is always a subjective, uncertain or vague one (Jamali & Feylizadeh, 2015). For the sake of disambiguation and making the decision-makers judgments more objective, fuzzy sets theory was introduced for expressing linguistic words in the decision-making process (Zadeh, 1965). Bellman and Zadeh (1970) developed the fuzzy multi-criteria decision-making methodology to make up for the lack of accuracy in assigning importance weights of criteria, in a way that alternatives were rated with regard to evaluation criteria. In order to present the proposed method, it is necessary first to review some important definitions and symbols in fuzzy sets theory based on Dubois and Prade (1980), Kaufmann and Gupta (1991), and Tsao (2009).

3.1.1. Fuzzy numbers

A fuzzy trapezoidal number of $\tilde{A} = [a_1, a_2, a_3, a_4]$, where $a_1 \leq a_2 \leq a_3 \leq a_4$, and $a_1, a_2, a_3, a_4 \in$ R, is expressed as a fuzzy set with a membership function of $f_\lambda(x)$. Membership Function $f_\lambda(x)$ is a continuous image of R to the closed interval of [0,1]; $f_\lambda(x) = 0$, for all $x \in [-\infty, a_1]$ and $x \in [a_4, +\infty]$. This function is strictly ascending on $x \in [a_1, a_2]$. Also $f_\lambda(x) = 1$ on $x \in [a_2, a_3]$ and is strictly descending on $x \in [a_3, a_4]$ for $x \in [a_3, a_4]$. As a special case of trapezoidal numbers $\tilde{B} = [b_1, b_2, b_3]$ is defined with the name of a triangular fuzzy number if $f_{\tilde{B}}(x)$ is as Eq. (1) and as illustrated in Fig. 2:

$$\mathrm{f}(x) = \begin{cases} (x - b_1)/(b_2 - b_1) & b_1 \leq x < b_2 \\ (x - b_3)/(b_2 - b_3) & b_2 \leq x \leq b_3 \\ 0 & otherwise \end{cases} \quad (1)$$

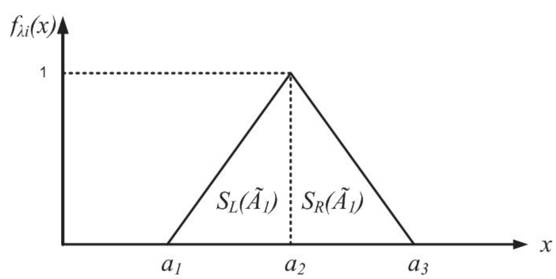

Fig. 2. Triangular fuzzy numbers

3.2. Fuzzy Group VIKOR Method

Assumptions and steps for the fuzzy group VIKOR method are as follows (Garg & Jain, 2017):

Assumptions:

There are k decision-makers, the importance of whose opinion in the final decision is different ($K = 1, \dots, k$).

There are m alternatives to be selected($i = 1, \dots, m$). There is n criteria/attributes for making decisions($j = 1, \dots, n$).

The steps of this method are as follows:

Step 1: k decision-makers and certain linguistic variables are used to determine the weights of criteria. It is assumed as a linguistic variable that can show the linguistic expressions of very good, good, average, poor, and very poor in the opinion of decision-maker k for the j^{th} criterion.

Thus, the decision/decision-maker matrix can be written this way:

$$\begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{ccccc} D_1 & D_2 & \dots & D_k & w_j \end{array} \\ \begin{bmatrix} \widetilde{x_{11}} & \widetilde{x_{21}} & \dots & \widetilde{x_{k1}} & \widetilde{w_1} \\ \widetilde{x_{12}} & \widetilde{x_{22}} & \dots & \widetilde{x_{k2}} & \widetilde{w_2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \widetilde{x_{1n}} & \widetilde{x_{2n}} & \dots & \widetilde{x_{kn}} & \widetilde{w_n} \end{bmatrix} \end{array}$$

w_j is the fuzzy weight of j^{th} criterion in the decision-making process. Then:

$$\widetilde{W}_j = (\min\{x_{j1}^L, x_{j2}^L, \dots, x_{jk}^L\}, \omega_1 x_{j1}^M + \omega_2 x_{j2}^M + \dots + \omega_k x_{jk}^M, \max\{x_{j1}^R, x_{j2}^R, \dots, x_{jk}^R\}) \tag{2}$$

Step 2: k decision-makers and linguistic variables are used to rank the alternatives. Also, it is assumed that it is a linguistic variable that includes the linguistics expressions of very low, low, average, high, very high in the opinion of decision-maker k for the i^{th} alternative based on the j^{th} criterion.

Step 3: If $\tilde{Z}_{ij}$ is a fuzzy variable about the i^{th} alternative based on the j^{th} criterion, then the combined matrix can be written as follows:

$$\tilde{Z}_{mn} = (\min\{y_{1mn}^L, \dots, y_{kmn}^L\}, \omega_1 x_{1mn}^M + \dots + \omega_k x_{kmn}^M, \max\{x_{1mn}^R, \dots, x_{kmn}^R\}) \tag{3}$$

Step 4: The elements of step 3 matrix are convertible to corresponding crisp numbers using one of the defuzzification methods (Van Leekwijck & Kerre, 1999).

Step 5: If the j^{th} criterion is of profit type, then its positive ideal and negative ideal values would be as follows:

$$f_j^+ = \max(f_{ij}) \tag{4}$$

$$f_j^- = \min(f_{ij}) \tag{5}$$

If the jth criterion is of loss type, then its positive ideal and negative ideal values would be as follows:

$$f_j^+ = \min(f_{ij}) \tag{6}$$

$$f_j^- = \max(f_{ij}) \tag{7}$$

Step 6: The values of S_i and R_i would be calculated as follows:

$$S_i = \sum_{j=1}^{n} \frac{w_j(f_j^+ - f_{ij})}{f_j^+ - f_i^-} \tag{8}$$

$$R_i = \max\left\{\frac{w_j(f_j^+ - f_{ij})}{f_j^+ - f_i^-}\right\} \tag{9}$$

where, S_i and R_i are respectively the amounts of utility and regret of the i^{th} alternative.

Step 7: Specifying the values of Q_i for all alternatives.

$$Q_i = \nu\left(\frac{S_i - S^+}{S^- - S^+}\right) + (1-\nu)\left(\frac{R_i - R^+}{R^- - R^+}\right) \tag{10}$$

where $S^+ = \min\{S_i\}$ and $S^- = \max\{S_i\}$ and $R^+ = \min\{R_i\}$ and$R^- = \max\{R_i\}$. Q_i is the index of VIKOR, and expresses the value of the i^{th} alternative. ν is the weight for the strategy of maximum group utility, which is usually 0.5 (Kachar, 1985; Opricovic, 1998; Opricovic & Tzeng, 2002, 2007; Zanakis et al., 1998).

Step 8: Ranking alternatives based on the descending order of values resulted for S_i, R_i, and Q_i.

Step 9: Selecting the best alternative (Feylizadeh and Dehghani, 2016)

$$Q\left(A^{[2]}\right) - Q\left(A^{[1]}\right) \geq DQ \tag{11}$$

$$DQ = \frac{1}{m-1} \tag{12}$$

The best alternative (with lowest Q_i) is realized only if the following two conditions are met:

Condition 1:

$A^{[k]}$: Based on the criterion Q, the alternative is ranked k^{th}.

$A^{[1]}$: is the best alternative with the lowest value for Q.

m**:** is the Rank of alternatives.

Condition 2:

The alternative $A^{[1]}$ should also have the best rank in S and/or in R.

If one of the above conditions is not met, then a set of compromise responses are proposed as follows:

- If only the second condition was not met, the alternatives $A^{[1]}$ and $A^{[2]}$ are selected as the best ones.
- If the first condition was not met, the alternatives $A^{[1]}$, $A^{[2]}$, …,$A^{[m]}$ are selected as the best ones.

$A^{[m]}$ is an alternative in the m^{th} position, for which the Eq. $Q\left(A^{[m]}\right) - Q\left(A^{[1]}\right) < DQ$ holds true.

3.3. Grey Theory

Dang (1982) introduced Grey systems theory and it is now being developed by Liu. Grey theory is an effective method to solve uncertainty problems with discrete and incomplete data. The goal of the Grey system is to fill the gap between the social sciences and the natural sciences. Grey systems are named according to the degree of transparency of data. If the system data is fully known, it is called the white system, and if the system data is completely unknown, it is called the black system. If part of the system data is known and part of it is unknown, the system is called grey (Liu & Forrest, 2010; Mahmoudi et al., 2017). The current research used grey TOPSIS due to the subjective and vague judgment of experts. This theory produces satisfactory output using inconsistent input data.

3.3. Grey Numbers

The grey number is an interval with an unknown value, but a known range of values. This interval contains unreliable data. The grey number is displayed with the symbol$\otimes$. Grey numbers are classified into several categories; the current research introduces the following three categories (Liu et al., 2017):

Definition (1): If $\otimes A$ is a grey number whose lower bound can only be estimated, it is called a grey number with only a lower bound and is represented as $\otimes A = [\, \underline{A}\,, \infty)$.

Definition (2): If $\otimes A$ is a grey number whose upper bound can only be estimated, it is called a grey number with only upper bound and is represented as $\otimes A = (\,\infty\,, \overline{A}\,]$.

Definition (3): $\otimes A$ is a grey number whose lower and upper bounds can be estimated, it is called Interval grey number and is represented as $\otimes A = [\underline{A}, \overline{A}]$.

If $\otimes A = [\underline{A}, \overline{A}]$ and $\otimes B = [\underline{B}, \overline{B}]$ are two grey numbers, then arithmetic operations can be performed on them as Eqs. (13) to (16):

$$\otimes A + \otimes B = [\underline{A} + \underline{B}, \overline{A} + \overline{B}] \tag{13}$$

$$\otimes A - \otimes B = \otimes A + (-\otimes B) = [\underline{A} - \overline{B}, \overline{A} - \underline{B}] \tag{14}$$

$$\otimes A \times \otimes B = [Min\{\underline{A}\,\underline{B}, \overline{A}\,\overline{B}, \overline{A}\,\underline{B}, \underline{A}\overline{B}\}, Max\{\underline{A}\,\underline{B}, \overline{A}\,\overline{B}, \overline{A}\,\underline{B}, \underline{A}\overline{B}\}] \tag{15}$$

$$\frac{\otimes A}{\otimes B} = \otimes A \times \otimes B^{-1} = \left[Min\left\{\frac{\underline{A}}{\underline{B}}, \frac{\underline{A}}{\overline{B}}, \frac{\overline{A}}{\underline{B}}, \frac{\overline{A}}{\overline{B}}\right\}, Max\left\{\frac{\underline{A}}{\underline{B}}, \frac{\underline{A}}{\overline{B}}, \frac{\overline{A}}{\underline{B}}, \frac{\overline{A}}{\overline{B}}\right\}\right] \tag{16}$$

The length of the grey number $\otimes A = [\underline{A}, \overline{A}]$ is obtained from Eq. (17):

$$L(\otimes A) = \overline{A} - \underline{A} \tag{17}$$

If there are two grey numbers $\otimes A = [\underline{A}, \overline{A}]$ and $\otimes B = [\underline{B}, \overline{B}]$, the degree of greyness between these two numbers is obtained using Eq. (18) (Liu et al., 2012).

$$P\{\otimes \boldsymbol{A} \leq \otimes B\} = \frac{Max\{0, L^* - Max(0, \overline{A} - \underline{B})\}}{L^*} \quad \text{where } L^* = L(\otimes A) + L(\otimes B) \tag{18}$$

3.4. Grey Group TOPSIS Method

The TOPSIS method was introduced by Huang and Yun in 1981. In this method, n alternatives are evaluated by the m criteria. The principle logic of this method defines the positive and negative ideal solutions (Parsaei et al., 2012). The positive ideal solution is a solution that increases the profit and reduces the cost benchmarks. The optimal alternative is the alternative that has the least distance from the positive ideal solution and the maximum distance from the negative ideal solution. Given the fact that the data are not exactly accurate in reality, the grey theory is used to take uncertainties into account. In the following steps, we will express the stages of the Grey Group TOPSIS method (Li et al., 2007; Nyaoga et al, 2016; Rastgar & naderi, 2016).

Step 1: First, we must determine the weight of each criterion by the decision makers. Expert opinions can be expressed on the basis of linguistic variables in grey theory. Assuming that the number of decision makers is k, the criterion j weight is calculated using Eq. (19).

$$\otimes w_j = \frac{1}{k}[\otimes w_j^1 + \otimes w_j^2 + \cdots + \otimes w_j^k] \tag{19}$$

Step 2: The linguistic variables should be used to determine the status of each research alternative in each of the criteria. Assuming that the number of decision makers is k, the value of alternative i in the criterion j is calculated by Eq. (20).

$$\otimes G_{ij} = \frac{1}{k}[\otimes G_{ij}^1 + \otimes G_{ij}^2 + \cdots + \otimes G_{ij}^k] \tag{20}$$

Step 3: Propose the grey decision matrix in the form of Eq. (21).

$$D = \begin{bmatrix} \otimes G_{11} & \otimes G_{12} & \dots & \otimes G_{1n} \\ \otimes G_{21} & \otimes G_{22} & \dots & \otimes G_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \otimes G_{m1} & \otimes G_{m2} & \dots & \otimes G_{mn} \end{bmatrix} \tag{21}$$

In Eq.(21), $\otimes G_{ij}$ expresses the importance of the alternative i in the criterion j.

Step 4: Normalize the grey decision matrix that is shown in (22)

$$D^* = \begin{bmatrix} \otimes G_{11}{}^* & \otimes G_{12}{}^* & \dots & \otimes G_{1n}{}^* \\ \otimes G_{21}{}^* & \otimes G_{22}{}^* & \dots & \otimes G_{2n}{}^* \\ \vdots & \vdots & \vdots & \vdots \\ \otimes G_{m1}{}^* & \otimes G_{m2}{}^* & \dots & \otimes G_{mn}{}^* \end{bmatrix} \tag{22}$$

If the criteria is of benefit attribute, Eq. (23) is used for normalization.

$$G^*{}_{ij} = \left[\frac{\underline{G}_{ij}}{G_j^{max}}, \frac{\overline{G}_{ij}}{G_j^{max}} \right] Where\ G_j^{max} = max_{1 \le j \le m}\{ \overline{G}_{ij}\} \tag{23}$$

If the criterion is of cost attribute, Eq. (24) is used for normalization.

$$G^*{}_{ij} = \left[\frac{G_j^{min}}{\overline{G}_{ij}}, \frac{G_j^{min}}{\underline{G}_{ij}} \right] Where\ G_j^{min} = min_{1 \le j \le m}\{ \underline{G}_{ij}\} \tag{24}$$

After normalizing, all the values of the grey matrix will be in the range [0,1].

Step 5: At this stage, we have to formulate a weighted normalized grey decision matrix as illustrated in Eq. (25).

$$V = \begin{bmatrix} \otimes V_{11} & \otimes V_{12} & \dots & \otimes V_{1n} \\ \otimes V_{21} & \otimes V_{22} & \dots & \otimes V_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \otimes V_{m1} & \otimes V_{m2} & \dots & \otimes V_{mn} \end{bmatrix} Where\ \otimes V_{ij} = \otimes G_{ij}^* \times \otimes w_j \tag{25}$$

Step 6: At this stage, the positive and negative ideal solutions are calculated by Eqs. (26) and (27).

$$S^{max} = \{[max_{1 \le j \le m} \underline{V}_{i1}, max_{1 \le j \le m} \overline{V}_{i1}], [max_{1 \le j \le m} \underline{V}_{i2}, max_{1 \le j \le m} \overline{V}_{i2}], \dots, [max_{1 \le j \le m} \underline{V}_{in}, max_{1 \le j \le m} \overline{V}_{in}]\} \tag{26}$$

$$S^{min} = \{[min_{1 \le j \le m} \underline{V}_{i1}, min_{1 \le j \le m} \overline{V}_{i1}], [min_{1 \le j \le m} \underline{V}_{i2}, min_{1 \le j \le m} \overline{V}_{i2}], \dots, [min_{1 \le j \le m} \underline{V}_{in}, min_{1 \le j \le m} \overline{V}_{in}]\} \tag{27}$$

Step 7: At this stage, the possibility degree of greyness between the alternatives and the ideal solutions are calculated using Eq. (28).

$$P\{S_i \le S^{max}\} = \frac{1}{n} \sum_{j=1}^{n} P\{\otimes V_{ij} \le \otimes G_j^{max}\} \tag{28}$$

Step 8: Based on the values obtained in step 7, we arrange the alternatives in ascending order. The alternative with the lowest possibility degree of greyness is a higher priority.

3. Case study

The research data was gathered from Armaghan Milk Company. The data was collected using the other studies and researches and by consultation with the company's managers and experts. The Company's maintenance department has four experts: one of them is the supervisor and manager of the department, and the others are the experts. The data was gathered using the opinions of these experts.

Choosing the Software

One of the biggest challenges in choosing appropriate software is the huge number of software applications in the market. It is important, but difficult, for any organization and company to choose one of these software applications. Considering the company's conditions and the opinions of its managers and experts, five software applications were selected. The selection was made based on the software's consistency with the company's features and the capabilities of experts in the maintenance department. ParsNet, PMWorks, TIMAR, AMMS, and M-pet were the software applications selected for this study.

Assigning weights to experts' opinions

In this article, the data gathered through verbal interviews with the experts in the maintenance department of Armaghan Milk Company. A consensus was reached through personal interviews with the company's internal manager, human resources manager, and through checking each expert's CV. The head and supervisor of the maintenance department, who was ranked higher than the others both in terms of experience and expertise, was assigned the weight 0.4. The other three experts working in the department were also examined. Based on the consensus and CV reviews, we concluded that the person who has more experience than the others in this group is assigned the weight 0.3, and the other two experts are each assigned the weight 0.15. The first expert with a weight of 0.4 was symbolized as D_1, the second expert with a weight of 0.3 as D_2, and the other two experts as D_3 and D_4.

Choosing the criteria

Using previous research and studies along with surveys and interviews with managers and experts, the criteria that were confirmed both in science and research and seemed necessary both practically and in terms of company conditions were selected from a huge number of criteria. Then, using the advice of experts and reviewing previous research and interviewing managers, 13 criteria that seemed more important and practical were selected from a huge number of criteria. Out of the 13 criteria, five of them were selected as the main ones, and each of them was categorized into several parts. The categories are as follows:

Software costs

The first main criterion is the software costs, which are subdivided into three sub-criteria.

A. The software's purchase cost (C_1)

B. The software's implementation cost (C_2). It is the expense that companies pay after purchasing the software in a bid to adapt the setting's conditions with the changes made, including personnel training, consultation cost, etc.

C. The software's update and upgrade costs (C_3). If the purchaser is forward-looking at the time of purchase, this factor should be considered, because the higher the capability to update and upgrade the software leads to more moderate costs for software development in future.

Software Implementation

The second main criterion is software implementation, which is sub-divided into two sub-criteria.

A. Ease of implementation (C_4), which is more focused on the time when the company is involved with adapting to the new system to the new system.

B. Aggregation level with other management software applications (C_5) such as ERP (Enterprise Resource Planning). The more management software applications, the better.

Software performance

The third main criterion is the software's performance, which is sub-divided into three sub-criteria.

A. Software's user-friendliness (C_6), which means the software should not be complex to use.

B. Software's technical characteristics (C_7), which is, in fact the software's compatibility with desired machinery, conditions, and place of use. The ability of aggregation and cooperation with other units is also considered.

C. Flexibility (C_8), which here refers to the software's ability to make an appropriate connection with office and other external software applications in order for others to access the software's output information without having the software, for instance, using applications such as Microsoft Office.

Data management

The fourth main criterion is data management, which includes three sub-criteria.

A. The number of available reports (C_9) that a maintenance software application presents is one of the important features of the software.

B. The accuracy of reports (C_{10}) is among other important parts, which should be taken into account.

C. Privatization of software (C_{11}), which refers to the company's maintenance department. The centralized or decentralized nature of maintenance department has caused the creation of this criterion. A software application that has this capability may be helpful under certain conditions.

Software security

The fifth main criterion is the software's security, which includes the following two criteria.

A. Security methods to protect systems against illegal access (C_{12})

B. Availability of an automatic system for backup (C_{13})

There were 13 criteria for choosing the software. The parameters and variables for case study are defined in Table 1.

Table 1
The parameters and variables

Variables and parameters			
C_1	Software’s purchase cost	C_{13}	Automatic system for backup
C_2	Software’s implementation cost	A_1	ParsNet software
C_3	Software’s update and upgrade costs	A_2	PMWorks software
C_4	Ease of implementation	A_3	TIMAR software
C_5	Aggregation level with other management software applications	A_4	AMMS software
C_6	Software's user-friendliness	A_5	M-pet software
C_7	Software's technical characteristics	D_i	i^{th} decision-maker
C_8	Software's flexibility		
C_9	Number of available reports in software		
C_{10}	Software's accuracy of reports		
C_{11}	Privatization of software		
C_{12}	Security methods to protect systems against illegal access		

4.1. Choosing the software using Fuzzy group VIKOR

Fuzzy group VIKOR method for the process of selecting appropriate software is consistent with the following steps:

Step 1: The opinions of decision-makers about the importance weight of each criterion are manifested in the form of linguistic expression, which is presented in Table 2.

Table 2
Linguistic weights of criteria using four decision-makers

Alternative	D_1	D_2	D_3	D_4
C_1	M	H	M	M
C_2	H	M	M	H
C_3	H	M	H	H
C_4	M	H	H	V H
C_5	L	L	M	L
C_6	H	H	M	H
C_7	H	H	V H	H
C_8	V H	V H	V H	V H
C_9	V H	H	H	V H
C_{10}	V H	V H	V H	H
C_{11}	V L	L	L	V L
C_{12}	H	M	H	H
C_{13}	H	H	M	H

Triangular fuzzy numbers for each linguistic expression are shown in Fig. 3 and Table 3.

Table 3
Fuzzy Numbers of linguistic expressions

Very Low	Low	Medium	High	Very High
V L	L	M	H	V H
(0,0,0.1)	(0.1,0.3,0.5)	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.9,1,1)

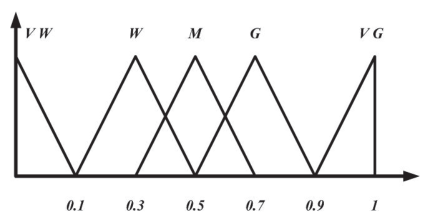

Fig. 3. Triangular fuzzy numbers for the weights of criteria

Step 2: The opinions of decision-makers about the ratings of alternatives are manifested in the form of linguistic expressions based on each criterion, which are shown in Table 4.

Table 4
Linguistic variables of decision-makers based on the criteria

	Alternative	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
D_1	A_1	M	W	G	W	M	G	G	W	G	M	M	M	G
	A_2	M	W	V G	W	W	G	M	M	M	M	M	W	M
	A_3	W	W	V G	W	W	G	M	M	M	W	W	M	M
	A_4	V G	G	W	G	G	W	V G	G	V G	V G	M	G	V G
	A_5	G	M	W	M	G	M	V G	G	V G	V G	M	G	V G
D_2	A_1	M	W	G	V W	M	G	M	M	G	G	G	G	M
	A_2	W	W	G	W	W	G	W	M	M	M	G	M	M
	A_3	W	V W	V G	V W	W	G	W	M	G	M	M	M	M
	A_4	V G	M	W	M	M	M	V G	G	V G	V G	G	V G	G
	A_5	G	M	W	G	M	M	V G	V G	V G	V G	G	V G	V G
D_3	A_1	W	W	G	W	G	V G	G	W	V W	G	M	G	M
	A_2	W	V W	V G	M	M	G	M	M	M	M	M	M	W
	A_3	M	V W	V G	W	M	G	M	M	M	M	M	G	M
	A_4	V G	G	W	G	G	W	V G	G	V G	G	G	V G	V G
	A_5	G	M	W	G	G	M	V G	V G	V G	G	G	G	V G
D_4	A_2	M	W	M	W	M	M	G	M	G	G	M	G	G
	A_3	W	W	G	M	M	G	M	G	M	M	M	G	M
	A_4	W	W	G	M	W	G	W	G	M	W	W	G	M
	A_5	V G	G	W	G	G	W	V G	G	G	G	G	V G	G
	A_5	G	M	W	M	G	M	G	V G	G	G	M	V G	V G

Fig. 4 shows the fuzzy numbers of each linguistic expression in Table 5.

Table 5
Numbers of linguistic expressions

Very Weak	Weak	Moderate	Good	Very Good
V W	W	M	G	V G
(0,0,0.1)	(0.1,0.3,0.5)	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.9,1,1)

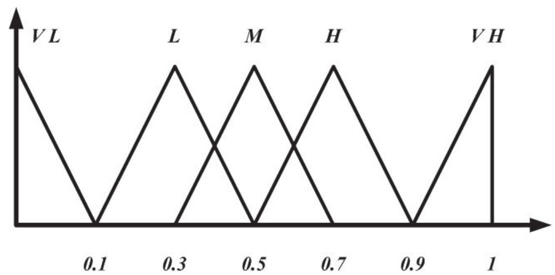

Fig. 4. Triangular fuzzy numbers for the ratings of alternatives

Step 3: Weights related to decision-makers are manifested in the forms of $\omega_1 = 0.4$, $\omega_2 = 0.3$ $\omega_3 = 0.15$ and $\omega_4 = 0.15$ then, the fuzzy weight of each criterion and the fuzzy ratings of alternatives can be calculated according to Eqs. (2) and (3). These are presented in Table 6.

Table 6
Fuzzy values for decision-making about the alternatives and the weights of each criterion

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
$\widetilde{w}_j$	(0.3,0.56,0.9)	(0.3,0.61,0.9)	(0.3,0.64,0.9)	(0.3,0.665,1)	(0.1,0.33,0.5)	(0.5,0.745,1)	(0.9,1,1)
A_1	(0.1,0.47,0.7)	(0.1,0.3,0.5)	(0.3,0.67,0.9)	(0,0.21,0.5)	(0.3,0.53,0.9)	(0.3,0.715,1)	(0.3,0.64,0.9)
A_2	(0.1,0.44,0.7)	(0,0.225,0.5)	(0.5,0.865,1)	(0.1,0.36,0.7)	(0.1,0.36,0.7)	(0.5,0.7,0.9)	(0.1,0.44,0.7)
A_3	(0.1,0.33,0.7)	(0,0.165,0.5)	(0.5,0.955,1)	(0,0.24,0.7)	(0.1,0.33,0.7)	(0.5,0.7,0.9)	(0.1,0.41,0.7)
A_4	(0.9,1,1)	(0.3,0.64,0.9)	(0.1,0.3,0.5)	(0.3,0.64,0.9)	(0.3,0.64,0.9)	(0.1,0.44,0.7)	(0.9,1,1)
A_5	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.1,0.3,0.5)	(0.3,0.59,0.9)	(0.3,0.64,0.9)	(0.3,0.5,0.7)	(0.5,0.955,1)

	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
$\widetilde{w}_j$	(0.3,0.67,0.9)	(0.5,0.865,1)	(0.5,0.955,1)	(0,0.135,0.5)	(0.3,0.64,0.9)	(0.3,0.67,0.9)
A_1	(0.1,0.39,0.7)	(0.5,0.745,1)	(0.3,0.62,0.9)	(0.3,0.56,0.9)	(0.3,0.62,0.9)	(0.3,0.61,0.9)
A_2	(0.3,0.53,0.9)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.3,0.56,0.9)	(0.1,0.45,0.9)	(0.1,0.47,0.7)
A_3	(0.3,0.53,0.9)	(0.3,0.56,0.9)	(0.1,0.39,0.7)	(0.1,0.39,0.7)	(0.3,0.56,0.9)	(0.3,0.5,0.7)
A_4	(0.5,0.7,0.9)	(0.5,0.955,1)	(0.5,0.91,1)	(0.3,0.62,0.9)	(0.5,0.88,1)	(0.5,0.865,1)
A_5	(0.5,0.88,1)	(0.5,0.955,1)	(0.5,0.91,1)	(0.3,0.59,0.9)	(0.5,0.835,1)	(0.9,1,1)

Step 4: Table 7 is obtained by applying formula ($\frac{a_{1i}+2a_{2i}+a_{3i}}{4}$), which is the weighted average, to Table 6.

Table 7
Crisp values for decision-making about the alternatives and the weight of each criterion

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
$\widetilde{w}_j$	0.58	0.605	0.62	0.657	0.315	0.747	0.975	0.635	0.807	0.872	0.192	0.62	0.635
A_1	0.435	0.3	0.635	0.23	0.565	0.682	0.62	0.395	0.747	0.61	0.58	0.61	0.605
A_2	0.42	0.237	0.807	0.38	0.38	0.7	0.42	0.565	0.5	0.5	0.58	0.475	0.435
A_3	0.365	0.207	0.852	0.295	0.365	0.7	0.405	0.565	0.58	0.395	0.395	0.58	0.5
A_4	0.975	0.62	0.3	0.62	0.62	0.42	0.975	0.7	0.852	0.83	0.61	0.815	0.807
A_5	0.7	0.5	0.3	0.595	0.62	0.5	0.852	0.815	0.852	0.83	0.595	0.792	0.975

Step 5: Table 8 shows the positive and negative ideal values of criteria with regard to fuzzy numbers and the positive and negative nature of criteria. Considering the negative aspect of criteria 1 to 4, f^+ is the lowest values of each column, and f^- is the highest value of each column, exactly opposite of positive criteria.

Table 8
Positive and negative Ideal values

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
f^+	0.365	0.207	0.3	0.23	0.62	0.7	0.975	0.815	0.852	0.83	0.61	0.815	0.975
f^-	0.975	0.62	0.852	0.62	0.365	0.42	0.405	0.395	0.5	0.395	0.395	0.475	0.435

Step 6: Using the Eqs. (8-9), S_i and R_i of each alternative are calculated and presented in Table 9.

Table 9
Values of S_i and R_i of each alternative

Alternatives	A_1	A_2	A_3	A_4	A_5		
S_i	3.45	5.521	5.069	2.959	2.158	$S^+ = 5.521$	$S^- = 2.158$
R_i	0.635	0.949	0.975	0.747	0.614	$R^+ = 0.975$	$R^- = 0.614$

Step 7: Using the value of v (which is usually set to be 0.5 based on the opinions of decision-makers) and values S_i, R_i the values of Q_i are estimated using Eq. (10) and presented in Table 10.

Table 10
Values of Q_i, each alternative

Alternatives	A_1	A_2	A_3	A_4	A_5
Q_i	0.221	0.963	0.932	0.303	0

Step 8: Table 11 shows the ranking of alternatives based on the ascending order of values S_i , R_i and Q_i (the less the value, the lower the rank).

Table 11
Ranking of alternatives based on Q, R, and S in ascending order

Alternatives ranking	1	2	3	4	5
S	A_5	A_4	A_1	A_3	A_2
	2.158	2.959	3.45	5.069	5.521
R	A_5	A_1	A_4	A_2	A_3
	0.614	0.635	0.747	0.949	0.975
Q	A_5	A_1	A_4	A_3	A_2
	0	0.221	0.303	0.932	0.963

Step 9: The best ranking is achieved based on S and R, but this is just a necessary condition for the selection, not a sufficient one. As long as the second condition, i.e. $Q(A_1) - Q(A_5) \geq \frac{1}{5-1}$, is not met, the process should be continued as far as an alternative where the condition is met, and this will happen by considering the next alternative, i.e. $(A_4) - Q(A_5) \geq \frac{1}{5-1}$. Thus, the alternative A_5, that are M-pe software application, is selected as the best alternative using fuzzy group VIKOR method.

4.2. Choosing the software using Grey group TOPSIS

The Grey group TOPSIS procedure for the case study is as follows:

Step 1: Based on the views of decision-makers and using linguistic variables, the weight of each of the criteria is obtained according to Table 12.

Table 12
Linguistic weights of criteria using four decision-makers

Criteria	D_1	D_2	D_3	D_4
C_1	M	H	M	M
C_2	H	M	M	H
C_3	H	M	H	H
C_4	M	H	H	V H
C_5	L	L	M	L
C_6	H	H	M	H
C_7	H	H	V H	H
C_8	V H	V H	V H	V H
C_9	V H	H	H	V H
C_{10}	V H	V H	V H	H
C_{11}	V L	L	L	V L
C_{12}	H	M	H	H
C_{13}	H	H	M	H

Table 13 depicts grey linguistic variables:

Table 13
Grey linguistic variables to determine the weights of the criteria

Very Low	Low	Medium	High	Very High
V L	L	M	H	V H
[0.0,0.2]	[0.2,0.4]	[0.4,0.6]	[0.6,0.8]	[0.8,1.0]

Step 2: Using linguistic variables, the status of each alternative in each of the criteria is provided by the decision-makers, as shown in Table 14.

Table 14
Linguistic variables of decision-makers based on the criteria

	Alternative	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
D_1	A_1	M	W	G	W	M	G	G	W	G	M	M	M	G
	A_2	M	W	V G	W	W	G	M	M	M	M	M	W	M
	A_3	W	W	V G	W	W	G	M	M	M	W	W	M	M
	A_4	V G	G	W	G	G	W	V G	G	V G	V G	M	G	V G
	A_5	G	M	W	M	G	M	V G	G	V G	V G	M	G	V G
D_2	A_1	M	W	G	V W	M	G	M	M	G	G	G	G	M
	A_2	W	W	G	W	W	G	W	M	M	M	G	M	M
	A_3	W	V W	V G	V W	W	G	W	M	G	M	M	M	M
	A_4	V G	M	W	M	M	M	V G	G	V G	V G	G	V G	G
	A_5	G	M	W	G	M	M	V G	V G	V G	V G	G	V G	V G
D_3	A_1	W	W	G	W	G	V G	G	W	V W	G	M	G	M
	A_2	W	V W	V G	M	M	G	M	M	M	M	M	M	W
	A_3	M	V W	V G	W	M	G	M	M	M	M	M	G	M
	A_4	V G	G	W	G	G	W	V G	G	V G	G	G	V G	V G
	A_5	G	M	W	G	G	M	V G	V G	V G	G	G	G	V G
D_4	A_1	M	W	M	W	M	M	G	M	G	G	M	G	G
	A_2	W	W	G	M	M	G	M	G	M	M	M	G	M
	A_3	W	W	G	M	W	G	W	G	M	W	W	G	M
	A_4	V G	G	W	G	G	W	V G	G	G	G	G	V G	G
	A_5	G	M	W	M	G	M	G	V G	G	G	M	V G	V G

Interval linguistic variables used in Table 14 are as Table 15.

Table 15
Grey linguistic variables to determine the importance of alternatives

Very Weak	Weak	Moderate	Good	Very Good
V W	W	M	G	V G
[0.0,0.2]	[0.2,0.4]	[0.4,0.6]	[0.6,0.8]	[0.8,1.0]

Step 3: Propose the grey decision matrix according to the step (2) which is shown in Table 16

Table 16
Grey decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
$\otimes w_j$	[0.45,0.65]	[0.50,0.70]	[0.55,0.75]	[0.60,0.80]	[0.25,0.45]	[0.55,0.75]	[0.65,0.85]
A_1	[0.35,0.55]	[0.20,0.40]	[0.55,0.75]	[0.15,0.35]	[0.45,0.65]	[0.60,0.80]	[0.55,0.75]
A_2	[0.25,0.45]	[0.15,0.35]	[0.70,0.90]	[0.30,0.50]	[0.30,0.50]	[0.60,0.80]	[0.35,0.55]
A_3	[0.25,0.45]	[0.10,0.30]	[0.75,0.95]	[0.20,0.40]	[0.25,0.45]	[0.60,0.80]	[0.30,0.50]
A_4	[0.80,1.00]	[0.55,0.75]	[0.20,0.40]	[0.55,0.75]	[0.55,0.75]	[0.25,0.45]	[0.80,1.00]
A_5	[0.60,0.80]	[0.40,0.60]	[0.20,0.40]	[0.50,0.70]	[0.55,0.75]	[0.40,0.60]	[0.75,0.95]

	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
$\otimes w_j$	[0.80,1.00]	[0.70,0.90]	[0.75,0.95]	[0.10,0.30]	[0.55,0.75]	[0.55,0.75]
A_1	[0.30,0.50]	[0.45,0.65]	[0.55,0.75]	[0.45,0.65]	[0.55,0.75]	[0.50,0.70]
A_2	[0.45,0.65]	[0.40,0.60]	[0.40,0.60]	[0.45,0.65]	[0.40,0.60]	[0.35,0.55]
A_3	[0.45,0.65]	[0.45,0.65]	[0.30,0.50]	[0.30,0.50]	[0.50,0.70]	[0.40,0.60]
A_4	[0.60,0.80]	[0.75,0.95]	[0.70,0.90]	[0.55,0.75]	[0.75,0.95]	[0.70,0.90]
A_5	[0.75,0.95]	[0.75,0.95]	[0.70,0.90]	[0.50,0.70]	[0.70,0.90]	[0.80,1.00]

Step 4: Normalize the matrix of step 3. Criteria 1 to 4 are of cost attribute and 5 to 13 are of benefit attribute. The result is shown in Table 17.

Table 17
Normalized grey decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
$\otimes w_j$	[0.45,0.65]	[0.50,0.70]	[0.55,0.75]	[0.60,0.80]	[0.25,0.45]	[0.55,0.75]	[0.65,0.85]
A_1	[0.45,0.71]	[0.25,0.50]	[0.27,0.36]	[0.43,1.00]	[0.60,0.87]	[0.75,1.00]	[0.55,0.75]
A_2	[0.56,1.00]	[0.29,0.67]	[0.22,0.29]	[0.30,0.50]	[0.40,0.67]	[0.75,1.00]	[0.35,0.55]
A_3	[0.56,1.00]	[0.33,1.00]	[0.21,0.27]	[0.38,0.75]	[0.33,0.60]	[0.75,1.00]	[0.30,0.50]
A_4	[0.25,0.31]	[0.13,0.18]	[0.50,1.00]	[0.20,0.27]	[0.73,1.00]	[0.31,0.56]	[0.80,1.00]
A_5	[0.31,0.42]	[0.17,0.25]	[0.50,1.00]	[0.21,0.30]	[0.73,1.00]	[0.50,0.75]	[0.75,0.95]

	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
$\otimes w_j$	[0.80,1.00]	[0.70,0.90]	[0.75,0.95]	[0.10,0.30]	[0.55,0.75]	[0.55,0.75]
A_1	[0.32,0.53]	[0.47,0.68]	[0.61,0.83]	[0.60,0.87]	[0.58,0.79]	[0.50,0.70]
A_2	[0.47,0.68]	[0.42,0.63]	[0.44,0.67]	[0.60,0.87]	[0.42,0.63]	[0.35,0.55]
A_3	[0.47,0.68]	[0.47,0.68]	[0.33,0.56]	[0.40,0.67]	[0.53,0.74]	[0.40,0.60]
A_4	[0.63,0.84]	[0.79,1.00]	[0.78,1.00]	[0.73,1.00]	[0.79,1.00]	[0.70,0.90]
A_5	[0.79,1.00]	[0.79,1.00]	[0.78,1.00]	[0.67,0.93]	[0.74,0.95]	[0.80,1.00]

Step 5: Calculate the weighted normalized grey decision matrix based on the calculated weights and the normalized grey decision matrix of step 4, which is shown in Table 18

Table 18
Weighted normalized grey decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	[0.20,0.46]	[0.13,0.35]	[0.15,0.27]	[0.26,0.80]	[0.15,0.39]	[0.41,0.75]	[0.36,0.64]
A_2	[0.25,0.65]	[0.14,0.47]	[0.12,0.21]	[0.18,0.40]	[0.10,0.30]	[0.41,0.75]	[0.23,0.47]
A_3	[0.25,0.65]	[0.17,0.70]	[0.12,0.20]	[0.23,0.60]	[0.08,0.27]	[0.41,0.75]	[0.20,0.43]
A_4	[0.11,0.20]	[0.07,0.13]	[0.28,0.75]	[0.12,0.22]	[0.18,0.45]	[0.17,0.42]	[0.52,0.85]
A_5	[0.14,0.27]	[0.08,0.18]	[0.28,0.75]	[0.13,0.24]	[0.18,0.45]	[0.28,0.56]	[0.49,0.81]

	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
A_1	[0.25,0.53]	[0.33,0.62]	[0.46,0.79]	[0.06,0.26]	[0.32,0.59]	[0.28,0.53]
A_2	[0.38,0.68]	[0.29,0.57]	[0.33,0.63]	[0.06,0.26]	[0.23,0.47]	[0.19,0.41]
A_3	[0.38,0.68]	[0.33,0.62]	[0.25,0.53]	[0.04,0.20]	[0.29,0.55]	[0.22,0.45]
A_4	[0.51,0.84]	[0.55,0.90]	[0.58,0.95]	[0.07,0.30]	[0.43,0.75]	[0.39,0.68]
A_5	[0.63,1.00]	[0.55,0.90]	[0.58,0.95]	[0.07,0.28]	[0.41,0.71]	[0.44,0.75]

Step 6: Calculate the positive and negative ideal solutions. (Table 19)

Table 19
The positive and negative ideal solutions

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
S^{max}	[0.25,0.65]	[0.17,0.70]	[0.28,0.75]	[0.26,0.80]	[0.18,0.45]	[0.41,0.75]	[0.52,0.85]
S^{min}	[0.11,0.20]	[0.07,0.13]	[0.12,0.20]	[0.12,0.22]	[0.08,0.27]	[0.17,0.42]	[0.20,0.43]

	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
S^{max}	[0.63,1.00]	[0.55,0.90]	[0.58,0.95]	[0.07,0.30]	[0.43,0.75]	[0.44,0.75]
S^{min}	[0.25,0.53]	[0.29,0.57]	[0.25,0.53]	[0.04,0.20]	[0.23,0.47]	[0.19,0.41]

Step 7: Calculate the possibility degree of greyness between the alternatives and the ideal solutions. The Eqs. (29) to (33) represent the possibility degree of greyness alternatives and the ideal solutions.

$$P(S_1 \leq S^{max}) = 0.74 \quad (29)$$

$$P(S_2 \leq S^{max}) = 0.81 \quad (30)$$

$$P(S_3 \leq S^{max}) = 0.78 \quad (31)$$

$$P(S_4 \leq S^{max}) = 0.67 \quad (32)$$

$$P(S_5 \leq S^{max}) = 0.64 \quad (33)$$

Step 8: Based on the values obtained in step 7, prioritization of the alternatives results is in Eq. (34)

$$A_5 > A_4 > A_1 > A_3 > A_2 \quad (34)$$

Based on the methods Grey group TOPSIS and Fuzzy Group VIKOR, M-pet is the best software to choose. Using two methods simultaneously increases the accuracy of the decision making in uncertainty conditions.

6. Conclusion

Managers are always in a position to make decisions and their decisions will affect the organization's future. Overlooking the uncertainties in decision making leads to making mistakes and can cause irreparable damage. The current paper used Grey Group TOPSIS and Fuzzy Group VIKOR methods to take into account decision uncertainties. Using two different fuzzy and grey approaches and comparing the results can lead to appropriate selection and improve the confidence in decision making. As you can see, both methods have acceptable performance and the output of the decisions are the same in both methods (A5). For future studies, other methods can be applied to obtain more desired results by different sensitivities analysis.

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