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A Dynamic Fuzzy Approach Based on the EDAS Method for Multi-Criteria Subcontractor Evaluation

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Abstract: Selection of appropriate subcontractors for outsourcing is very important for the success of construction projects. This can improve the overall quality of projects and promote the qualification and reputation of the main contractors. The evaluation of subcontractors can be made by some experts or decision-makers with respect to some criteria. If this process is done in different time periods, it can be defined as a dynamic multi-criteria group decision-making (MCGDM) problem. In this study, we propose a new fuzzy dynamic MCGDM approach based on the EDAS (Evaluation based on Distance from Average Solution) method for subcontractor evaluation. In the procedure of the proposed approach, the sets of alternatives, criteria and decision-makers can be changed at different time periods. Also, the proposed approach gives more weight to newer decision information for aggregating the overall performance of alternatives. A numerical example is used to illustrate the proposed approach and show the application of it in subcontractor evaluation. The results demonstrate that the proposed approach is efficient and useful in real-world decision-making problems.

Keywords: multi-criteria decision-making; group decision-making; subcontractor evaluation; MCDM; MADM; fuzzy sets; fuzzy EDAS

1. Introduction

Subcontracting is one of the most important characteristics of the construction industry. In many construction projects, the main contractor has usually the role of project coordinator, and a high percentage of work is done by subcontractors [1,2]. The completion time of a construction project (project delivery) and the reputation of the main contractor are heavily dependent on cooperation between a subcontractor and its main contractor [3]. Therefore, the performance of subcontractors could have a significant effect on the success of construction projects. Because of the increasing use of subcontracting in the construction industry, evaluation of subcontractors can be considered as an essential problem for the main contractors.

The subcontractor evaluation process (SEP) usually involves several alternatives (subcontractors), multiple criteria and a group of decision-makers (experts). Thus, we can consider this process as a multi-criteria group decision-making (MCGDM) problem [4]. Moreover, the main contractor generally needs to evaluate its subcontractors in multiple periods of time. This process makes the SEP into a dynamic MCGDM problem. In a dynamic MCGDM problem, the set of alternatives, criteria and decision-makers can be changed in different time periods [5]. Thus, we can make the evaluation process with a high degree of flexibility. In addition, the assessments of experts can be made under uncertainty in the SEP. The fuzzy sets theory is a useful tool to deal with the uncertainty of evaluation process [6–11].

There have been some studies on the problems related to the SEP and multi-criteria decision-making (MCDM) methods under certain and uncertain environments. Cheng, et al. [12] proposed a hierarchical structure for the target and factors for evaluation of subcontractors, and used the analytic hierarchy process (AHP) to select an appropriate subcontractor. Kargi and Öztürk [13] used the AHP method and the Expert Choice software for evaluation of subcontractors in a Turkish company. Yayla, et al. [14] presented a case study for selection of the optimal subcontractor in a Turkish textile firm. They used generalized Choquet integral methodology and a hierarchical decision model to solve the selection problem. Ng and Skitmore [15] proposed an approach based on the balanced scorecard methodology for evaluation of subcontractor and performed a questionnaire survey administered in Hong Kong. Abbasianjahromi, et al. [16] developed a model for subcontractor evaluation based on the fuzzy preference selection index. In their model, the weighting criteria phase is eliminated in the evaluation process of subcontractors. Shahvand, et al. [17] developed a multi-criteria fuzzy expert system for supplier and subcontractor evaluation in the construction industry and used it in three companies. Polat [2] presented an integrated MCDM approach based on AHP and preference ranking organization method for enrichment evaluations (PROMETHEE), and applied it to the subcontractor selection problem. Ulubeyli and Kazaz [18] proposed a fuzzy multi-criteria decision-making approach, called CoSMo (Construction Subcontractor selection Model), for evaluation of subcontractors in the construction projects. Abbasianjahromi, et al. [19] developed a new model to allocate the tasks of a construction project to some subcontractors for optimization of the portfolio of subcontractors and main contractor. Polat, et al. [20] proposed an integrated approach based on the AHP and Evidential Reasoning (ER) methods. They used AHP and ER to find the criteria weights for evaluation of subcontractors and rank the alternatives, respectively.

Dynamic MCDM approaches have been used by researchers in several fields. Campanella and Ribeiro [21] introduced a flexible framework for dynamic MCDM that can be used in many dynamic decision processes, and applied it to a small helicopter landing problem. Wei [22] utilized grey relational analysis (GRA) to develop a dynamic MCDM approach. Chen and Li [23] proposed a dynamic MCDM method based on triangular intuitionistic fuzzy numbers. Wang, et al. [24] presented a three-dimensional grey interval relational degree approach for dynamic multi-criteria decision-making problems. They applied the presented approach to the investment decision-making problems. Junhua, et al. [25] developed a dynamic stochastic MCDM approach based on conjoint analysis and prospect theory. Li, et al. [26] proposed a dynamic fuzzy MCDM method using a mathematical programming model and fuzzy technique for order preference by similarity to ideal solution (TOPSIS). Yan, et al. [27] presented a dynamic grey target MCDM method using interval numbers and based on the status of alternatives. Liu, et al. [28] proposed a dynamic fuzzy framework based on GRA and used it for evaluation of emergency treatment technology. Yan, et al. [29] developed a new dynamic MCDM approach with three-parameter grey numbers. In their approach, not only the attribute values of alternatives at all periods are aggregated, but also changes of these values between the adjacent periods are considered.

The EDAS (Evaluation based on Distance from Average Solution) method is a new and efficient method which introduced by Keshavarz Ghorabaee, et al. [30] and extended for using in the fuzzy environment [31]. The evaluation process in the EDAS method is made based on the distances of alternative from an average solution. Two types of distances (positive and negative) are defined for alternatives in this method, and the utility of alternatives is determined based on these distances. This method has been developed for using in different uncertain environments such as intuitionistic fuzzy sets [32], interval-valued neutrosophic sets [33], interval-valued fuzzy soft sets [34], neutrosophic soft sets [35], interval grey numbers [36] and interval type-2 fuzzy sets [37]. Also, the EDAS method has been applied to some real-world MCDM problems such as life cycle and sustainability assessment [38], supplier selection [39], architectural shape of the buildings [40], cultural heritage structures [41], quality assurance [42], evaluation in logistics [43,44] and stairs shape assessment [45].

In this study, we propose a new dynamic fuzzy MCGDM approach based on the EDAS method for evaluation of subcontractors. The main advantage of the proposed approach is its flexibility so that we can define different sets of alternatives, criteria and decision-makers in different time periods and make the evaluation in a fuzzy environment. Because of the importance of new information, we use a function that gives greater weights to newer time periods for aggregating the performance score of each alternative. A numerical example of subcontractor evaluation is presented to illustrate the proposed approach and show the efficiency of it.

The rest of this article is organized as follows. Section 2 describes the methodology. In this section, first, we present concepts and some definitions related to the fuzzy sets theory and the arithmetic operations of the fuzzy numbers, then the steps and flowchart of the proposed approach is depicted in detail. In Section 3, a numerical example is used to show the application of the proposed approach in subcontractor evaluation. Conclusions are briefly discussed in Section 4.

2. Methodology

In this section, we first present some concepts and definitions about the fuzzy sets theory, and then an extended dynamic fuzzy EDAS is described for multi-criteria group decision-making.

2.1. Concepts and Definitions of Fuzzy Sets

To deal with the uncertainty of information in real-world problems, the fuzzy sets theory was developed by Zadeh [46]. The membership of elements in a fuzzy set is described by means of a membership function with a range in [0, 1]. Therefore, fuzzy sets generalize classical sets in which the membership of elements has a two-valued condition (zero or one). The fuzzy set theory has been applied to many problems in different fields of science and engineering. To describe this theory, some definitions are presented as follows:

Definition 1. *Let denote by X a universal set. Then a fuzzy set $\widetilde{G}$ can be defined by a membership function $\mu_{\widetilde{G}}(x)$ as follows [47]:*

$$\widetilde{G} = \left\{ \left(x,\ \mu_{\widetilde{G}}\left(x\right) \right) \middle| x \in X \right\} \tag{1}$$

In the above equation, x denotes the elements belong to X, and $\mu_{\widetilde{G}}\left(x\right) : X \rightarrow [0,\ 1]$.

Definition 2. *A fuzzy number can be defined as a special case of a fuzzy set which is convex and normal [48].*

Definition 3. *If the membership function of a fuzzy number $\widetilde{G}$ is defined by the following equation then we can call it a triangular fuzzy number [49]:*

$$\mu_{\widetilde{G}}\left(x\right) = \begin{cases} (x - g_1)/(g_2 - g_1), & g_1 \leq x \leq g_2 \\ (g_3 - x)/(g_3 - g_2), & g_2 \leq x \leq g_3 \\ 0, & otherwise \end{cases} \tag{2}$$

A triplet $\widetilde{G} = (g_1, g_2, g_3)$ can also be used to define this fuzzy number. Figure 1 represents an example of triangular fuzzy numbers.

In this study, we use the triangular fuzzy sets due to their simplicity of presentation and computation. However, the other types of fuzzy numbers such as trapezoidal fuzzy number can also be used in the methodology proposed in the following sub-section.

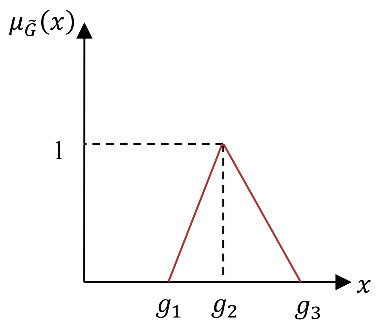

Figure 1. A triangular fuzzy number.

Definition 4. *Let us define* $\widetilde{G} = (g_1, g_2, g_3)$ *and* $\widetilde{H} = (h_1, h_2, h_3)$ *as two triangular fuzzy numbers which are also positive (i.e.,* $g_1 \geq 0$ *and* $h_1 \geq 0$*), and suppose that* q *is a crisp number. In the following equations, the arithmetic operations of these fuzzy numbers are presented [49]:*

- Addition:

$$\widetilde{G} \oplus \widetilde{H} = (g_1 + h_1, g_2 + h_2, g_3 + h_3) \tag{3}$$

$$\widetilde{G} + q = (g_1 + q, g_2 + q, g_3 + q) \tag{4}$$

- Subtraction:

$$\widetilde{G} \ominus \widetilde{H} = (g_1 - h_3, g_2 - h_2, g_3 - h_1) \tag{5}$$

$$\widetilde{G} - q = (g_1 - q, g_2 - q, g_3 - q) \tag{6}$$

- Multiplication:

$$\widetilde{G} \otimes \widetilde{H} = (g_1 \times h_1, g_2 \times h_2, g_3 \times h_3) \tag{7}$$

$$\widetilde{G} \times q = \begin{cases} (g_1 \times q, g_2 \times q, g_3 \times q) & \text{if } q \geq 0 \\ (g_3 \times q, g_2 \times q, g_1 \times q) & \text{if } q < 0 \end{cases} \tag{8}$$

- Division:

$$\widetilde{G} \oslash \widetilde{H} = (g_1/h_3, g_2/h_2, g_3/h_1) \tag{9}$$

$$\widetilde{G}/q = \begin{cases} (g_1/q, g_2/q, g_3/q) & \text{if } q > 0 \\ (g_3/q, g_2/q, g_1/q) & \text{if } q < 0 \end{cases} \tag{10}$$

Definition 5. *The defuzzified or crisp value of a triangular fuzzy number* $\widetilde{G} = (g_1, g_2, g_3)$ *can be defined by the following equation [50]:*

$$\mathfrak{D}\left(\widetilde{G}\right) = \frac{1}{3}(g_1 + g_2 + g_3) \tag{11}$$

Definition 6. *To find the maximum between a triangular fuzzy number* $\widetilde{G} = (g_1, g_2, g_3)$ *and zero, the following function can be used [31].*

$$\mathcal{S}\left(\widetilde{A}\right) = \begin{cases} \widetilde{G} \quad if \quad \mathfrak{D}\left(\widetilde{G}\right) > 0 \\ \widetilde{0} \quad if \quad \mathfrak{D}\left(\widetilde{G}\right) \leq 0 \end{cases} \tag{12}$$

where $\widetilde{0} = (0, 0, 0)$.

2.2. Dynamic Fuzzy EDAS

The EDAS method is a new and efficient MCDM method introduced by Keshavarz Ghorabaee, Zavadskas, Olfat and Turskis [30], and has been extended to deal with fuzzy MCDM problems [31]. In this section, a new approach is proposed to handle dynamic fuzzy multi-criteria group decision-making based on the EDAS method, which is called dynamic fuzzy EDAS.

In a dynamic multi-criteria group decision-making, the multi-criteria evaluation process is made by multiple decision-makers in multiple periods. In each period, we have a set of alternatives that needs to be evaluated with respect to a set of criteria. Suppose that there are T periods and DM_t, CR_t and AL_t denote the sets of decision-makers, criteria, and alternatives at period t, respectively. The cardinality of these sets can be defined as $|DM_t| = k_t$, $|CR_t| = m_t$ and $|AL_t| = n_t$. In other words, we have k_t decision-makers, m_t criteria and n_t alternatives at period t.

Step 1: Start with the first period (t = 1).

Step 2: Define the sets of decision-makers, criteria, and alternatives (DM_t, CR_t and AL_t) at period t.

Step 3: Determine the union of the sets of alternatives at period t denoted by AL_t^T, where $AL_t^T = AL_{t-1}^T \cup AL_t$ and $AL_0^T = \varnothing$.

Step 4: Construct the decision-matrix and the matrix of criteria weights related to each decision-maker at period t as follows:

$$X_{pt} = \left[\widetilde{x}_{ijpt}\right]_{n_t \times m_t} \tag{13}$$

$$W_{pt} = \left[\widetilde{w}_{jpt}\right]_{1 \times m_t} \tag{14}$$

where $\widetilde{x}_{ijpt}$ denotes the rating of ith alternative (A_i) on jth criterion (C_j) given by pth decision-maker, and $\widetilde{w}_{jpt}$ shows the importance or weight of jth criterion given by pth decision-maker ($1 \leq i \leq n_t$, $1 \leq j \leq m_t$ and $1 \leq p \leq k_t$).

Step 5: Determine the average decision-matrix at period t using the following equations:

$$X_t = \left[\widetilde{x}_{ijt}\right]_{n_t \times m_t} \tag{15}$$

$$\widetilde{x}_{ijt} = \frac{1}{k_t} \bigoplus_{p=1}^{k_t} \widetilde{x}_{ijpt} \tag{16}$$

where $\widetilde{x}_{ijt}$ shows the average ratings at period t. If the decision-makers or experts, depending on their experience and knowledge, have different importance in the process of decision-making, we can use a weighted average instead of ordinary average of Equation (16).

Step 6: Compute the average matrix of criteria weights at period t presented as follows:

$$W_t = \left[\widetilde{w}_{jt}\right]_{1 \times m_t} \tag{17}$$

$$\widetilde{w}_{jt} = \frac{1}{k_t} \bigoplus_{p=1}^{k_t} \widetilde{w}_{jpt} \tag{18}$$

where $\widetilde{w}_{jt}$ denotes the average weights of criteria at period t. Like the previous step, we can also use a weighted average instead of ordinary average of Equation (18) if there are different weights for decision-makers.

It should be noted that if we have a problem with a hierarchical structure including some criteria and sub-criteria, we should calculate the average weights of criteria and sub-criteria first. Then the global weights of sub-criteria should be determined by multiplying the average calculated weights of them by the average weights of their upper level criterion.

Step 7: Calculate average solutions at period t using the following formula:

$$\widetilde{g}_{jt} = \frac{1}{n_t} \underset{i=1}{\overset{n_t}{\oplus}} \widetilde{x}_{ijt} \quad (19)$$

Step 8: Let denote by BC_t and NC_t the sets of beneficial and non-beneficial criteria at period t, respectively. The values of positive and negative distances from the average solutions at each period are calculated as follows:

$$\widetilde{pd}_{ijt} = \begin{cases} \frac{\mathcal{S}(\widetilde{x}_{ijt} \ominus \widetilde{g}_{jt})}{\mathfrak{D}(\widetilde{g}_{jt})} & if \quad j \in BC_t \\ \frac{\mathcal{S}(\widetilde{g}_{jt} \ominus \widetilde{x}_{ijt})}{\mathfrak{D}(\widetilde{g}_{jt})} & if \quad j \in NC_t \end{cases} \quad (20)$$

$$\widetilde{nd}_{ijt} = \begin{cases} \frac{\mathcal{S}(\widetilde{g}_{jt} \ominus \widetilde{x}_{ijt})}{\mathfrak{D}(\widetilde{g}_{jt})} & if \quad j \in BC_t \\ \frac{\mathcal{S}(\widetilde{x}_{ijt} \ominus \widetilde{g}_{jt})}{\mathfrak{D}(\widetilde{g}_{jt})} & if \quad j \in NC_t \end{cases} \quad (21)$$

where $\widetilde{pd}_{ijt}$ and $\widetilde{nd}_{ijt}$ denote the values of positive and negative distances from the average solutions at period t, respectively.

Step 9: Compute the weighted sum of the positive and negative distances for each alternative at period t using the following equations:

$$\widetilde{sp}_{it} = \underset{j=1}{\overset{m_t}{\oplus}} \left(\widetilde{w}_{jt} \otimes \widetilde{pd}_{ijt}\right) \quad (22)$$

$$\widetilde{sn}_{it} = \underset{j=1}{\overset{m_t}{\oplus}} \left(\widetilde{w}_{jt} \otimes \widetilde{nd}_{ijt}\right) \quad (23)$$

Step 10: Calculate the normalized values of $\widetilde{sp}_{it}$ and $\widetilde{sn}_{it}$ as follows:

$$\widetilde{np}_{it} = \frac{\widetilde{sp}_{it}}{\max_l(\mathfrak{D}(\widetilde{sp}_{lt}))} \quad (24)$$

$$\widetilde{nn}_{it} = 1 - \frac{\widetilde{sn}_{it}}{\max_l(\mathfrak{D}(\widetilde{sn}_{lt}))} \quad (25)$$

Step 11: Compute the overall performance score of ith alternative at period t ($\widetilde{U}_{it}$) by the following formula:

$$\widetilde{U}_{it} = \frac{1}{2}(\widetilde{np}_{it} \oplus \widetilde{nn}_{it}) \quad (26)$$

Step 12: Calculate the dynamic scores (S_{it}) for all alternatives which are the elements of the set AL_t^T ($A_i \in AL_t^T$) by the following equation:

$$S_{it} = \begin{cases} \mathfrak{D}\left(\widetilde{U}_{it}\right) & if \quad A_i \in AL_t \\ 0 & if \quad A_i \notin AL_t \end{cases} \quad (27)$$

Step 13: Let ρ_t denotes the weight or importance of period t. Compute the aggregated dynamic scores (H_{it}) of the alternatives belong to the set AL_t^T as follows:

$$H_{it} = (1 - \rho_t)H_{i(t-1)} + \rho_t S_{it} \quad (28)$$

where $H_{i0} = 0$, and if $A_i \notin AL^T_{t-1}$ then $H_{i(t-1)} = \min_{l, l \in AL^T_{t-1}} H_{l(t-1)}$.

Because newer information is more important in decision-making, a weight function of periods that gives greater weight to the current period should be defined. We define the following function for setting the weights of periods:

$$\rho_t = \frac{t}{2t-1} \tag{29}$$

In Equation (29), the value of ρ_t is equal to 1 for the first period ($t = 1$), and it is always greater than 0.5.

Step 14: Increase the value of period by 1 ($t \leftarrow t+1$). If $t < T$ go to Step 2, otherwise continue.

Step 15: Evaluate the alternatives according to the values of aggregated dynamic scores (H_{it}). The higher values of H_{it} get the better alternatives.

To make the proposed approach clear, its procedure is depicted by a flowchart in Figure 2.

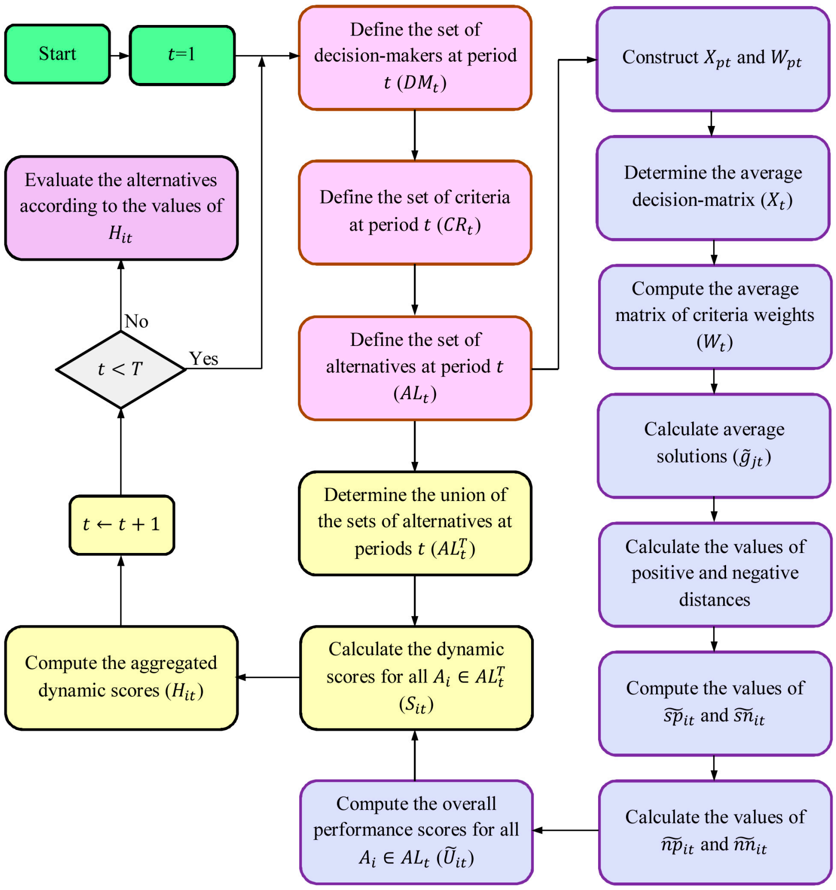

Figure 2. The flowchart of the proposed approach.

3. Illustrative Example (Subcontractor Evaluation)

In this section, the proposed approach is applied to a dynamic multi-criteria subcontractor evaluation problem in a construction project. The evaluation process is made by the main contractor of the project in four periods. According to the procedure of the proposed approach, we can define any number of decision-makers, criteria, and alternatives at each period. In this problem, four criteria are defined for evaluation of subcontractors based on the study of Lin, et al. [51]. These criteria are defined as follows:

- ***Reliability*** (C_1): This criterion is related to evaluation of subcontractors with respect to their records, reputation, and financial condition. It is clear that a subcontractor with good reputation and better financial condition is more favorable.
- ***Schedule-control ability*** (C_2): This criterion is related to the mobilization and efficiency of subcontractors. Activation of the subcontractor's physical and manpower resources for transfer to a construction site until the completion of the contract can be measured by this criterion.
- ***Management ability*** (C_3): The level of safety, quality and environmental management of subcontractors is very important in the overall performance of a subcontractor. This criterion can be used to assess these dimensions of subcontractors.
- ***Labor quality*** (C_4): This criterion can be used for assessment of the level of workers' skill and the coordination of managers and workers. The quality of the outcomes of a construction project is significantly affected by this criterion.

The criteria defined are used in all the periods. In other words, we can define the set of criteria as $CR_t = \{C_1, C_2, C_3, C_4\}$ where $t \in \{1, 2, 3, 4\}$. The evaluation process is made based on the assessments of some experts of the main contractor which are considered as decision-makers. In each period, some of the decision-makers may be available and some may be not available for the assessment. In this problem, the sets of decision-makers at each period are as follows:

$$DM_1 = \{D_1,\ D_2, D_3, D_4\},$$
$$DM_2 = \{D_1, D_3, D_4\},$$
$$DM_3 = \{D_1, D_2, D_3, D_4\},$$
$$DM_4 = \{D_1, D_2, D_3\}.$$

The number of subcontractors also varies from period to period. Here, we have four sets of alternatives (subcontractors):

$$AL_1 = \{A_1, A_2, A_3, A_4, A_5, A_6, A_7, A_8, A_9\},$$
$$AL_2 = \{A_1, A_2, A_3, A_4, A_6, A_7, A_{10}, A_{11}, A_{12}, A_{13}\},$$
$$AL_3 = \{A_1, A_2, A_5, A_6, A_7, A_8, A_9, A_{10}, A_{12}\},$$
$$AL_4 = \{A_2, A_3, A_6, A_7, A_8, A_{10}, A_{13}\}.$$

The decision-makers give the importance of criteria and rating of alternatives at each period using linguistic variables. The linguistic variables and their fuzzy equivalents are presented in Table 1 [52]. Because we use a spectrum from "Very poor" to "Very good" for rating of alternatives, all the criteria in the problem should be considered as beneficial criteria. Based on the linguistic variables defined in Table 1, the decision-matrix and the matrix of criteria weights related to each decision-maker can be constructed at each period. The decision-matrices of different periods are presented in Tables 2–6 presents the matrices of criteria weights in different periods.

Based on the steps of the proposed approach and Tables 1–6, we can determine the overall performance scores of alternatives at each period. According to the defuzzified values of overall performance scores, the rank of each alternative at each period can be obtained. The results of each period are shown in Table 7. Also, in this table, we present the ranking results which are obtained by using defuzzified decision-matrices and criteria weights and the TOPSIS method [53]. In addition, to show the validity of the ranking result of each period, the Spearman's rank correlation coefficients (r_s) between the results of the fuzzy EDAS and TOPSIS methods are calculated. As can be seen in Table 7, all the correlation values are greater than 0.9, and we can say that there is a strong relationship between the results in all the periods.

Table 1. The linguistic variables and their fuzzy equivalents.

	Linguistic Variables	Triangular Fuzzy Number
Importance of criteria	Very low (VL)	(0, 0, 0.1)
	Low (L)	(0, 0.1, 0.3)
	Medium low (ML)	(0.1, 0.3, 0.5)
	Medium (M)	(0.3, 0.5, 0.7)
	Medium high (MH)	(0.5, 0.7, 0.9)
	High (H)	(0.7, 0.9, 1)
	Very high (VH)	(0.9, 1,1)
Rating of alternatives	Very poor (VP)	(0, 0, 1)
	Poor (P)	(0, 1, 3)
	Medium poor (MP)	(1, 3, 5)
	Fair (F)	(3, 5, 7)
	Medium good (MG)	(5, 7, 9)
	Good (G)	(7, 9, 10)
	Very good (VG)	(9, 10, 10)

Table 2. The decision-matrix of each decision-maker at first period (t = 1).

	D_1				D_2				D_3				D_4			
	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4
A_1	P	F	MP	MP	P	P	MP	P	VP	MP	MP	P	VP	F	F	VP
A_2	P	MP	P	P	MP	F	MP	VP	MP	MG	MP	VP	MP	F	P	MP
A_3	F	G	MP	G	F	F	F	G	P	G	MP	G	P	F	MG	P
A_4	VG	G	G	MG	VG	VG	MG	MG	G	VG	F	G	G	G	F	G
A_5	MG	G	VG	VG	F	F	VG	MG	F	G	MG	VG	G	F	MG	G
A_6	MP	F	MG	MG	F	F	MG	F	F	G	MP	F	MP	G	F	MP
A_7	MP	F	F	F	VP	P	MP	F	VP	F	MP	MG	P	P	F	P
A_8	F	VP	F	P	F	MP	MP	MP	MP	VP	P	P	MG	VP	MP	MG
A_9	F	MG	MG	G	G	MG	VG	G	G	G	G	F	G	MG	VG	G

Table 3. The decision-matrix of each decision-maker at second period (t = 2).

	D_1				D_2				D_3				D_4			
	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4
A_1	P	MP	MP	VP	—	—	—	—	P	MP	MG	P	VP	MP	F	MP
A_2	P	MP	F	VP	—	—	—	—	P	MG	P	VP	VP	MG	MP	P
A_3	P	F	MP	MG	—	—	—	—	P	MG	MG	G	P	MG	F	F
A_4	MG	VG	MG	MG	—	—	—	—	MG	G	MG	G	G	G	MG	G
A_6	P	MG	F	MP	—	—	—	—	P	G	MP	MP	F	G	MG	F
A_7	P	F	P	MP	—	—	—	—	P	P	MP	F	P	P	F	MG
A_{10}	VG	VG	G	MG	—	—	—	—	G	VG	G	G	G	G	G	MG
A_{11}	P	MG	G	MG	—	—	—	—	MP	MG	G	MG	F	G	MG	F
A_{12}	P	VP	P	MP	—	—	—	—	VP	VP	MP	P	VP	VP	P	MP
A_{13}	MG	P	VP	MP	—	—	—	—	MP	P	P	P	F	MP	P	MP

Table 4. The decision-matrix of each decision-maker at third period (t = 3).

	D_1				D_2				D_3				D_4			
	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4
A_1	P	P	MP	P	VP	F	MP	MP	P	MP	F	MP	VP	F	F	MP
A_2	MP	F	P	VP	VP	MP	P	P	P	MG	F	MP	MP	MP	F	MP
A_5	MG	G	MG	VG	F	G	MG	MG	MG	G	VG	G	G	F	G	MG
A_6	P	G	MG	MP	MP	MG	F	F	MP	F	F	MP	P	F	MG	F
A_7	VP	P	MP	MG	MP	MP	MP	F	VP	F	P	F	VP	MP	P	MP
A_8	F	MP	F	P	MG	MP	P	MP	MG	P	F	MP	MG	P	F	F
A_9	MG	G	VG	F	MG	G	VG	F	G	VG	G	F	MG	VG	VG	G
A_{10}	G	G	G	G	MG	G	VG	MG	G	G	G	F	MG	VG	VG	G
A_{12}	VP	P	P	P	P	P	P	F	MP	VP	MP	F	P	P	P	F

Table 5. The decision-matrix of each decision-maker at fourth period (t = 4).

	D_1				D_2				D_3				D_4			
	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4
A_2	MP	MG	F	P	MP	MP	F	MP	MP	MG	MP	VP	—	—	—	—
A_3	F	MG	MP	F	F	G	MG	MG	MP	F	MP	F	—	—	—	—
A_6	MP	F	F	MP	MP	MG	MP	MG	P	F	F	MP	—	—	—	—
A_7	VP	P	P	MP	P	F	MP	F	MP	MP	P	MP	—	—	—	—
A_8	MP	P	P	MP	MP	VP	MP	MP	MP	VP	MP	F	—	—	—	—
A_{10}	MG	G	VG	G	VG	VG	G	MG	VG	G	G	G	—	—	—	—
A_{13}	MP	VP	VP	P	F	VP	VP	MP	MG	MP	P	VP	—	—	—	—

Table 6. The matrices of criteria weights in different periods.

		D_1	D_2	D_3	D_4
t = 1	C_1	ML	L	M	M
	C_2	M	ML	M	M
	C_3	MH	VH	MH	H
	C_4	H	MH	M	MH
t = 2	C_1	L	—	ML	L
	C_2	ML	—	M	M
	C_3	VH	—	VH	MH
	C_4	H	—	MH	M
t = 3	C_1	L	L	M	L
	C_2	ML	ML	MH	ML
	C_3	MH	MH	H	VH
	C_4	M	M	M	H
t = 4	C_1	ML	M	L	—
	C_2	ML	ML	MH	—
	C_3	MH	MH	H	—
	C_4	MH	MH	H	—

According to the results presented in Table 7 and Steps 12 and 13 of the proposed approach, the dynamic and aggregated dynamic scores of alternatives can be calculated.

It should be noted that we use Equation (29) to set the weights for aggregating the dynamic scores. However, this function can be replaced with any custom function which can consider the importance of newer decision information. Also, the user of the proposed approach can set the weights manually without defining a function.

The values of S_{it}, H_{it} and the rank of each alternative related to each period are represented in Table 8. We also show the changes in the members of AL_t and AL_t^T in this table. The members of these sets should be known for the calculations of Steps 12 and 13."

As it can be seen in Table 8, A_9 is the best alternative (subcontractor) in the first period (t = 1), but this alternative is not available in the second period. The unavailability of A_9, and availability of some better alternatives in the second period lead to a decrease in the value of the aggregated dynamic score for this alternative. Therefore, the rank of A_9 is changed from 1 to 6 at t = 2. On the other hand, the rank of A_4, which has the second rank at t = 1, is changed to 1 in the second period, and A_{10}, which is a new available subcontractor, has the second rank in the second period. We can say that the rank of alternatives is dynamic and changes in different periods according to the new information of decision-making process.

In this example, the changes in the rank of subcontractors at different time periods are depicted in Figure 3.

Table 7. The overall performance scores and ranking results at each period.

		$\tilde{u}_{it}$	$\mathfrak{D}(\tilde{u}_{it})$	Rank	
				Fuzzy EDAS	**TOPSIS**
$t = 1$	A_1	(−0.716, 0.05, 0.67)	0.0013	8	9
	A_2	(−0.712, 0.0290, 0.683)	0	9	8
	A_3	(−0.0580, 0.617, 1.305)	0.6216	4	4
	A_4	(0.349, 0.914, 1.614)	0.9591	2	3
	A_5	(0.366, 0.898, 1.562)	0.9421	3	2
	A_6	(−0.137, 0.550, 1.258)	0.5572	5	5
	A_7	(−0.524, 0.252, 0.903)	0.2105	6	6
	A_8	(−0.639, 0.101, 0.757)	0.0730	7	7
	A_9	(0.415, 0.953, 1.632)	1	1	1
				$r_s = 0.97$	
$t = 2$	A_1	(−0.402, 0.263, 0.762)	0.2075	7	7
	A_2	(−0.453, 0.166, 0.707)	0.1402	8	8
	A_3	(0.037, 0.59, 1.125)	0.5838	4	4
	A_4	(0.439, 0.874, 1.472)	0.9281	2	2
	A_6	(−0.089, 0.517, 1.111)	0.5130	5	5
	A_7	(−0.353, 0.309, 0.874)	0.2767	6	6
	A_{10}	(0.514, 0.965, 1.522)	1	1	1
	A_{11}	(0.249, 0.77, 1.334)	0.7843	3	3
	A_{12}	(−0.636, 0.041, 0.595)	0	10	10
	A_{13}	(−0.526, 0.091, 0.694)	0.0864	9	9
				$r_s = 1$	
$t = 3$	A_1	(−0.652, 0.194, 0.848)	0.1298	7	7
	A_2	(−0.65, 0.15, 0.801)	0.1005	8	8
	A_5	(0.436, 0.875, 1.501)	0.9376	3	2
	A_6	(−0.215, 0.489, 1.144)	0.4725	4	4
	A_7	(−0.569, 0.184, 0.782)	0.1324	6	6
	A_8	(−0.473, 0.278, 0.991)	0.2652	5	5
	A_9	(0.448, 0.9, 1.482)	0.9434	2	3
	A_{10}	(0.503, 0.947, 1.55)	1	1	1
	A_{12}	(−0.745, 0.05, 0.695)	0	9	9
				$r_s = 0.98$	
$t = 4$	A_2	(−0.26, 0.357, 0.93)	0.3424	4	4
	A_3	(0.179, 0.614, 1.102)	0.6318	2	2
	A_6	(−0.026, 0.507, 1.016)	0.4992	3	3
	A_7	(−0.586, 0.242, 0.946)	0.2007	6	6
	A_8	(−0.592, 0.244, 0.969)	0.2070	5	5
	A_{10}	(0.59, 0.971, 1.438)	1	1	1
	A_{13}	(−0.599, 0.043, 0.611)	0.0183	7	7
				$r_s = 1$	

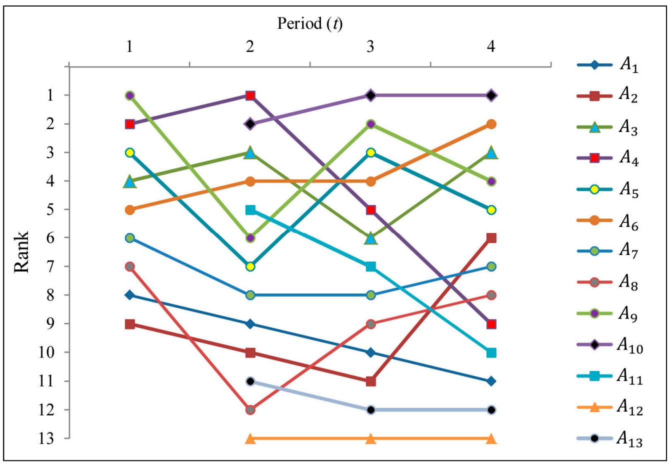

Figure 3. The changes in the rank of alternatives at different time periods.

Table 8. The final scores and ranks of alternatives at each period.

		A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}
	AL_t	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\times$	$\times$	$\times$	$\times$
	AL_t^T	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\times$	$\times$	$\times$	$\times$
t = 1	S_{it}	0.0013	0	0.6216	0.9591	0.9421	0.5572	0.2105	0.0730	1	—	—	—	—
	H_{it}	0.0013	0	0.6216	0.9591	0.9421	0.5572	0.2105	0.0730	1	—	—	—	—
	Rank	8	9	4	2	3	5	6	7	1	—	—	—	—
	AL_t	$\surd$	$\surd$	$\surd$	$\surd$	$\times$	$\surd$	$\surd$	$\times$	$\times$	$\surd$	$\surd$	$\surd$	$\surd$
	AL_t^T	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$
t = 2	S_{it}	0.2075	0.1402	0.5838	0.9281	0	0.5130	0.2767	0	0	1	0.7843	0	0.0864
	H_{it}	0.1388	0.0935	0.5964	0.9384	0.314	0.5277	0.2546	0.0243	0.3333	0.6667	0.5229	0	0.0576
	Rank	9	10	3	1	7	4	8	12	6	2	5	13	11
	AL_t	$\surd$	$\surd$	$\times$	$\times$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\times$	$\surd$	$\times$
	AL_t^T	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$
t = 3	S_{it}	0.1298	0.1005	0	0	0.9376	0.4725	0.1324	0.2652	0.9434	1	0	0	0
	H_{it}	0.1334	0.0977	0.2386	0.3754	0.6882	0.4946	0.1813	0.1689	0.6994	0.8667	0.2091	0	0.023
	Rank	10	11	6	5	3	4	8	9	2	1	7	13	12
	AL_t	$\times$	$\surd$	$\surd$	$\times$	$\times$	$\surd$	$\surd$	$\surd$	$\times$	$\surd$	$\times$	$\times$	$\surd$
	AL_t^T	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$
t = 4	S_{it}	0	0.3424	0.6318	0	0	0.4992	0.2007	0.2070	0	1	0	0	0.0183
	H_{it}	0.0572	0.2375	0.4633	0.1609	0.2949	0.4972	0.1924	0.1907	0.2997	0.9429	0.0896	0	0.0203
	Rank	11	6	3	9	5	2	7	8	4	1	10	13	12

According to the evaluation of the last period (t = 4), A_{10} is the best alternative, and the final ranking is as follows:

$$A_{10} \succ A_6 \succ A_3 \succ A_9 \succ A_5 \succ A_2 \succ A_7 \succ A_8 \succ A_4 \succ A_{11} \succ A_{13} \succ A_{12}$$

Although the final evaluation can be made based on the above-mentioned ranking, the main contractor should be cautious about the subcontractors which have higher degree of fluctuation in their ranks at different periods. The fluctuation in the rank of subcontractors could be occurred due to the unavailability of them or their low performance in some periods. Both reasons lead to unreliability of a subcontractor. As we can see in Figure 3, the ranks of A_{10}, A_6, A_7, A_{12} and A_{13} have lower fluctuation than the other alternatives. Therefore, the main contractor can select A_{10} as a reliable subcontractor and consider A_6 as a backup alternative.

4. Conclusions

In the management of a contract, it has become usual to outsource specialized tasks by the main contractor. This can be done to ensure the quality of construction projects. Although outsourcing most tasks to a subcontractor is convenient and safe for the main contractor, the failure of the selected subcontractor can lead to the failure of the entire project. Hence the process of evaluation and selection of subcontractors can be considered as one of the important actions that should be carried out by the main contractor.

In this study, we have defined the subcontractor evaluation process as a dynamic multi-criteria group decision-making problem. Due to the uncertainty of information in the process of evaluation, a fuzzy dynamic MCGDM approach has been proposed to deal with SEP. The proposed approach has been designed based on the EDAS method which is a new and efficient MCDM approach. In the procedure of the proposed approach, we can define different sets of alternatives, criteria, and decision-makers in different time periods. The performance of each alternative is updated in each period by an aggregation function which gives greater weights to newer information. Thus, we can ensure that the final evaluation involves the importance of up-to-date decision information.

We have used an example of subcontractor evaluation problem to illustrate the process of the proposed approach and show the utility of it in real-world decision-making problems. Because the weights of criteria as well as the set of criteria can be changed at each period in the process of using the proposed dynamic approach, the sensitivity analysis on the weights of criteria has not been made in this study. Lack of this analysis can be considered as a limitation of this study. To make the sensitivity analysis in the proposed approach, we need to devise a new research methodology, and this can be addressed in future research. Also, future research can examine the effect of different weight functions for aggregation of the dynamic scores of alternatives and apply the proposed approach to the other MCDM problems such as supplier evaluation, service quality assessment and risk evaluation. Moreover, other types of fuzzy sets such as interval type-2 fuzzy sets, intuitionistic fuzzy sets and hesitant fuzzy sets can be used to extend the propose approach.

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