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A Decision Support Model for Decision Making with the Use of 2-Tuple Linguistic Model in Subcontractor Selection

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ABSTRACT: There are various parties in the execution phase of construction projects but contractors have a direct impact on the execution phase. Due to some challenges such as growing complexity, and the need for specific specialties, contractors' eager to subcontract project's tasks to other parties is named subcontractors. Regarding the impact of subcontractors on critical success factors of projects, the first step in their management process is the selection of the best subcontractor. The subcontractor selection is a subject, in which uncertainty and vagueness are dealt with in decision-making. In these situations, linguistic terms can help people in expressing their ideas. This paper applied the 2-tuple linguistics computing to work with linguistic terms and use group decision making to mitigate the deviation of experts' ideas. For further understanding, a numerical example is presented. Also, a consistency test to investigate the accuracy of the model is offered.

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1- Introduction

There are three main parties in the execution phase of construction projects, including client, consultant, and contractor. Although all of the parties have a noticeable role in the project, contractors have a direct impact on the execution phase [1]. Since modern societies need to promote the convenience of their inhabitants, the construction industry has been forced to define some new projects [2] in a more complex and specialized manner than those in last decades. This attitude causes the concept of risk to be one of the most considerable issues [3] which has consequences on project success [4]. In addition, the structural transformation of construction projects such as the appearance of new contracts (EPC, DB, and BOT) leads to the contractors' place in a risky situation than the previous ones. The contractors are eager to perform construction work using internal capacity when it is more economical and less risky [1], otherwise, they subcontract those tasks to other parties named subcontractors (SCs). Contractors have found that SCs are one of the best alternatives for helping them in managing projects [5]. According to the definition of the Iranian general condition of the contract, SC is a natural or legal person who is an expert in performing some special tasks and the contractor signs a contract with him for the execution of some parts of the projects' task based on his specialty. With respect to this definition, considering two points is important. The first one is that SCs are expert parties for performing some portions of project's tasks. The delivery of a construction project involves different skills at different construction stages [6] thus the contractors need to apply SCs for performing some special tasks that contractors do not have any specialty in or it is not economical to do it themselves due to reasons such as the lack of resources. The other point is that there is a legal contract between the contractor and SCs in projects. A medium to large-scale projects typically involves hundreds of different companies supplying materials, components, and a wide range of construction services [7]; therefore, the project success is directly dependent on the success of SCs. Regarding the map of construction supply chain expressed by Pryke [8], the contractors' place is in the first tier of the construction supply chain and the second one is SCs. Based on the concept of supply chain and its internal networks, contractors are eager to transfer risks of projects to sub-layers such as SCs. Recently, evidence from executed projects has demonstrated that many contractors only act as a construction management agent in construction projects and sub-contract a large volume of their work to SCs [9]. Generally, contractors apply a legal contract to satisfying this goal.

The construction projects absorb a considerable portion of each country's annual budget. For instance, in Iran, the construction budget absorbs about 7.5% of the total budget of about 38 billion dollars per year [10] and it is noticeable that SCs perform as much as 90% of the total project value [11]. SCs influence some critical success factors of projects, including cost, time, and quality. These considerations show that the role of SCs in the construction projects is very important and implementing the systematic approach to manage them is necessary. Applying and working with SCs who are not qualified enough to handle their subcontracted works

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leads to failing the project and some key aspects of project delivery such as cost, time and quality will be jeopardized. Contractors attempt to decrease the probability of failure by focusing on the selection of best candidates and controlling them among the projects. The first step is the selection of the best SC in the SC management process. The selection of right SCs leads to contractor's assurance about doing tasks in the right way promote. Regarding the deficiencies existing in the previous investigations about the SC selection, authors intend to present a new contribution based on the concept of group decision making with the use of 2-tuple linguistic terms. In the construction industry, the probability of determining the deterministic values in the evaluation and selection process is very low [12] the reason behind this problem is the lack of strong documentations in contractor companies. Almost all of contractor companies do not gather their experience in the previous projects to develop a data-base for quantifying some criteria, therefore some subjects such as selection, evaluations, etc. are done by expert judgments. Experts are also comfortable to announce their opinions in evaluation problems by linguistic terms because of the lack of valid data in the construction industry. The SC selection is a subject, in which uncertainty and vagueness are dealt with in decision-making. Decision makers should evaluate SCs based on some quantitative and qualitative criteria. Linguistic terms are one of the most useful approaches for expressing experts' opinions and the inherent uncertainty in decision-making. Although the uncertainty in the decision making can be expressed by probabilistic approaches, there exist some cases in which decision makers cannot prepare the required information for probabilistic approaches because of the lack or vagueness of their knowledge. In these situations, linguistic terms can help people in expressing their ideas. The 2-tuple linguistic model has improved the accuracy of a retranslation step of working with linguistic terms [13]. In addition, group decision-making can mitigate the deviation of experts' ideas. According to the mentioned issues, this paper proposed a new approach for modeling group decision making with the use of a 2-tuple linguistic model. In the remainder of this paper, a literature survey will be presented. In section three, the papers' model will be explained and for further understanding an example will be presented in the next section. The consistency test will be offered to investigate the accuracy of the model and finally, a conclusion section will be presented.

2- Literature Survey

The selection of right SCs enhances the chance of the succession of the main contractor [3]. There are several investigations about the SC selection. Wang et al. [14] offered a fuzzy hybrid model for SC selection. They applied two tools, including the fuzzy expert system and genetic algorithm. They divided every project into some sub-projects and finally allocated each subproject to SCs. The main objective of their model is to optimize the cash flow of projects. The main deficiency of their model is neglecting risks and other criteria in SC selection. Ng and Luu [15] presented a model by applying case-based reasoning. They gathered a database from successful and unsuccessful SCs. When each decision maker wants to choose an SC, he/she can compare the characteristics of his/her candidates with the database with the use of the concept of case-based reasoning. The main innovation of their model was to offer an option for the decision maker to alter criteria for the evaluation of each case. Although this approach is a good idea, in some companies with the poor ability of documentation, it is too difficult to apply. Mbachu [16] surveyed the effective criteria in the SC selection in South Africa. He developed a model based on the experts' opinions with respect to the presented criteria for each SC. The SC with the greatest score can be selected. His model is too qualitative and does not have a generality for application in other countries. Arslan et al. [17] presented a web-based model named "WEBSES" for the selection of SCs. They offered 25 criteria for evaluation of SCs and selected the SC with a high score. The main criticism to their work is the same weight of criteria in the evaluation process. Hartman and Caertelling [18] spoke about the impact of cost and confidence in the SC selection phase. They concluded that the impact of cost is higher than other criteria. Regarding the result of their questionnaire, MC usually tends to subcontract the project's tasks to SC with the lowest cost; however, this SC is not known.Yin et al. [19] introduced a two-step model for SC selection. In the first step, they chose all of the SCs with the capability for carrying out the project's tasks. Next, they evaluate prequalified SCs with some detailed criteria regarding the task for subcontracting to SCs. They applied data envelopment analysis (DEA) for selection. Xiaolin et al. [20] used benchmarking for SC selection. They evaluated SCs and suppliers with respect to the virtual benchmark developed by the main contractor. They calculated the deviation of SCs from the main contractor with the use of the case-based reasoning approach. In addition, they applied a gray system theory for the evaluation of SCs according to the presented criteria. Tserng and Lin [21] proposed a web-based decision support system for trading-off between risk and profit in SC selection. They opined that subcontracting a supply chain of construction projects considered as a global procurement system and an optimal combination of SCs can be obtained with this system. According to the literature survey, there are several models for SC selection in the real world. However, these models can choose SC properly but they can be improved with respect to some considerations. Regarding the nature of SC selection and reasons expressed in introduction sections, modeling linguistic terms in the evaluation process are very important. Models developed previously can be improved considerably in this area with the use of new approaches. In addition, presenting a step-by-step model is very crucial. This can prevent disorderly efforts in the selection of SCs. This paper intends to improve the previous efforts in the SC selection area with respect to these items.

Another consideration in SC selection is finding the most important criteria for the evaluation of candidates (Table 1)

3- Model Development

Regarding the nature of the SC selection problem, the authors need to apply 2-tuple Linguistic concepts for modeling the inherent uncertainties and work with linguistic terms in this problem. In addition, modeling group decision making and rating alternatives are considered. The descriptions below explain the basic definitions of the two tools applied in this paper.

3- 1- Basic concept

Before the description of the model's steps, the reader should

Table 1. The Most Important Criteria for SC Selection

NO	Criteria	Reference	NO	Criteria	Reference
1	Financial Capability	[2], [3], [15], [17]	5	Experience	[3], [9], [15], [19], [21]
2	Financial Stability	[2], [3], [15], [11], [18]	6	Management Capability	[2], [9], [17], [16], [21]
3	The Resource Capability	[1], [2], [3], [9], [15]	7	Reputation	[3], [9], [17], [16], [21]
4	Technical Ability	[3], [5], [9], [15], [18]	8	Price	[2], [3], [9], [15] [17], [16], [21]

be familiar with some basic definitions as below:

Definition (1): A 2-tuple linguistic model is a useful tool to improve the accuracy and facilitate the process of computing by means of linguistic terms and by treating the linguistic domain as continuous but keeping the linguistic basis [22]. For the first time, Herrera developed the concept of the 2-tuple linguistic model based on the linguistic representation model [22]. He can improve the process of working with words by avoiding information distortion and losing those which occurred formerly in other approaches.

- Application: The main application of the 2-tuple linguistic model is in the decision making or decision analysis, however, it has wide uses in fuzzy systems [22].
- Formulation: Suppose that S_i represents a possible value for each linguistic term where S_i belongs to $S=\{S_i|i=0, 1, 2, ..., t\}$ and it should satisfy the following characteristics [22-23].
  - The set is linearly ordered: $S_i > S_j$, if $i>j$
  - Max operator: $\max(S_i,S_j) = S_i$, if $S_i > S_j$
  - Min operator: $\min(S_i,S_j) = S_j$, if $S_i > S_j$

For example, S can be defined as:

$$S=\begin{Bmatrix} S_0 = extremely\ poor(EP), S_1 = poor(P), \\ S_2 = medium(M), \\ S_3 = good(G), S_4 = extremely\ good(EG) \end{Bmatrix}$$

Definition (2): Let β be the result of an aggregation of the indices of a set of labels assessed in a linguistic term set , i.e., the result of a symbolic aggregation operation. $\beta \in [0,t]$ being $t+1$ the cardinality of S. Let $i=round(\beta)$ and $\alpha= \beta-i$ be two values, such that, $i \in [0,t]$ and $\alpha \in [-0.5,0.5)$ then α is called a symbolic translation [22]. According to this concept, S_i can be expressed as the linguistic label of the information and α_i can be described as the value of the translation from the original result β to the closest index label, i , in the linguistic term set ($S_i \in S$). Finally, Herrera et al. [22] demonstrated the information of linguistic terms by means of 2-tuples (S_i, α_i).

Definition (3): Let $S=\{S_i|i=0, 1, 2, ..., t\}$ be a linguistic term set and $\beta \in [0,t]$ a value supporting the result of a symbolic aggregation operation, then the 2-tuple that expresses the equivalent information is obtained with the following function:

$$\Delta : [0,t] \rightarrow S \times [-0.5, 0.5) \tag{1}$$

$$\Delta(\beta) = \begin{cases} S_i, i = round(\beta) \\ \alpha = \beta - i, \alpha \in [-0.5, 0.5) \end{cases} \tag{2}$$

Where round is the usual rounding operation, S_i has the closest index label to β and α is the value of the symbolic translation [22-23].

Definition (4): Let $S=\{S_i|i=0, 1, 2, ..., t\}$ be a linguistic term set and (S_i, α_i) be a 2-tuple. There is always a function Δ^{i-1}, such that, from a 2-tuple, it returns to its equivalent numerical value $\beta \in [0,t] \subset R$ ([22-23].

$$\Delta^{-1} : S \times [-0.5, 0.5) \rightarrow [0,t] \tag{3}$$

$$\Delta^{-1}(S_i, \alpha) = i + \alpha \tag{4}$$

Definition (5): Let $S=\{S_i|i=0, 1, 2, ..., t\}$ be a set of 2-tuples. The following operations are defined [22-23]:

- If $k < l$ then (S_k, α_k) is smaller than (S_l, α_l)
- If $k = l$ then
  - If $\alpha_k = \alpha_l$ then (S_k, α_k) and (S_l, α_l) represent the same information
  - If $\alpha_k < \alpha_l$ then (S_k, α_k) is smaller than (S_l, α_l)
  - If $\alpha_k > \alpha_l$ then (S_k, α_k) is bigger than (S_l, α_l)
- $neg(S_i, \alpha)=\Delta(t-(\Delta^{-1}(S_i, \alpha)))$ is a 2-tuple negation operator.
- The 2-tuple arithmetic mean is defined as:

$$(\bar{S}, \bar{\alpha}) = \Delta\left(\frac{1}{n}\sum_{j=1}^{n}\Delta^{-1}(S_i, \alpha_i)\right) \ \bar{S} \in S, \quad \bar{\alpha} \in [-0.5, 0.5) \tag{5}$$

Definition (6): Let $x=\{(s_1, \alpha_1), (s_2, \alpha_2), ..., (s_n, \alpha_n)\}$, be a set of 2-tuples and $\omega_i \in \omega(\omega_1, \omega_2, ..., \omega_n)$ represent the weight vector of criteria and $\omega_i \in [0,1]$. The 2-tupple weighted averaging is [22-23]:

$$(\tilde{S}, \tilde{\alpha}) = \Delta\left(\sum_{j=1}^{n}\omega_j\Delta^{-1}(S_i, \alpha_i)\right) \ \tilde{S} \in S, \ \tilde{\alpha} \in [-0.5, 0.5) \tag{6}$$

Definition (7): Let $S=\{(S_1, \alpha_1), (S_2, \alpha_2), ..., (S_n, \alpha_n)\}$ the distance between two 2-tuples (S_l, α_l) and (S_k, α_k) can be obtained as follows [24]:

$$d[(S_l, \alpha_l), (S_k, \alpha_k)] = \frac{\left|\Delta^{-1}(S_l, \alpha_l) - \Delta^{-1}(S_k, \alpha_k)\right|}{n} \tag{7}$$

Definition (8): The degree of similarity between (S_l, α_l) and (S_k, α_k) can be defined as equation (8) [24]:

$$sim[(S_l, \alpha_l), (S_k, \alpha_k)] = 1 - \frac{d[(S_l, \alpha_l), (S_k, \alpha_k)]}{\sum_{i=1}^{n} d[(S_i, \alpha_i), (S_k, \alpha_k)]} \tag{8}$$

Where $(S_i, \alpha_i) \in \{(S_1, \alpha_1), (S_2, \alpha_2), ..., (S_n, \alpha_n)\}$

Definition (9): Let $S^{n(a)} = \{S_0^{n(a)}, S_1^{n(a)}, ..., S_{n(a)-1}^{n(a)}\}$ and $S^{n(b)} = \{S_0^{n(b)}, S_1^{n(b)}, ..., S_{n(b)-1}^{n(b)}\}$ be two linguistic term sets, with $a < b$. The linguistic transformation function TF_a^b: $\bar{S}^{n(a)} \rightarrow \bar{S}^{n(b)}$ is defined by [13]:

$$TF_a^b\left(S_j^{n(a)}, \alpha_j\right) = \Delta_S\left(\frac{\Delta_S^{-1}\left(S_j^{n(a)}, \alpha_j\right).(n(b)-1)}{(n(a)-1)}\right) = \left(S_k^{n(b)}, \alpha_k\right) \tag{9}$$

3- 2- Model's steps

Regarding the novelty of the model developed in this paper, this section describes the various steps, which lead to picking up an appropriate SC with the use of 2-tuple linguistic terms. In addition, the steps below can be applied as a framework for SC selection.

3- 2- 1- Criteria Identification

For the selection of the right SCs and implementing the decision makers' considerations, decision-makers should develop some criteria. Regarding the uniqueness of construction projects, the authors believe that developing useful criteria for each project directly depends on the condition of each project. Some main parameters such as financial ability, previous experience, resources, reputation, skills, etc. can be considered as useful and general criteria. In addition, users can develop each title by some sub-criteria. In other words, developing a hierarchical criteria approach is an applicable opinion. Therefore, the authors suggest that each company or decision maker should develop his/her selection criteria independently.

3- 2- 2- Weighting the criteria

After developing criteria, weighting is the next step, which is vital in determining the importance of attributes. The weight of criteria can be derived from expert judgments or previous historical records. Deriving the weights of criteria can be done by each validate approach such as AHP. Although it is not important which tool is used for weighting criteria, it is important to normalize the weights of criteria in [0,1] for working in the next steps.

3- 2- 3- Definition of linguistic terms

The definition of linguistic terms depends on various parameters such as the type of criteria, alternatives, the condition of the problem, decision makers' knowledge, etc. This paper defines three types of linguistic terms which users can use every one of them. Table (2) demonstrates the required information about the defined linguistic terms [25]. It should be noted that the type of linguistic terms can be altered according to the users' opinions. After each decision maker picked up his type of linguistic terms, all of their ideas should be unified according to definition 9.

3- 2- 4- Determining the performance of SCs based on developed criteria

Experts should evaluate SCs or candidates according to the presented criteria with respect to the linguistic terms. This evaluation can be done with respect to the presented documents by the SCs or any other regular way.

3- 2- 5- Transferring linguistic terms into a 2-tuple linguistic model

The opinions of experts derived in the previous step should be transformed to the 2-tuple linguistic model. If the decision matrix is $R_k=(r_{ij}^{\,k})_{m\times n}$, the transformation will be done by matrix $R_k=(r_{ij}^{\,k},0)_{m\times n}$.

3- 2- 6- Implementing the concept of group decision making

Normally, there exist some decision makers when each SC is chosen. The combination of SCs heavily depends on the policy of the company or project. Therefore, it is possible that the opinions of members not to be the same due to differences in the level of their knowledge about criteria and alternatives. It is necessary to present an approach to weight the decision makers based on their familiarity with the subject. The concept of this paper is to compare the opinion of each decision maker with respect to the average opinions. To have a long distance from the average opinion leading to this opinion is less reliable than others. Suppose that there are decision makers like the set of $D_k=\{D_0, D_1, D_2 ..., D_K\}$. If the opinion of each decision maker is expressed by a 2-tuple (S_i, α_i) and the average opinions are presented by the 2-tuple arithmetic mean $(\bar{S}, \bar{\alpha})$, the weight of each decision maker w_k^* will be calculated as follows:

$$\overset{*}{w}_k = \frac{sim\left[(S_l,\alpha_l),(\bar{S},\bar{\alpha})\right]}{\sum_{i=1}^{n} sim\left[(S_i,\alpha_i),(\bar{S},\bar{\alpha})\right]} \tag{10}$$

After determining the weight of each decision maker, the final rating $F_j(A_i)$ can be calculated as equation (11).

$$F_j(A_i) = \sum_{k=1}^{K} \overset{*}{w}_k \times F_j^k(A_i) = \Delta\left(\sum_{k=1}^{K} \overset{*}{w}_k \Delta^{-1}\left(S_{ij}^k, \alpha_{ij}^k\right)\right) = \left(S_{ij}, \alpha_{ij}\right) \tag{11}$$

Where the opinion of the k-th expert for the i-th candidate with respect to the j-th criterion is expressed by $F_j^k(A_i)$.

3- 2- 7- Determining the required performance for each criteria

The authors develop this step to establish a base for the measurement of SCs' performances. In each case, SCs should be selected according to the requisites of projects. The selection of SCs with specifications more than necessary in the project will lead to an increase in the cost of the project and vice versa. If SCs are chosen with specifications less than needed in the project, the probability of the project failing will be increased. Consequently, decision makers should determine these limitations by defining the required performance for each criteria. Determining the required performance can be done by the concept of group decision making and linguistic terms defined in the previous steps.

3- 2- 8- Preparing the selection index

For a final ranking of the candidates, decision makers should develop a selection index (SI) as below.

$$SI_i = \sum_{j=1}^{m} w_j \times \left(\Delta^{-1}\left(S_{ij}, \alpha_{ij}\right) - \Delta^{-1}\left(\overset{*}{S}_j, \overset{*}{\alpha}_j\right)\right) \tag{12}$$

Where w_j is the weight of the j-th criteria. According to the SI index, the following results can be obtained:

- The alternative with the highest *SI* is the best choice.
- The sign of *SI* can give some information to decision makers.
    - The positive *SI* means that the overall performance of the alternative is more than that required by decision makers.
    - The negative *SI* means that the performance of the alternative is less than that required by decision makers.

This sign can help the decision maker in selecting SCs (alternatives) with the performance equal or more than required.

The proposed steps would be able to select the best SC in each project. The most important benefit of this model is working with linguistic terms and this is the most important reason why the proposed model is practical. Each user can evaluate candidates' SCs based on linguistic terms shown in Table (2) and this does not require to know any information about the concept of fuzzy or group decision making. But the most important challenge of this model is some of the calculations to reach the goal. In practice, doing these calculations can be cumbersome or impractical. Therefore, the authors suggest that any software such as MATLAB, Visual Basic, etc. can be applied for modeling the mentioned steps. For the convenience of users and preparing a graphical user interface (GUI), developing a software is essential.

As a result, working with this model can be divided into two sections. The first one is the evaluation of SCs which is done by linguistic terms according to the real situations and the second is the calculations and introducing the best SC. This section can be modeled in any software for the convenience of users.

The proposed steps of this paper for SC selection can be modeled in any software such as MATLAB, Visual Basic. etc. for preparing a graphical user interface (GUI).

4- Numerical Example

This section presents a numerical example to demonstrate how the paper's model can be applied in the real situation. Suppose there is a job task in a construction project which decision makers want to subcontract. From another point of view, the selection of the right SC among some candidates is the goal of this example. According to this concept, there are three decision makers, including DM1, DM2, and DM3. Also, there are four candidates, including SC1, SC2, SC3 and SC4 for the selection of the best SC. The steps below will be followed for the selection purpose:

Criteria Identification: As stated previously, criteria definition should be done separately in each case, however, in this case, to show how the model's paper works, five criteria are considered as depicted in Figure (2).

Weighting the criteria: Suppose that decision makers agreed to the weight of criteria as demonstrated in the weight vector

Definition of linguistic terms: This step has been done according to Table (2).

Determining the performance of SCs based on developed criteria: Table (3) represents the performance of candidates based on the developed criteria according to the decision makers' opinions.

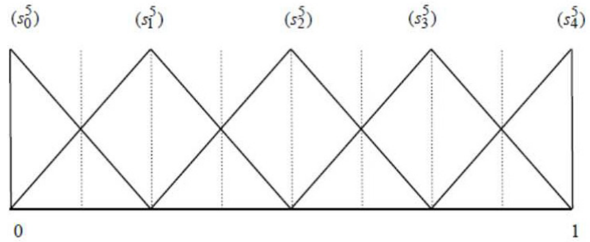
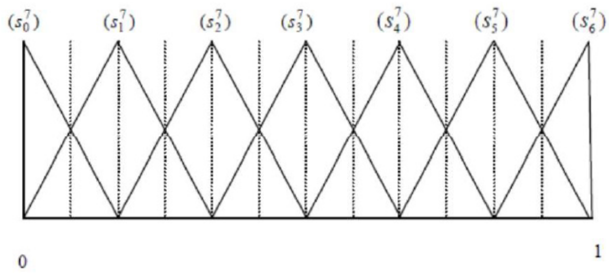
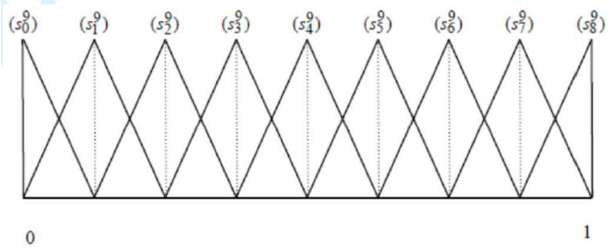
Transferring linguistic terms into a 2-tuple linguistic model: Table (4) also represents the transformation of linguistic terms into a 2-tuple linguistic model.

Implementing the concept of group decision making: Table (5) presents the transformation of three types of linguistic terms into one 2-tuple linguistic.

Determining the required performance for each criterion: According to the concept of group decision making, the authors express their idea about the needed performance for each criteria. The above operations should be done to get the final answers.

Preparing the selection index: Table (11) presents the final results.

Table 2. Linguistic Terms and Their Related Information

Type	Linguistic Terms for Alternatives	Linguistic Terms for Criteria	Figure
1	Extremely Poor, Poor (S_1^5), Fair (S_2^5), Good (S_3^5), Extremely Good (S_4^5)	Extremely Low, Low (S_1^5), Medium (S_2^5), High (S_3^5), Extremely High (S_4^5)	
2	Extremely Poor, Poor (S_1^7), Medium Poor (S_2^7), Fair (S_3^7), Medium Good (S_4^7), Good (S_5^7), Extremely Good (S_6^7)	Extremely Low (S_0^7), Low (S_1^7), Medium Low (S_2^7), Medium (S_3^7), Medium High (S_4^7), High (S_5^7), Extremely High (S_6^7)	
3	Extremely Poor, Very Poor (S_1^9), Poor (S_2^9), Medium Poor (S_3^9), Fair (S_4^9), Medium Good (S_5^9), Good (S_6^9), Very Good (S_7^9), Extremely Good (S_8^9)	Extremely Low (S_0^9), Very Low (S_1^9), Low (S_2^9), Medium Low (S_3^9), Medium (S_4^9), Medium High (S_5^9), High (S_6^9), Very High (S_7^9), Extremely High (S_8^9)	

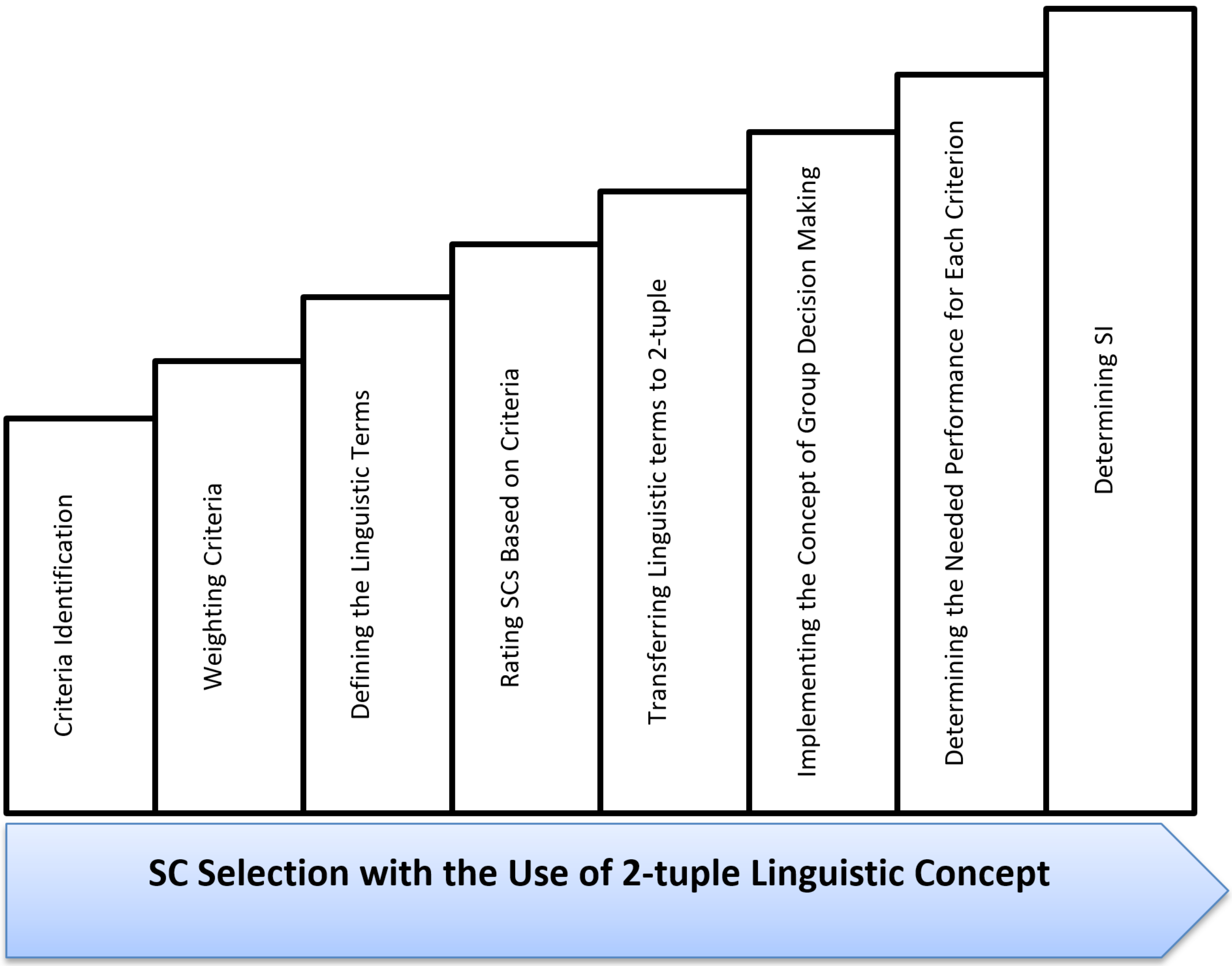


Fig. 1. The Proposed Model

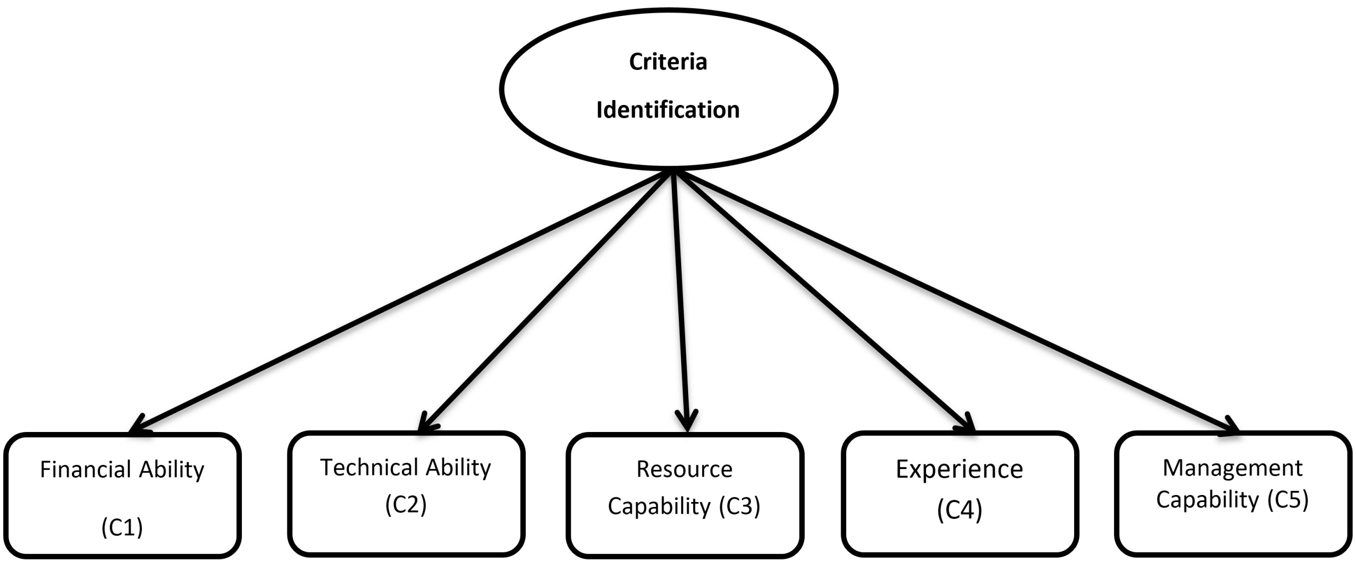


Fig. 2. Criteria Identification

Table 3. SCs' Performance Evaluation

	DM	C1	C2	C3	C4	C5
SC1	DM1	(S_3^5)	(S_2^5)	(S_3^5)	(S_2^5)	(S_4^5)
	DM2	(S_4^7)	(S_4^7)	(S_5^7)	(S_3^7)	(S_5^7)
	DM3	(S_7^9)	(S_4^9)	(S_5^9)	(S_5^9)	(S_7^9)
SC2	DM1	(S_2^5)	(S_3^5)	(S_4^5)	(S_1^5)	(S_3^5)
	DM2	(S_4^7)	(S_3^7)	(S_5^7)	(S_3^7)	(S_2^7)
	DM3	(S_3^9)	(S_5^9)	(S_6^9)	(S_4^9)	(S_4^9)
SC3	DM1	(S_3^5)	(S_5^5)	(S_2^5)	(S_5^5)	(S_2^5)
	DM2	(S_4^7)	(S_4^7)	(S_5^7)	(S_6^7)	(S_4^7)
	DM3	(S_5^9)	(S_5^9)	(S_7^9)	(S_5^9)	(S_6^9)

Table 4. SCs' Performance Evaluation

	DM	C1	C2	C3	C4	C5
SC1	DM1	$(S_3^5, 0)$	$(S_2^5, 0)$	$(S_3^5, 0)$	$(S_2^5, 0)$	$(S_4^5, 0)$
	DM2	$(S_4^7, 0)$	$(S_4^7, 0)$	$(S_5^7, 0)$	$(S_3^7, 0)$	$(S_5^7, 0)$
	DM3	$(S_7^9, 0)$	$(S_4^9, 0)$	$(S_5^9, 0)$	$(S_5^9, 0)$	$(S_7^9, 0)$
SC2	DM1	$(S_2^5, 0)$	$(S_3^5, 0)$	$(S_4^5, 0)$	$(S_1^5, 0)$	$(S_3^5, 0)$
	DM2	$(S_4^7, 0)$	$(S_3^7, 0)$	$(S_5^7, 0)$	$(S_3^7, 0)$	$(S_2^7, 0)$
	DM3	$(S_3^9, 0)$	$(S_5^9, 0)$	$(S_6^9, 0)$	$(S_4^9, 0)$	$(S_4^9, 0)$
SC3	DM1	$(S_3^5, 0)$	$(S_5^5, 0)$	$(S_2^5, 0)$	$(S_5^5, 0)$	$(S_2^5, 0)$
	DM2	$(S_4^7, 0)$	$(S_4^7, 0)$	$(S_5^7, 0)$	$(S_6^7, 0)$	$(S_4^7, 0)$
	DM3	$(S_5^9, 0)$	$(S_5^9, 0)$	$(S_7^9, 0)$	$(S_5^9, 0)$	$(S_6^9, 0)$

Table 5. SCs' performance evaluation in the same linguistic set

	DM	C1	C2	C3	C4	C5
SC1	DM1	$(S_3^5, 0)$	$(S_2^5, 0)$	$(S_3^5, 0)$	$(S_2^5, 0)$	$(S_4^5, 0)$
	DM2	$(S_4^7, 0.33)$	$(S_4^7, 0.33)$	$(S_5^7, -0.33)$	$(S_3^7, 0)$	$(S_5^7, 0.33)$
	DM3	$(S_7^9, 0)$	$(S_4^9, 0)$	$(S_5^9, 0)$	$(S_5^9, 0)$	$(S_7^9, 0)$
SC2	DM1	$(S_2^5, 0)$	$(S_3^5, 0)$	$(S_4^5, 0)$	$(S_1^5, 0)$	$(S_3^5, 0)$
	DM2	$(S_4^7, 0.33)$	$(S_3^7, 0)$	$(S_5^7, -0.33)$	$(S_3^7, 0)$	$(S_2^7, -0.33)$
	DM3	$(S_3^9, 0)$	$(S_5^9, 0)$	$(S_6^9, 0)$	$(S_4^9, 0)$	$(S_4^9, 0)$
SC3	DM1	$(S_3^5, 0)$	$(S_5^5, 0)$	$(S_2^5, 0)$	$(S_5^5, 0)$	$(S_2^5, 0)$
	DM2	$(S_4^7, 0.33)$	$(S_4^7, 0.33)$	$(S_5^7, -0.33)$	$(S_6^7, 0)$	$(S_4^7, 0.33)$
	DM3	$(S_5^9, 0)$	$(S_5^9, 0)$	$(S_7^9, 0)$	$(S_5^9, 0)$	$(S_6^9, 0)$

Table 6. The Calculation of Decision Makers' Weight

	DM	C1		C2		C3		C4		C5	
		Similarit-y Degree	w_k^*	Similarit-y Degree	w_k^*	Similarit-y Degree	w_k^*	Similarit-y Degree	w_k^*	Similarit-y Degree	w_k^*
SC1	DM1	0.938	0.47	0.964	0.48	0.652	0.33	0.752	0.38	0.497	0.25
	DM2	0.561	0.28	0.354	0.18	0.391	0.19	0.752	0.38	0.645	0.32
	DM3	0.5	0.25	0.681	0.34	0.957	0.48	0.496	0.24	0.858	0.43
SC2	DM1	0.86	0.43	0.5	0.25	0.262	0.13	0.799	0.4	0.501	0.25
	DM2	0.528	0.27	0.5	0.25	0.781	0.39	0.6	0.3	0.818	0.41
	DM3	0.611	0.3	1	0.5	0.957	0.48	0.6	0.3	0.681	0.34
SC3	DM1	0.495	0.25	0.5	0.25	0.756	0.38	0.75	0.38	0.5	0.25
	DM2	0.9	0.45	0.794	0.4	0.658	0.33	0.75	0.38	0.9	0.45
	DM3	0.604	0.3	0.706	0.35	0.585	0.29	0.5	0.24	0.6	0.3

Table 7. SCs' performance evaluation in the same linguistic set

Final Rating	C1	C2	C3	C4	C5
SC1	$(S_6^9, 0.06)$	$(S_4^9, 0.24)$	$(S_6^9, -0.35)$	$(S_4^9, 0.24)$	$(S_7^9, 0.14)$
SC2	$(S_4^9, -0.03)$	$(S_5^9, 0)$	$(S_7^9, -0.48)$	$(S_3^9, -0.2)$	$(S_3^9, 0.27)$
SC3	$(S_5^9, 0.25)$	$(S_6^9, -0.12)$	$(S_6^9, -0.25)$	$(S_7^9, 0.25)$	$(S_5^9, -0.1)$

Table 8. Required Performance for Each Criterion

	C1	C2	C3	C4	C5
DM1	S_3^5	S_2^5	S_2^5	S_3^5	S_4^5
DM2	S_5^7	S_4^7	S_5^7	S_4^7	S_4^7
DM3	S_6^9	S_6^9	S_5^9	S_5^9	S_7^9

Table 9. Weight of Experts Regarding Their Idea in Determining the RequiredPerformance

	C1		C2		C3		C4		C5	
	Similarit-y Degree	w_k^*	Similarit-y Degree	w_k^*	Similarit-y Degree	w_k^*	Similarit-y Degree	w_k^*	Similarit-y Degree	w_k^*
DM1	0.92	0.34	0.91	0.46	0.45	0.23	0.35	0.18	0.7	0.35
DM2	0.84	0.32	0.81	0.41	0.59	0.3	0.81	0.4	0.61	0.31
DM3	0.92	0.34	0.27	0.13	0.95	0.47	0.85	0.42	0.69	0.34

Table 10. Final 2-Tuple for the Required Performance

	C1	C2	C3	C4	C5
DM	$(S_6^9, -0.09)$	$(S_4^9, 0.49)$	$(S_5^9, -0.02)$	$(S_5^9, 0)$	$(S_7^9, -0.41)$

Table 11. Final Answers

Name	SI index	Ranking
SC1	0.053	2
SC2	-0.282	3
SC3	0.613	1

Table (11) demonstrates that SC3 is the best choice and its performance is more than that required by decision makers. In addition, it depicts that SC2 does not reach the required performance. SC3 and SC1 can meet the minimum requirements to get the job. Although SC3 has a higher rank than SC1, decision makers can decide to select SC3 or SC1 based on some considerations such as their bidding price, etc. Nevertheless, SC2 cannot meet the minimum requirement and it is not eligible for subcontracting.

Results show that the proposed methodology is able to evaluate candidates and answer this question whether each candidate is qualified enough to handle the project's tasks or not. In the next section, the model attempts to select the best candidate with the highest similarity index. In this example, SC3 has a high performance in the criteria especially criteria number one and five. These criteria are those with the highest weight. Counterclockwise, SC2 who cannot pass the prequalification phase (negative similarity index) shows a poor performance in all criteria. The model can be more useful when the performance of candidates and also the weights of criteria will be competitive. In this situation, decision making will be more complicated than other conditions.

5- Consistency Test

To investigating the accuracy of the proposed methodology, one of the most famous numerical examples which has been solved by previous authors are considered. An investment company wants to invest a sum of money in the best option (adapted from [23]). There is a panel with five possible alternatives to invest the money including:

(1) A1 is a car company;
(2) A2 is a food company;
(3) A3 is a computer company;
(4) A4 is an arm company;
(5) A5 is a TV company.

These alternatives should be evaluated according to the following four attributes:

(1) G1 is the risk analysis;
(2) G2 is the growth analysis;
(3) G3 is the social-political impact analysis;
(4) G4 is the environmental impact analysis.

The five possible alternatives $A_i(i=1, 2, ..., n)$ are to be evaluated using the linguistic term set:

$$S=\begin{Bmatrix} S_1=extremely\ poor(EP), & S_2=very\ poor(VP), & S_3=poor(P), & S_4=medium(M), \\ S_5=good(G), & S_6=very\ good(VG), & S_7=extremely\ good(VG) \end{Bmatrix} \quad (13)$$

The question is which one of the alternatives is the best choice. As stated, this problem has been solved by some researchers, but in this paper, three approaches are explained and their results are compared with the results of the papers' methodology.

- Wei [26] developed the TOPSIS method for 2-tuple linguistic multiple attribute group decision making with incomplete information. The main concept of his work was to combine the TOPSIS method with the 2-tuple linguistic model and solve the problem with incomplete weight information. The TOPSIS method ranks alternatives based on their distance from the positive and negative ideal solution. For more information, refer to Wei [26]. This example was solved by this model.

- Wei [27] solved this problem by a combination of gray relation analysis and a 2-tuple linguistic approach. The gray theory works with the level of available information. If the system information is fully known, the system is called a white system; if the information is unknown, it is called a black system. The Grey relation theory is a part of the gray system theory which is suitable for solving problems with complicated interrelationships between multiple factors and variables [27]. Wei proposed a methodology based on the combination of grey relation analysis and 2-tuple linguistic multiple attribute group decision making with incomplete weight information. For more information refer to [27].
- Wei and Zhao [24] proposed the multiple attribute group decision-making model in which the attribute values take the form of 2-tuple linguistic information and solved the above example in their study. The main concept of their model is based on developing some dependent 2-tuple linguistic aggregation operators: the dependent 2-tuple ordered weighted averaging (D2TOWA) operator and the dependent 2-tuple ordered weighted geometric (D2TOWG) operator. In their model, ideas with the bias from the optimized idea take a lower weight than others and vice versa. For more information refer to [24].

All of them used the experts' idea as the matrixes below. Regarding the concept of incomplete weight information in some of the above works, the weight vector for each paper is different. Table (12) demonstrates the results of solving this example by the proposed model by this paper and other works in the two methods, including TOPSIS (NO 1) and grey relation analysis (NO 2), the aggregation of the experts' idea has been made by averaging, but in D2TOWA and D2TOWG, the final answer has been obtained based on the weight of each expert which was calculated according to the distance of their ideas from the accepted one. Regarding the concept of group decision-making applied to previous works, there are some differences in the selection of the best alternative. In TOPSIS and grey relation analysis, the best alternative is A_4 but the paper's methodology has picked up A_3. Due to the concept of weighting experts' opinions in D2TOWA and D2TOWG, the best choice in D2TOWA, D2TOWG, and the paper's model is the same as A_4. This test showed that the paper's methodology for modeling the concept of group decision making works properly. To investigate the accuracy of results based on the *SI* index, the final expert's idea obtained by TOPSIS and gray relation analysis was applied for getting the *SI* index. Table (12) depicts the results of this comparison. As shown in Table (13), with the use of same collective 2-tuple linguistic decision matrix, the final results are similar. This test can validate the accuracy of the *SI* index.

6- Conclusion

Nowadays, the existing complexity in the construction

$$R_1=\begin{pmatrix}(M,0)&(G,0)&(P,0)&(P,0)\\(P,0)&(VP,0)&(M,0)&(P,0)\\(G,0)&(M,0)&(G,0)&(EP,0)\\(VG,0)&(P,0)&(P,0)&(G,0)\\(EG,0)&(EP,0)&(VP,0)&(M,0)\end{pmatrix}\quad R_2=\begin{pmatrix}(P,0)&(M,0)&(VP,0)&(VP,0)\\(VP,0)&(EP,0)&(G,0)&(G,0)\\(M,0)&(G,0)&(P,0)&(EG,0)\\(EG,0)&(VP,0)&(VP,0)&(M,0)\\(P,0)&(VP,0)&(M,0)&(VP,0)\end{pmatrix}$$

$$R_3=\begin{pmatrix}(G,0)&(P,0)&(VP,0)&(VG,0)\\(VP,0)&(G,0)&(P,0)&(G,0)\\(VG,0)&(VP,0)&(G,0)&(P,0)\\(G,0)&(VG,0)&(EG,0)&(VP,0)\\(M,0)&(VP,0)&(M,0)&(G,0)\end{pmatrix}$$

Fig. 3. Decision Matrix

Table 12. Final Results Based on Different Approaches

NO	Model Name	Weight Vector	Results
1	TOPSIS and 2-tuple linguistic	ω = (0.18, 0.23, 0.356, 0.144)	$A_4 > A_3 > A_1 > A_2 > A_5$
0	Paper's model		$A_3 > A_4 > A_1 > A_2 > A_5$
2	Grey Relation Analysis and 2-tTuple Linguistic	ω = (0.2, 0.3, 0.35, 0.15)	$A_4 > A_3 > A_1 > A_2 > A_5$
0	Paper's Model		$A_3 > A_4 > A_2 > A_1 > A_5$
3	D2TOWA	ω = (0.2, 0.3, 0.35, 0.15)	$A_4 > A_3 > A_5 > A_2 > A_1$
3	D2TOWG		$A_4 > A_3 > A_5 > A_1 > A_2$
0	Paper's Model		$A_4 > A_3 > A_5 > A_2 > A_1$

Table 13. Checking Selection Index

NO	Model Name	Weight Vector	Results
1	TOPSIS and 2-tTuple Linguistic Model	$\omega = (0.18, 0.23, 0.356, 0.144)$	$A_4 > A_3 > A_1 > A_2 > A_5$
0	Paper's Model	$R=\begin{pmatrix} (M,0) & (M,0) & (VP,0.33) & (M,-0.33) \\ (VP,0.33) & (P,-0.33) & (M,0) & (M,0.33) \\ (G,0) & (M,-0.33) & (M,0.33) & (M,-0.33) \\ (VG,0) & (M,-0.33) & (M,0) & (M,-0.33) \\ (G,-0.33) & (VP,-0.33) & (P,0.33) & (M,-0.33) \end{pmatrix}$	$A_4 > A_3 > A_1 > A_2 > A_5$
2	Grey Relation Analysis and 2-Tuple linguistic Model	$\omega = (0.2, 0.3, 0.35, 0.15)$	$A_4 > A_3 > A_1 > A_2 > A_5$
0	Paper's Model	$R=\begin{pmatrix} (M,0) & (M,0) & (VP,0.33) & (M,-0.33) \\ (VP,0.33) & (P,-0.33) & (M,0) & (M,0.33) \\ (G,0) & (M,-0.33) & (M,0.33) & (M,-0.33) \\ (VG,0) & (M,-0.33) & (M,0) & (M,-0.33) \\ (G,-0.33) & (VP,-0.33) & (P,0.33) & (M,-0.33) \end{pmatrix}$	$A_4 > A_3 > A_1 > A_2 > A_5$

projects needs to gather various skills to carry out the project's tasks. SC is the party to help contractors in project execution. Owing to the impact of SCs on various aspects of project indices such as cost, time and quality, SC management is one of the crucial efforts made in the construction projects. SCs are the projects' party who carry out most of the project's tasks thus their performances affect the project performances directly. The first step in the SC management is the selection. The right selection leads to an increase in the probability of the project's success. Regarding the importance of the selection phase, this paper presented a model for SC selection. In view of the fact that SC selection is done by group decision-making and the fact that experts usually expressed their ideas based on the linguistic terms, because of the inherent vagueness and the lack of information documented in contractor companies especially for evaluation of SCs, this model applied the 2-tuple linguistic approach for working with words and proposed a methodology to calculate the weights of experts according to their opinions. In addition, an index was offered to decide on the selection of SCs based on its sign and value. The proposed methodology is not only used for calculating the weight of experts in group decision making but it is also a useful tool for judging about the selection of suitable SC for a specific job. Results of proposed methodology showed that the model is able enough to screen and select candidates and also when the characteristics of candidates are close to each other, applying this model would be beneficial.

While the proposed steps is able to select the best SC in each project, it can encounter with some serious challenges. The most important benefit of this model is working with linguistic terms and this is the main reason why the proposed model is practical. In the real situation, when decision makers want to select the best SC, they evaluate them in various criteria by applying linguistic terms, such as a good performance or bad performance. Every user can evaluate candidates based on linguistic terms shown in Table (2) and this does not need to know any information about the concept of fuzzy or group decision making. But the most important challenge of this model is some the calculations to achieve the goal. In practice, doing these calculations can be cumbersome or impractical. Therefore, the authors suggest that any software such as MATLAB, Visual Basic, etc. can be applied for modeling the mentioned steps and developing a user-friendly software. For more convenience of users and preparing a graphical user interface (GUI), developing a software is essential. As a result, working with this model can be divided into two sections. The first one is the evaluation of SCs which is done by linguistic terms as the same as the real situations and the second section is the calculation and introducing the best SC. This section can be modeled in any software for more convenience of users.

Regarding knowledge of the authors with various aspects of SC subject, the future works can be defined in preparing a user-friendly software for working with the model steps and SCs selection in real situation and the other area can be defined in modeling other steps of SC management such as performance evaluation, order allocation and aligning SCs in the project. For all of these subjects, the 2-tuple linguistic model can be applied to working with words.

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