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Multi-attribute fuzzy decisions in construction strategies

Ziad A. Eldukair
King Saud University, Department of Civil Engineering, P.O. Box 10480, Riyadh 11433, Saudi Arabia
Bilal M. Ayyub
University of Maryland, Department of Civil Engineering, College Park, MD 20742, USA

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Abstract: Construction operations usually involve several strategies which need to be considered to effectively ensure safety in the preparation and execution of work activities. The condition or state of the factors affects the safety of construction operations, the schedule of construction, and the total cost of the project. The decision establishing the level of the factors is important to set safe, as well as cost effective, construction strategies.

In this paper, a methodology for selecting desirable construction strategies for construction operations is presented. The methodology is based on a Fuzzy Multi-Attribute Decision Making Analysis (FMADMA). The development of the framework of the decision analysis minimizes the relative risk of failures and accidents while reducing the total expected cost of performing the construction strategy.

In this method, each alternative of the state of the factors is subjectively evaluated based on experts' judgment with respect to certain defined criteria or desirable goal elements for a construction strategy. Then, the subjective aggregation of the ratings of the available state of the factors and the relative importance of the criteria required to determine safe and reliable, as well as economical construction strategies is evaluated by means of fuzzy membership functions and operations. Finally, a ranking measure of the alternatives is developed according to the aggregated subjective judgments. The development of the framework of the decision analysis minimizes the relative risk of failures and accidents while reducing the total expected cost of performing the construction strategy.

The methodology is verified with an example to define the optimum construction strategy, i.e., resources, for a reinforced concrete slab operation for a certain project with all concerns to the market situation, the contractors and engineering capabilities, and the financial circumstances for the project.

The methodology can be implemented during the planning, design, and construction phases of the building process. The most effective stage for implementing this methodology is realized during the construction phase of the building process since many external factors may affect, without any proper engineering controls, the execution of the construction operation.

Keywords: Multi-attribute decision making; optimization techniques; ranking of multiple alternatives; construction strategies; fuzzy set theory.

1. Introduction

The performance of construction operations is considered hazardous and subject to many failures and accidents. There are many factors affecting construction operations that might lead to unreliable work situations.

Construction strategies are defined as the selection and implementation of necessary resources of materials, equipment, knowledge and experience in planning, engineering, contracts, procurement, and work operation environment to optimize and control all project objectives safely, cost-effectively, and efficiently. The definition of construction strategies is an important process to achieve construction operations which are essential elements to accomplish the different phases and activities of the building process.

There are many factors which define construction strategies. For example, a construction strategy for reinforced concrete buildings is defined by the methods of construction, sequence of construction, condition of temporary structures, level of workers' skill and attitude, level of engineering knowledge, level of engineering supervision and control, and type and use of materials and equipment [1, 4, 5, 7, 8].

The condition or state of the factors affects the safety of construction operations, the schedule of work activities, and the total cost of the project. The decision establishing the level of the factors is important to set safe, as well as cost effective construction strategies.

2. Decisions in construction strategies

There are many factors which define construction strategies. The methodology followed to determine the different levels of the factors is based on a Fuzzy Multi-Attribute Decision Making analysis (FMADMA). In this method, each alternative of the state of the factors is subjectively evaluated based on experts' judgment with respect to certain defined set of criteria and desirable goal elements for a construction strategy.

The criteria elements include the minimization of the risk of failure and accident of construction operations and the total cost of the operations. The subjective aggregation of the ratings of the available state of the factors and the relative importance of the criteria required to determine safe, reliable, and economical construction strategies are evaluated by means of fuzzy membership functions and operations. Then, the aggregation of the experts' judgment about all goals and per decision alternative is considered. Finally, a ranking or a rating of the alternative, i.e., level of the factor, is developed according to the aggregated subjective judgments [2, 6, 11, 12].

The uncertainty involved in the determination and evaluation of construction strategies is modeled using fuzzy sets. The ratings of the state of the factors represent the constraints on selecting construction strategies. The various goals or standards of the decision environment become the criteria for selecting construction strategies [3, 9]. The combination of the constraints, i.e., alternatives; and the goals, i.e., criteria, produces the decision framework for selecting appropriate construction strategies as shown in Figure 1.

The methodology for the optimization of the factors is divided into three phases. The first phase defines the elements of the decision model. The second phase determines effective construction strategies. The final phase which is beyond the scope of this paper, estimates relative risks and expected costs of the construction strategy, i.e., determines the total costs of the operation [6].

2.1. Elements of the optimization methodology

The optimization methodology for construction operations involves two major elements [6]. The first element includes the definition of a set of alternative state of the factors, i.e., resources, which

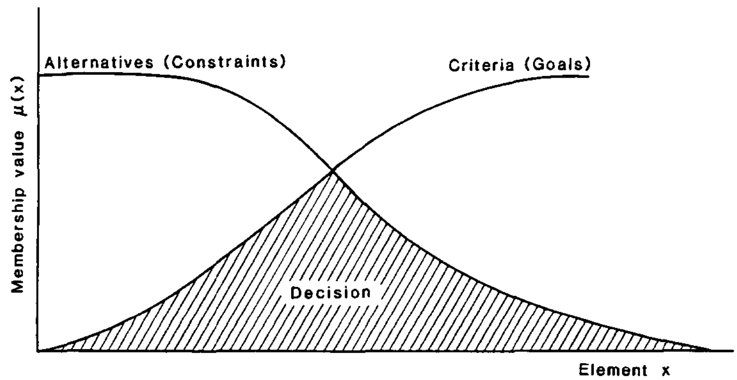

Fig. 1. Elements of the decision-making environment [3].

accomplish and affect the safety of construction operations. The different states of the factors are usually determined subjectively based on experts' judgment. Therefore, they are classified in linguistic terms which may range from 'very good' to 'very poor' conditions.

The second major element of the optimization methodology includes the definition of a set of decision criteria to be considered in the evaluation and selection of effective construction strategies. The criteria used to determine the alternatives of the state of the factors include the minimization of the risk of failures and accidents, and of failure and accident costs during construction operations, and minimization of the initial costs for selecting construction strategies.

The different states of the factors and the criteria for decision-making are the input resources for the selection of construction strategies. On the other hand, the relative states of the factors are constraints or restrictions for evaluating construction strategies.

2.2. Determination of construction strategies

It is essential to determine the levels or states of the factors to develop safe and cost-effective construction operations.

Each alternative of the state of the factors is rated with respect to the decision criteria. The rating of the alternatives with respect to the criteria is assumed to be a linguistic variable whose measures can range from 'very good' to 'very poor'. The linguistic measures of the rating variable are translated into mathematical measures using the theory of fuzzy sets and systems [6].

Another important parameter for selecting the alternative states of the factors, is to evaluate the weight of the decision criteria which define the construction strategy. The weights of the criteria are also considered linguistic variables. The expression of the linguistic measures for defining the weight of the decision criteria ranges from 'very important' to 'fairly important'.

3. Mathematical framework

The mathematical framework for the fuzzy multi-attributive decision model for determining the optimizing construction operations are developed as follows:

Let $A = \{a_i\}$ be a set of alternatives for the state of the factors, where $i = 1, 2, \ldots, n$. Let $C = \{c_k\}$, $k = 1, 2, \ldots, r$, be a set of criteria elements representing the goals for the desired construction strategy. Consider the rating of each available alternative of the state of the factors with respect to the criteria elements. The fuzzy set R_{ik} represents the rating of the state of the alternative, a_i, with respect to the criterion, c_k, which is expressed by linguistic measures. The membership function of the rating of the state of the alternatives is represented by $\mu_{R_{ik}}(r_{ik})$.

Similarly, assume that the relative importance of the criteria elements c_k, which defines the goals for the construction strategy, is represented by a fuzzy set W_j with a membership function $\mu_{W_j}(w_j)$.

There are certain steps which need to be followed so that effective construction strategies may be determined. They include that the states of the factors must be assumed to be the available resources for the construction operation. On the other hand, the various categories of the available states of the factors affecting the safety of construction operations must be defined in linguistic measures.

In addition, a rating framework for each alternative a_i with respect to criteria c_k needs to be established along with a relative weight for each of the goals of the construction strategies. Then, a fuzzy relation, S_{ij}, between the rating R_{ik} of the alternatives and the relative weight W_j of the criteria c_k needs to be developed. The relation is assumed to be based on a 'hard' version of the fuzzy Cartesian product, $R_{ik} \times W_j$, which is defined by the following membership function:

$$\mu_S(r_{ik}, w_j) = \min[\mu_R(r_{ik}), \mu_W(w_j)]. \tag{1}$$

The next step is to consider the total effect of all the alternative ratings of the states of the factors on the relative weight of the criteria, S_{ij}. The evaluation of the effect of the fuzzy relationship S_{ij} can be developed by considering the aggregation of the product; of the maximum sum of the products of the membership function of the ordered pairs (r_{ik}, w_j) and the fuzzy rating elements of each alternative; and the maximum sum of the products of the membership function of the ordered pairs (r_{ik}, w_j) and the fuzzy elements of the decision criteria. This approach evaluates the attributes of the ratings of each alternative with respect to the relative importance or weight of the criteria elements. Mathematically, the evaluation of the fuzzy relationship S_{ij} can be developed as

$$A = \sum_{S_{ij}} \left\{ \left(\max \sum_{i=1}^{n} r_{ik} * \mu_{(r_{ik} \times w_j)} \right) * \left(\max \sum_{j=1}^{m} w_j * \mu_{(r_{ik} \times w_j)} \right) \right\}, \tag{2}$$

where A is the relationship representing the effect of the rating of the alternative states and the relative weight of the decision criteria, r_{ik} is the fuzzy rating element of alternative a_i with respect to criteria c_k, $\mu_{(r_{ik} \times w_j)}$ is the membership function for the ordered pairs $(r_{ik} \times w_j)$ of rating alternative a_i with respect to the relative importance of the decision criteria c_k, w_j is the fuzzy element of the relative weight or importance of the criteria c_k, and $*$ is the notation of the algebraic product.

Another important step towards ranking the priority of the alternatives, i.e., the best selection of the state of the resources, is to evaluate the total effect of the relative weight of the decision criteria c_k. The total effect of the relative importance or weight of the decision criteria is based on determining the sum of the products of the elements of the relative weight of the criteria and the membership function of the relative importance of the criteria. Therefore, mathematically, the total effect of the criteria, B, on the decision-making process to define effective construction strategies can be developed as

$$B = \sum_{j=1}^{m} w_j * \mu_{w_j}, \tag{3}$$

where w_j is the fuzzy element of the relative weight or importance of the criterion c_k, μ_{w_j} is the membership value of the relative importance of criterion c_k, and $*$ is the notation for the algebraic product.

Finally, a rank measure, $\tilde{R}_{i_l}$, for each alternative course of action a_i of factor l, i.e., resource selection, with respect to the total effect of the relative importance of the decision criteria needs to be evaluated. The rating measure can be developed by obtaining the weighted average of each alternative, a_i, with respect to the overall effect of the decision criteria. The rank measure of the alternatives can be represented by

$$\tilde{R}_{jl} = \frac{\sum \{(\max \sum r_{ik} * \mu_{(r_{ik} \times w_j)}) * (\max \sum w_j * \mu_{(r_{ik} \times w_j)})\}}{\sum w_j * \mu_{w_j}}. \tag{4}$$

The alternative a_i with the maximum expected rank measure $\tilde{R}_{il}$, is considered to be the most desirable state for the resource factor of the construction strategy.

4. Example to determine a construction strategy for RC slabs

Consider a reinforced concrete (RC) slab for a multi-story commercial complex. Assume that the project is in the early stages of the construction phase of the building process. The project manager is interested in determining a safe and cost-effective construction strategy to execute slab operations.

There are many possible construction strategies for the slab construction operation. Multi-attribute decision analysis based on a fuzzy approach can be used to determine the most desirable construction strategy bearing in mind all the levels and the availability of the resources. Assume for this example that the construction strategy of the reinforced concrete slab operation can be defined as shown in Table 1.

The interest of any construction team is to implement the 'best and most effective' resources to perform the construction operation. But this is not always the case, since the alternative states of the

Table 1. Factors affecting the construction operation

Factor number, l	Description of the factors
1	Level of workers' skill and attitude
2	Level of engineering experience
3	Level of supervision and control
4	Condition of construction methods
5	Falsework condition
6	Type and use of materials and equipment

factors are dependent on the construction market and on the budget constraints and limitations on performing the construction operation. Therefore, we assume that the levels of the state of all the factors affecting the reinforced concrete slab operation can range from 'very good' to 'very poor'. The assessment of the alternative states of the factors is defined in Table 2.

The next step is to determine the set of criteria which evaluates and defines the desirable construction strategy. The different alternative states of each factor should be rated with respect to the criteria which define the construction strategy. In addition, since the total weight of the criteria should be considered for the decision-making process, a relative importance or weight for each criterion must be developed.

The variables for the ratings of each factors' state and relative importance of the criteria are often expressed in linguistic terms because they are usually based on the subjective judgment of experts.

At this stage, the concept of fuzzy sets is used to translate the linguistic or qualitative measures, associated with the rating and the relative importance variables, into mathematical terms. This is done by assuming the following membership functions for evaluating the subjectivity of the factors. The development of these fuzzy membership functions depends on the judgment and experience of the expert [1, 10].

$$\text{Good} = \text{Important} = [0.8 \mid 0.5, 0.9 \mid 0.9, 1.0 \mid 1.0], \tag{5}$$

$$\text{Fairly; Good, Important} = [0.8 \mid 0.7, 0.9 \mid 0.95, 1.0 \mid 1.0], \tag{6}$$

$$\text{Very; Good, Important} = [0.8 \mid 0.25, 0.9 \mid 0.81, 1.0 \mid 1.0], \tag{7}$$

$$\text{Moderate} = [0.3 \mid 0.2, 0.4 \mid 0.8, 0.5 \mid 1.0, 0.6 \mid 0.8, 0.7 \mid 0.2], \tag{8}$$

$$\text{Proof} = [0.0 \mid 1.0, 0.1 \mid 0.9, 0.2 \mid 0.5], \tag{9}$$

$$\text{Fairly poor} = [0.0 \mid 1.0, 0.1 \mid 0.95, 0.2 \mid 0.7], \tag{10}$$

$$\text{Very poor} = [0.0 \mid 1.0, 0.1 \mid 0.81, 0.2 \mid 0.25]. \tag{11}$$

Table 2. Alternative states of the factors

Factor number	Alternative states[a], a_i						
	(1) VG	(2) G	(3) FG	(4) M	(5) FP	(6) P	(7) VP
1	–	×	–	×	–	–	–
2	×	×	–	×	–	–	–
3	–	×	×	×	–	–	–
4	–	×	×	×	×	–	–
5	–	×	–	×	–	–	–
6	–	×	–	×	–	–	–

[a] VG = very good; G = good; FG = fairly good; M = moderate; FP = fairly poor; P = poor; VP = very poor; × = existence of state; – = state level is unavailable.

Table 3. Assessment and rating of the alternative states of factor 1[a]

Criteria c_k	Importance w_j	Alternative states of Factor 1 G (r_{1k})[b]	M (r_{2k})[b]
1. Minimize risk	V important	G	M
2. Minimize initial costs	F important	P	G
3. Minimize damage costs	Important	G	M

[a] G = good; M = moderate; V = very; F = fairly; P = poor.
[b] Rating of alternatives.

4.1. Evaluation of the construction strategy

The evaluation of the construction strategy is developed based on assessing each factor affecting the performance of the reinforced concrete operation relative to the importance of decision criteria and the availability of the resources for the operation. Therefore, the assessment of the first factor defining the construction strategy for the slab construction operation can be developed as follows:

Factor No. 1: Level of workers' skill and attitude

There are two alternative states for this factor depending on the availability of the resources in the construction market and the financial budget for the project. The alternative states of the factors are defined as shown in Table 2 as either 'good', or 'moderate'. The rating r_{ik} of each alternative state a_i with respect to the criteria c_k of the construction strategy, and the relative importance w_j of the criteria, is expressed subjectively based on the experience of the project manager by qualitative measures. Table 3 presents the ratings and weights of the alternative states and the criteria elements, respectively.

In order to determine a reliable and cost-effective construction strategy, a ranking measure for each alternative state needs to be considered.

Alternative 1: Good level of workers' skill and attitude

The qualitative rating, r_{ik} of the alternative with respect to the criteria of the construction strategy, and the relative importance of the criteria w_j, are presented in Table 3. Translating the linguistic measures of the rating and weight variables into mathematical terms using appropriate values from equations (5)–(11), then combining the ratings of the alternative r_{ik}, with respect to the criteria importance by means of the fuzzy Cartesian relation, the following relationships can be developed:

$$
\begin{array}{ll|lll}
S_{11} = c_1 \times r_{11} & & \multicolumn{3}{l}{\text{Rating } r_{11} = \text{Good}} \\
 & & 0.8 & 0.9 & 1.0 \\
\hline
\text{Criterion } c_1 & 0.8 & 0.25 & 0.25 & 0.25 \\
= \text{V important} & 0.9 & 0.5 & 0.81 & 0.81 \\
 & 1.0 & 0.5 & 0.9 & 1.0
\end{array}
\tag{12}
$$

$$
\begin{array}{ll|lll}
S_{12} = c_2 \times r_{12} & & \multicolumn{3}{l}{\text{Rating } r_{12} = \text{Poor}} \\
 & & 0.0 & 0.1 & 0.2 \\
\hline
\text{Criterion } c_2 & 0.8 & 0.7 & 0.7 & 0.5 \\
= \text{F important} & 0.9 & 0.95 & 0.9 & 0.5 \\
 & 1.0 & 1.0 & 0.9 & 0.5
\end{array}
\tag{13}
$$

$$
\begin{array}{ll|lll}
S_{13} = c_3 \times r_{13} & & \multicolumn{3}{l}{\text{Rating } r_{13} = \text{Good}} \\
 & & 0.8 & 0.9 & 1.0 \\
\hline
\text{Criterion } c_3 & 0.8 & 0.5 & 0.5 & 0.5 \\
= \text{Important} & 0.9 & 0.5 & 0.9 & 0.9 \\
 & 1.0 & 0.5 & 0.9 & 1.0
\end{array}
\tag{14}
$$

The next stage is to evaluate equations (12)–(14) to determine the effect of the rating of the alternative on the criteria. The rating of the alternative is evaluated by the products of the maximum sum of the products of the ordered pairs membership function and the rating elements, and the maximum sum of the products of the ordered pairs membership function and the criterion elements of the alternative. The effect of the rating S_{ij} of this alternative on the decision criteria c_k can be developed as

$S_{11} = c_1 \times r_{11}$		Rating r_{11} = Good 0.8	0.9	1.0	Row summation
Criterion c_1	0.8	0.25	0.25	0.25	0.6
= V important	0.9	0.5	0.81	0.81	1.91
	1.0	0.5	0.9	1.0	2.4
Column summation		1.0	1.76	2.06	

(15)

Effect of $S_{11} = c_1 \times r_{11} = 2.06 \times 2.4 = 4.94.$ (16)

$S_{12} = c_2 \times r_{12}$		Rating r_{12} = Poor 0.0	0.1	0.2	Row summation
Criterion c_2	0.8	0.7	0.7	0.5	1.52
= F important	0.9	0.95	0.9	0.5	2.11
	1.0	1.0	0.9	0.5	2.4
Column summation		0.0	0.25	0.3	

(17)

Effect of $S_{12} = c_2 \times r_{12} = 0.3 \times 2.4 = 0.72.$ (18)

$S_{13} = c_3 \times r_{13}$		Rating r_{13} = Good 0.8	0.9	1.0	Row summation
Criterion c_3	0.8	0.5	0.5	0.5	1.2
= Important	0.9	0.5	0.9	0.9	2.07
	1.0	0.5	0.9	1.0	2.4
Column summation		1.2	2.07	2.4	

(19)

Effect of $S_{13} = c_3 \times r_{13} = 2.4 \times 2.4 = 5.76.$ (20)

At this stage, the relative importance of each criteria presented in Table 1, needs to be evaluated by translating the linguistic measures for the relative importance of each criteria into mathematical terms. The total effect of the decision criteria, c_k, is determined based on the sum of the products of the elements of the importance of the criteria w_j, and the corresponding membership values $\mu(w_j)$. Therefore, using equation (3), the total effect of the relative importance of the criteria elements can be shown to be

$$\begin{aligned} \text{Total weight of the criteria} &= 1.929 + 2.415 + 2.21 \\ &= 6.554. \end{aligned} \tag{21}$$

In order to evaluate and determine the relative weight of the alternative, a certain rank measure of the first alternative, i.e., $a_i = 1$, for the first factor, i.e., $l = 1$, $\tilde{R}_{il}$, needs to be developed. The rank measure can be obtained by determining the weighted average of the total effect of the rating of the alternative with respect to the overall effect of the decision criteria. The rank measure of the alternatives of the factors can be represented by

$$\tilde{R}_{il} = \frac{\sum_{S_{ij}} \{(\max \sum r_{ik} \cdot \mu_{(r_{ik} \times w_j)}) \cdot (\max \sum w_j \cdot \mu_{(r_{ij} \times w_j)})\}}{\sum_{j=1}^{3} w_j \cdot \mu_{w_j}}. \tag{22}$$

Therefore, the estimates of the rank measure of alternative $a_i = 1$ and factor $l = 1$, i.e., 'good level of workers' skill and attitude', can be shown to be

$$\bar{R}_{11} = \frac{4.94 + 0.72 + 5.76}{6.554} = 1.74. \tag{23}$$

Similarly, the estimates of the rank measure of alternative 2, i.e., 'moderate level of workers' skills and attitude', can be shown to be

$$\bar{R}_{21} = 2.05. \tag{24}$$

In order to evaluate the rest of the factors, the project manager needs to assess subjectively based on his judgment, knowledge and experience, the ratings of the alternatives of the factors and the relative importance of the decision criteria elements. Some of the suggested ways which the project manager can follow to assess the factors affecting the safety of construction operations are through regular daily and weekly work meetings and quality circles. During these meetings, the various engineering parties involved in the job assess the condition of the factors that affect the work progress and evaluate the problems and progress of project operations. The discussions are usually based on experts' judgment to implement effective, efficient, and safe construction methods and operations.

The assessment and the rating of the alternative states of the factors are presented in Tables 4 and 5, respectively.

The definition of desirable construction strategies is closely related to the state of the factors that affect the safety of construction operations. The proposed method for selecting the most desirable construction strategy for work operations is based on determining a rank measure for each alternative of the state of the factors. The rank measure can be obtained by rating the state of the factors with respect to a definitive set of decision criteria. The alternative with the maximum rank measure, $\bar{R}_{il}$, is considered to be optimal for a given construction strategy.

Similarly, the rank measure for other factors' alternatives can be developed following the same procedures to evaluate the first factor, i.e., 'level of workers' skills and attitude'. Thus, the rank measures for each available alternative state of the factors can be calculated as shown in Table 6.

The alternatives with the maximum rank measures are considered appropriate to optimize the safety and the cost function of performing the construction operation. The alternative states of the factors which define the most desirable construction strategy for performing the reinforced concrete slab operations of the structure are presented in Table 7.

Table 4. Assessment of the alternative states of the factors[a]

Factors l_i	Alternative states a_i			
	a_1	a_2	a_3	a_4
l_1	G	M	N/A	N/A
l_2	VG	G	M	N/A
l_3	G	FG	M	N/A
l_4	G	FG	M	FP
l_5	G	M	N/A	N/A
l_6	G	M	N/A	N/A

[a] Assume a_{il} represents alternative state a_i of factor l. G = good; M = moderate; V = very; F = fairly; P = poor.

Table 5. Rating of the alternative states of the factors[a]

Criteria c_k	Importance w_j	Rating of alternatives r_{ik}	Alternative states a_i			
			a_1	a_2	a_3	a_4
1. Minimize risk	V important	r_{11}	G	M	N/A	N/A
		r_{12}	P	G	N/A	N/A
		r_{13}	G	M	N/A	N/A
		r_{21}	VG	G	FP	N/A
		r_{22}	VP	FP	M	N/A
		r_{23}	VG	G	M	N/A
2. Minimize initial costs	F important	r_{31}	G	G	M	N/A
		r_{32}	P	M	G	N/A
		r_{33}	G	FG	M	N/A
		r_{41}	G	FG	M	P
		r_{42}	VP	P	FG	G
		r_{43}	G	FG	FG	P
3. Minimize damage costs	Important	r_{51}	G	M	N/A	N/A
		r_{52}	M	P	N/A	N/A
		r_{53}	VG	FP	N/A	N/A
		r_{61}	G	FP	N/A	N/A
		r_{62}	P	G	N/A	N/A
		r_{63}	G	M	N/A	N/A

[a] Assume r_{ik} represents the rating of the alternative state of the factors a_i with respect to criteria c_k. G = good; M = moderate; V = very; F = fairly; P = poor.

5. Summary and conclusions

The performance of construction operation is considered hazardous and subject to many unsafe construction practices, as well as failures and accidents. Construction operations usually involve certain strategies which need to be defined effectively in order to ensure proper safety and reliability for preparation and execution of project activities.

Table 6. Rank measures for the factors affecting the selection of the RC-slab construction strategy[a]

Description of the factors	Rank measures for alternative states						
	VG	G	FG	M	FP	P	VP
1. Level of workers' skill and attitude	NA	1.74	NA	$\boxed{2.05}$	NA	NA	NA
2. Level of engineering experience and attendance	1.41	$\boxed{1.80}$	NA	1.34	NA	NA	NA
3. Level of supervision and control	NA	1.74	$\boxed{2.35}$	2.05	NA	NA	NA
4. Condition of construction methods	NA	1.70	1.91	$\boxed{2.55}$	1.17	NA	NA
5. Condition of the falsework	NA	$\boxed{2.14}$	NA	1.73	NA	NA	NA
6. Type and use of materials and equipment	NA	$\boxed{1.74}$	NA	1.68	NA	NA	NA

[a] VG = very good; G = good; FG = fairly good; M = moderate; FP = fairly poor; P = poor; VP = very poor; NA = not applicable.

Table 7. Desirable construction strategy for the RC slab operation

Description of the factors	State
1. Level of workers' skill and attitude	Moderate
2. Level of engineering experience	Good
3. Level of supervision and control	Fairly good
4. Condition of construction methods	Moderate
5. Falsework condition	Good
6. Type and use of construction materials and equipment	Good

Most of the factors affecting the safety of construction operations are associated with human-based type of uncertainty. They are usually vague, qualitative, and imprecisely defined. The relative engineering experience and knowledge are very important elements to enhance the assessment and evaluation of the factors that affect the safety and cost-effectiveness of performing the construction operations.

The objective of formulating construction strategies is to select different levels of resources to effectively and safely perform construction operations. It is not necessary to select the highest levels of factors' conditions to formulate the construction strategy. The most important measure to evaluate and select the alternative states of the factors is to rank the different states of the factors with respect to a predefined set of criteria.

The aggregation of the alternative states of the factors (i.e., constraints) and a set of criteria (i.e., objectives) in a fuzzy environment formulate a decision process for selecting cost effective and safe construction operations.

The proposed methodology for the assessment and evaluation of construction strategies is considered effective and practical, since it considers criteria elements which involve both technical and economic aspects in defining desirable strategies for performing construction operations.

The methodology can be implemented during the planning, design and construction phases of the building process. The implementation of the methodology in the planning and design phases of the building process can determine an effective set of resource standard for a construction strategy to perform the construction operation efficiently and safely. On the other hand, the implementation of the methodology in the construction phase can assist to verify the affectivity of the construction activities. In addition, it can help construction managers to modify existing strategies of construction operations to be more reliable and cost effective.

The multi-attribute fuzzy decision making analysis is a valuable tool for contractors, engineers and construction managers to use in selecting the best resource alternatives for construction strategies especially when decision makers have vague and imprecise information regarding the options for the state of the resource alternatives to execute construction operations.

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