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Evaluating Project Management Criteria Using Fuzzy Analytic Hierarchy Process

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Abstract. Project management is one of the most important issues to fulfil organizational objectives. The project management criteria are playing a vital role for completion of any project. The aim of this paper is to evaluate five main project criteria (time, cost, quality, risk, and safety) mathematically by using a multi-criteria method in order to assist stakeholders or project managers in decision-making. The fuzzy Analytic Hierarchy Process (AHP) is selected with the use of triangular fuzzy numbers for pairwise comparison scales in prioritizing the criteria in managing projects. Utilizing the fuzzy AHP technique can facilitate uncertainty in doing evaluation. In this study, one expert who is a project manager with many years of experience was asked to carry out the evaluation. The results show that the expert's main concern in managing project is time, and cost is the second important. The study demonstrates how uncertainty in making evaluation of multiple criteria can be solved by using fuzzy method such as fuzzy AHP, in contrary to the crisp or the traditional AHP which is based on specific values, the evaluator(s) are always ambiguous and vague to give exact judgment. Hence, the application of this fuzzy method can make the assessment outcomes more accurate, scientific, and objective. It is anticipated that this work may serve as a support tool for stakeholders in improving the project management quality level.

INTRODUCTION

Decision making in a project context is a complicated endeavor. The term complexity is an increasingly important point of reference when we are trying to understand the managerial demands of modern projects in general, and of the various situations encountered in projects [1]. Project management is the application of knowledge, tools, skills, and techniques necessary to achieve the project's requirements. It is an approach to handling resources in order to accomplish specific project objective successfully as well as it is a way to implement the strategies of organizations [2,3]. A successful project management can then be defined as achieving a continuous stream of project objectives within time, within cost, at the desired performance/technology level, while utilizing the assigned resources effectively and efficiently, and having the results accepted by the customer and/or stakeholders [4].

Decision making is a cognitive procedure of ranking or selecting the most preferable and available criteria or/and alternatives [5,6]. [7] mentioned that multi-criteria decision-making (MCDM) describes making judgments in the existence of several criteria and MCDM is considered to be an active area of research. A decision maker evaluates alternatives (projects) prescribed under multi-criteria. Many tasks, such as weights of criteria, conflicts among criteria, and preference dependence, seem to complicate the problems and need to be processed by more sophisticated methods. This paper focuses on evaluating criteria of project management using a MCDM model, specifically the Analytic Hierarchy Process (AHP) technique.

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Nevertheless, there are some criticisms of AHP method because of some tedious procedures, particularly with the presence of fuzziness in handling uncertainty in linguistic judgment. Furthermore, most of the decisions in real life have uncertain results [8, 9, 10]. Fuzzy set theory deals with the vague information by using the fuzzy numbers and changing vague information into useful data [11]. The fuzzy AHP applies fuzzy aggregation operators and fuzzy arithmetic in order to address the hierarchical structure of the multi-criteria problems [12, 13].The review of literature revealed the efficiency of fuzzy AHP in various fields, nonetheless, the application of fuzzy AHP in the field of project management for prioritization of criteria is yet to appear in literature. This paper demonstrates the application of fuzzy AHP for prioritization of main criteria in handling project management.

METHODOLOGY

Multi-Criteria Decision Making

Multi-Criteria Decision Making (MCDM) approaches have a considerable benefit over conventional decision assisting methods where all criteria require to be transformed to the same unit, since these approaches can evaluate a variety of alternatives based on several criteria that have various units [14, 15, 16]. Additionally, most MCDM methods have the capability to analyze together both qualitative and quantitative assessment criteria. Based on the literature, AHP method is the most popular technique utilized for dealing with decision-making problems, which created by [17]. It utilizes a hierarchical design of a complex system to streamline the assessment process. The main characteristic of this technique is the use of pairwise comparisons, that is by comparing the alternatives based on a variety of criteria [18,19].

The use of pairwise comparisons is a vital role of the prioritization procedure in AHP, which provides a rational framework for organizing a decision problem. The pairwise judgments in this technique are structured in a pairwise comparisons matrix, and a prioritization procedure is implemented to draw a corresponding priority vector. Thus, if the judgments are consistent, all prioritization procedures would give the same results. At the same time, if the judgments are inconsistent, prioritization procedures would provide different priority vectors [20]. However, there are some objection of the AHP due to some tiresome procedures, specifically when fuzziness exists in dealing with uncertainty in linguistic judgment as well as a lot of the decisions in real life have uncertain outcomes [15, 8, 10]. In this paper, fuzzy AHP was used to assess the main criteria in evaluating project management which are time, cost, quality, risk, and safety [21]. The first three variables are considered as a golden triangle criteria and are rank as the three most important criteria. All other criteria are organized based on this so-called golden triangle [22]. The other two criteria, risk and safety are very important due to the current situation in Iraq which is not fully stable in all aspects. Other criteria such as customer satisfaction, efficiency, are basically extended from the triple set of criteria (time cost and quality) [23, 24].

Fuzzy Sets and Numbers

Fuzzy set was developed by Zadeh for the first time in 1965 and it has been widely studied in literature. A fuzzy set is defined as a class of objects with a continuum of grades of membership [25]. Such a set is characterized by a membership (characteristic) function which assigns to each object a grade of membership ranging between zero and one. If the assigned value is one, the element belongs completely to the set, whereas if the value assigned is zero, then the element does not belong to the set, while the value which exists or lies between zero and one belongs to the fuzzy set partially [26]. A triangular fuzzy number is represented with three parameters ($\widetilde{M} = (l, m, u)$) that describes a fuzzy event, where l represents the smallest possible value, m is the most promising value, and u is the largest possible value [27]. A triangular membership function of $\widetilde{M}$ is described in Equation (1).

$$\mu_{\widetilde{M}}(x) = \begin{cases} 0, & x < l \\ \dfrac{x-l}{m-l}, & l \le x \le m \\ \dfrac{u-x}{u-m}, & m \le x \le u \\ 0, & x > u \end{cases} \tag{1}$$

Fuzzy Analytic Hierarchy Process

In AHP technique, the principle of pairwise comparison is used as a more reliable manner of getting the real weights than getting them directly. The decision maker makes paired comparison in the application process based on Saaty's scale in which numbers from 1 to 9 are utilized. On the other hand, in real life, most of the decisions have uncertain outcomes. In such situations, fuzzy AHP is more appropriate for geting more accurate decisions. In this paper, the values were handled by using fuzzy numbers in order to get productive outcomes regarding criteria weights of project management. The measurement of fuzzy sets theory is done by converting linguistic values into fuzzy numbers. Comparisons scale used in this paper is demonstrated in Table 1.

TABLE 1. Fuzzy Expressions of Linguistic Terms [11]

Linguistic Scale	Triangular Fuzzy Scale (l, m, u)	Reciprocal Triangular Fuzzy Numbers	Fuzzy Numbers
Equally important	(1, 1, 3)	$\left(\frac{1}{3}, 1, 1\right)$	$\tilde{1}$
Moderately important	(1, 3, 5)	$\left(\frac{1}{5}, \frac{1}{3}, 1\right)$	$\tilde{3}$
Strongly important	(3, 5, 7)	$\left(\frac{1}{7}, \frac{1}{5}, \frac{1}{3}\right)$	$\tilde{5}$
Very strongly important	(5, 7, 9)	$\left(\frac{1}{9}, \frac{1}{7}, \frac{1}{5}\right)$	$\tilde{7}$
Extremely important	(7, 9, 9)	$\left(\frac{1}{9}, \frac{1}{9}, \frac{1}{7}\right)$	$\tilde{9}$

According to Chang's method, for each level of the constructed hierarchy, the pairwise linguistic judgments are converted in triangular fuzzy numbers and organized in fuzzy comparison matrices as follows:

$$\tilde{A} = (\tilde{a}_{ij})_{n*n} \begin{bmatrix} (1,1,1) & (l_{12,}m_{12,}u_{12}) & \cdots & (l_{1n,}m_{1n,}u_{1n}) \\ (l_{21,}m_{21,}u_{21}) & (1,1,1) & \cdots & (l_{2n,}m_{2n,}u_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ (l_{n1,}m_{n1,}u_{n1}) & (l_{n2,}m_{n2,}u_{n2}) & \cdots & (1,1,1) \end{bmatrix} \tag{2}$$

where

$$\tilde{a}_{ij} = (l_{ij,}m_{ij,}u_{ij}) = \tilde{a}_{ji}^{-1} = \left(\frac{1}{l_{ij,}}, \frac{1}{m_{ij,}}, \frac{1}{m_{ij,}}\right), i, j = 1, \dots, n;\ i \neq j \tag{3}$$

represents the linguistic judgment for the items i and j; thus $\tilde{A}$ is a square and symmetrical matrix.

The following equations are proposed for applying fuzzy AHP by [28]. The value of fuzzy synthetic extent with respect to the ith object, or in this study the ith criterion, S_i, is determined as:

$$S_i = \sum_{j=1}^{n} M_{g_i}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{n} M_{g_i}^{j}\right]^{-1} \tag{4}$$

Where all $M_{g_i}^{j}$, , $j = 1, \dots, n$, and l_j, m_j, u_j are triangular fuzzy number.

$$\sum_{j=1}^{n} M_{g_i}^{j} = \left(\sum_{j=1}^{n} l_j, \sum_{j=1}^{n} m_j, \sum_{j=1}^{n} u_j\right) \tag{5}$$

The fuzzy addition operation of $M_{g_i}^{j}$ $(j = 1,2, \dots, m)$ values is performed to obtain $(\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^{j})^{-1}$, as follows:

$$\sum_{i=1}^{n}\sum_{j=1}^{n} M_{g_i}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \tag{6}$$

and then the inverse of the vector in Equation (7) is computed as in the following equation:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \tag{7}$$

The crisp weights are calculated by converting fuzzy weights as follows [29]:

Where $\tilde{S}_i = (l_{ij}, m_{ij}, u_{ij})$,

$$w_i = S_i(\tilde{S}_i) = \frac{l_i + m_i + u_i}{3} \tag{8}$$

Via normalization, the normalized crisp weight vector is:

$$W = (w_1', w_2', \ldots, w_n') \tag{9}$$

APPLICATION

In this paper, since this study is still at a preliminary stage, the evaluation about the criteria was conducted through questionnaire to only one expert in this area, who is a project manager with more than ten years of experience in managing various projects in Iraq. The main criteria of project management (time, cost, quality, risk, safety) have been identified from literature [21] and believed to be the most important criteria in the context of managing projects in Iraq. The expert was asked to compare the five main criteria by using fuzzy expressions of linguistic terms (see Table 1). The results of the evaluation are shown in Table 2 as a fuzzy pairwise comparisons matrix.

TABLE 2. Fuzzy Pairwise Comparisons Matrix

Criteria	**Time**	**Cost**	**Quality**	**Safety**	**Risk**
Time	1, 1, 1	1, 3, 5	3, 5, 7	1, 3, 5	1, 1, 3
Cost	1/5, 1/3, 1	1, 1, 1	1, 3, 5	3, 5, 7	1, 3, 5
Quality	1/7, 1.5, 1/3	1/8, 1/3, 1	1, 1, 1	1, 3, 5	3, 5, 7
Risk	1/9, 1/7, 1/5	1/7, 1/5, 1/3	1/5, 1/3, 1	1, 1, 1	1, 1, 3
Safety	1/9, 1/7, 1/5	1/9, 1/7, 1/5	1/7, 1/5, 1/3	1/3, 1, 1	1, 1, 1

TABLE 3. Normalized Weights and Ranking of Criteria

Rank	**Criteria**	**Normalized Weights**
1	Time	0.286
2	Cost	0.279
3	Quality	0.246
4	Risk	0.115
5	Safety	0.074

Based on the evaluation of each criterion given by the expert, the weights were calculated by using fuzzy AHP method based on Equations (2) - (9). Table 3 and Figure 1 display the normalized weight for each criterion as resulted from fuzzy AHP method of evaluation.

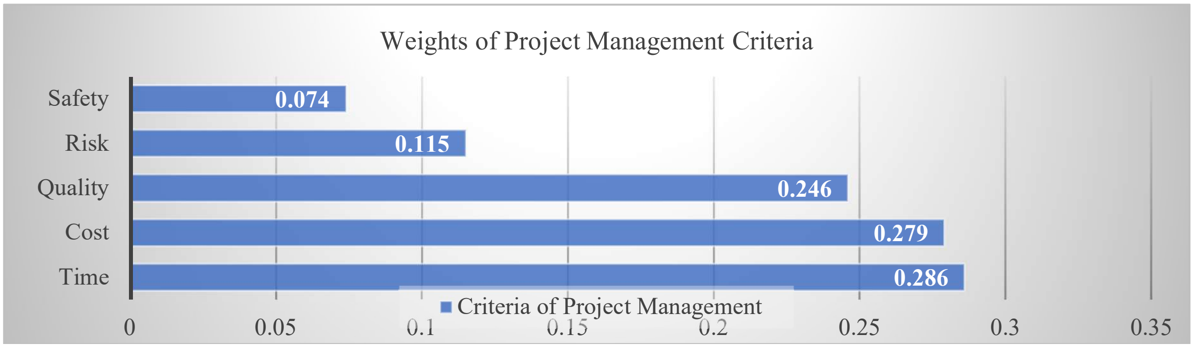

FIGURE 1. Criteria Weights of Project Management

As shown in the Table 3 and Figure 1 above, normalized weights and prioritization of criteria were obtained using fuzzy AHP method for all the criteria based on their usage and relevance in the project management. The result of this paper illustrates that the expert has evaluated that time is the first priority or the most important criterion. Next priority is assigned to cost, then quality is the third ranking of importance, followed by risk and safety.

CONCLUSION

In this paper, we present a fuzzy AHP methodology for criteria's prioritization of project management. Fuzzy AHP effectively reflects the vagueness connected with human thoughts. The benefit of utilizing a fuzzy approach is to assign the relative importance of criteria by utilizing fuzzy numbers rather than precise numbers. Multiple criteria decision-making techniques based on fuzzy AHP helps stakeholders to choose the best decision-making strategy using a weighting process through pairwise comparisons. The research area will be extended by using another multiple-criteria decision-making approach such as TOPSIS (Technique for order preference by similarity to the ideal solution) for prioritizing alternatives (projects). For further study, it is planned to use fuzzy AHP and fuzzy TOPSIS to evaluate projects in project management sector, with involvement of more than one evaluator.

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