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Providing a Fuzzy Hierarchical Model Based on PMBOK Standard Knowledge Areas for Desirable and Successful Management of Construction Projects and Factors affecting them

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Abstract

Today, the fundamental and undeniable role of project management in achieving successful projects and their main objectives has led to development of techniques, tools and standards in this regard. According to the fact that the major part of the capitals of every society is allocated to construction projects and since time delays, increased costs and reduced quality of them are always observed especially in developing countries, their successful management requires considering factors affecting them and determining the importance of each to prioritize them in a scientific, standard and comprehensive framework. Given that PMBOK standard is one of the most common and appropriate standards of project management and considers all dimensions of the project, in this paper a fuzzy hierarchy model is provided with the aim of successful management of construction projects by the knowledge areas of this standard and fuzzy analytical hierarchy process (FAHP) to prioritize and determine the importance of factors including multi-criteria decision-making methods.

Keywords: Project Management, Construction projects, Project Management Body of Knowledge (PMBOK) Standard, Multiple-Criteria Decision-Making (MCDM), Fuzzy Analytical Hierarchy Process (FAHP).

1. Introduction

Project is a temporary attempt performed in order to create a product, service or unique result (PMBOK, 2004). Project management requires knowledge, ability, tool and technique in project activities which are eligible for project definition (Schwalbe, 2007). Undoubtedly, project management is one of the most important and widely used categories of management during the last few decades and its role in achieving the main and predetermined objectives for each project is undeniable, so that different tools, techniques and standards have been developed so far in the field of project management that PMBOK standardizing of the most important and common of them. A major part of the projects are construction projects that inordinate amount of public and private funds are spent on such projects. Despite the crucial importance of such projects, we observe time delays, additional costs on the initial estimate, reduced quality and then falling projects efficiency. Considering the importance of the issue and the mentioned problem, managers have studied for many years to solve this problem and have suggested different models that project management triangle (cost, time, and quality) is one of the most important models(Hassanzadeh et al., 2010). Lack of adequate attention to factors affecting these three areas that are also key and fundamental areas of project management body of knowledge (PMBOK) has caused problems in effective and desirable management of construction projects so that according to the statistics of the former Management and Planning Organization, 54% of civil plans have fundamental problems in design stage, 27% of them are implemented incompletely and 28%of them have problems in utilization stage (Farsinezhad et al., 2006).

2. Literature Review

2.1. Project Management Body of Knowledge (PMBOK)

The growing acceptance of project management implies the application of appropriate knowledge, processes, skills, tools and techniques that can be effective on the projects 'success. PMBOK guide recognizes subset of the project management body of knowledge as a generally known good solution. "Generally known" means that knowledge and described solutions are applied in most projects and in most times and there is consensus about their value and usefulness. PMBOK guide also provides and promotes common words into the profession of project management in line with discussion, writing and application of project management concepts. Such standard words are considered a necessary element of a professional system.

Project Management Institute (PMI) considers this standard as a fundamental reference of project management for professional development programs and certificates. PMBOK standard explains project management in form of 9 areas including knowledge integration, scope, time, cost, quality, human resource, communications, risk and procurement that each includes some processes and it has also added the area of stakeholders to other areas in its fifth edition version. Areas mentioned are in fact the basis of provided hierarchical model structure in this paper that in the following some explanations will be provided on this issue.

2.2 Factors affecting construction projects

Certainly, to perform a successful management for each project, detection and determination of important factors affecting the project and its management are considered primary and important steps, so that many studies have been conducted so far on detection of these factors, their classification and determination of their importance. In this regard, investigation of the reasons of delays and increased costs in Nigeria construction projects (Mezher et al., 1998), detection of the reasons of delays in Lebanon construction industry (Fugar et al., 2010), examination of large projects in 1999 in Jordan (Haseeb et al., 2011)etc. can be noted.

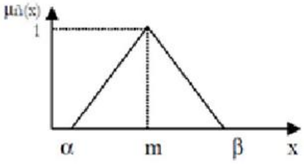
As an example, Gundog et al. identified the delay factors in construction projects, since delays are considered to be a serious problem in the construction industry. Through detailed interview with experts from Turkish construction industry, a total of 83 different delay factors were identified. The identified delay factors were categorized into 9 groups. The demonstration of these groups of delay factors was achieved by utilizing the Ishikawa (Fish bone) diagram as it is capable of showing factors, interrelations between different groups of factors, and consequences affected from factors. They quantified relative importance of delay factors and demonstrated the ranking of the factors and groups according to their importance level on delay. According to the computed relative importance indices (RIIs), all factors and groups were ranked, and they addressed the most significant factors and groups to cause delays (Gunduz et al., 2012).The reasons for the underperformance of the quality of Indian construction projects were studied to suggest possible remedial measures. A preliminary survey identified 55 attributes responsible to impact quality performance of the projects (Jab et al., 2006).

2.3 Fuzzy Logic

Fuzzy logic was introduced by Professor Lotfi Zadeh in 1965 as a mathematical theory to model the uncertainty and vagueness inhuman perception and thoughts (Lin et al., 2007). In many cases, we are deprived of the ability to measure with any degree of accuracy, so we are faced with inaccurate information. Here we are not dealing with lack of knowledge information, but we are faced with an uncertainty in information. Such uncertainty can be formulated by non-randomized intervals. These uncertainties can be modelled easily by fuzzy sets. Fuzzy approach is a very suitable tool to deal and cope with these uncertainties and unreliability and modelling of linguistic variables. Fuzzy calculations (fuzzy logic) attempt to provide a basis for approximate reasoning (modelling of imprecise propositions) by using fuzzy sets theory (Menhaj, 2007).Generally, uncertainties can be considered in three main categories: implicit or approximate data, linguistic terms and interval data (Cheng, 2000). The uncertainty in data of this model is the third kind in which data do not have a specific value but include a range of values. There are different types of fuzzy numbers that trapezoidal and triangular numbers have higher popularity regarding their ease of use in modelling and interpretation (Petroni et al., 2002). In this paper the triangular fuzzy numbers are used.

2.3.1 Triangular fuzzy numbers

A triangular fuzzy number is shown in diagram 1bya triplets (l,m,u) that its membership function is defined as follows:



$$\mu(x)=\begin{cases}\frac{x-l}{m-l} & l \le x \le m \\ \frac{x-u}{m-u} & m \le x \le u \\ 0 & \text{others,}\end{cases}$$

Diagram 1: Fuzzy Triple Number Membership function of a triangular fuzzy number

In the above relation [l, u] is a support interval and the point of (m, 1) is the peak. Triangular numbers have a membership function including two linear parts L (left) and R (right) connected to each other on the peak (m, 1) which causes the graphic representation and operation become very easy by triangular numbers. Also, this point is very important that they are made easily and based on little information.

Two triangular numbers M1 and M2 that plotted in diagram 2 are considered.

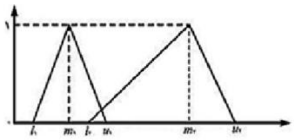


Diagram 2: Fuzzy Numbers M1,M2

Some arithmetic operator's required are defined as the following relations:

$$M1+M2 = (l1 + l2, m1 + m2, u1 + u2)$$

$$M1*M2 = (l1 * l2, m1 * m2, u1 * u2)$$

$$M_1^{-1} = (\frac{1}{u1}, \frac{1}{m1}, \frac{1}{l1}) \qquad M_2^{-1} = (\frac{1}{u2}, \frac{1}{m2}, \frac{1}{l2})$$

It should be noted that the product of two triangular fuzzy numbers, or the inverse of a triangular fuzzy number, is not a triangular fuzzy number anymore. These relations only express an approximation of the actual product of two triangular fuzzy numbers and the inverse of a triangular fuzzy number.

3. Results and Discussion

In this paper, the analytical hierarchy process (AHP) has been used to provide a model. Analytical hierarchy process (AHP) was provided by Thomas L. Saaty in 1980as one of the main methods for multi criteria decision-making in the area of decision-making and management sciences. This process requires the breaking of a problem with multiple indicators into a hierarchy of levels. High level indicates the main objective of decision-making process. The second level indicates main and fundamental indicators (which may be broken into sub-indicators and more detailed indicators in next level). The final level provides decision options (Mehregan, 2004). According to the discussions mentioned so far, a hierarchical model (Figure 1) with 4 levels is provided as follows with the aim of successful management of construction projects. This model can help project managers in decision-making.

3.1 The first level: The first step for creating a hierarchical model is to determine the objective. Briefly and generally, the main objective of this paper and its suggested model is the successful management of construction projects.

3.2 The second level: The main criteria of the model are at this level. As mentioned before, among the main criteria for measuring the success of a project we can refer to cost, time and quality that are one of the important areas of PMBOK standard. Therefore, in this model, three mentioned areas have been considered as the main criteria.

3.3 The third level: This level is related to sub-criteria of the model. At this level other PMBOK knowledge areas (integration, scope, human resource, communications, risk, procurement, and stakeholders) are considered as sub-criteria.

3.4 The fourth level: In fact, this level is the lowest level of the hierarchical models that important factors affecting project are placed at this level after they are detected. Finally, after solving the model, the level of importance of each of them is determined and will be prioritized based on that.

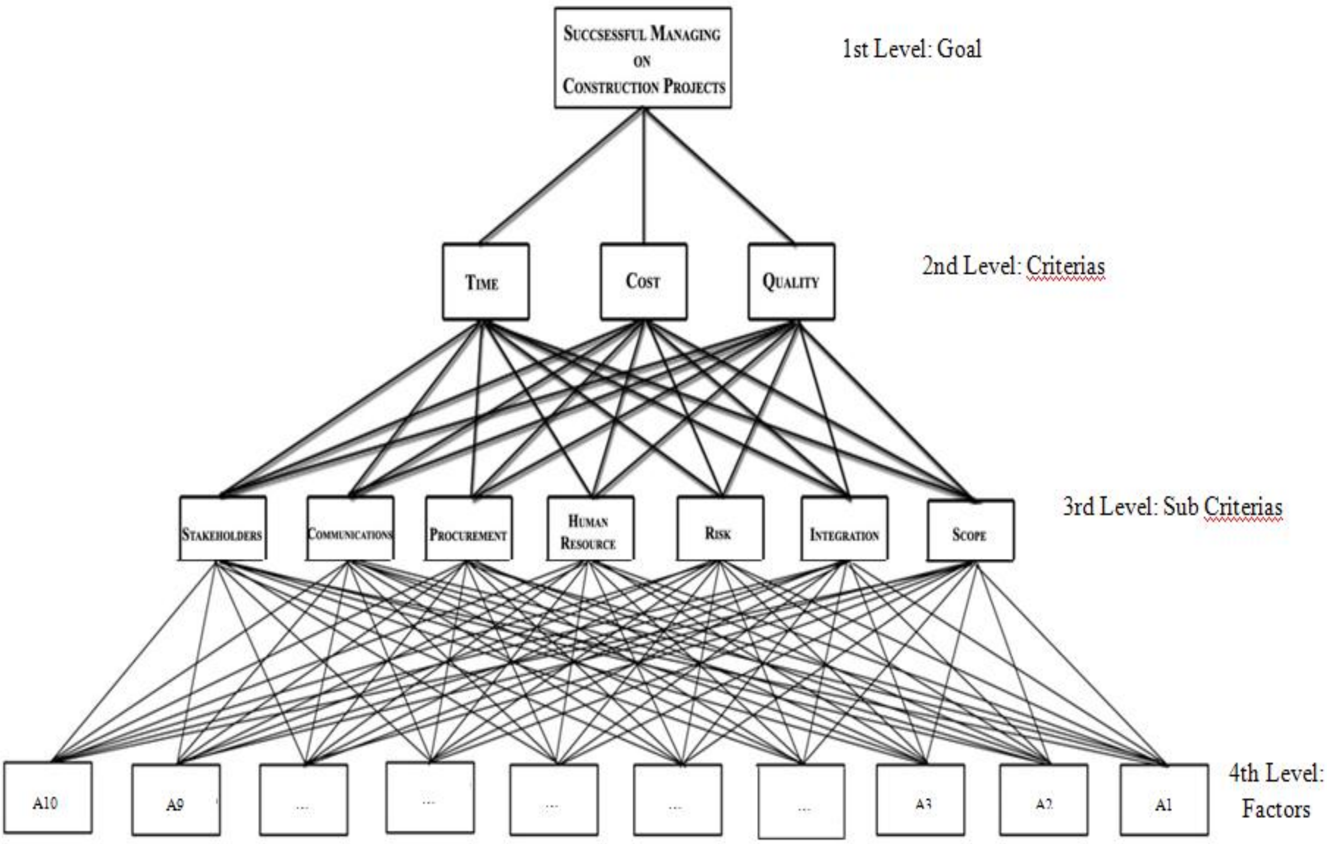


Figure 1: Hierarchy Model

3.5. Solving the fuzzy hierarchical model

Fuzzy analytical hierarchy process (FAHP) will be used to solve the hierarchical model. The fundamental idea of AHP is achieving experts' knowledge related to the phenomenon under study through the performance of pairwise comparisons. But classic AHP has been criticized due to inability to consider uncertainty and vagueness of information of some decision-makers (Chang, 1996). Yurdakul and I studied the advantages of fuzzy numbers in multi criteria decision-making (MCDM) models. They suggested using fuzzy numbers when there are a lot of uncertainties in data (Yurdakul et al., 2009).So, in this paper Chang's fuzzy extent analysis method are used.

In the following the required steps for solving the model are presented by citing an example that 10 factors are Putin its fourth level.

3.5.1. Definition of fuzzy numbers

As noted previously, in this model triangular fuzzy numbers are used that for this purpose Önüt range is used which is shown in the following table.

Table 1: fuzzy Triple Numbers (Önüt, et al. 2008)

Linguistic values (judgment)	Symbol	Fuzzy numbers
quite equal importance	$\tilde{1}$	(1,1,1)
almost equal importance	$\tilde{2}$	(1,1,3)
low importance	$\tilde{3}$	(1,3,5)
relatively more importance	$\tilde{5}$	(3,5,7)
more importance	$\tilde{7}$	(5,7,9)
much more importance	$\tilde{9}$	(7,9,9)

3.5.2 Performance of pairwise comparison sand inconsistency rate calculation

After experts 'opinions were completed and converted to fuzzy numbers by tables of pairwise comparisons, matrix inconsistency rate equivalent to m fuzzy is calculated for each of them. Consistency test shows the extent to which the priorities from pairwise matrices can be trusted. Inconsistency in AHP method is determined by a number called consistency rate. In general case, it can be proved that if λ_1, λ_2, $\lambda_3$are eigenvalues of the pairwise comparisons matrix A, their total values is equal to n.

$$\sum_{i=1}^{n} \lambda_i = n$$

Also the maximum eigenvalue of the pairwise comparison matrix A is always greater than or equal to n. In this case, some of λs
Will be negative Therefore:

$$\lambda_{\max} \geq n$$

Every complete consistent matrix has the following properties:

1. Elements weight value is equal to the normalized value of each element.
2. Eigenvalue is equal to matrix length (AW = NW).
3. Inconsistency value in this matrix is zero.

If matrix elements distance themselves a little from consistency mode, their eigenvalue will distance itself little from its consistency mode as well. So, if AW=λW where λ and Ware eigenvector and matrix eigenvalue A, respectively, an eigenvalue is equal to n (the largest eigenvalue) and the others are equal to zero. Therefore in this case it can be written:

AW= n.W

When λ_{max}distances itself a little from n, λ_{max}-n value can show a consistency rate and to normalize the index we introduce the following terms as inconsistency rate.

$$I.I = \frac{\lambda_{\max} - n}{n-1}$$ Inconsistency Index

Now, we obtain inconsistency rate from the following formula.

$$I.R = \frac{I.I}{I.I.R_{n \times n}}$$ Inconsistency Rate

Where Random Index (R.I) is determined according to the following table, depending on the dimensions of the matrix that is assumed n (Asgharpour, 1998)

10	9	8	7	6	5	4	3	2	1	**N**
1.51	1.45	1.41	1.32	1.24	1.12	0.9	0.58	0	0	**R.I**

Based on experience, when R.I in relation to a comparison table is less than 0.1, the consistency of the table is acceptable. But if R.I is more than 0.1, comparisons should be done again.

3.5.3 Combination of experts' opinions with using geometric mean

After ensuring the consistency of pairwise comparisons by experts, we obtain their geometric mean and then we will use it in calculations. Table 2 that shows the triangular fuzzy matrix is the geometric mean of pairwise comparisons at fourth level to the sub-criteria of project scope.

Table 2: Geometric mean of triangular fuzzy matrix of the fourth level pairwise comparisons to the sub-criteria of project scope

U	M	L	U	M	L	U	M	L	U	M	L	U	M	L	
A5			A4			A3			A2			A1			range
4.29	3.07	3.00	3.57	1.00	5.68	3.72	5.68	3.83	3.37	4.29	3.07	3.00	3.57	1.00	A1
3.25	2.77	0.47	1.00	0.28	4.78	3.78	5.43	3.54	2.98	3.25	2.77	0.47	1.00	0.28	A2
3.78	2.77	1.00	2.13	0.33	4.78	4.18	5.68	4.68	3.46	3.78	2.77	1.00	2.13	0.33	A3
4.01	1.00	0.36	0.36	0.33	4.47	2.77	4.78	4.16	2.90	4.01	1.00	0.36	0.36	0.33	A4
1.00	0.25	0.26	0.31	0.23	1.07	0.42	3.27	0.52	0.26	1.00	0.25	0.26	0.31	0.23	A5
3.84	0.34	0.29	0.33	0.29	3.00	0.50	4.78	2.07	1.00	3.84	0.34	0.29	0.33	0.29	A6
1.93	0.24	0.21	0.29	0.26	2.66	0.51	4.10	1.00	0.48	1.93	0.24	0.21	0.29	0.26	A7
0.30	0.21	0.17	0.18	0.17	1.00	0.20	1.00	0.24	0.21	0.30	0.21	0.17	0.18	0.17	A8
2.64	0.36	0.24	0.26	0.27	4.28	1.00	5.00	2.16	2.00	2.64	0.36	0.24	0.26	0.27	A9
0.93	0.22	0.21	0.21	0.17	1.00	0.23	1.20	0.37	0.33	0.93	0.22	0.21	0.21	0.17	A10

U	M	L	U	M	L	U	M	L	U	M	L	U	M	L
A10			A9			A8			A7			A6		
9.00	8.35	6.33	6.37	4.01	2.81	9.00	8.35	6.33	6.59	4.32	2.50	5.72	3.68	1.55
8.56	6.54	4.51	6.54	4.51	2.41	8.56	7.80	5.71	6.07	4.01	1.82	4.91	2.65	1.55
8.56	6.54	4.51	7.36	5.35	3.32	9.00	8.35	6.33	8.35	6.33	4.29	5.92	3.87	1.73
7.94	5.92	3.87	4.51	2.41	1.00	8.56	6.54	4.51	7.30	5.26	3.13	4.75	2.52	1.39
1.79	1.62	0.80	0.50	0.37	0.30	5.53	3.50	1.39	0.68	0.46	0.25	0.42	0.22	0.15
5.00	3.00	1.00	1.00	1.00	0.33	8.56	6.54	4.51	2.93	1.93	1.00	1.00	1.00	1.00
4.29	2.16	1.00	1.00	0.51	0.38	7.18	5.08	2.79	1.00	1.00	1.00	1.00	0.54	0.36
1.00	1.00	1.00	0.19	0.14	0.11	1.00	1.00	1.00	0.36	0.20	0.14	0.22	0.15	0.12
7.55	5.53	3.50	1.00	1.00	1.00	9.00	7.00	5.00	3.09	2.16	1.00	3.00	1.00	1.00
1.00	1.00	1.00	0.28	0.18	0.13	1.25	1.25	1.21	1.00	0.46	0.23	1.00	0.33	0.20

3.5.4 Calculation of values or S_is

For calculation of values,that is a fuzzy number, the following formula is used.

$$S_k = \sum_{j=1}^{n} M_{ij} * \left[\sum_{i=1}^{m} \sum_{j=1}^{n} M_{ij}\right]^{-1}$$

Table 3: Triangular values of the fourth level to the sub-criteria of project scope

	$\sum$ U	$\sum$ M	$\sum$ L
	61.423	44.993	28.261
	47.094	32.827	20.652
	55.350	40.424	25.795
	43.626	29.729	18.196
	11.495	8.095	4.496
	27.585	19.334	10.979
	19.992	12.282	7.568
	4.202	3.291	2.997
	29.603	20.843	14.320
	6.629	4.428	3.804
$\sum\sum$ M	**306.998**	**216.246**	**137.068**
$\sum\sum$ M^{-1}	**0.007**	**0.005**	**0.003**

	L	M	U
S1	0.092	0.208	0.448
S2	0.067	0.152	0.344
S3	0.084	0.187	0.404
S4	0.059	0.137	0.318
S5	0.015	0.037	0.084
S6	0.036	0.089	0.201
S7	0.025	0.057	0.146
S8	0.010	0.015	0.031
S9	0.047	0.096	0.216
S10	0.012	0.020	0.048

3.5.5 Calculating the degree of the probability of values largeness

For this purpose, we use the following function.

$$V(\tilde{S}_i \geqslant \tilde{S}_j) = \begin{cases} 1, & \text{if } m_i \geqslant m_j, \\ \frac{u_i - l_j}{(u_i - m_i) + (m_j - l_j)}, & \text{if } l_j \leqslant u_i, \quad i, j = 1, \ldots, n; j \neq i \\ 0, & \text{others,} \end{cases}$$

Table 4: The degree of probability of S_is to each other for the fourth level to the sub-criteria of project scope

S1>S2	S1>S3	S1>S4	S1>S5	S1>S6	S1>S7	S1>S8	S1>S9	S1>S10
1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
S2>S1	S2>S3	S2>S4	S2>S5	S2>S6	S2>S7	S2>S8	S2>S9	S2>S10
0.817	0.881	1.000	1.000	1.000	1.000	1.000	1.000	1.000
S3>S1	S3>S2	S3>S4	S3>S5	S3>S6	S3>S7	S3>S8	S3>S9	S3>S10
0.937	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
S4>S1	S4>S2	S4>S3	S4>S5	S4>S6	S4>S7	S4>S8	S4>S9	S4>S10
0.762	0.946	0.826	1.000	1.000	1.000	1.000	1.000	1.000
S5>S1	S5>S2	S5>S3	S5>S4	S5>S6	S5>S7	S5>S8	S5>S9	S5>S10
0.000	0.127	0.000	0.197	0.481	0.754	1.000	1.000	1.000
S6>S1	S6>S2	S6>S3	S6>S4	S6>S5	S6>S7	S6>S8	S6>S9	S6>S10
0.479	0.682	0.546	0.747	1.000	1.000	1.000	1.000	1.000
S7>S1	S7>S2	S7>S3	S7>S4	S7>S5	S7>S6	S7>S8	S7>S9	S7>S10
0.262	0.453	0.322	0.518	1.000	0.771	1.000	0.715	1.000
S8>S1	S8>S2	S8>S3	S8>S4	S8>S5	S8>S6	S8>S7	S8>S9	S8>S10
0.000	0.000	0.000	0.000	0.419	0.000	0.126	0.000	0.776
S9>S1	S9>S2	S9>S3	S9>S4	S9>S5	S9>S6	S9>S7	S9>S8	S9>S10
0.526	0.729	0.593	0.792	1.000	1.000	1.000	1.000	1.000
S10>S1	S10>S2	S10>S3	S10>S4	S10>S5	S10>S6	S10>S7	S10>S8	S10>S9
0.000	0.000	0.000	0.000	0.665	0.155	0.395	1.000	0.022

3.5.6 Calculation of weights

In this stage the weight vertical vector related to fourth level to area sub-criteria is calculated and then normalized.

$$V\left(\tilde{S}_i \geqslant \tilde{S}_j \middle| j = 1, \ldots, n; j \neq i\right) = \min_{j \in \{1,\ldots,n\}, j \neq i} V\left(\tilde{S}_i \geqslant \tilde{S}_j\right), \quad i = 1, \ldots, n. \qquad W_i = \frac{W_i'}{\sum W_i'}$$

Table 5: The weights obtained for the fourth level to the sub-criteria of project scope

	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1	
Unnormalized Weight	0.000	0.526	0.000	0.262	0.479	0.000	0.762	0.937	0.817	1.000	4.783
Normalized Weight	0.000	0.110	0.000	0.055	0.100	0.000	0.159	0.196	0.171	0.209	

$$W_{scope} = \begin{pmatrix} 0.209 \\ 0.171 \\ 0.196 \\ 0.159 \\ 0 \\ 0.100 \\ 0.055 \\ 0 \\ 0.110 \\ 0 \end{pmatrix}_{10\times 1} \begin{matrix} A1 \\ A2 \\ A3 \\ A4 \\ A5 \\ A6 \\ A7 \\ A8 \\ A9 \\ A10 \end{matrix}$$

After the weight vertical vector related to the fourth level to the sub-criteria of project scope was calculated, weight vertical vectors related to other sub-criteria are calculated as well that finally a weight matrix is obtained for the fourth level.

Similarly, the above calculations are performed for other levels of hierarchical structure so that weight matrices of the third, second and first levels will be formed.

$W_4 =$ (10×7)

	Scope	Int.	Risk	H.R	Pro.	Com.	Stakeholders
A1	0.209	0.181	0.179	0.145	0.166	0.166	0.194
A2	0.171	0.206	0.195	0.242	0.227	0.154	0.171
A3	0.196	0.186	0.102	0.101	0.024	0.162	0.139
A4	0.159	0.171	0.075	0.118	0.021	0.135	0.159
A5	0	0.017	0.146	0.030	0.151	0.010	0.057
A6	0.100	0.037	0.075	0.049	0.018	0.096	0.017
A7	0.055	0.070	0.089	0.003	0.024	0.126	0.072
A8	0	0.081	0.102	0.201	0.242	0.032	0.122
A9	0.110	0.052	0.038	0.063	0.047	0.067	0.009
A10	0	0	0	0.048	0.080	0.051	0.060

$W_3 =$ (7×3)

	Time	Cost	Quality
Scope	0.127	0.154	0.159
Integration	0.134	0.126	0.091
Risk	0.194	0.176	0.070
H.R	0.094	0.120	0.180
Procurement	0.201	0.194	0.247
Communication	0.064	0.075	0.053
Stakeholders	0.155	0.154	0.199

$W_2 =$ (3×1)

	Successful managing on construction projects
Quality	0.236
Cost	0.438
Time	0.325

$W_1 = 1$ (1×1)

3.5.7.Determiningfactors importance level and prioritizing them

To finally solve the model and obtainthe final answer that is prioritization of factors affecting the successful managementof construction projects,it is necessary that matrix multiplication will be doneonthe obtained weight matrices so that the final weight vector will be calculated as a matrix 10 × 1. Therefore we have:

$W_4 \times W_3 \times W_2 \times W_1 = W$

For example, we will reach the following answerby using the above weight matrices multiplication.

$W =$ (10×1)

A1	0.1741
A2	0.1947
A3	0.1170
A4	0.1094
A5	0.0677
A6	0.0486
A7	0.0540
A8	0.1239
A9	0.518
A10	0.369

According to weights obtained for factors, their prioritization is as follows.

(A2) 0.1947 – (A1) 0.1741 – (A8) 0.1239 – (A3) 0.1170 – (A4) 0.1094 – (A5) 0.0677 – (A7) 0.0540 – (A9) 0.0517 – (A6) 0.0486 – (A10) 0.0369

5. Conclusions and suggestions

Among the features of the hierarchical model with 4 levels provided in this paper two cases can be referred to: first, it is based on a scientific framework and second, it is designed based on PMBOK standard knowledge areas. Therefore, using this model can be an effective step in successful and desirable management of a variety of projects including construction projects and factors affecting them. Since this model is based on analytical hierarchy processor AHP, experts 'opinions and performance of pairwise comparisons are needed to solve it.Due to uncertainty and vagueness in this context, fuzzy analytical hierarchy process(FAHP) approach is used so that the model will be solved with higher accuracy. The result of solving the model and determining the importance of factors and prioritizing them can certainly improve the decision-makings and control of factors affecting construction projects and as a result will lead to more successful and effective management.

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