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Identification and Evaluation of Construction Projects' Critical Success Factors Employing Fuzzy-TOPSIS Approach

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Abstract

The construction industry is a significant motive for the economic and industrial developments in countries. Consequently, the success of the construction projects is crucial for any country because the failure of these projects imposes extreme costs to the economic and industrial development of the country. Thus, the identification of the critical success factors of the construction projects and ranking these factors has a major role in the success and failure of the projects. In this study, the critical success factors are determined through the survey of the literature, and the set of critical success factors are considered as options. After that, a questionnaire was prepared with respect to the criteria such as time, cost, quality, and safety, which are the measurements of the success and failure of the projects. This questionnaire was distributed to the professionals and experts of the construction industry that form the statistical population to determine the percentage of approval and importance of each criterion. Then, the Fuzzy TOPSIS multiple criteria decision-making methods have been used to rank the critical success factors of the construction projects. Finally, a comparison of proposed method and Entropy-based Fuzzy Multi-MOORA has been shown. According to the research results, the level of the effect of each critical factor on the successful execution of Iran's construction projects will be provided.

Keywords: *critical success factors, construction projects, ranking, fuzzy TOPSIS, integrated shannon's entropy*

1. Introduction

The project is a temporary endeavor that is committed to creating a product or service; the aim of the project is to achieve the goals of its respective owners. Projects are often used as a way to reach the organization's strategic plan through the project team in the organization or the service production (Mahmood *et al.*, 2014). The construction industry includes a significant proportion of the gross domestic product of the countries such as Iran; the success of this industry leads to the increase of the long-term economic growth. According to the international reports, the projects of the construction industry in different countries allocate a huge amount of the country's annual budget. Therefore, the success of construction projects is imperative for government and society. In the recent decades, many efforts have been made to optimize the management of the construction projects in order to successfully carry out the projects of the construction industry and increase the success rate of the construction projects.

Project success is the foundation of management and control of the ongoing projects and planning for the future projects. Project success is a temporary organizational success that is affected by the resources and the effectiveness of its constituent member organizations. The success of every organization is affected by the efficiency and success of its projects (Zavadskas *et al.*, 2012). The ultimate goal of every project is success; mostly the project managers have the main responsibility for the project success. Hence, identifying the factors that lead to the project success is important for the project managers. Project success factors are a set of environmental factors or affecting factors that can influence the output of the project. These factors can accelerate a project or face it with difficulty, but they cannot be the basis for assessing the projects (Lim and Mohamed, 1999).

Due to the complex conditions of the construction projects and the variety of sources that are used to execute them and the unpredictability of the conditions, the project success factors are so vast and uncontrollable in practice by the project managers. Therefore, among the project success factors, the critical success factors should be identified, so that focusing on them could increase the project efficiency and lead to the project success. Roukart in (1982) has defined the critical success factors as follows: the category of limiting factors that their satisfactory results will ensure the successful competitive efficiency for the organization. The critical success factors are the inputs of the project management system that directly increase the possibility of achieving the project success (Gudienė *et al.*, 2014). Identifying, ranking and managing the critical success factors of projects indicate their importance while these factors directly affect the

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main objectives of the project such as time, cost, quality, and safety (in this study they are considered as the decision criteria).

In order to study the project success, focusing on the project success factors is an effective approach. To classify and manage the project critical success factors, many approaches have been presented in the literature.

There are various methods and techniques to rank projects critical success factors. One of the suitable methods for ranking the alternatives is the Multiple Criteria Decision Making (MCDM); among the MCDM methods, the Fuzzy Technique for Order Preference by Similarity to Ideal Solution (Fuzzy TOPSIS) has the following capabilities: (a) there are no restrictions on the number of criteria and options; (b) the use of positive and negative criteria; (c) the use of qualitative and quantitative criteria; (d) the possibility to distribute a large number of questionnaires in the statistical population with the MCDM method; (e) the suitability of the measures to solve the problem by the additive or subtractive methods; (f) the simplicity and high speed of problem solving method.

Ranking in TOPSIS Fuzzy logic is conducted by the Technique for Order Preference by Similarity to Ideal Solution; accordingly, the options have the minimum distance from the ideal solution and maximum distance from the negative ideal solution. Also, due to the nature of the problem, the complexity of the real world, and the ambiguity of the obtained data from the Fuzzy numbers, the Fuzzy TOPSIS method has been used. In this study, the project critical success factors in Iran's construction industry have been investigated, identified and ranked with the multiple criteria decision-making techniques of the Fuzzy TOPSIS method. The contribution of this study is summed up in three points, which includes:

1. Identification of the critical success factors of construction projects have been obtained through combining of the use of literature and experts' opinions.
2. The use of multiple criteria decision-making techniques of the Fuzzy TOPSIS method to rank the critical success factors of the construction project.
3. The statistical population consists of the professionals and experts of the construction industry projects in Iran.

This paper is structured as follow. Section 2 reviews a survey on project Critical Success Factors (CSF) and the application of multiple criteria decision analysis on CSF. Section 3 reviews research methodology. Section 4 presents results and discussions on the applications of proposed approach in a real-world case study in construction projects in Iran. Finally, Section 5 offers conclusions and recommendations for the future researchers.

2. Literature Review

2.1 A Survey on Project Critical Success Factors

Daniel has proposed first the project critical success factors in the 1960s (Leidecker and Bruno, 1984). In the 1980s, broader research had been conducted on identification and evaluation of the project critical success factors including the study of Leidecker and Bruno (1984); they identified the eight potential sources of critical success factors (Leidecker and Bruno, 1984). Pinto *et al.* (1988; 1989) demonstrated the changes in the project critical success factors throughout the project lifecycle and commonality of the critical success factors between construction sector and research and development sector of the project. Sanvido *et al.* (1992) proposed the critical success factors for construction projects from the perspective of the project owner, planner, engineer, and contractor of the project; these considered critical success factors were examined on sixteen projects and eventually four vital success factors were obtained.

Belassi and Tukel (1996) provided a new framework to determine the critical success and failure factors of the project; the classification of relevant factors and description of the effects of these factors were emphasized on the performance of the project. Songer and Molenaar (1997) studied the characteristics of successful projects in the public sector for design and construction; they obtained five characteristics and presented the success criteria of the public sector including budget, scheduling, and user expectations.

Dvir *et al.* (1998) classified the projects with a general approach to determine the project success factors; they proposed different project success factors for various projects and classified the project success factors by the multivariate method. Chua *et al.* (1999) studied the critical success factors of construction projects based on the various project objectives. In the previous studies, the success factors of construction projects had been evaluated in general, but in this study, they tried to identify these factors with respect to the objectives of the project including budget, schedule, and quality. Also, they used the Analytic Hierarchy Process (AHP) technique in order to determine the relative importance of success.

Lim and Mohamed (1999) proposed the difference between project success criteria and project success factors and provided some definitions for the criteria and factors of project success. They classified the project success into the micro and macro categories. Chan *et al.* (2001) obtained the project success factors of the design and construction projects through the multivariate regression analysis by applying their relative importance. Cooke-Davies (2002) presented the real success factors of projects using the questionnaires answered by 70 multinational firms and achieved the 12 critical success factors of the project. Shen and Liu (2003) studied the critical success factors with value management in the construction industry, and used the factor analysis method with an emphasis on recognizing the importance of project success factors.

Chan *et al.* (2004) developed a conceptual framework on the critical success factors of the construction projects and proposed the key performance indicators and the cause and effect relationships between the critical success factors. Subsequently, they introduced five major groups of independent variables. Belout and Gauvreau (2004) studied human resources' management's effect on the project success factors. Zhang (2005) examined the project critical success factors for public - private cooperation in developing the infrastructure. Yu *et al.* (2006) discussed the identification, classification, and prioritization of the general set of the critical success factors in the briefing session of the construction projects by using the content analysis method.

Moe and Pathranarakul (2006) discussed the critical success factors for natural disaster management and administration of general projects in Thailand. Chen and Chen (2007) studied the critical success factors of construction projects in Taiwan. Aksorn and Hadikusumo (2008) examined the critical success factors that affect the safety of the program performance on the construction projects of Thailand by using the factor analysis method.

Toor and Ogunlana (2008; 2009) named the following factors as the critical COMs of success: comprehension, competence, commitment and communication. Also, they examined the relationship between the critical success factors of the project and critical COMs of construction projects in large-scale in Thailand. Yang *et al.* (2009) evaluated the critical success factors from the perspective of stakeholder management of construction projects. Lu and Yuan (2010) studied the critical success factors of the project for waste management in the construction projects of China; this study led to the adoption of the strategy of effective development of construction and destruction waste management.

Al Haadir and Panuwatwanich (2011) identified and prioritized the affecting factors of successful implementation of safety programs among the construction companies in Saudi Arabia by using the Analytic Hierarchy Process (AHP). Al-Tmeemy *et al.* (2011) provided a framework to classify the success criteria of construction projects in Malaysia from the perspective of contractors for short-term and long-term objectives.

Mavi *et al.* (2012) studied the selection of construction projects by using the Fuzzy VIKOR method to help the contractors to participate in tendering. Zavadskas *et al.* (2012) presented the multiple criteria decision support system for the assessment of construction project managers by using the AHP method based on the determination of the value of the criteria's weights. Alzahrani and Emsley (2013) investigated the effect of the characteristics of construction contractors on the success of the project from the perspective of the construction job evaluation by using the logistic regression to develop the prediction model of the probability of project success. They classified the critical success factors of contractors in nine clusters.

Zou *et al.* (2014) studied and identified the critical success factors for communication management in the public- private participation projects. They showed that the relative importance is not enough for the critical success factors of construction projects, and senior management is a key factor for the success of the project. Hesampour *et al.* (2014) developed the ranking of the effective factors on the success of the projects in the aviation industry with the AHP technique. They have evaluated and classified the16 critical success factors of the aviation industry into five categories. Mahmood *et al*. (2014) examined the effective factors led to the success or failure of the research projects and the search for the effective factors on the success of research projects, finally, they identified 11 effective factors.

Serrador and Turner (2014) evaluated the relationship between project success and project efficiency. Taylan *et al.* (2014) studied the Fuzzy AHP and Fuzzy TOPSIS methods by using the analytical tools to assess the construction projects and overall risks under the uncertain conditions. Gudiene *et al.* (2014) proposed the AHP method as a tool for ranking the critical success factors of construction projects in Lithuania.

Lückmann (2015) conducted a review of 66 articles on identifying the success factors for cross-cultural project customer engagement, by categorizing the literature knowledge areas into three sectors such as stakeholder management, customer management and intercultural management. He *et al.* (2015) employed a complexity measurement model consisting of 28 factors, which were grouped under six categories, namely, technological, organizational, goal, environmental, cultural and information complexities. These factors formulated through literature review using content analysis method. The proposed model was based on Fuzzy Analytic Network Process.

Carvalho *et al.* (2015) employed a comparison in three countries (i.e. Argentina, Brazil, and Chile), with business units from 10 different industries over a 3-year period to investigate the effects of project management on projects success. Consequently, they found that the project complexity had a huge effect on two aspects of project success: margin and schedule. Todorović *et al.* (2015) conducted the project success analysis through the definition of critical success factors, key performance indicators and performance-measuring process which had a very positive influence on knowledge acquisition and transfer in the project's environment. This research employed an integrated framework for project success analysis as a new knowledge-based method in project management.

Costantino *et al.* (2015) developed a novel decision support system to predict project performances by employing an Artificial Neural Network (ANN) based on critical success factors. Yalegama *et al.* (2016) identified critical success factors for Community-driven Development (CDD) projects in Sri Lanka. Liang *et al.* (2016) evaluated and assessed critical success factors for sustainable development of biofuel industry in China. Critical success factors were identified by employing grey decision-making trial and evaluation laboratory (DEMATEL). Marzagão and Carvalho (2016) studied and identified critical success factors in six sigma projects by employing Partial Least Squares method (PLS). Doulabi and Asnaashari (2016) evaluated success factors of health-care facility construction projects in Iran through open-ended interviews.

Montequin *et al.* (2016) analyzed the cluster patterns using self-organizing Maps (SOMs) for evaluating success factors and failure causes in projects. Rodríguez-Segura *et al.* (2016) classified critical success factors in large projects in the aerospace and defence sectors by employing a configurationally comparative method i.e. a fuzzy-set qualitative comparative analysis (fsQCA).

3. Research Methodology

Regarding the purpose, the type of this research is practical. In terms of content and data collection, it is descriptive and

Table 1. Classification of the Literature Based on the Studied Project Success Criteria

Row	Researchers	Time	Cost	Quality	Customer satisfaction	Environ-ment	Safety	Expecta-tions	Performance (efficiency)
1	Belassi and Tukel (1996)	√	√	√	√				
2	Songer and Keith R. Molenar (1997)	√	√					√	
3	Chua *et al.* (1999)	√	√	√					
4	Lim *et al.* (1999)	√	√	√			√	√	√
5	Rahele Noorifar (2005)	√	√	√			√		
6	Al-Tmeemy *et al.* (2011)	√	√	√	√				
7	Jaman I. Al Zahrani *et al.* (2013)			√		√	√		
8	Serrador and Turner (2014)	√	√						√
9	Osman Taylan *et al.* (2014)	√	√	√		√	√		
10	Lückmann (2015)	√	√	√	√				
11	Liang *et al.* (2016)	√	√	√		√	√		
12	Doulabi and Asnaashari (2016)	√	√	√			√		
13	Rodríguez-Segura *et al*. (2016)	√	√	√			√	√	√

quantitative, and the type of review is a case study. Given that the success of the project is evaluated from the perspective of the project's manager, the study population includes the specialists, experts, and officials of the implementation of construction projects in Iran. A set of the success criteria of the construction projects from the previous research has been collected and classified in Table 1, in which Time, Cost, Quality and Safety are chosen from the criteria based on previous research.

In the current study, after identifying the critical success factors by using the multiple criteria decision-making tool of Fuzzy TOPSIS method, the critical success factors of construction projects in Iran will be ranked. A comparison of Fuzzy TOPSIS method integrated Shannon's entropy and entropy weighted Fuzzy Multi-MOORA has been obtained.

3.1 Methods and Tools for Data Collection

In this study, both the library and field methods have been used to collect the data. For the research literature, the articles, books and theses that are related to construction projects have been used. Also, in order to analyze the critical success factors of construction projects, and having access to the additional data, the Fuzzy TOPSIS questionnaires and the interviews with experts and executors of the construction industry have been used. In Table 2, a list of alternatives (the critical success factors of the project) based on the highest frequency analyzed which is obtained from the literature review is provided.

3.2 Data Analysis Method

In the Fig. 1, the data analysis method has been developed. In the first stage, the key success factors of the project have been identified and assessed as alternatives. In the second stage, according to the indicators of the success of the project, we have developed the decision matrix, and conducted the Fuzzy integrated Shannon's entropy weighting technique on the decision-making table to determine the weights of the criteria. In the third stage, the decision matrix ranks the critical success factors of the

Table 2. The List of the Selected Options for Ranking the Critical Success Factors of Construction Projects

The main factors of project success	options (the critical success factors of the project)	Abbreviation
Factors of project activities	Strategic and effective planning of project	CSF1
	project monitoring and control mechanism	CSF2
	Complete and clear documents of contracts and project goals	CSF3
	Tender awarded to competent contractors	CSF4
	Qualified and experienced project management	CSF5
	Senior management support of the project	CSF6
Factors of Project Management	Commitment to the project	CSF7
	Having contact with stakeholders and people in the project	CSF8
	Ongoing consultation with the project employer	CSF9
Factors of human resources	Availability of resources	CSF10
External environment factors	Allocating appropriate funding	CSF11
	Experienced and multidisciplinary project team	CSF12
	Accurate and reliable estimates of project costs	CSF13
	Prediction of project risks	CSF14
	Regulations and political or economic and social issues	CSF15
	The urgency of completing the project	CSF16

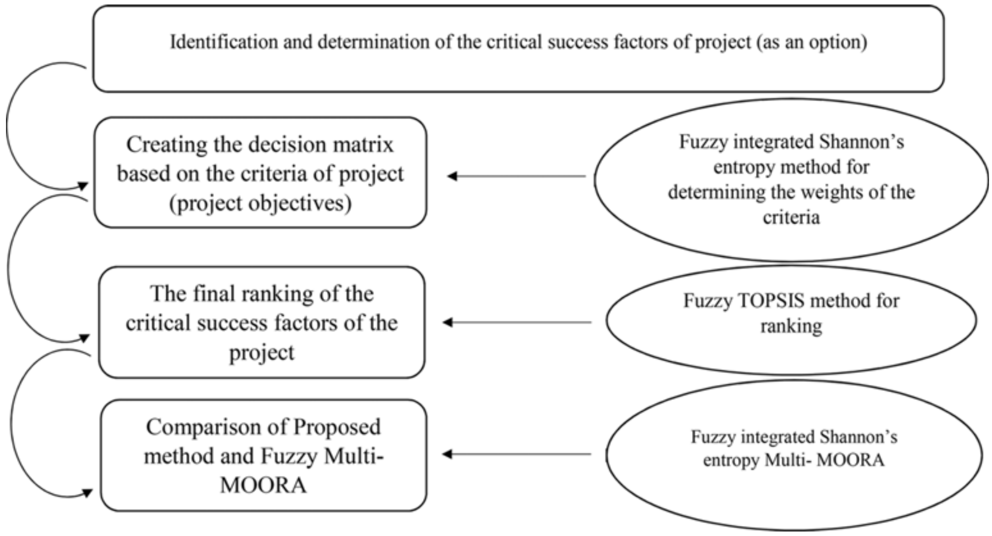

Fig. 1. The Analysis Method of the Collected Data

project by using the obtained criteria weights from the previous stage and the Fuzzy TOPSIS method.

3.3 Theory of Fuzzy Numbers

The theory of Fuzzy Sets and Fuzzy numbers was first presented by Lotfali Asgarzadeh (1965) the Iranian-born professor at the University of California at Berkeley. When the available data for solving the multiple criteria decision-making problems have ambiguity and uncertainty, the Fuzzy theory should be used (Zadeh, 1965).

Definition 1: the $\tilde{A}$ Fuzzy set with the $\mu_{\tilde{A}}(x)$ membership function to each element of the set assigns a real number in the [0, 1] interval. The numerical value of $\mu_{\tilde{A}}(x)$ shows the degree of the membership of the x element in the $\tilde{A}$ set.

Definition 2: A $\tilde{a}$ triangular Fuzzy number is introduced as $\tilde{a} = (a_1, a_2, a_3)$ by three parameters. The membership function of this number is defined as Eq. (1):

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{x-a_1}{a_2-a_1}, & a_1 \le x \le a_2 \\ \frac{x-a_3}{a_2-a_3}, & a_2 \le x \le a_3 \\ 0 & Otherwise \end{cases} \quad (1)$$

In Eq. (1), a_2 is the apex of the triangular Fuzzy number of $\mu_{\tilde{A}}(a_2) = 1$ that shows the right a_2 and left a_3 bounds of Fuzzy number with the $\mu_{\tilde{A}}(a_3) = \mu_{\tilde{A}}(a_1) = 1$ set membership.

Definition 3: The α section of the $\tilde{A}$, A_α Fuzzy number specifies the members that their degree of their membership is not lower than α value. In the triangular Fuzzy numbers, it will create an interval that is called α level set.

Definition 4: Consider the two $W_1 = (l_1, m_1, u_1)$ and $W_2 = (l_2, m_2, u_2)$ Fuzzy numbers. The mathematical calculations between them will be conducted as Eq. (2)-(6):

$$W_1 + W_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2)$$

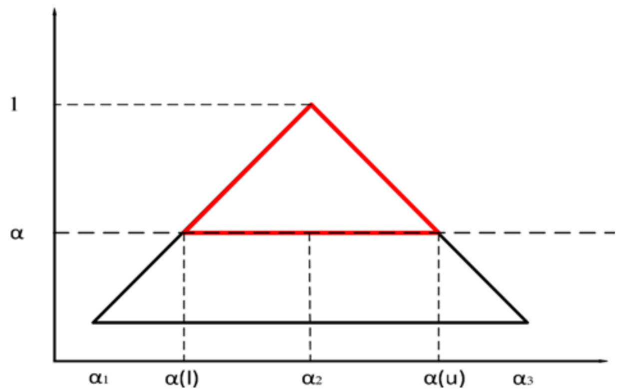

Fig. 2. A Conceptual Triangular Fuzzy Set

$$W_1 \cdot W_2 = (l_1 l_2, m_1 m_2, u_1 u_2) \quad (3)$$

$$\rho \cdot W_1 = (\rho l_2, \rho m_2, \rho u_2), \rho > 0;\ \rho \in R \quad (4)$$

$$W_1^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \quad (5)$$

$$W_2^{-1} = \left(\frac{1}{u_2}, \frac{1}{m_2}, \frac{1}{l_2}\right) \quad (6)$$

It should be noted that the multiplication of the two triangular Fuzzy numbers or inverse of a Fuzzy triangular number is no longer a Fuzzy triangular number. These equations just express an approximation of the actual multiplication of two triangular Fuzzy numbers and the inverse of a Fuzzy triangular number.

Definition 5: In the Fuzzy multiple criteria decision problems, there is no numerical value for the qualitative indicators and their assessment is based on the verbal quantities of decision-makers. Table 3 shows the verbal values for the indicators' weights and evaluation of the options that are equivalent to the Fuzzy triangular numbers based on the time spectrum.

Table 3. The Membership Functions of Fuzzy Triangular Numbers of the Verbal Values

Verbal value	Triangular fuzzy number of weight variable	Triangular fuzzy number of priority
Too low	(0.0.1.0.3)	(0.1.3)
Low	(0.1.0.3.0.5)	(1.3.5)
Average	(0.3.0.5.0.7)	(3.5.7)
Much	(0.5.0.7.0.9)	(5.7.9)
Too much	(0.7.0.9.1)	(7.9.10)

Table 4. The Decision Matrix Structure with Interval Data

	Criterion 1	Criterion 2	…..	Criterion n
Option 1	$[x^l_{11}, x^u_{11}]$	$[x^l_{12}, x^u_{12}]$	…..	$[x^l_{1n}, x^u_{1n}]$
Option 2	$[x^l_{21}, x^u_{21}]$	$[x^l_{22}, x^u_{22}]$	…..	$[x^l_{2n}, x^u_{2n}]$
…..	…..	…..	…..	…..
Option m	$[x^l_{m2}, x^u_{m2}]$	$[x^l_{m2}, x^u_{m2}]$	…..	$[x^l_{mn}, x^u_{mn}]$
Weight	$[W^l_1, W^u_1]$	$[W^l_2, W^u_2]$	…..	$[W^l_n, W^u_n]$

3.4 Integrated Shannon Significance Coefficient Entropy

Hoseinzadeh *et al.* have developed Shannon Entropy for the cases that the data are Fuzzy or they are in an interval (Momeni, 2006; Hoseinzadeh *et al.*, 2012). The main Fuzzy Integrated Shannon's entropy weighting steps are as follows:

Step1: Conversion of Fuzzy data to an interval or α set level by using α section, and the evaluation of the option i based on the j criterion is shown as $[x^l_{ij}, x^u_{ij}]$ matrix. Also the interval of the weight of j criterion is $[W^l_j, W^u_j]$ matrix. In the Table 4, the decision matrix structure when the criteria data are as an interval is shown.

$$x^l_{ij} = min\{x_{ij} \in R | \mu_{x_{ij}}(x_{ij}) \geq \alpha\},\quad x^u_{ij} = max\{x_{ij} \in R | \mu_{x_{ij}}(x_{ij}) \geq \alpha\}, 0 < \alpha < 1 \tag{7}$$

Step 2: calculation of p^u_{ij} and p^l_{ij} normalized values from Eq. (8):

$$p^l_{ij} = \frac{x^l_{ij}}{\sum^m_{i=1} x^u_{ij}},\ p^u_{ij} = \frac{x^u_{ij}}{\sum^m_{i=1} x^l_{ij}}, u = 1, \ldots, m, j = 1, \ldots, n \tag{8}$$

Step 3: calculation of the U_j upper limit and L_j lower limit of entropy

$$L_j = min\{-\xi \sum^m_{i=1} p^l_{ij} lnp^l_{ij} - \xi \sum^m_{i=1} p^u_{ij} lnp^u_{ij}\}, j = 1, \ldots, n \tag{9}$$

$$U_j = max\{-\xi \sum^m_{i=1} p^l_{ij} lnp^l_{ij} - \xi \sum^m_{i=1} p^u_{ij} lnp^u_{ij}\}, j = 1, \ldots, n \tag{10}$$

In Eq. (9) and 10, $p^u_{ij} ln\ p^u_{ij}$ and $p^l_{ij} ln\ p^l_{ij}$ and $\xi = (\ln m)^{-1}$ will be zero if $p^l_{ij} = 0$ or $p^u_{ij} = 0$.

Step 4: with the definition of the degree of dispersion of d^u_j upper limit and d^l_j lower limit of dispersion interval, the calculation of the upper and lower limit of the weight interval is conducted as Eq. (11):

$$d^l_j = 1 - U_j, d^u_j = 1 - L_j, j = 1, \ldots, n;\ W^l_j = \frac{d^l_j}{\sum^m_{i=1} d^u_j},\quad W^l_j = \frac{d^u_j}{\sum^m_{i=1} d^l_j}, j = 1, \ldots, n \tag{11}$$

3.5 Fuzzy TOPSIS Method

The Fuzzy TOPSIS technique is provided in this paper in order to rank the options. Hwang and Yoon introduced TOPSIS method in 1981 for a multiple criteria decision problem with n criteria and m options (Hwang and Yoon, 1981; Yoon and Hwang, 1995).

Step 1: determination of weight to evaluate options

The weights of the criteria are calculated by the Fuzzy integrated Shannon's entropy method that has been described in section 5. To determine the weights of criteria, α = 0.99 is considered.

Step 2: creating the Fuzzy decision matrix

Each element of this matrix is $\tilde{x}_{ij} = (l_{ij}, m_{ij}, u_{ij})$, evaluation of each A_i option is based on C_j criterion.

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mm} \end{bmatrix}, i = 1, \ldots, m; j = 1, \ldots, n \tag{12}$$

Step 3: normalizing the Fuzzy decision matrix

The elements of the $\tilde{R}$ Fuzzy normalized decision matrix, according to positivity or negativity of the criteria will lose their scales as shown on Eq. (13) and (14):

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n}, i = 1, \ldots, m; j = 1, \ldots, n \tag{13}$$

$$r_{ij} = \left(\frac{l_{ij}}{u^*_j}, \frac{m_{ij}}{u^*_j}, \frac{u_{ij}}{u^*_j}\right), u^*_j = \max u_{ij};\ r_{ij} = \left(\frac{l^*_j}{u_{ij}}, \frac{l^*_j}{m_{ij}}, \frac{l^*_j}{l_{ij}}\right), l^*_j = minl_{ij} \tag{14}$$

Step 4: creating the Weighted Fuzzy decision matrix

Given the weight of the weighted decision matrix, by the multiplication of importance coefficient and the Fuzzy matrix that has no scale, we will have the Eq. (15) and (16):

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n}, i = 1, \ldots, m;\ j = 1, \ldots, n \tag{15}$$

$$\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \tilde{W}_j \tag{16}$$

Step 5: determination of the Fuzzy ideal option and Fuzzy non-ideal option

$$A^+ = (v^+_1, v^+_2, \ldots, v^+_n);\ A^- = (v^-_1, v^-_2, \ldots, v^-_n) \tag{17}$$

Given that the positive triangular Fuzzy numbers belong to the [0, 1] interval, to calculate the values of the Fuzzy ideal option and Fuzzy non-ideal option the constant $A^+ = (1, 1, 1)$, $A^- = (0, 0, 0)$ values will be used.

Step 6: Calculation of the distance from the ideal fuzzy option and the non-ideal Fuzzy option

In this step, the distance from the ideal Fuzzy option and the non-ideal Fuzzy option will be obtained as shown in Eq. (18) and (19).

$$d^+_i = \sum^n_{j=1} d(\tilde{v}_{ij}, v^+_j), i = 1, \ldots, m; j = 1, \ldots, n \tag{18}$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, v_j^-), i = 1,\dots,m; j = 1,\dots,n \quad (19)$$

The distance between the Fuzzy triangular numbers of $v_1 = (l_1, m_1, u_1)$ and $v_2 = (l_2, m_2, u_2)$ will be obtained as Eq. (20):

$$d(v_1, v_2) = \sqrt{\frac{1}{3}[(l_1-l_2)^2 + (m_1-m_2)^2 + (u_1-u_2)^2]} \quad (20)$$

Step 7: Calculation of the similarity index and ranking the options

By specifying the similarity index of alternatives, the alternatives ranking will be determined. The alternative that has the higher similarity index has a higher rank. Similarity index is acquired from Eq. (21):

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-}, \quad i = 1,\dots,m \quad (21)$$

4. Results and Discussions

The necessary research data has been collected by using questionnaire. Table 5 shows the statistical population and characteristics of the respondents regarding their education and occupation and experience. Table 6 lists the characteristics of the construction projects in which the respondents took part. The mentioned questionnaire contains 64 questions based on four parts about the subject of the research, and it has been distributed among 97 experts, specialists, and executors of construction projects in Iran.

Finally, 62 complete and accurate questionnaires were filled in and received. In order to control the quality of the questionnaire results, the proper objective features should be examined. Among these features, validity and reliability are the most important. The purpose of the validity feature of the question is to indicate to what extent it can accurately measure the variables that are designed for it. For the validity test, the experience and knowledge of the experts and specialists in the construction industry will be used. In the collected statistical sample from the questionnaires, at least 12 professionals and experts of the construction industry have confirmed the validity of the prepared questionnaire of this research.

The purpose of the reliability feature of the question is to indicate to what extent it can measure the same results by using the questionnaire in other different spatial and temporal conditions. One of the most common methods to determine the reliability of the questionnaire is using the Cronbach's alpha method. When the Cronbach's alpha value gets closer to 100 percent, the reliability of the collection tools will be increased. The Cronbach's alpha reliability coefficient of the questionnaire by using the SPSS software has been obtained 88% which indicates the acceptability of the reliability test in the questionnaire.

Table 6. The Features of the Projects

Type of project	Number of projects	The number of answers
Construction	5	38
Road and tunnel construction	2	10
General Construction	2	8
Digging canals and wells	1	6
Total	10	62

This study is based on one case i.e. construction projects in Iran. As explained by Easton (Easton, 2010), focusing on one case leads to a better understanding of the existing data and a robust exploration and reflection of data examination obtained by researchers. Flyvbjerg (Flyvbjerg, 2006), clarified that to employ in-depth research on any topic, "one can study only one case, and the result can be generalized". Accordingly, the mentioned project in this research was not chosen randomly. It was intended and targeted to select a specific project to be able to obtain certain understandings that other projects would not be able to offer. As a result, the current case was selected to gain a deep understanding of the critical success factors in construction projects in Iran.

According to the identification and determination of the critical success factors of the project and also by collecting the required data through the questionnaire with the multiple criteria decision-making methodology; in order to rank the critical success factors of the projects the following stages will be carried out.

Determining the weights of the criteria (the project success indicators) through the Fuzzy Shannon entropy methodology

Rankings the options (critical success factors of the project) through the Fuzzy TOPSIS methodology

In order to weight the four success indicators of the project by using the Fuzzy Shannon entropy methodology in the first stage, the decision matrix will be made. Table 7 shows the decision Matrix that includes 16 options (critical success factors of the project) and four criteria (time, cost, quality and safety) and the Fuzzy triangular data which were collected from the distributed

Table 5. The Experimental and Educational and Occupational Characteristics of the Questionnaire Respondents

The level of experience	The number of answers	Level of education	The number of answers	Job responsibility	The number of answers
1 to 5 years	15	Associate degree	9	Assistant Engineer (Second Engineer)	31
5 to 10 years	19	Bachelor degree	32	Supervisor	15
10 to 15 years	17	Master degree	14	Project director	10
More than 15 years	11	PhD.	7	General director	6
Total	62	Total	62	Total	62

Table 7. Decision Matrix of the Collected Fuzzy Data

Alternatives / Criteria	Time			Cost			Quality			Safety		
Strategic and effective planning of project	10	9	7	10	9	7	10	9	7	9	7	5
project monitoring and control mechanism	10	9	7	9	7	5	10	9	7	9	7	5
Complete and clear documents of contracts and project goals	9	7	5	9	7	5	9	7	5	7	5	3
Tender awarded to competent contractors	9	7	5	9	7	5	10	9	7	9	7	5
Qualified and experienced project management	10	9	7	9	7	5	10	9	7	9	7	5
Senior management support of the project	9	7	5	9	7	5	9	7	5	7	5	3
Commitment to the project	9	7	5	7	5	3	10	9	7	7	5	3
Having contact with stakeholders and all the people in the project	7	5	3	7	5	3	9	7	5	7	5	3
Ongoing consultation of the project employer	7	5	3	7	5	3	9	7	5	7	5	3
Availability of resources	10	9	7	10	9	7	9	7	5	9	7	5
Allocating appropriate funding	10	9	7	10	9	7	10	9	7	9	7	5
Experienced and multidisciplinary project team	10	9	7	10	9	7	10	9	7	9	7	5
Accurate and reliable estimates of project costs	9	7	5	10	9	7	7	5	3	7	5	3
Prediction of project risks	7	5	3	9	7	5	9	7	5	7	5	3
Regulations and political or economic and social issues	7	5	3	9	7	5	7	5	3	7	5	3
The urgency of completing the project	9	7	5	10	9	7	9	7	5	7	5	3

Table 8. Decision Matrix with Interval Data to Determine the Weights of the Criteria

Alternatives / Criteria	Time	Cost	Quality	Safety
Strategic and effective planning of project	[8.958, 9.024]	[8.958, 9.024]	[8.958, 9.024]	[6.952, 7.048]
project monitoring and control mechanism	[8.958, 9.024]	[6.952, 7.048]	[8.958, 9.024]	[6.952, 7.048]
Complete and clear documents of contracts and project goals	[6.952, 7.048]	[6.952, 7.048]	[6.952, 7.048]	[4.952, 5.048]
Tender awarded to competent contractors	[6.952, 7.048]	[6.952, 7.048]	[8.958, 9.024]	[6.952, 7.048]
Qualified and experienced project management	[8.958, 9.024]	[6.952, 7.048]	[8.958, 9.024]	[6.952, 7.048]
Senior management support of the project	[6.952, 7.048]	[6.952, 7.048]	[6.952, 7.048]	[4.952, 5.048]
Commitment to the project	[6.952, 7.048]	[4.952, 5.048]	[8.958, 9.024]	[4.952, 5.048]
Having contact with stakeholders and all the people in the project	[4.952, 5.048]	[4.952, 5.048]	[6.952, 7.048]	[4.952, 5.048]
Ongoing consultation of the project employer	[4.952, 5.048]	[4.952, 5.048]	[6.952, 7.048]	[4.952, 5.048]
Availability of resources	[8.958, 9.024]	[8.958, 9.024]	[6.952, 7.048]	
Allocating appropriate funding	[8.958, 9.024]	[8.958, 9.024]	[8.958, 9.024]	[6.952, 7.048]
Experienced and multidisciplinary project team	[8.958, 9.024]	[8.958, 9.024]	[8.958, 9.024]	[6.952, 7.048]
Accurate and reliable estimates of project costs	[6.952, 7.048]	[8.958, 9.024]	[4.952, 5.048]	[4.952, 5.048]
Prediction of project risks	[4.952, 5.048]	[6.952, 7.048]	[6.952, 7.048]	[4.952, 5.048]
Regulations and political or economic and social issues	[4.952, 5.048]	[6.952, 7.048]	[4.952, 5.048]	[4.952, 5.048]
The urgency of completing the project	[6.952, 7.048]	[8.958, 9.024]	[6.952, 7.048]	[4.952, 5.048]

Table 9. Determining the Final Weights of the Criteria of the Fuzzy Shannon Entropy Method

Criteria	U_j	L_j	d_j^u	d_j^l	W_j^u	W_j^l	Weights
Time	0.99141	0.99042	0.00958	0.00859	0.35624	0.27654	0.31639
Cost	0.99279	0.99182	0.00818	0.00721	0.30415	0.23210	0.26812
Quality	0.99400	0.99309	0.00691	0.00600	0.25712	0.19300	0.22506
Safety	0.99492	0.99360	0.00640	0.00508	0.23811	0.16369	0.2009

questionnaires based on verbal values for the indicators' weights and evaluation of the options that are equivalent to the Fuzzy triangular numbers on the time spectrum which is demonstrated in Table 3.

Considering that the decision table has the Fuzzy triangular data, so to process the Fuzzy Shannon entropy methodology of the decision table, in the first step, the decision table will be converted to the Table 8 with interval data.

In the Table 9, a summary of the steps 2 to 4 of the Fuzzy integrated Shannon's entropy methodology to determine the weights of the project success indicators has been developed. After calculating the normalized values of the interval decision table, the U_j upper limit and L_j lower limit of entropy will be calculated. Afterwards, the degree of dispersion interval d_j^u with

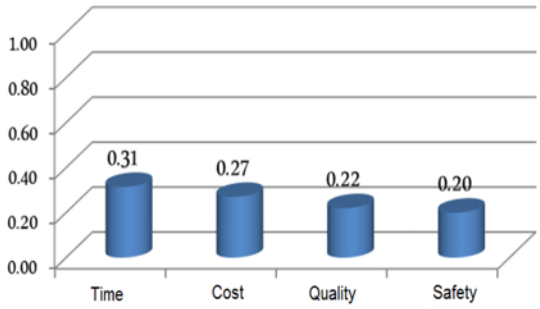

Fig. 3. The Comparing Diagram of the Obtained Weights from the Fuzzy Shannon Entropy Method for the Safety, Quality, Cost and Time Criteria

upper limit and d_j^l lower limit will be calculated; finally, the weights of the project success criteria will be calculated in intervals and also the final weights will be calculated.

As it can be seen in Fig. 3, based on the conducted analysis on the collected data through the questionnaire from the experts and specialists of the construction industry, the highest weight of the project success criteria belongs to the time variable and lowest weights of the project success criteria belongs to the safety variable.

In fact, the experts and specialists in the construction industry have given greater importance to the project completion time and the least critical to the safety of the project. In the next step, by using the criteria's weights that have been calculated in this step,

Table 10. The Decision Matrix with cOllected Fuzzy Data Along with the Calculated Weights of the Criteria

Alternatives / Criteria	Time			Cost			Quality			Safety		
Strategic and effective planning of project	10	9	7	10	9	7	10	9	7	9	7	5
project monitoring and control mechanism	10	9	7	9	7	5	10	9	7	9	7	5
Complete and clear documents of contracts and project goals	9	7	5	9	7	5	9	7	5	7	5	3
Tender awarded to competent contractors	9	7	5	9	7	5	10	9	7	9	7	5
Qualified and experienced project management	10	9	7	9	7	5	10	9	7	9	7	5
Senior management support of the project	9	7	5	9	7	5	9	7	5	7	5	3
Commitment to the project	9	7	5	7	5	3	10	9	7	7	5	3
Having contact with stakeholders and all the people in the project	7	5	3	7	5	3	9	7	5	7	5	3
Ongoing consultation of the project employer	7	5	3	7	5	3	9	7	5	7	5	3
Availability of resources	10	9	7	10	9	7	9	7	5	9	7	5
Allocating appropriate funding	10	9	7	10	9	7	10	9	7	9	7	5
Experienced and multidisciplinary project team	10	9	7	10	9	7	10	9	7	9	7	5
Accurate and reliable estimates of project costs	9	7	5	10	9	7	7	5	3	7	5	3
Prediction of project risks	7	5	3	9	7	5	9	7	5	7	5	3
Regulations and political or economic and social issues	7	5	3	9	7	5	7	5	3	7	5	3
The urgency of completing the project	9	7	5	10	9	7	9	7	5	7	5	3
Weights	0.31			0.27			0.22			0.20		

Table 11. Final Ranking of the Critical Success Factors of the Project that are Calculated by the Fuzzy TOPSIS Method

Critical success factors of the project	Distance from the ideal solution	Distance from the negative ideal solution	Similarity index	Ranking
Strategic and effective planning of project	0.29609	0.61052	0.67341	1
Allocating appropriate funding	0.29609	0.61052	0.67341	2
Experienced and multidisciplinary project team	0.29609	0.61052	0.67341	3
Availability of resources	0.33005	0.57905	0.63695	4
project monitoring and control mechanism	0.33679	0.57214	0.62947	5
Qualified and experienced project management	0.33679	0.57214	0.62947	6
Tender awarded to competent contractors	0.38526	0.52750	0.57792	7
The urgency of completing the project	0.41424	0.49542	0.54462	8
Accurate and reliable estimates of project costs	0.45373	0.45622	0.50137	9
Complete and clear of contracts and project goals	0.45494	0.45704	0.50115	10
Senior management support of the project	0.45494	0.45704	0.50115	11
Commitment to the project	0.46867	0.44112	0.48486	12
Prediction of project risks	0.51112	0.40176	0.44010	13
Regulations and political or economic and social issues	0.55061	0.36256	0.39703	14
Having contact with stakeholders and all the people in the project	0.55882	0.35437	0.38806	15
Ongoing consultation of the project employer	0.55882	0.35437	0.38806	16

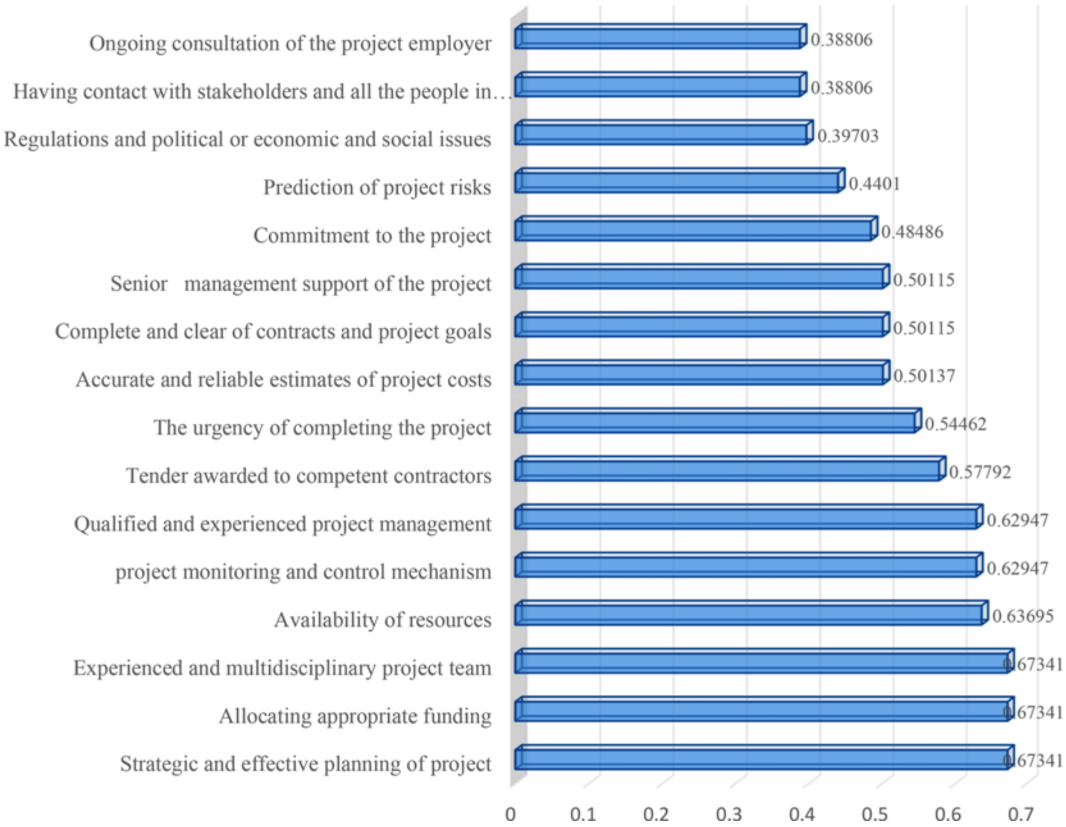

Fig. 4. Comparison Chart of the Final Ranking of thE Critical Success Factors of the Projects

Table 12. Comparison of Critical Success Factors Rank Obtained by Fuzzy TOPSIS method and Fuzzy Multi-MOORA Method

Row	Alternatives	Fuzzy TOPSIS Integrated Shannon's entropy method	Fuzzy Multi-MOORA Integrated Shannon's entropy method
1	Strategic and effective planning of project	1	2
2	project monitoring and control mechanism	5	11
3	Complete and clear documents of contracts and project goals	10	10
4	Tender awarded to competent contractors	7	8
5	Qualified and experienced project management	6	7
6	Senior management support of the project	11	9
7	Commitment to the project	12	14
8	Having contact with stakeholders and all the people in the project	15	15
9	Ongoing consultation with the project employer	16	16
10	Availability of resources	4	3
11	Allocating appropriate funding	2	5
12	Experienced and multidisciplinary project team	3	4
13	Accurate and reliable estimates of project costs	9	1
14	Prediction of project risks	13	13
15	Regulations and political or economic and social issues	14	12
16	The urgency of completing the project	8	6

the key success factors of the project will be ranked by using the multiple criteria methodology.

The critical success factors of construction projects will be ranked by using the Fuzzy TOPSIS methodology. Table 10 shows the decision matrix with the Fuzzy triangular numbers data and the obtained weights from the previous step which in the Fuzzy TOPSIS method is considered as the initial step for the calculation of the prioritization.

In the previous section (Fuzzy TOPSIS method) steps of proposed method have been developed in detail. Table 11, after taking the various steps of the mentioned method for each of the options (the key success factors of the project), the distance from positive ideal and the distance from negative ideal and the similarity index have been calculated. Finally, the alternatives have been ranked based on the descending order of the similarity index number.

In Fig. 4, the critical success factors of construction projects have been developed in a bar chart. As it can be seen, three key success factors with equal rankings have a higher priority than the other critical success factors.

The multi-objective optimization on the basis of ratio analysis (MOORA) and its updated form MULTIMOORA method has been proposed and developed by Brauers and Zavadskas (Brauers and Zavadskas, 2006; Brauers and Ginevičius, 2010). Table 12, shows a comparison between ranks of Fuzzy TOPSIS method and Fuzzy Multi-MOORA method.

The results of Fuzzy TOPSIS method have shown that the three most important critical success factors in the construction industry are: strategic and effective planning of the project, allocating appropriate funding and experienced and multidisciplinary project team. Also among the studied alternatives, the ongoing consultation of the project employer, having contact with stakeholders and people in the project and regulations and political or economic and social issues have the least importance respectively from the perspective of the construction projects' executors. Nevertheless, the result of fuzzy Multi-MOORA method has shown that the three most important critical success factors in the current study are: Accurate and reliable estimates of project costs, allocating appropriate funding and Experienced and multidisciplinary project team. As mentioned the least important critical success factors in multi-MOORA technique have the same result as Fuzzy TOPSIS method.

By using the findings of this research, the construction project executors have a ranked list of construction project key success factors that are needed for the success of the project. They can make their plans based on the priorities of these factors. So that, before having any issues, they can implement the effective strategic planning of the project with more emphasis and accuracy. They can also predict an appropriate budget for the various stages of their construction project. On the other hand, the presence of the experienced and multidisciplinary project team for the success of the construction projects is imperative that should be considered with high sensitivity. As the results of Table 13 have shown, the ongoing consultation of the project employer has the least importance among the key success factors of the project. In addition to the crucial importance of this factor among the key success factors, it should be possibly limited to the original approvals of the project and it should be only used to solve the unexpected and accidental cases. Such consultations during the implementation of the construction projects cause many damages to the time, quality and cost of the projects which should be considered by the project executors.

5. Conclusions

The successful implementation of the construction projects with the qualitative, affordable, on time and safe indicators is the top priority for the economic development of the countries. Iran is a densely populated and developing country which needs to implement successful construction projects in order to achieve economic development. In this study, the construction projects in Iran have been studied to identify, evaluate and rank the critical success factors of the project. The critical success factors have been obtained as alternatives through the frequency of the factors in the research literature.

The factors have been classified into four main following groups: (a) project activities; (b) project management; (c) human resources; (d) external environment. These four main groups of the success factors that are obtained from the research literature and have been classified into 36 sub-groups. Among the 36 key success factors of the projects given to the level of their frequency in the literature, 16 key success factors have been determined as the candidates for ranking. The Fuzzy Shannon entropy method has been used in the step of the determination of the weights of the project success indicators and the weights of the criteria have been calculated. By using the obtained weights of the decision matrix from the collected data along with the weights of the indicators, the input of the determination of the ranking of the key success factors of the project have been conducted by the Fuzzy TOPSIS method.

Finally, the factors of strategic and effective planning of project, allocating appropriate funding, and having an experienced and multidisciplinary project team, availability of resources project monitoring and control mechanism and qualified and experienced project management have respectively gained the first to sixth ranks among the critical success factors of the project by employing Fuzzy TOPSIS integrated Shannon's entropy method. This research helps the huge construction projects' managers and eventually the country's construction industry policymakers to have more emphasis on the afore-mentioned and prioritized factors in order to be successful in the implementation of the construction products.

In future studies regarding this field, different hypotheses and assumptions based on the real-world facts may be considered, also other countries can apply the proposed approach and compare the result to this current study. On the other hand, other methods can be used to determine the weights of criteria such as Fuzzy AHP and Fuzzy BWM. Also, other multiple criteria decision making methods such as Fuzzy VIKOR, Fuzzy ELECTERE, Fuzzy PROMTHEE, Fuzzy Axiomatic Design method can be applied for ranking the alternatives, and the results can be compared with the results of this study.

This study also had its limitations. While the findings have valuable contributions to identification and assessment of critical success factors in construction projects, one limitation of this study is that this study was based on a single case study. This research was conducted in one construction project and with the participation of the experts of that project, so generalization should be done cautiously.

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