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A Hybrid Fuzzy TOPSIS – Best Worst Method for Risk Prioritization in Megaprojects

Ashraf Norouzi [a*], Hamid Ghayur Namin [b]

[a] *Tarbiat Modares University, Faculty of Industrial Engineering, Tehran, Iran.*

[b] *Islamic Azad University of Yazd, Safaeih , Yazd, Iran.*

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Abstract

Megaprojects are usually complex and in many cases encounter failure in terms of finish late or overspent. This study aims to investigate the critical risk factors behind these projects as well as their priority. Project risk management is a mature research stream. But when focus on megaprojects the amount of research decreases significantly. This research provides a hierarchy of risk structure in Tehran-Rasht railway megaproject and prioritizes the risk factors through a two-phase methodology. This method is a new hybrid MCDM technique consist of group fuzzy TOPSIS and fuzzy Best-Worst Method. BWM is the latest MCDM technique which in this paper, its fuzzy version combined with fuzzy TOPSIS is employed. This research also considers all the project success criteria including time, cost and quality simultaneously and calculates the risk priority Index (RPI) accordingly. The results imply that quality is the most important project success factor and the risk elements with greater impact on project quality, get higher PRI. The identified and ranked risk factors help practitioners and academics to follow the subsequent steps of the risk management process of Iranian transportation megaprojects.

Keywords: Best-Worst Method (BWM); Decision-making; Fuzzy TOPSIS; Megaprojects; Risk Assessment.

1. Introduction

The primary aim of every project is its successful completion. The criteria to evaluate this success are generally based on the triple constraints of managing time, cost and quality of projects. In other words, any failure in the implementation of the project with projected time, cost, and quality is considered as the project risk. According to PMI definition, project risk management is a systematic process consisting of consequent steps containing planning, risk identification, qualitative and quantitative risk analysis, response planning and risk monitoring and control [1]. This study deals with the first steps of this process i.e. risk identification and analysis. It is obvious that as the size and complexity of the project increases, its risk increases as well. Therefore the risk management in the construction of megaprojects is more complicated and challenging. There are various definitions of the megaproject. But the most important distinguishing feature is about its investment value. Generally projects with investment over than one billion are considered as megaprojects. Unfortunately, construction megaprojects do not have a good reputation for successful implementation. According to the Standish report in 2009, successful projects in terms of time, cost and quality were only about 32% of projects. The projects with delayed schedule and cost overruns were 44%, and the canceled projects were 24% [2].

Ernest and Young (2014) findings confirm these results. They reported that 73 percent of megaprojects they studied,

* Corresponding author: a.norouzi@modares.ac.ir

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encounter time overruns and 64 percent had cost overruns [3]. The situation is more difficult in infrastructure transportation megaprojects. In these projects, the cost is often underestimated while the traffic is overestimated and the achievement to predefined cost and schedule is rare [4, 5]. Every year a large number of megaprojects including infrastructure transportation projects are carried out in the Middle East. This study aims to investigate and prioritize critical risk factors impacting on the construction of new railway lines in Iran. Due to the geopolitical position of Iran, construction of transportation infrastructures is of great importance for this country. But like other developing countries its unstable economic and political situations increases the complexity and challenges associated with the construction of megaprojects. The great amount of required investment for infrastructure transportation projects and their general trend toward failure in terms of cost overrun, delay and poor quality, reveals the importance of more investigation on risk management of these projects. To the best of our knowledge there is a little literature of this research stream in Iran.

In order to fulfill this research, we employ a structured approach. Our proposed approach consists of two phases. In the first phase, using the fuzzy Best-Worst Method (BWM) developed by Guo and Zhao, (2017) the relative weights of iron triangle success factors (i.e. time, cost and quality) are extracted from a group decision making process [6]. BWM is the latest multi criteria decision making (MCDM) technique developed by Rezaei et al. (2015) [7]. This method has fewer data requirements compared to other traditional MCDM techniques but can provide reliable results [8]. Guo and Zhao (2017) developed the fuzzy version of BWM where the judgments made by decision makers are expressed by linguistic terms [6]. The authors demonstrated the effectiveness of their proposed method by implementing it over several illustrative examples. The ranking of risk factors takes place in the second phase where we employed the fuzzy TOPSIS method developed by Chen et al. (2006) [9]. This method uses a hierarchy MCDM model based on fuzzy set theory. This approach has been widely used in the literature [10-15]. Each of these methodological phases has been used in the literature before. Although the aggregation and application of them within a project risk assessment model is novel. We also contribute to the research stream of megaprojects risk assessment by considering the effect of risk elements based on triple constraints of time, cost and quality of the project and evaluate them simultaneously in a group decision making process. There are few studies that investigate the impact of risk elements on project implementation considering all time, cost and quality constraints simultaneously. Most of the previous researches about risk management in megaprojects have investigated the impact of risk elements on project cost overrun [16-19] or time overrun [20-23]. A practical implementation of the proposed approach in the Iranian railway construction context is another practical contribution of our study. This paper is organized as follows: next section provides a literature review on risk assessment in the construction of megaprojects. Section 3 introduces the two-phase methodology of this research and section 4 provides the results of its application. Consequently, section 5 provides summary and conclusion. Figure 1 demonstrates the steps of this study.

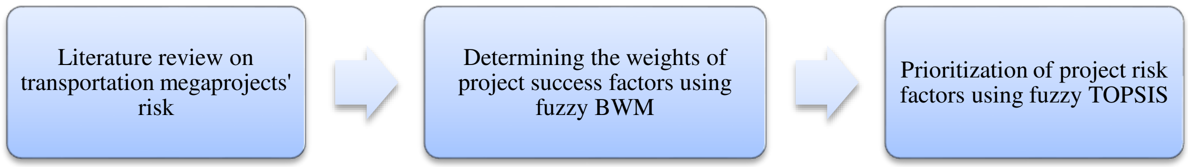

Figure 1. Empirical phases of the research

2. Literature Review

Megaprojects are characterized by their complexity, dynamic interface, uncertainty, ambiguity, significant political and external influences and long duration of implementation [24]. These projects are complex and associated with many uncertainties and interactions which can conclude to project failure in many ways. They usually consist of complex and uncertain activities executed by temporary teams from different organizations and cultures. They also involve different partners and stakeholders with various and sometimes conflicting viewpoints [25-34]. Hence these projects contain a lot of risk factors which avoid them to fulfill their predefined cost, time and quality goals [26, 33]. There is great literature about project risk management in general. But when focus on megaproject, the amount of research decreases dramatically [28]. The current body of knowledge emphasizes that megaprojects are more sensitive to specific factors than the small-sized projects [24]. If a megaproject starts to fail on any aspect, the downside spiral causes failure for every other outcome in a dramatic manner [35].There are numerous evidence emphasizing that megaprojects usually become money pits where funds are simply consumed without achieving sufficient results. This problem is more severe in the case of railway construction projects than other transportation modes [2]. According to Flyvbjerg (2009) research on 258 transportation projects across 20 countries, 90 percent of these projects face cost overrun [36].

The rate of cost overrun for rail, bridge and tunnel and road projects were about 45%, 34%, and 20% respectively. The author concludes that cost underestimation has not improved over the last 70 years. As mentioned in section 1 there are lots of previous researches that confirm these findings. Based on the SBC report 10 percent of megaprojects face large cost overrun in 1997 [24]. They defined large cost overrun as cost underestimation more than 50 percent. This rate has increased over time. It was estimated at 17 percent in 2005 and 30 percent in 2011. A famous example of cost underestimation in megaproject construction is Boston's "Big Dig". The project's aim was to build a two-mile underground highway from central artery to the heart of Boston. The project was the most expensive highway project in the US and was plagued by delays, design flaws, and poor execution and substandard materials. The project was initially scheduled to be completed in 1995 at an estimated cost of $2.8 billion which was adjusted to $6 billion for inflation in 2006. However, the project was completed in 2007 at a cost of over $14.6 billion [24]. Another example of time and cost overrun in megaprojects is Tehran-Shomal freeway. This project aim was to connect Tehran to the southern coasts of the Caspian Sea through passing the Alborz Mountains. The project has 180 tunnels with an overall length of 100 kilometers. The project was initially approved by the government in 1978 with an estimated 10 years schedule and 750 billion Rials (Iranian Currency) budget. But due to Iran 1979 revolution and eight years' war with Iraq and some financing problems, the project ultimately began in 1996 and its building still continuous after 22 years of construction. The project consists of four sections with a length of 32, 22, 47 and 20 km respectively. Until now only section 4 has been exploited and other sections are still under construction. The long delays of this project are mainly related to financing problems, land acquisition, growing material prices and interaction problems with foreign contractors. A study on project cost data sourced from EVA-TREN and cost action TU 1003 stated that cost overrun from some selected high-speed rail megaprojects in the European Union was between 8% and 116%. These projects include Inter-City Express of Frankfurt-Cologne (116%), Eurotunnel (69%), Madrid-Seville Alta Velocidad Española (23%), Paris-Lille Train Grande Vitesse (25%), Lyon-Marseille TGV (8%) and the Oeresund Fixed Link (63%). Others are the Edinburgh Tram Network project (42%), Seville-Madrid HSR (71%) and Madrid-Barcelona HSR (50%) [25].

The prevailing trend toward the poor performance of these projects reveals the need to undertake a precise study on risk factors associated with the construction of transportation megaprojects. There are few studies that provide guidance on the successful implementation of megaprojects and critical factors behind their success [24]. Many challenges which lead to megaproject failures are obvious such as requirements to manage numerous complicated activities while maintaining a tough schedule and budget [24]. Some other challenges are less tangible such as complicated risk structure with dynamic interactions and governance structure of the project. There are numerous potential risk elements which could impact on megaproject development. These factors could influence on each stage of the project lifecycle from planning and conceptual design to delivery stages of the project. Generally, risk management is a vital on-going iteratively process which is fulfilled during each stage in order to formulate appropriate mitigation strategies to respond risk. Hence, this is very difficult to provide a comprehensive list of all the potential risk elements impacting on the construction of a megaproject. In addition, megaprojects have a complex risk structure and different risk factors may have different impacts on project outcomes in terms of cost, time and project quality. To deal with these complexities and employ the results in the practical context of constructing new railway lines in Iran, we used a hybrid approach where we provide a list of potential risk factors from literature and then obtain the experts' opinions about them. As the number of risk elements increases, the number of pairwise comparisons increases as well. This can cause confusion of experts and affect the quality of the results. To deal with this issue, this study proposes a new hybrid MCDM approach and puts it into practice in obtaining the experts' opinions of the case study. Review on megaproject risk literature reveals that most of the previous researches attempt to identify factors that contribute to the project and do not prioritize them or provide specific solutions to mitigate them [24].

Some of these factors include: inappropriate front-end planning, unrealistic cost or schedule estimate, non-comprehensive analysis of geopolitical risk, failure in establishing effective and experienced teams which are usually from different organizations and cultures, poor communications and ineffective stakeholder management, land purchase problems, community resistance, changes in project specifications, underestimation of project costs and inflation rate change [24, 25, 29, 31, 32, 34, 37, 45]. Each of these potential risk factors may have a different impact on project delay, cost overrun or decrease in project quality. Therefore it is crucial to measure and analyze these factors carefully. A couple of previous researches categorized these factors according to STEEP model. [4, 25, 38, 46]. Using this model, the risk elements are classified based on the nature of risk such as social, technical, economic, environmental and political categories. In this research, we provide a list of STEEP risks impacting on megaproject performance in the construction phase. This model reflects different aspects of external macro business environment. The result is illustrated in Table1.

Table 1. Risk factors associated with megaproject construction

Risk factor code	Risk factor description	References
S1	Inability to obtain required land rights	[25, 38-39]
S2	Higher costs due to land access rights	[25, 47]
S4	Social issues and complaints against project	[25, 38-39]
S5	Social partnership with project implementation	[38-39]
S6	Cultural incompatibility with project	[38-39]
S7	The pressure of project stakeholders (including governmental and local authorities) to change the project scope	Expert opinion

T1	Ambiguity of project scope and its creep during implementation	[25, 29, 31-32, 37, 40-41, 42, 48]
T2	Delays in design and regulatory approvals	[31]
T3	Changes in project specifications	[31, 40-41, 42]
T4	Defective design	[29, 31, 34, 37]
T5	Engineering and design changes	[31, 25]
T6	Inappropriate planning and scheduling	Expert opinion
T7	Underestimation of project costs	[25, 29, 34]
T8	Inadequate project complexity analysis	[25, 44]
T9	Unforeseen project modifications	[25, 38-39]
T10	Lack of transparency in the bidding process	[29, 31]
T11	Low competency of subcontractors	[29, 31]
T12	Inadequate experience of contractors	Expert opinion
T13	Poor expertise of contractors	[29, 31, 39]
T14	Poor management of the work site	Expert opinion
T15	Supply chain breakdown	[25, 31]
T16	Inaccessibility to new tools and equipment	Expert opinion
T17	Inaccessibility to innovative technology	[29, 31]
T18	Lack of experience with new technologies	[31, 34]
T19	Resource and equipment shortage	[25, 29, 31-32, 34, 41, 42, 45]
T20	Delay in the delivery of the required materials	[31]
T21	Waste of project resources	[25]
T22	Inability to meet the project's required standards	[25]
T23	Delay in the decision-making process of project managers	[29]
T24	Shortage of skilled labor	[31, 38-39]
T25	Weakness in establishing the efficient project team	Expert opinion
T26	Poor communication between different working teams	[29, 32, 34, 42, 45]
T27	Poor management of the owners of the project	Expert opinion
T28	Contractor human resource management problems	Expert opinion
T29	Delay due to labor disputes	[25]
EC1	Governmental financial policies changes	[25]
EC2	Taxation changes	[25, 49]
EC3	Increase in the wage rate	[25, 31]
EC4	Inflation rate change	[25, 29, 32, 41, 45]
EC5	Foreign exchange rate changes	[25]
EC6	Material price changes	[25, 31]
EC7	Economic recession	[25]
EC8	Energy price change	[25, 31]
EC9	Project time overruns	[25, 31-32, 37, 40, 42]
EC10	Project cost overruns	[25, 37, 40, 48]
EC11	Interest rate changes	[39]
EC12	Low labor productivity	[31]
EN1	Environmental negative impacts of project	[25, 38-39]
EN2	Undesirable weather conditions	[25, 29, 32, 34, 40, 48]
P1	Project termination due to political changes	[25, 49]
P2	Changes in government funding policy	[25, 49]
P3	Political opposition to project implementation	[25, 38-39]
P4	Political indecision	[25]
P5	Unstable political situation	Expert opinion
P6	Delay in obtaining approval of legal authorities	[25, 32]
P7	Legislative/regulatory changes	[25]

Among these factors, 9 elements are added by experts during obtaining their opinions. It may not be so simple for many experts to make judgments about success factors in terms of pairwise comparison. To deal with this problem, we used the best-worst method where the decision maker has to make a fewer comparison. Also to consider the ambiguity of linguistic scale in explaining different participants' mental latencies we used the fuzzy BWM developed by Guo and Zhao (2017) [6]. In the second phase in order to evaluate the overall impact of each risk element on project objectives, we employed the fuzzy TOPSIS method. The proposed two-step approach provides a simple and straightforward basis for ranking risk factors of megaproject in the construction phase and could be easily employed by project managers. The computational details of this two-phase methodology are described in the next section. All the computational work of this paper is carried out by MATLAB 14.0 software.

3. Research Design

This section provides descriptions on two-phase methodology for risk assessment in the construction of megaprojects.

3.1. Fuzzy BWM

In this section fuzzy best-worst method developed by Guo and Zhao (2017) is introduced [6]. Suppose there are n criterions and their fuzzy pairwise comparisons could be performed through linguistic terms such as "equally important" to "absolutely important". These terms are transformed into fuzzy numbers based on rules listed in Table 2.

Table 2. Transformation of linguistic variables into triangular fuzzy numbers

Level of influence	Importance level	Likert 5-point scale	Triangular fuzzy numbers
Extremely Influential (EI)	Absolutely Important (A)	9	(7/2, 4, 9/2)
Moderately Influential (MI)	Very Important (V)	7	(5/2, 3, 7/2)
Somewhat Influential (SOI)	Fairly Important (F)	5	(3/2, 2, 5/2)
Slightly Influential (SLI)	Weakly Important (W)	3	(2/3, 1, 3/2)
Not at all Influential (NI)	Equally Important (E)	1	(1, 1, 1)

Definition: a pairwise comparison $\tilde{a}_{ij}$ is defined as a fuzzy comparison if i is the best element and/or j is the worst element. The fuzzy comparison matrix can be presented as follows:

$$\tilde{A} = \begin{matrix} & c_1 & c_2 & \cdots & c_n \\ c_1 & \tilde{a}_{11} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ c_2 & \tilde{a}_{21} & \tilde{a}_{21} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ c_n & \tilde{a}_{n1} & \tilde{a}_{n1} & \cdots & \tilde{a}_{nn} \end{matrix} \tag{1}$$

Where $\tilde{a}_{ij}$ represents the relative fuzzy importance of ith criterion over the jth criterion, which is a triangular fuzzy number. Suppose there are n decision criterions in the form of $\{c_1, c_2, \dots, c_n\}$. Determine the best (the most important) and the worst (the least important) criterions and represent them as C_B and C_W respectively. The fuzzy reference comparison for the best criterion over all other criterions is executed. These fuzzy comparisons are represented by Best-to-Other vector as $\tilde{A}_B = (\tilde{a}_{B1}, \tilde{a}_{B2}, \dots, \tilde{a}_{Bn})$.Then the fuzzy reference comparison for all criterions over the worst criteria is executed. These fuzzy comparisons are represented by Other-to-Worst vector as $\tilde{A}_W = (\tilde{a}_{1W}, \tilde{a}_{2W}, \dots, \tilde{a}_{nW})$. The next step is to determine the optimal fuzzy weights. The optimal fuzzy weights of each criterion, are ones that satisfy the equations $\frac{\tilde{w}_B}{\tilde{w}_j} = \tilde{a}_{Bj}$ and $\frac{\tilde{w}_j}{\tilde{w}_W} = \tilde{a}_{jW}$. To meet these constraints, the maximum absolute gaps $\left|\frac{\tilde{w}_B}{\tilde{w}_j} - \tilde{a}_{Bj}\right|$ and $\left|\frac{\tilde{w}_j}{\tilde{w}_W} - \tilde{a}_{jW}\right|$ for all j should be minimized. Therefore we could obtain the optimal fuzzy weights $(\tilde{w}_1^*, \tilde{w}_2^*, \dots, \tilde{w}_n^*)$ as follows:

$$\min \max_j \left\{ \left|\frac{\tilde{w}_B}{\tilde{w}_j} - \tilde{a}_{Bj}\right|, \left|\frac{\tilde{w}_j}{\tilde{w}_W} - \tilde{a}_{jW}\right| \right\}$$
$$s.t. \begin{cases} \sum_{j=1}^{n} R(\tilde{w}_j) = 1 \\ l_j^w \le m_j^w \le u_j^w \\ l_j^w \ge 0 \\ j = 1,2,\dots,n \end{cases} \tag{2}$$

Where $\tilde{w}_B = (l_B^w, m_B^w, u_B^w)$, $\tilde{w}_j = (l_j^w, m_j^w, u_j^w)$, $\tilde{w}_W = (l_W^w, m_W^w, u_W^w)$, $\tilde{a}_{Bj} = (l_{Bj}, m_{Bj}, u_{Bj})$, $\tilde{a}_{jW} = (l_{jw}, m_{jw}, u_{jw})$.

Equation 2 could be transformed into the following nonlinearly constrained problem:

$$\min \tilde{\xi}$$
$$s.t.\begin{cases} \left|\frac{\tilde{w}_B}{\tilde{w}_j} - \tilde{a}_{Bj}\right| \le \tilde{\xi} \\ \left|\frac{\tilde{w}_j}{\tilde{w}_W} - \tilde{a}_{jW}\right| \le \tilde{\xi} \\ \sum_{j=1}^{n} R(\tilde{w}_j) = 1 \\ l_j^w \le m_j^w \le u_j^w \\ l_j^w \ge 0 \\ j = 1,2,\dots,n \end{cases} \tag{3}$$

Where $\tilde{\xi} = (l^{\xi}, m^{\xi}, u^{\xi})$.

Considering $l^{\xi} \le m^{\xi} \le u^{\xi}$ we suppose $\tilde{\xi}^* = (k^*, k^*, k^*), k^* \le l^{\xi}$ then Equation 3 can be transformed into Equation 4.

$$\min \tilde{\xi}^*$$
$$s.t.\begin{cases} \left|\frac{(l_B^w, m_B^w, u_B^w)}{(l_j^w, m_j^w, u_j^w)} - (l_{Bj}, m_{Bj}, u_{Bj})\right| \le (k^*, k^*, k^*) \\ \left|\frac{(l_j^w, m_j^w, u_j^w)}{(l_W^w, m_W^w, u_W^w)} - (l_{jW}, m_{jW}, u_{jW})\right| \le (k^*, k^*, k^*) \\ \sum_{j=1}^{n} R(\tilde{w}_j) = 1 \\ l_j^w \le m_j^w \le u_j^w \\ l_j^w \ge 0 \\ j = 1,2,\dots,n \end{cases} \tag{4}$$

Also, the consistency ratio of fuzzy BWM can be calculated as $\frac{K^*}{C.I.}$ where the consistency index with regard to different linguistic terms are as presented in Table 3 [6]. For further explanations about fuzzy BWM please refer to Guo and Zhao (2017) [6].

Table 3. Consistency index (CI) for fuzzy BWM

Linguistic terms	Equally important (E)	Weakly important (W)	Fairly important (F)	Very important (V)	Absolutely important (A)
$\tilde{a}_{BW}$	(1, 1, 1)	(2/3, 1, 3/2)	(3/2, 2, 5/2)	(5/2, 3, 7/2)	(7/2, 4, 9/2)
CI	3.00	3.80	5.29	6.69	8.04

3.2. Fuzzy TOPSIS Method

In this section, the fuzzy TOPSIS method developed by Chen, et al. (2006) is introduced [9]. Consider a decision-making problem with m alternatives and n criterions. Decision makers represent their viewpoint by linguistic terms. These values are transformed into their corresponding fuzzy triangular numbers according to Table 2. Assume $\tilde{x}_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk})$ is the value assigned to ith alternative regarding to the jth criterion by decision maker k. The aggregated value of $\tilde{x}_{ijk}$ over all decision makers are obtained as follows:

$$a_{ij} = min_k\{a_{ijk}\}$$
$$b_{ij} = \frac{\sum_k b_{ijk}}{k} \tag{5}$$
$$c_{ij} = max_k\{c_{ijk}\}$$

Now the decision matrix $\tilde{D}$ is as follows;

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix} \tag{6}$$

Where $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij});\ i = 1,2,\dots,m,\ j = 1,2,\dots,n.$

The fuzzy weights vector $\widetilde{W}$ is also represented by triangular fuzzy numbers. We obtained these fuzzy weights from fuzzy BWM in the previous phase as $\widetilde{W} = [\widetilde{w}_1, \widetilde{w}_2, \dots, \widetilde{w}_n]$ where $\widetilde{w}_j = (w_{j1}, w_{j2}, w_{j3})$. The normalized fuzzy decision matrix can be represented as $\tilde{R} = [\tilde{r}_{ij}]_{m\times n}$. Assuming positive (benefit) and negative (cost) criterions as B and C sets respectively, the normalized values of fuzzy decision matrix are derived as:

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), \quad j \in B,$$
$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), \quad j \in C, \tag{7}$$
$$c_j^* = \max_i c_{ij}, \quad j \in B,$$
$$a_j^- = \min_i a_{ij}, \quad j \in C,$$

Considering the importance of each criterion, the weighted normalized fuzzy decision matrix is constructed as $\tilde{V} = [\tilde{v}_{ij}]_{m\times n,}$ $i = 1,2,\dots,m,$ $j = 1,2,\dots,n,$ where $\tilde{v}_{ij} = \tilde{r}_{ij}(.)\widetilde{w}_j$. According to the weighted normalized fuzzy decision matrix, the normalized positive fuzzy numbers, can approximate the elements $\tilde{v}_{ij}$, $\forall i, j$. Then the fuzzy positive-ideal solution (FPIS, A^*) and the fuzzy negative-ideal solution (FNIS, A^-) can be defined as:

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*),$$
$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-), \tag{8}$$

Where $\tilde{v}_j^* = \max_i\{v_{ij3}\}$ *and* $\tilde{v}_j^- = \min_i\{v_{ij1}\}$ $i = 1,2,\dots,m,$ $j = 1,2,\dots,n$. The distance of each alternative from A^* and A^- can be calculated as:

$$d_i^* = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_j^*), \quad i = 1,2,\dots,m,$$
$$d_i^- = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_j^-), \quad i = 1,2,\dots,m, \tag{9}$$

Where $d_v(.,.)$ is the distance measurement between two fuzzy numbers. The closeness coefficient which is defined to determine the ranking of alternatives can be calculated as follows:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, \quad i = 1,2,\dots,m \tag{10}$$

This coefficient value varies between 0 and 1. The larger the value of closeness coefficient, the higher the priority of its corresponding alternative. For more details and examples about fuzzy TOPSIS please refer to Chen et al. (2006) [9]. According to the values of CC_i, the factors could be categorized. Chen et al. (2006) proposed five classes for categorizing the alternatives as shown in Table 4 [9]. We use these categories to classify risk elements.

Table 4. Classes of alternatives according to the closeness coefficient [9]

Closeness coefficient CC_i	Assessment status
$CC_i \in [0, 0.2)$	Do not prefer
$CC_i \in [0.2, 0.4)$	Preferred with high risk
$CC_i \in [0.4, 0.6)$	Preferred with low risk
$CC_i \in [0.6, 0.8)$	Preferred
$CC_i \in [0.8, 1]$	Highly preferred

4. Results

In this section, the application of our two-phase methodology in the context of constructing new railway lines in Iran is discussed. We consider three criterions of project success: "time", "cost" and "quality". A committee comprising of five decision makers who are managers with more than 10 years of experience in Iran railway construction projects, take part in this research.

4.1. Calculating the Criterions' Weights According to Fuzzy BWM

Consider the list of our criterions as $\{C_1, C_2, C_3\}$ where C_1 stands for Cost, C_2 stands for time and C_3 stands for quality. According to decision maker 1 opinion, C_3 is the best and C_2 is the worst criterion. Table 5 and 6 represent the linguistic terms expressed by DM1 for fuzzy preferences of C_3 over all other criterions and other criterions over C_2 respectively.

Table 5. The fuzzy preferences of the best criterion over all criterions for DM1

Criteria	C_1	C_2	C_3
Best criteria C_3	FI	VI	EI

So the fuzzy best-to-other vector can be obtained as $\tilde{A}_B = \left[\left(\frac{3}{2}, 2, \frac{5}{2}\right), \left(\frac{5}{2}, 3, \frac{7}{2}\right), (1, 1, 1)\right]$.

Table 6. The fuzzy preferences of all criterions over the worst criterion for DM1

Criteria	Worst criteria C_2
C_1	FI
C_2	EI
C_3	VI

According to Table 2, the fuzzy other-to-worst vector is $\tilde{A}_W = \left[\left(\frac{3}{2}, 2, \frac{5}{2}\right), (1, 1, 1), \left(\frac{5}{2}, 3, \frac{7}{2}\right)\right]$. Now according to Equation 4, the optimal criteria weights can be derived from solving the following nonlinear constrained optimization problem:

$$\min \xi^*$$
$$s.t.\begin{cases} \left|\frac{(l_3, m_3, u_3)}{(l_1, m_1, u_1)} - \left(\frac{3}{2}, 2, \frac{5}{2}\right)\right| \leq (K^*, K^*, K^*) \\ \left|\frac{(l_3, m_3, u_3)}{(l_2, m_2, u_2)} - \left(\frac{5}{2}, 3, \frac{7}{2}\right)\right| \leq (K^*, K^*, K^*) \\ \left|\frac{(l_1, m_1, u_1)}{(l_2, m_2, u_2)} - \left(\frac{3}{2}, 2, \frac{5}{2}\right)\right| \leq (K^*, K^*, K^*) \\ \frac{1}{6}(l_1 + 4m_1 + u_1 + l_2 + 4m_2 + u_2 + l_3 + 4m_3 + u_3) = 1 \\ l_1 \leq m_1 \leq u_1 \\ l_2 \leq m_2 \leq u_2 \\ l_3 \leq m_3 \leq u_3 \\ l_1, l_2, l_3 > 0 \\ K \geq 0 \end{cases} \quad (11)$$

By solving Equation 11 the optimal fuzzy weights of three criteria ('cost', 'time', and 'quality') are obtained as $W_1^* = (0.244, 0.299, 0.345)$, $W_2^* = (0.151, 0.167, 0.189)$, $W_3^* = (0.512, 0.535, 0.559)$. In this case $\tilde{a}_{BW} = \tilde{a}_{32} = \left(\frac{5}{2}, 3, \frac{7}{2}\right)$. According to Table 3, the consistency index is 6.69. Therefore the consistency ratio is equal to 0.0312 which is very close to zero and indicates a very high consistency. Similar calculations are done for other decision makers' opinions about comparing the criterions. Table 7 provides a summary of the results.

Table 7. Optimal weights of criterions

DM	Quality			Time			Cost			ξ^*	I.R.
	l_3	m_3	u_3	l_2	m_2	u_2	l_1	m_1	u_1		
1	0.512	0.535	0.559	0.151	0.167	0.189	0.244	0.299	0.345	0.209	0.031
2	0.399	0.399	0.551	0.235	0.235	0.333	0.306	0.306	0.423	0.303	0.057
3	0.634	0.634	0.634	0.171	0.197	0.234	0.136	0.168	0.193	0.217	0.027
4	0.634	0.634	0.634	0.136	0.168	0.193	0.171	0.198	0.234	0.217	0.027
5	0.308	0.370	0.445	0.163	0.166	0.178	0.401	0.458	0.532	0.236	0.035

We used the geometric mean of decision makers' opinions over each criterion fuzzy weights. Hence the aggregated optimal fuzzy weights of three criterions are obtained as $W_1^* = (0.233, 0.268, 0.323)$, $W_2^* = (0.168, 0.185, 0.219)$, $W_3^* = (0.479, 0.502, 0.560)$.

4.2. Prioritization of Risk Factors According to the Fuzzy TOPSIS Method

The computational procedure of this phase is summarized as follows: Decision makers use the linguistic terms to evaluate the influence of each risk elements on every criterion. The judgments made by decision maker1 are illustrated in Table 8.

Table 8. The impact of each risk factor on criterions according to DM1

Risk element	Cost	Time	Quality	Risk element	Cost	Time	Quality
S1	EI	SOI	SLI	T23	MI	MI	SLI
S2	MI	EI	MI	T24	SOI	MI	MI
S4	SLI	MI	SLI	T25	SOI	MI	MI
S5	MI	MI	MI	T26	SOI	MI	MI
S6	SOI	SLI	NI	T27	SLI	SOI	EI
S7	NI	EI	MI	T28	SOI	MI	EI
T1	SLI	MI	NI	T29	SLI	MI	MI
T2	SOI	MI	SLI	EC1	MI	MI	SLI
T3	SLI	MI	SLI	EC2	MI	SOI	SLI
T4	MI	MI	MI	EC3	MI	SOI	SLI
T5	SLI	MI	SOI	EC4	MI	SOI	SOI
T6	MI	MI	MI	EC5	MI	SLI	SOI
T7	EI	MI	MI	EC6	EI	SOI	SLI
T8	SLI	EI	SLI	EC7	MI	MI	SOI
T9	SOI	MI	SLI	EC8	SOI	SLI	SLI
T10	SOI	EI	SLI	EC9	MI	MI	SLI
T11	SOI	MI	EI	EC10	MI	SOI	SLI
T12	SOI	MI	EI	EC11	SOI	SLI	SLI
T13	SLI	EI	EI	EC12	MI	MI	SOI
T14	SOI	EI	EI	EN1	MI	MI	SLI
T15	MI	EI	SLI	EN2	EI	EI	SOI
T16	EI	EI	SOI	P1	MI	MI	SLI
T17	MI	EI	MI	P2	MI	EI	SLI
T18	MI	MI	SOI	P3	SLI	EI	SLI
T19	SLI	MI	SLI	P4	SLI	EI	SOI
T20	SOI	EI	SLI	P5	SLI	EI	SOI
T21	EI	EI	MI	P6	SLI	MI	SLI
T22	SOI	SOI	EI	P7	SLI	EI	SOI

Similar evaluations are made by all decision makers. Based on Table 2 these judgments are transformed into their corresponding TFN. According to Equation 5, the aggregated value of these TFN over all Decision makers is calculated. Then the weighted normalized fuzzy decision matrix is constructed. The results are shown in Table 9.

Table 9. The weighted normalized fuzzy decision matrix of risk elements

Risk element	Cost	Time	Quality
S1	(0.182, 0.238, 0.323)	(0.056, 0.14, 0.219)	(0.071, 0.112, 0.187)
S2	(0.078, 0.155, 0.251)	(0.093, 0.156, 0.219)	(0.071, 0.223, 0.436)
S4	(0.035, 0.060, 0.108)	(0.056, 0.107, 0.17)	(0.071, 0.134, 0.311)
S5	(0.078, 0.155, 0.251)	(0.025, 0.09, 0.17)	(0.071, 0.178, 0.436)
S6	(0.035, 0.083, 0.179)	(0.025, 0.049, 0.122)	(0.071, 0.112, 0.187)
S7	(0.035, 0.107, 0.251)	(0.056, 0.131, 0.219)	(0.266, 0.357, 0.56)
T1	(0.035, 0.155, 0.323)	(0.093, 0.131, 0.219)	(0.071, 0.178, 0.436)
T2	(0.078, 0.155, 0.251)	(0.093, 0.148, 0.219)	(0.071, 0.134, 0.311)
T3	(0.035, 0.119, 0.251)	(0.056, 0.123, 0.219)	(0.071, 0.245, 0.436)
T4	(0.078, 0.191, 0.323)	(0.093, 0.131, 0.219)	(0.266, 0.401, 0.560)
T5	(0.035, 0.107, 0.251)	(0.056, 0.107, 0.17)	(0.071, 0.245, 0.436)
T6	(0.13, 0.203, 0.323)	(0.093, 0.148, 0.219)	(0.266, 0.379, 0.56)
T7	(0.182, 0.238, 0.323)	(0.056, 0.115, 0.17)	(0.16, 0.334, 0.56)

T8	(0.035, 0.179, 0.323)	(0.093, 0.156, 0.219)	(0.071, 0.245, 0.56)
T9	(0.078, 0.179, 0.323)	(0.056, 0.123, 0.219)	(0.071, 0.112, 0.187)
T10	(0.078, 0.155, 0.251)	(0.056, 0.14, 0.219)	(0.071, 0.223, 0.436)
T11	(0.078, 0.143, 0.251)	(0.093, 0.123, 0.17)	(0.266, 0.379, 0.56)
T12	(0.078, 0.131, 0.251)	(0.093, 0.123, 0.17)	(0.266, 0.401, 0.56)
T13	(0.035, 0.131, 0.251)	(0.093, 0.131, 0.219)	(0.266, 0.401, 0.56)
T14	(0.035, 0.095, 0.179)	(0.056, 0.14, 0.219)	(0.16, 0.357, 0.56)
T15	(0.035, 0.131, 0.323)	(0.056, 0.131, 0.219)	(0.071, 0.201, 0.56)
T16	(0.13, 0.214, 0.323)	(0.093, 0.148, 0.219)	(0.071, 0.245, 0.436)
T17	(0.078, 0.179, 0.323)	(0.025, 0.115, 0.219)	(0.16, 0.312, 0.436)
T18	(0.035, 0.167, 0.323)	(0.056, 0.123, 0.219)	(0.071, 0.245, 0.436)
T19	(0.035, 0.083, 0.179)	(0.056, 0.107, 0.17)	(0.071, 0.112, 0.187)
T20	(0.035, 0.107, 0.179)	(0.056, 0.123, 0.219)	(0.071, 0.112, 0.187)
T21	(0.13, 0.214, 0.323)	(0.025, 0.123, 0.219)	(0.16, 0.29, 0.436)
T22	(0.078, 0.167, 0.323)	(0.056, 0.107, 0.17)	(0.373, 0.446, 0.56)
T23	(0.13, 0.203, 0.323)	(0.093, 0.148, 0.219)	(0.071, 0.223, 0.436)
T24	(0.035, 0.083, 0.179)	(0.056, 0.115, 0.17)	(0.266, 0.379, 0.56)
T25	(0.035, 0.095, 0.179)	(0.056, 0.115, 0.17)	(0.266, 0.379, 0.56)
T26	(0.035, 0.131, 0.251)	(0.056, 0.115, 0.17)	(0.266, 0.379, 0.56)
T27	(0.035, 0.083, 0.179)	(0.056, 0.098, 0.17)	(0.266, 0.401, 0.56)
T28	(0.035, 0.083, 0.179)	(0.025, 0.09, 0.17)	(0.160, 0.312, 0.56)
T29	(0.035, 0.06, 0.108)	(0.025, 0.09, 0.17)	(0.071, 0.268, 0.436)
EC1	(0.078, 0.155, 0.251)	(0.093, 0.148, 0.219)	(0.071, 0.156, 0.311)
EC2	(0.035, 0.119, 0.251)	(0.025, 0.115, 0.219)	(0.071, 0.112, 0.187)
EC3	(0.078, 0.155, 0.251)	(0.025, 0.057, 0.122)	(0.071, 0.112, 0.187)
EC4	(0.13, 0.191, 0.323)	(0.056, 0.107, 0.219)	(0.071, 0.201, 0.311)
EC5	(0.13, 0.203, 0.323)	(0.025, 0.066, 0.122)	(0.071, 0.201, 0.311)
EC6	(0.13, 0.214, 0.323)	(0.056, 0.09, 0.17)	(0.071, 0.178, 0.436)
EC7	(0.078, 0.143, 0.251)	(0.093, 0.131, 0.219)	(0.071, 0.178, 0.311)
EC8	(0.078, 0.131, 0.251)	(0.025, 0.049, 0.122)	(0.071, 0.112, 0.187)
EC9	(0.078, 0.155, 0.251)	(0.093, 0.156, 0.219)	(0.071, 0.178, 0.311)
EC10	(0.13, 0.214, 0.323)	(0.025, 0.074, 0.219)	(0.071, 0.134, 0.311)
EC11	(0.078, 0.143, 0.251)	(0.025, 0.057, 0.122)	(0.071, 0.134, 0.311)
EC12	(0.078, 0.131, 0.251)	(0.093, 0.123, 0.17)	(0.071, 0.223, 0.436)
EN1	(0.13, 0.191, 0.323)	(0.056, 0.123, 0.219)	(0.071, 0.112, 0.187)
EN2	(0.078, 0.191, 0.323)	(0.093, 0.14, 0.219)	(0.160, 0.29, 0.436)
P1	(0.078, 0.179, 0.323)	(0.093, 0.14, 0.219)	(0.071, 0.178, 0.436)
P2	(0.035, 0.131, 0.251)	(0.093, 0.156, 0.219)	(0.071, 0.112, 0.187)
P3	(0.035, 0.072, 0.179)	(0.093, 0.148, 0.219)	(0.071, 0.134, 0.311)
P4	(0.035, 0.072, 0.179)	(0.093, 0.148, 0.219)	(0.071, 0.156, 0.311)
P5	(0.035, 0.095, 0.251)	(0.093, 0.148, 0.219)	(0.071, 0.245, 0.436)
P6	(0.035, 0.072, 0.179)	(0.056, 0.115, 0.219)	(0.071, 0.112, 0.187)
P7	(0.035, 0.095, 0.179)	(0.056, 0.131, 0.219)	(0.071, 0.156, 0.311)

Then according to Equations 7 and 8, we determined the FPIS and FNIS as:

$A^{*} = \{(0.182, 0.238, 0.323), (0.093,0.156,0.219), (0.373, 0.446,0.560)\}$

$A^{-} = \{(0.035, 0.060,0.108), (0.025, 0.049, 0.122), (0.071, 0.111, 0.187)\}$.

The distance of each risk element from FPIS and FNIS with respect to each criterion is calculated. Consequently as shown in Table 10, the values of d_i^* and d_i^- and CC_i for each risk element are calculated. CC_i is used as a proxy of RPI for each risk element.

Table 10. Calculation of d_i^*, d_i^- and CC_i

Risk element	d_i^*	d_i^-	CC_i
S1	0.339	0.269	0.443
S2	0.245	0.327	0.572
S4	0.345	0.324	0.484
S5	0.266	0.311	0.539
S6	0.380	0.301	0.442
S7	0.148	0.416	0.738
T1	0.263	0.332	0.558
T2	0.302	0.295	0.494
T3	0.252	0.340	0.575
T4	0.095	0.407	0.811
T5	0.256	0.341	0.571
T6	0.082	0.403	0.832
T7	0.145	0.367	0.716
T8	0.229	0.368	0.617
T9	0.346	0.284	0.450
T10	0.246	0.323	0.568
T11	0.122	0.405	0.769
T12	0.122	0.415	0.773
T13	0.132	0.418	0.760
T14	0.198	0.402	0.670
T15	0.249	0.379	0.603
T16	0.224	0.320	0.589
T17	0.182	0.341	0.652
T18	0.242	0.331	0.578
T19	0.372	0.305	0.450
T20	0.367	0.297	0.447
T21	0.177	0.327	0.648
T22	0.086	0.442	0.837
T23	0.231	0.322	0.582
T24	0.171	0.420	0.711
T25	0.167	0.415	0.713
T26	0.141	0.407	0.743
T27	0.170	0.424	0.714
T28	0.217	0.393	0.645
T29	0.289	0.357	0.553
EC1	0.294	0.295	0.501
EC2	0.360	0.297	0.452
EC3	0.360	0.271	0.429
EC4	0.272	0.294	0.520
EC5	0.283	0.281	0.499
EC6	0.251	0.303	0.546
EC7	0.289	0.301	0.510
EC8	0.363	0.284	0.439
EC9	0.287	0.298	0.509
EC10	0.297	0.277	0.482
EC11	0.316	0.287	0.476
EC12	0.250	0.331	0.570
EN1	0.342	0.282	0.452
EN2	0.181	0.336	0.650
P1	0.254	0.324	0.561
P2	0.356	0.298	0.455
P3	0.327	0.329	0.501
P4	0.320	0.330	0.507
P5	0.254	0.355	0.583
P6	0.372	0.316	0.459
P7	0.317	0.313	0.497

According to Table 4 and closeness coefficient calculated for every 56 alternatives, the risk elements are categorized into three classes as illustrated in Table 11. The RPI for risk elements of classes 1 and 2 is represented in Figure 2.

Table11. The classes of risk elements in the construction of railway megaprojects in Iran

Class of risk	Risk element
Class I	T22, T6, T4
Class II	T12, T11, T13, T26, S7, T7, T27, T25, T24, T14, T17, EN2, T21, T28, T8, T15
Class III	T16, P5, T23, T18, T3, S2, T5, EC12, T10, P1, T1, T29, EC6, S5, EC4, EC7, EC9, P4, P3, EC1, EC5, P7, T2, S4, EC10, EC11, P6, P2, EN1, EC2, T9, T19, T20, S1, S6, EC8, EC3

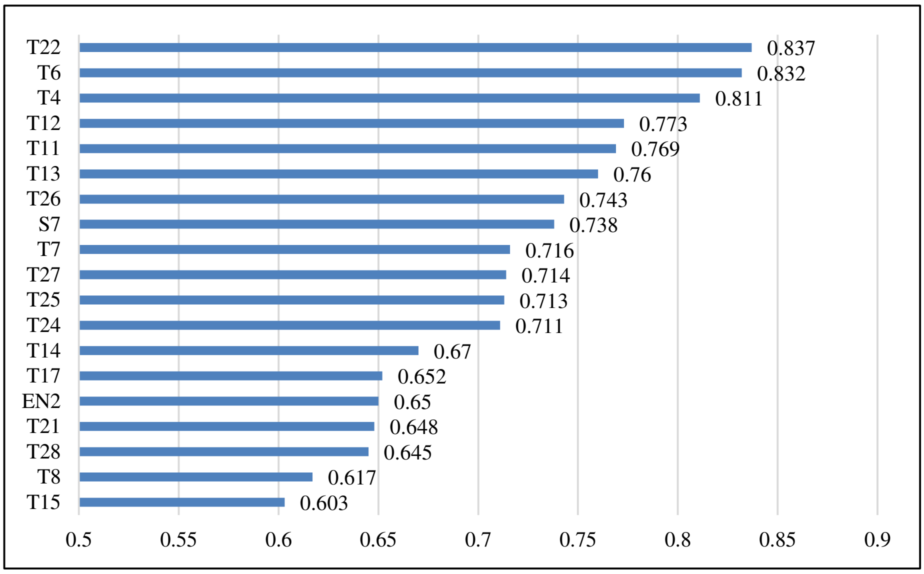

Figure 2. Risk priority index for risk classes 1 and 2

According to the calculated value of CC_i, the risk elements are prioritized. The lower the value of CC_i is, the closer the corresponding element to FNIS. Similarly the greater the value of this index is, the closer the risk element to FPIS. According to Table 4, the risk elements are classified into five different classes. Based on this classification T22, T6 and T4 risk factors were identified as the ones with the highest priority. These factors were the inability to meet the project required standards, inappropriate planning and scheduling and defective design respectively. Among the 53 remaining risk factors, 16 factors were in class II and 37 factors were in class III. The results indicates that most of the technical risk elements belong to classes I and II. Only 0.41 of these factors were in class III. Percentage of risk factors belonging to each class of risk are presented in Table 12 and Figure 3.

Table 12. Percentage of risk items membership to different classes

Risk factor categories	Class I	Class II	Class III
Political factors	0%	0%	100%
Technical factors	10%	48%	42%
Economic factors	0%	0%	100%
Environmental factors	0%	50%	50%
Social factors	0%	17%	83%

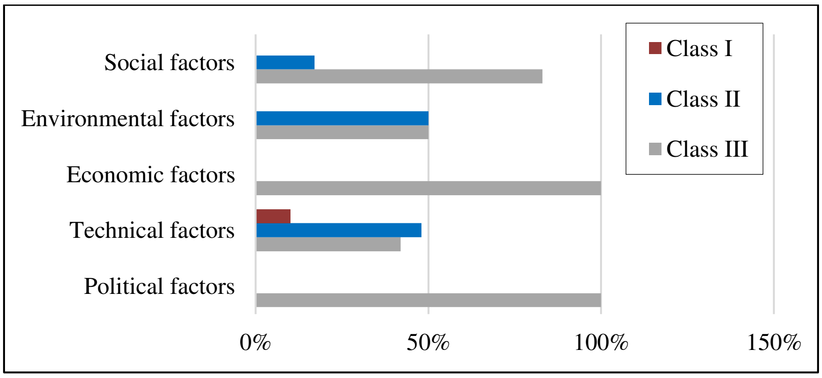

Figure 3. Risk factor categories

A closer look at the ranking of these risk factors indicates that the elements that have a greater impact on project quality, also get higher risk priority index. T22 and T4 of class I are directly related to design and quality problems. Also, lots of risk factors in class II are those that have a direct effect on the quality of project outcomes. For example, the following factors can be mentioned: contractor problems such as low competency, inadequate experience, poor expertise of contractors, shortage of skilled labor and poor management of work site, communication problems between parties such as poor communication between working teams, supply chain breakdown, and weakness in establishing the efficient project team. Class II also contains some problems that affect the project quality indirectly such as inaccessibility to innovative technology. The obtained ranking and the calculated RPI could be employed in subsequent steps of the risk management cycle.

5. Conclusion

This paper provides an empirical study about the risk factors involved in the construction of railway megaprojects in Iran and aims to evaluate and prioritize these risk elements. We identified the potential risk elements from the literature review and experts' opinions where all experts were managers who have over 10 years of experience in construction of railway megaprojects. There are previous researches dealing with identifying failure factors in the construction of megaproject which we reviewed them in section 2. As mentioned earlier a small part of this research stream has been devoted to the ranking of risk factors. These studies are generally prioritized risk elements by considering only one project constraint such as cost [16-19, 50-52] or time of project [20, 21-23,53, 54]. This study aims to investigate and rank risk factors considering all three constraints of project success including time, cost and quality of the project. For this purpose, the impact of each risk element on each criterion and their aggregated impact on the project are evaluated through a two-phase methodology. This research proposes a hybrid BWM-TOPSIS method in order to take advantage of the strengths of these two methods together. In the first phase, the relative weights of criterions are determined using fuzzy BWM. In the second phase, the impact of different risk factors on each criterion and the whole project is evaluated using fuzzy TOPSIS method. Finally the RPI according to each risk element is calculated. The authors are not aware of any previous research that employs the BWM in ranking project risk factors. Also the aggregation of these two techniques within a two-phase methodology and apply it in a real case study is novel. In this hybrid method, we also used the fuzzy theory to consider the ambiguity associated with the linguistic scale expressed by experts. The results of implementing this hybrid model indicate that according to experts opinions quality is the most important criteria and also the factors with the highest effect on quality of project outcomes have higher priority in ranking.

The results imply that according to experts' opinions, the weak performance of contractor evaluation and selection has the highest impact on megaproject defection in the context of constructing railway lines in Iran. Although some other managerial related factors such as inappropriate planning and scheduling, budget underestimation and a waste of project resources are also determined as the most important factors in ranking. Also in contrast to what authors initially expected, the political and economic risk factors have lower ranks compared to technical and environmental factors.

According to the results of this study, most of the problems affecting the failure of Iranian railway megaprojects are related to the weakness of contractors and the lack of contractors with the necessary competencies. As shown in Table 11, 10 out of 19 risk factors of classes 1 and 2 are directly related to the performance of contractors, which includes various aspects from contractors experience and expertise to poor management of human resources. Therefore, in order to reduce the risk associated with the construction of railway megaprojects in Iran, it's crucial to promote the level of contractors involved in these projects. In addition, the risk factors related to project stockholders are another important source of risk in Iranian railway megaprojects which includes 6 risk elements of classes 1 and 2. Inappropriate planning and scheduling, inadequate project complexity analysis and underestimation of project costs are some of these risk factors. These factors clearly demonstrate that the poor performance of the project owners (here the Iranian Railways Company) has a major impact on the failure of railway megaprojects. International consulting companies with experience in the construction of transportation megaprojects could be employed to mitigate these risk factors.

However, the results of this research could be employed by academics for further investigation on risk management of Iranian transportation megaprojects. In spite of the innovations made by this research, it also has some limitations. As stated earlier this research only deals with first steps of project risk management including risk identification and evaluation and its results could be employed in consequent steps of project risk management cycle. This study prioritizes the risk factors from a project shareholder perspective. However, it is valuable to conduct similar research from other stakeholder perspectives including contractors, consultants, government and society and compare the results. In addition, the results of this study are limited to data provided by Iranian railway authorities. If the data could be extended to other megaprojects, as well as other countries and contexts, it would be possible to generalize the results and employ it in prioritizing risk factors associated with megaprojects in the construction phase. However, due to the simplicity and straightforwardness of the proposed approach, it could be easily applied by practitioners in other cases and contexts in order to provide tangible and applicable results.

6. Conflicts of Interest

The authors declare no conflict of interest.

7. References

[1] Larson, E.W. and Gray, C.F., "IEEE Guide--Adoption of the Project Management Institute (PMI(R)) Standard A Guide to the Project Management Body of Knowledge (PMBOK (®) Guide)--Fourth Edition" (2015). doi:10.1109/ieeestd.2011.6086685.

[2] Davies, Andrew, Mark Dodgson, David Gann, and Sam MacAulay. "Five rules for managing large, complex projects." MIT Sloan Management Review 59, no. 1 (2017): 73-78.

[3] Ernest and Young. 2014, Spotlight on oil and gas megaprojects. Available (May 2019): https://www.ey.com/Publication/vwLUAssets/EY-spotlight-on-oil-and-gas-megaprojects/$FILE/EY-spotlight-on-oil-and-gas-megaprojects.pdf.

[4] Boateng, Prince, Zhen Chen, and Stephen O. Ogunlana. "Megaproject Risk Analysis and Simulation" (April 26, 2017). doi:10.1108/9781786358301.

[5] Salling, Kim Bang, and Steen Leleur. "Accounting for the Inaccuracies in Demand Forecasts and Construction Cost Estimations in Transport Project Evaluation." Transport Policy 38 (February 2015): 8–18. doi:10.1016/j.tranpol.2014.11.006.

[6] Guo, Sen, and Haoran Zhao. "Fuzzy Best-Worst Multi-Criteria Decision-Making Method and Its Applications." Knowledge-Based Systems 121 (April 2017): 23–31. doi:10.1016/j.knosys.2017.01.010.

[7] Rezaei, Jafar. "Best-Worst Multi-Criteria Decision-Making Method." Omega 53 (June 2015): 49–57. doi: 10.1016/ j.omega.2014.11.009.

[8] Rezaei, Jafar, Thomas Nispeling, Joseph Sarkis, and Lori Tavasszy. "A Supplier Selection Life Cycle Approach Integrating Traditional and Environmental Criteria Using the Best Worst Method." Journal of Cleaner Production 135 (November 2016): 577–588. doi:10.1016/j.jclepro.2016.06.125.

[9] Chen, Chen-Tung, Ching-Torng Lin, and Sue-Fn Huang. "A Fuzzy Approach for Supplier Evaluation and Selection in Supply Chain Management." International Journal of Production Economics 102, no. 2 (August 2006): 289–301. doi:10.1016/j.ijpe.2005.03.009.

[10] Beikkhakhian, Yokabed, Mohammad Javanmardi, Mahdi Karbasian, and Bijan Khayambashi. "The Application of ISM Model in Evaluating Agile Suppliers Selection Criteria and Ranking Suppliers Using Fuzzy TOPSIS-AHP Methods." Expert Systems with Applications 42, no. 15–16 (September 2015): 6224–6236. doi:10.1016/j.eswa.2015.02.035.

[11] Boran, Fatih Emre, Serkan Genç, Mustafa Kurt, and Diyar Akay. "A Multi-Criteria Intuitionistic Fuzzy Group Decision Making for Supplier Selection with TOPSIS Method." Expert Systems with Applications 36, no. 8 (October 2009): 11363–11368. doi:10.1016/j.eswa.2009.03.039.

[12] Lima Junior, Francisco Rodrigues, Lauro Osiro, and Luiz Cesar Ribeiro Carpinetti. "A Comparison between Fuzzy AHP and Fuzzy TOPSIS Methods to Supplier Selection." Applied Soft Computing 21 (August 2014): 194–209. doi:10.1016/j.asoc.2014.03.014.

[13] Igoulalene, Idris, Lyes Benyoucef, and Manoj Kumar Tiwari. "Novel Fuzzy Hybrid Multi-Criteria Group Decision Making Approaches for the Strategic Supplier Selection Problem." Expert Systems with Applications 42, no. 7 (May 2015): 3342–3356. doi:10.1016/j.eswa.2014.12.014.

[14] Karsak, E. Ertugrul, and Mehtap Dursun. "An Integrated Fuzzy MCDM Approach for Supplier Evaluation and Selection." Computers & Industrial Engineering 82 (April 2015): 82–93. doi:10.1016/j.cie.2015.01.019.

[15] Scott, James, William Ho, Prasanta K. Dey, and Srinivas Talluri. "A Decision Support System for Supplier Selection and Order Allocation in Stochastic, Multi-Stakeholder and Multi-Criteria Environments." International Journal of Production Economics 166 (August 2015): 226–237. doi:10.1016/j.ijpe.2014.11.008.

[16] Flyvbjerg, Bent, Mette Skamris Holm, and Soren Buhl. "Underestimating Costs in Public Works Projects: Error or Lie?" Journal of the American Planning Association 68, no. 3 (September 30, 2002): 279–295. doi:10.1080/01944360208976273.

[17] Love, Peter E.D., Chun-Pung Sing, Xiangyu Wang, Zahir Irani, and Didibhuku W. Thwala. "Overruns in Transportation Infrastructure Projects." Structure and Infrastructure Engineering 10, no. 2 (August 23, 2012): 141–159. doi:10.1080/15732479.2012.715173.

[18] Lind, Hans, and Fredrik Brunes. "Explaining Cost Overruns in Infrastructure Projects: a New Framework with Applications to Sweden." Construction Management and Economics 33, no. 7 (July 3, 2015): 554–568. doi:10.1080/01446193.2015.1064983.

[19] Siemiatycki, Matti. "The Making and Impacts of a Classic Text in Megaproject Management: The Case of Cost Overrun Research." International Journal of Project Management 36, no. 2 (February 2018): 362–371. doi:10.1016/j.ijproman.2016.07.003.

[20] Fallahnejad, Mohammad Hossein. "Delay Causes in Iran Gas Pipeline Projects." International Journal of Project Management 31, no. 1 (January 2013): 136–146. doi:10.1016/j.ijproman.2012.06.003.

[21] Boateng, P. Chen, Z. Ogunlana, S. "A conceptual system dynamic model to describe the impacts of critical weather conditions in megaproject construction", Journal of Construction Project Management Innovation., Vol. 2 (2012): 208–224.

[22] Vu, Hong Anh, Viet Hung Cu, Lian Xing Min, and Jian Qiong Wang. "Risk Analysis of Schedule Delays in International Highway Projects in Vietnam Using a Structural Equation Model." Engineering, Construction, and Architectural Management 24, no. 6 (November 20, 2017): 1018–1039. doi:10.1108/ecam-06-2016-0138.

[23] Yang, Jyh-Bin, and Pei-Rei Wei. "Causes of Delay in the Planning and Design Phases for Construction Projects." Journal of Architectural Engineering 16, no. 2 (June 2010): 80–83. doi:10.1061/(asce)1076-0431(2010)16:2(80).

[24] Caldas, Carlos, and Ashish Gupta. "Critical Factors Impacting the Performance of Mega-Projects." Engineering, Construction, and Architectural Management 24, no. 6 (November 20, 2017): 920–934. doi:10.1108/ecam-05-2016-0117.

[25] Boateng, Prince, Zhen Chen, and Stephen O. Ogunlana. "An Analytical Network Process Model for Risks Prioritisation in Megaprojects." International Journal of Project Management 33, no. 8 (November 2015): 1795–1811. doi:10.1016/j.ijproman.2015.08.007.

[26] Brookes, Naomi J. "Mankind and Mega-Projects." Frontiers of Engineering Management 1, no. 3 (2014): 241. doi:10.15302/j-fem-2014033.

[27] Dimitriou, Harry T., Nicholas Low, Sophie Sturup, Genevieve Zembri, Elisabeth Campagnac, George Kaparos, Pantoleon Skayannis, et al. "What Constitutes a 'successful' Mega Transport project? Planning Theory & Practice 15, no. 3 (July 3, 2014): 389–430. doi:10.1080/14649357.2014.935084.

[28] Irimia-Diéguez, Ana I., Alvaro Sanchez-Cazorla, and Rafaela Alfalla-Luque. "Risk Management in Megaprojects." Procedia - Social and Behavioral Sciences 119 (March 2014): 407–416. doi:10.1016/j.sbspro.2014.03.046.

[29] Long, Nguyen Duy, Stephen Ogunlana, Truong Quang, and Ka Chi Lam. "Large Construction Projects in Developing Countries: a Case Study from Vietnam." International Journal of Project Management 22, no. 7 (October 2004): 553–561. doi:10.1016/j.ijproman.2004.03.004.

[30] Mentis, Mike. "Managing Project Risks and Uncertainties." Forest Ecosystems 2, no. 1 (January 28, 2015). doi:10.1186/s40663-014-0026-z.

[31] Qazi, Abroon, John Quigley, Alex Dickson, and Konstantinos Kirytopoulos. "Project Complexity and Risk Management (ProCRiM): Towards Modelling Project Complexity Driven Risk Paths in Construction Projects." International Journal of Project Management 34, no. 7 (October 2016): 1183–1198. doi:10.1016/j.ijproman.2016.05.008.

[32] Renuka, S. M., C. Umarani, and S. Kamal. "A review on critical risk factors in the life cycle of construction projects." Journal of Civil Engineering Research 4, no. 2A (2014): 31-36.

[33] Spirkova, Daniela. "Management of megaproject during the turbulent period of economic and political transformation in Slovakia." Journal of US-China Public Administration 11, no. 9 (2014): 750-762.

[34] Hamzaoui, Fethi, Franck Taillandier, Rasool Mehdizadeh, Denys Breysse, and Amine Allal. "Evolutive Risk Breakdown Structure for Managing Construction Project Risks: Application to a Railway Project in Algeria." European Journal of Environmental and Civil Engineering 19, no. 2 (July 18, 2014): 238–262. doi:10.1080/19648189.2014.939416.

[35] Merrow, Edward W., ed. "Industrial Megaprojects" (January 2, 2012). doi:10.1002/9781119201045.

[36] Flyvbjerg, Bent. "Survival of the Unfittest: Why the Worst Infrastructure Gets Built - And What We Can Do About It." SSRN Electronic Journal (2009). doi:10.2139/ssrn.2229768.

[37] Al Nahyan, Moza Tahnoon, Yaser E. Hawas, Mohsin Raza, Hamad Aljassmi, Munjed A. Maraqa, Basil Basheerudeen, and Mohammad Sherif Mohammad. "A Fuzzy-Based Decision Support System for Ranking the Delivery Methods of Mega Projects." International Journal of Managing Projects in Business 11, no. 1 (March 5, 2018): 122–143. doi:10.1108/ijmpb-06-2017-0055.

[38] Chen, Zhen. "ANP Models and Steep Criteria." In Arcom Research Workshop on Decision-Making across Levels, Time and Space: Exploring Theories, Methods, p. 46. 2010.

[39] Khumpaisal, Sukulpat, Mohd Noor Nazali, Zairul Musa Nisham, and Andrew David Ross. "AN APPLICATION OF THE ANALYTIC NETWORK PROCESS TO ASSESS RISKS IN A MEGA-CONSTRUCTION PROJECT." International Journal of the Analytic Hierarchy Process 2, no. 2 (December 31, 2010). doi:10.13033/ijahp.v2i2.43.

[40] Enshassi, Adnan, Jomah Al-Najjar, and Mohan Kumaraswamy. "Delays and Cost Overruns in the Construction Projects in the Gaza Strip." Journal of Financial Management of Property and Construction 14, no. 2 (July 31, 2009): 126–151. doi:10.1108/13664380910977592.

[41] Eybpoosh, Matineh, Irem Dikmen, and M. Talat Birgonul. "Identification of Risk Paths in International Construction Projects Using Structural Equation Modeling." Journal of Construction Engineering and Management 137, no. 12 (December 2011): 1164–1175. doi:10.1061/(asce)co.1943-7862.0000382.

[42] Goh, Cheng Siew, Hamzah Abdul-Rahman, and Zulkiflee Abdul Samad. "Applying Risk Management Workshop for a Public Construction Project: Case Study." Journal of Construction Engineering and Management 139, no. 5 (May 2013): 572–580. doi:10.1061/(asce)co.1943-7862.0000599.

[43] Kwak, Young Hoon, John Walewski, Dana Sleeper, and Hessam Sadatsafavi. "What Can We Learn from the Hoover Dam Project That Influenced Modern Project Management?" International Journal of Project Management 32, no. 2 (February 2014): 256–264. doi:10.1016/j.ijproman.2013.04.002.

[44] Nielsen, Karina, and Raymond Randall. "Opening the Black Box: Presenting a Model for Evaluating Organizational-Level Interventions." European Journal of Work and Organizational Psychology 22, no. 5 (October 2013): 601–617. doi:10.1080/1359432x.2012.690556.

[45] Sun, Ming, and Xianhai Meng. "Taxonomy for Change Causes and Effects in Construction Projects." International Journal of Project Management 27, no. 6 (August 2009): 560–572. doi:10.1016/j.ijproman.2008.10.005.

[46] Banerjee, Debalina, P Jagadeesh, and Rama Mohana P Rao. "A Review of System Dynamic Model for Risk Assessment in Construction of Megaprojects in India." International Journal of Technology 5, no. 2 (2015): 86. doi:10.5958/2231-3915.2015.00002.4.

[47] Funderburg, Richard G., Hilary Nixon, Marlon G. Boarnet, and Gavin Ferguson. "New Highways and Land Use Change: Results from a Quasi-Experimental Research Design." Transportation Research Part A: Policy and Practice 44, no. 2 (February 2010): 76–98. doi:10.1016/j.tra.2009.11.003.

[48] Rezakhani, Pejman. "Fuzzy MCDM Model for Risk Factor Selection in Construction Projects." Engineering Journal 16, no. 5 (October 1, 2012): 79–94. doi:10.4186/ej.2012.16.5.79.

[49] Trapenberg Frick, Karen. "The Cost of the Technological Sublime: Daring Ingenuity and the New San Francisco–Oakland Bay Bridge." Decision-Making on Mega-Projects (2008). doi:10.4337/9781848440173.00020.

[50] Mylonas, Chrysostomos, and Yiannis Xenidis. "Megaproject development in the context of sustainable urban regeneration." RELAND: International Journal of Real Estate & Land Planning 1 (2018): 377-384.

[51] Hrustalev, Boris, Angelina Moses, and Tatiana Uchaeva. "Risk and Uncertainty in Economic Modelling of Complex Building Systems." Edited by A. Mottaeva and B. Melović. MATEC Web of Conferences 193 (2018): 05028. doi:10.1051/matecconf/201819305028.

[52] Siemiatycki, Matti. "The Making and Impacts of a Classic Text in Megaproject Management: The Case of Cost Overrun Research." International Journal of Project Management 36, no. 2 (February 2018): 362–371. doi:10.1016/j.ijproman.2016.07.003.

[53] Plácido, Jânio, et al. "Quantitative Risk Analysis in Megaprojects Schedules: a critical comparison between the theoretical findings and the empirical evidence from a Brazilian oil and gas company." The Journal of Modern Project Management 6, no. 2 (2018).

[54] Shenhar, Aaron, and Vered Holzmann. "The Three Secrets of Megaproject Success: Clear Strategic Vision, Total Alignment, and Adapting to Complexity." Project Management Journal 48, no. 6 (December 2017): 29–46. doi:10.1177/875697281704800604.

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