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Article

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Operations Research Perspectives

Provided in Cooperation with:

Elsevier

Suggested Citation: Jokar, Ebrahim; Aminnejad, Babak; Lork, Alireza (2021) : Assessing and prioritizing risks in Public-Private Partnership (PPP) projects using the integration of fuzzy multi-criteria decision-making methods, Operations Research Perspectives, ISSN 2214-7160, Elsevier, Amsterdam, Vol. 8, pp. 1-20,
<https://doi.org/10.1016/j.orp.2021.100190>

This Version is available at:

<https://hdl.handle.net/10419/246449>

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Assessing and Prioritizing Risks in Public-Private Partnership (PPP) Projects Using the Integration of Fuzzy Multi-Criteria Decision-Making Methods

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ARTICLE INFO

Keywords:

Infrastructure Project Risks
Public-Private Partnership (PPP)
Risk Management Pattern
Integrated Fuzzy Multi-Criteria Decision Making Techniques

ABSTRACT

Public-private partnership (PPP)-based infrastructure projects generally face many risks and uncertainties at all stages of the project, including initial studies, design, construction, and operation. This causes many challenges such as increased costs, delays in the project and loss of materials and equipment, and so on. Given the need to use the PPP method in the development of infrastructure projects and its broad dimensions, it is important to accurately identify and evaluate the risks involved in these projects. In the present paper, the most important risks in these projects are identified by case study in PPP-based freeway projects in Iran and using the six step-by-step process of risk management based on PMBOK standard, a model for risk assessment it is developed. Also, for quantitative risk analysis, an attempt was made to determine the importance of risks and their priority in the studied projects by using fuzzy multi-criteria decision making techniques (FAHP and FTOPSIS). The results of quantitative risk analysis by FAHP method showed that first level risks in seven different categories including economic and financing risks, construction, operational, legal, political, other risks and government risks, respectively, have the greatest impact on PPP-based freeway projects. They are dedicated to themselves. Also, the results of the general ranking of the sub-criteria showed that high risk financing costs, quality of performance and standards, lack of support infrastructure have the greatest impact on these projects. Finally, the results of FTOPSIS similarity index showed that according to project experts, projects A (Isfahan-Shiraz Freeway), B (Salafchegan-Arak Freeway) and C (Khorramabad-Arak Freeway) with scores of 0.433, 0.3369 and 0.283, respectively, had a greater impact on risks, respectively. Also, the remaining risks that were jointly or at least one of the studied projects had a high impact were identified as final risks and were allocated among the various pillars of the project. The results of this research can be used as a management model in the process of risk assessment and management of PPP projects.

Introduction

A cursory look at the state of the construction industry and the participation in it in the past shows that due to factors including, emphasis on the strength of the government, high costs, long payback period, financial weakness and lack of protection legislation for the private sector, it always has been the public sector's obligation, i.e., the government, to build the infrastructure [1]. Several government efforts in financing the infrastructure projects have shown that the public sector cannot develop the infrastructures as needed, without the help of the private sector [2]. On the other hand, the private sector cannot be an appropriate complement for the government to develop participation

because of the lack of high financial strength, cohesion between organizations, and interaction with the operating banks in issuing and obtaining guarantees [3]. Thus, various governments around the world were driven to encouraging and expanding private-sector investment in these projects and setting out an example of this type of investment, called the public-private partnerships (PPP), in the face of declining liquidity, increasing debt and meeting public demand, infrastructure construction, and development, in the 1970s and 1980s [4]. PPP is a mechanism in which the public sector, i.e., the government and other government agencies, uses the private sector capacities, including knowledge, experience, and financial resources, to provide infrastructure services [5–7].

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<https://doi.org/10.1016/j.orp.2021.100190>

Received 9 October 2020; Received in revised form 18 May 2021; Accepted 19 May 2021

Available online 28 May 2021

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The long-term nature of projects concluded with PPP contracts, the need for project profitability for the private sector and the ongoing relationship between government agencies and the private sector have made these contracts very sensitive to environmental conditions, project financing methods and project technical characteristics. Therefore, to guarantee the success of such projects, necessary measures should be taken to control and manage project risks. Because accurate identification of project risks and management and allocation of identified risks in this type of project among the contract partners, will have a significant impact on the successful performance of projects based on the PPP method [8–10].

With the development of PPP-based contracts in infrastructure projects, in-depth discussions on how to finance and service the projects, the risk and its transfer between different pillars of the project, and other similar issues are of the exciting topics in research. Thus, numerous papers and books have been extensively developed on PPP-based projects in recent years [11,12]. However, the use of PPP in projects does not necessarily increase the benefits and payback of the project, and in some cases, the use of participatory methods may increase the project risks for different pillars of this type of contract [5,7]. One of the main reasons for facing various risks in PPP projects is the lack of cooperation, trust, and fruitful communication between all the elements, stakeholders, and teams involved in projects, which appears in the form of delays in project delivery, problems in resolving disputes, imposing double costs and conflicts of win-lose situations in a project [8,13,14].

The objectives of our research are that: (i) identifying the most important risks in this type of project by in-depth study of the research literature; (ii) developing a model for managing identified risks through a case study on public-private partnership freeway projects in Iran and (iii) provide appropriate solutions to respond to risks.

The rest of this article consists of the following three sections. We first review the research literature to gain an understanding of the results of risk identification and risk assessment of PPP projects. Second, the methodology of this study is presented, including the research design, data analysis and inference, questionnaire, statistical population and decision-making process. In the last section, we discuss our presentation results and findings.

Background

The Emergence Of The Public-Private Partnership Concept

The term public-private partnership was originated in the United States and associated with the joint provision of funds by the private and public sectors for educational programs, which later expanded to providing similar funds for public utilities in the 1950s [5]. This method became more widely used and was dedicated to public-private investments for urban renewal in the 1960s [4]. In the United States, this concept is also applied to the provision of social services by non-public institutions using public funds, which are often provided by the nonprofit and volunteer sections [9]. This concept also refers to the provision of public funds for private-sector research and development in areas such as technology [15]. In the field of international development, it refers to the implementation of joint initiatives by the government, relief agencies, and the private sector in the general advancement of economic development [5]. Many of these are described as policy-based or program-based public-private partnerships [9]. The following are the main features and components of the PPP approach [2,5]:

- ü They are long-term contracts (contract-based partnership) concluded between the public sector and the private sector as the two parties.
- ü They are established by the private sector to design, build, finance, and operate the public infrastructures and facilities (public facilities).

- ü During the term of the partnership agreement, payments are made to the private sector in return for the use of the created facilities by the general population or the public sector.
- ü The ownership of the created infrastructure facilities is either in the hands of the public sector from the beginning or transferred to it at the end of the partnership agreement.

In some cases, a partnership agreement may regard the upgrade of the existing infrastructures rather than building new ones. However, the private sector's acquisition or management of the existing public infrastructure facilities cannot be an example of a partnership, without new and significant investment or a major upgrade in these facilities [12]. The same is true in the case of providing soft infrastructure services by the private sector without significant investment in fixed assets and, consequently, no need for private sector financing; this is an example of outsourcing rather than partnership [16]. Given that infrastructure services are often associated with infrastructure construction in these cases, there is no precise demarcation in this regard [9]. However, partnership projects are perceived only as a joint venture between the public and private sectors if not attached to a partnership agreement [5].

Risks in PPP projects

A project is a unique endeavor that meets the defined goals using a variety of resources or a set of requirements. According to the definition, it should be said that projects are inherently risky. A project risk is an unknown event or situation with either positive or negative effects on project objectives. Concerning the project, the risk is actually a chance for the occurrence of an unfortunate event and all its unpleasant consequences [17]. Some features in the structure of a project naturally make it risky. These factors include uniqueness, project delivery items, erroneous and predetermined assumptions about different aspects of the project, discrepancies, and sometimes, contradictions in the project success criteria, and the project environment and organization [18].

The unique complexity of PPP infrastructure projects demonstrates that traditional project management approaches cannot solve the management issues in such projects [19,20]. Proper leadership of these projects requires implementing a project management system instead of a successful provision of project costs, time, and quality goals. Studies show that many of the risks posed by delays and rework, excess of the costs incurred, and deviations from the program in PPP projects are predictable, plannable, and assessable [21]. In other words, not only can the risks in the process of implementing PPP projects be predicted, but by implementing appropriate countermeasures, its value and magnitude can be reduced to an acceptable level [22]. Based on this, it can be said that in order to prevent the increase of budget and time of projects, it is necessary to use project management systems such as the analysis and planning of the risks and uncertainties [23]. To this end, most organizations have gone so far as to implement project management standards in their projects, such as risk management, to achieve their goals, namely, increasing the project productivity and decreasing program deviations [24]. Therefore, first of all, the necessary measures should be taken to identify, evaluate, and respond to the risks in the project [25].

Risk management is a systematic process that involves identifying, analyzing, and responding to project risks, in addition to maximizing the probability and impacts of positive events and minimizing the adverse effects and events [3]. Infrastructure projects, especially those implemented with the PPP method, generally face risky conditions at all stages of the project, including the initial studies, designing, construction, and operation [23,26]. This has led to many problems, such as rising costs and delays, waste of human resources, materials, and equipment. Considering the need to use the PPP method and its broad dimensions in the development of infrastructure projects, it is necessary to identify the risks in these projects accurately [21]. Different phases are proposed for risk management in different sources [27,28], the most widely used of which is the six-step process, including (1) risk

management planning, (2) risk identification, (3) qualitative risk analysis, (4) quantitative risk analysis, (5) risk response planning, and (6) risk monitoring, which is suggested by the Project Management Institute in the PMBOK guide [29]. It should be noted that in the present study, this process was used to develop the risk management model of PPP projects.

A Review of Research Literature

In recent years, many studies have been conducted by researchers around the world on PPP contracts and the riskiness of this contract method in infrastructure construction projects, including Zhang's (2005) study on the most important critical success factors (CSFs) [30]. Moreover, Ng et al. (2007) also provided a simulation model to identify the guarantee period based on the expected investment and tariffs in PPP contracts [31]. Moreover, in their study, Zoe et al. (2008) examined the most important risks of the life cycle of PPP infrastructure projects and studied the methods of attracting private sector investment to conclude these types of contracts in the UK [32].

In addition to the above research, we can mention the Cheung's study (2009) in developing the best way to implement PPP projects in Hong Kong [33], and the study of Ke et al. (2010) on allocating the existing risks to implement PPP contracts in construction projects in China using the Delphi technique [34]. Li and Zou (2011) assessed the risks of a PPP transport project in China using FMCDM. Their research showed that lack of planning, the low residual value of the project (after 30 years of operation), lack of qualified candidates, lack of design, and the short project approval time for completing the project were identified as the five main risks in the project. In examining the success factors of PPP-based government activities [35], Yusuf et al. (2006) cited factors such as government commitment and the shared vision between the customer, the employer, and the contracting party as the most important factors [36]. Furthermore, in their research, Valipour et al. (2014) presented a multi-objective optimization approach for risk allocation in PPP transport projects in Malaysia [37]. In examining the CSFs and benefits of PPP in construction projects, Famakin et al. (2014) concluded that such projects have significant benefits such as cost-effectiveness and improved service quality [38]. In addition, we can mention the Mota and Moreira's (2015) research to identify hidden factors in private sector investment expansion by emphasizing the importance of non-financial factors, such as political, legal, and macroeconomics in the context of the PPP approach in European countries [39]; the Kościelniak and Górka's study (2016) by using the PPP approach for financing sustainable green cities [40]; the study of Kumar et al. (2018) on evaluating the financial risks of PPP contract-based highway infrastructure projects in India using the Net Present Value model [41]; and the systematic review of Cui et al. (2018) in PPP-based infrastructure projects [42]. Moreover, Wu et al. (2018) provided a framework for assessing the operational, economic, legal, socio-political, and government risks in PPP-based waste-to-energy projects [43]. Akbari Ahmadabadi and Heravi (2019), provided a framework for evaluating the interaction between the risks and success of PPP projects in their research [44]. Wu et al. (2020) in their research have presented a risk assessment framework in the project of water storage through seawater based on PPP method [10]. The results of Du and Gao (2021) study using MCDM technique on PPP projects showed that the increased synergy of project participants not only reduces the impact of investment risk on project revenue but also promotes project participants to increase their willingness to undertake risks, actively undertake project risks, and achieve synergy effects of PPP projects [45].

Quantitative risk assessment issues in construction projects are complex, and this assessment is associated with several uncertainties. The fuzzy method, which is inherently an approximate approach and modeled as a conceptual method for calculating the significance of the risk effects, can more accurately determine the significance of the risk impacts with a degree of uncertainty, and the risk impacts in various

projects can be estimated by combining the fuzzy analyses. The previous studies on risk management in PPP projects showed that researchers have significant consensus on not only the various dimensions of risk management in these projects, but also on the factors and risks, and the practical strategies in effectively implementing risk management in such projects. Many variable risks have been observed in the literature, but there is no consistent agreement for PPP projects in Iran and there are a number of deficiencies in existing research.

This paper considers risk indices based on the current Iranian political and economic situation, unlike previous studies that focused solely on risk identification and assessment methods for PPP projects. The present study aimed to identify the various risks in the implementation of these types of projects and develop a pattern of identification, evaluation, and risk management by selecting the PPP-based infrastructure projects in Iran. This work is expected to contribute to research in construction by providing a risk assessment tool for risk management and strategy in PPP projects.

Research Methodology

Research Plan

The present study was conducted to provide a model for prioritizing the risks in PPP infrastructure projects. Given the model was not comprehensively proposed in the previous studies, and it provides a practical solution for implementing risk management in infrastructure projects, the present research is a basic-applied study, because the research must be basic in the part of the research which concerns the theoretical issues and theoretical analysis of the risks identified in PPP infrastructure projects and aims to extract an overall pattern of risk prioritization by reasoning and analysis, applicable for project-based organizations.

A comprehensive study of the risks in PPP-based transport infrastructure projects has been conducted through an in-depth review of literature to gain a deeper understanding. These studies have been used to provide the necessary information for the analysis and provision of a preliminary model for prioritizing the identified risks. By using the information and developing the existing risks and their adaptation to the nature and functions of infrastructure projects, a desirable model is presented for risk classification and segregation, which is data analysis and inference for extracting a prioritization model for risk management in these projects. Also, a field method has been used for collecting the required information to validate the prioritization model in the section of pattern development, such as risk priority information.

Data Analysis and Inference

Qualitative and quantitative research can complement each other through discovery (by qualitative research) and validation (by quantitative research) [46]. Also, despite all the differences between qualitative and quantitative methods, it is better for researchers today to use a combination of quantitative and qualitative approaches to better understand the phenomena in their research. A hybrid approach is a type of research in which the researcher combines elements and features of quantitative and qualitative approaches with the aim of proving and understanding more deeply. The present study is a combination of qualitative and quantitative data. Given that the purpose of this study was to provide a model for prioritizing and allocating risk between different pillars in PPP infrastructure projects, after identifying the primary data (risks), a database of risks was prepared to summarize them. It is first necessary to identify the risks involved in PPP infrastructure projects to establish a risk database. Three main types of research were used to identify the risks, including the risks identified in the literature review, the risks identified through semi-structured interviews with specialists and experts, and the risks identified in documentary studies of Iran transport projects. Then, all the identified risks

were placed in different categories, and the PMBOK method was used to evaluate the risk in a combined way, the steps of which are as follow. The identified risks were put to a referendum among the professionals and experts working in the field of PPP infrastructure projects in the statistical population of the research, and the more critical risks were determined according to the risk rate. After determining the critical risks, using the FMCDM methods, a model was proposed for quantitative risk assessment in PPP infrastructure projects by conducting a case study in transport projects in Iran.

Questionnaire and Validation

The purpose of the questionnaire is to obtain specific information on a specific topic. The large size of the study group or community is one of the important reasons for using a questionnaire that allows large samples to be studied. The primary tool for measuring and collecting data in the survey method used in the present study is a questionnaire. In this study, the analytic hierarchy process (AHP) and the statistical analysis questionnaire were used as a pairwise comparison. In order to prepare the required questionnaires, first, the most important risks in these projects were identified by literature review and several stages of interviews with different stakeholders in PPP transport infrastructure projects. The Likert scale was used, and the respondents were asked to score the impact of each factor by from one to five to interpret the questions and their importance (one stands for very low and five stands for very high). After compiling the preliminary questionnaire, it is necessary to measure its validity and reliability to analyze the results, as discussed in the next section.

Considering that the present research is survey-type field research and the analysis of its results is conducted based on the opinions of experts and specialists in the manufacturing industry, the best way to achieve the correct results is to determine the validity and reliability of the questionnaires.

Statistical sample and population

A statistical population is a set of individuals or units with at least one common attribute [47]. The present study, as a case study in Iran, aimed at using the information on infrastructure projects, particularly the PPP-based public transport methods. Therefore, the statistical population included all the civil contractors and engineers, experts, contracting companies, consultants, and employers in the country's PPP infrastructure projects, who are known as project stakeholders. Given that the statistical population in the present study was comprised of a significant number of subjects, and all the subjects were not easily accessible, the sampling method was used. Determining the sample size is very important in the ability to generalize test results to the community. There are several methods for determining the sample size, the most accurate of which are mathematical methods for calculating the sample size. One of these methods is to use the Cochran's formula. The Cochran's formula is used when dealing with large statistical populations. Due to the limited number of people in the statistical population in this study, namely 120 engineers, contractors, and employers and other contractors in infrastructure construction projects, the Cochran's sampling method and multivariate variables were used by random sampling to determine the sample size. For this purpose, the Cochran's formula for determining the sample size is given in Equation 1 [48]:

$$n = \frac{NZ_{\alpha/2}^2 pq}{d^2(N-1) + Z_{\alpha/2}^2 pq} \quad (1)$$

where n is the statistical sample size, N is the statistical population, $Z_{\alpha/2}^2$ is the normal distribution value, q is the ratio of the absence of an attribute in the statistical community, p is the ratio of the presence of an attribute in the statistical community, and d^2 is the error level.

By setting the statistical population as 120, the error level value as

5% (95% confidence level), the normal distribution of the table below the normal curve as 1.96 with 95% of confidence level, and the values of p and q of past statistics and information as 0.5, the number of people in the sample is:

$$n = \frac{120 \times 1.96^2 \times 0.5 \times 0.5}{0.05^2 \times (120 - 1) + 1.96^2 \times 0.5 \times 0.5} = 91.6$$

Based on the equation, the sample size was set to 92.

In this method, some subjects are selected according to the sample acceptance criteria for survey research. In this study, the criteria of judicial sampling for selecting the experts was based on three characteristics, (1) at least two years of work experience in implementing project risk management, (2) experience in PPP infrastructure projects, and (3) academic education in the field of research. During the survey of experts, studies were conducted to identify experts in this field based on the researcher's judgment on having at least one of the above criteria along with the experience in PPP infrastructure projects and familiarity with the transportation industry. After determining the number of subjects in the statistical sample, their demographic information, including literacy, expertise, and experience level, and similar issues have been studied, and the results are presented in the next chapter of the paper.

The decision-making process and selection of options

Decision-making, as a process, is a group of active actions that begins with identifying the stimulus and ends with a commitment to a specific solution [49]. However, with a comprehensive view, three main components can be identified, (1) selecting from several options, (2) the implementation of the adopted decisions, and (3) utilizing the information of its final consequences for shaping future decisions in the decision-making process. The selection process involves selecting the most effective actions from those examined [50].

The decision-making process of this research involves the provision of a selection pattern, prioritization of the preferred risks in the field of PPP-based infrastructure projects, selection from several available options, and improvement of the risk management process. It is clear that the decision-making is done in a discrete space due to the discontinuity of the answers and requires the use of one of the FMCDM methods [49]. As a result, the process outlined in this study is a combination of fuzzy decision-making methods.

Assume a multi-criteria decision problem with m number of criteria and n number of options. Consider C_1 to C_m as criteria and A_1 to A_n as options. The standard multi-criteria decision-making method is in accordance with the decision-making matrix (Eq. 2) [51].

$$\begin{matrix} w_1 & C_1 & \begin{bmatrix} A_1 & \dots & A_n \\ a_{11} & \dots & a_{n1} \\ \vdots & \ddots & \vdots \\ \vdots & \ddots & \vdots \\ w_m & C_m & \begin{bmatrix} a_{m1} & \dots & a_{mn} \end{bmatrix} \end{bmatrix} \end{matrix} \quad (2)$$

Each row belongs to a criterion, and each column indicates the performance of an option.

The a_{ij} score indicates the performance of the A_j option in the C_i criterion. For simplicity, we assume that a larger value indicates better performance, as each minimization problem can easily be converted to a maximization problem. W_i weights reflect the importance of any measure in decision-making and were considered as positive. The weight of the criteria was usually determined mentally. These numbers indicated the attitude of a decision-maker or a group of experts in group decision-making [52].

AHP is one of the most popular decision support tools in group decision making involving multiple actors, scenarios and criteria [53]. One of the most widely used MCDM methods for ranking and / or selecting options is the TOPSIS method. Its logic is simply understandable as it is to select the one having its overall performance at the longest distance from the worst values of the peer group and having the shortest

Table 1. Fuzzy spectrum and corresponding verbal expression provided by Saati in FAHP method

Code	Linguistic Value	Fuzzy Numbers(l_i, m_i, u_i)
1	Equal preference	(1,1,1)
2	Low preference	(1,3,5)
3	Highly preferred	(3,5,7)
4	Highly preferred	(5,7,9)
5	Quite a big preference	(7,9,9)

distance from the best performers of each criterion. At the end of the process, the closeness coefficient to the ideal solutions can be computed for each alternative, which is then used as a composite index to compare and rank alternatives [54]. In some consensus decision-making problems, experts' opinions are uncertain. To describe this uncertainty, fuzzy information is widely used to express the preferences of experts, especially when crisp value cannot completely represent the real viewpoints of experts [55]. The use of fuzzy numbers permits appropriate representation of the subjective preferences in AHP pairwise comparisons and the resulting fuzzy AHP method is thus suited to handling the uncertainty in decision-making problems [56]. TOPSIS-Fuzzy method is established through simulation which was derived from a set of numbers and calculations. Simulation is capable for researchers to examine the influences of causes and impacts on different variables and potential reactions of various scenarios [57].

Since the decision-making method of the present study is a combination of decision-making methods, i.e., the hierarchical analysis and fuzzy TOPSIS methods, the methods are introduced in the next section.

Fuzzy Hierarchical Analysis Technique (FAHP)

Chang (1996) provided a simple method to expand the process of hierarchical analysis into the fuzzy space. This method, which was based on the arithmetic mean of experts' opinions and the Saati normalization method, and developed using fuzzy triangular numbers, was welcomed by researchers. The eight steps to perform this method are as follows [58,59]:

Step 1: Draw a hierarchical tree

At this step, the structure of the decision hierarchy was devised using the target, criteria, and option levels.

Step 2: Form a matrix of pairwise comparisons

At this stage, the linguistic expressions provided by Saati were used in terms of a range of 5 options to form a pairwise comparison matrix. In this way, the respondents were asked to determine the importance of each of the parameters examined in the research using the verbal expressions presented in Table 1.

A comparison matrix was then formed using the opinions of several decision-makers and experts, and the fuzzy triangular numbers $\beta_{ij}=(a_{ij}, b_{ij}, c_{ij})$. It should be noted that the fuzzy judgment matrix was calculated according to the following relation:

$$\tilde{A} = \begin{bmatrix} (1, 1, 1) & \left\{ \tilde{a}_{121}, \dots, \tilde{a}_{12p_{12}} \right\} & \dots & \left\{ \tilde{a}_{1n1}, \dots, \tilde{a}_{12p_{12}} \right\} \\ \left\{ \tilde{a}_{211}, \dots, \tilde{a}_{21p_{21}} \right\} & (1, 1, 1) & \dots & \left\{ \tilde{a}_{2n1}, \dots, \tilde{a}_{2n2p_{2n}} \right\} \\ \dots & \dots & \dots & \dots \\ \left\{ \tilde{a}_{n11}, \dots, \tilde{a}_{n1p_{n1}} \right\} & \left\{ \tilde{a}_{n21}, \dots, \tilde{a}_{n2p_{n2}} \right\} & \dots & (1, 1, 1) \end{bmatrix} \quad (4)$$

where the p_{ij} matrix is the number of people commenting on the priority of i index over j .

Step 3: The arithmetic mean of opinions

In this step, the arithmetic mean of the decision makers' opinions was calculated using the following matrix.

$$\tilde{A} = \begin{bmatrix} (1, 1, 1) & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & (1, 1, 1) & \dots & \tilde{a}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & (1, 1, 1) \end{bmatrix} \quad (4a)$$

It should be noted that the arithmetic mean of the decision makers' opinions was obtained according to the following relation.

$$\tilde{a}_{ij} = \sum_{k=1}^{p_{ij}} a_{ijk} / p_{ij}, j = 1, 2, \dots, n \quad (5)$$

Step 4: Calculate the sum of the elements in the row

At this stage, the sum of the rows' elements was calculated according to the following equation.

$$\tilde{s}_i = \sum_{j=1}^n a_{ij} \quad i, j = 1, 2, \dots, n \quad (6)$$

Step 5: Normalize the total number of rows

At this stage, the sum of the rows was normalized using the following equation:

$$\tilde{M}_i = \tilde{s}_i \otimes \left[\sum_{i=1}^n \tilde{s}_i \right]^{-1} \quad i, j = 1, 2, \dots, n \quad (7)$$

If we show \tilde{s}_i as (l_i, m_i, u_i) , the above equation would be as follows:

$$\tilde{M}_i = \left(\frac{l_i}{\sum_{i=1}^n l_i}, \frac{m_i}{\sum_{i=1}^n m_i}, \frac{n_i}{\sum_{i=1}^n n_i} \right) \quad i, j = 1, 2, \dots, n \quad (8)$$

Step 6: Determine the degree of probability of being larger

In this step, the degree of probability of being larger, μ_i , compared with the other μ_i values was calculated and called the $d'(A_i)$ matrix. Accordingly, the probability of a higher fuzzy triangular number of $\mu_2=(l_2, m_2, u_2)$ than the fuzzy triangular number of $\mu_1=(l_1, m_1, u_1)$ was calculated by:

$$V(M_2 > M_1) = \text{Sub}_{y \geq x} [\min(\mu_{M_1}(x), \mu_{M_2}(y))] \quad (9)$$

This equation can be summarized:

$$V(M_2 \geq M_1) = \begin{cases} 1 & \text{if } m_2 \geq m_1 \\ 0 & \text{if } l_2 \geq u_1 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - u_1)} & \text{otherwise} \end{cases} \quad (10)$$

In which d is the coordinates of the highest point in the collision area of the two membership functions of μ_{M_1} and μ_{M_2} .

It is necessary to calculate both $V(M_2 \geq M_1)$ and $V(M_1 \geq M_2)$ values to compare M_1 and M_2 . The probability of a higher convex fuzzy number (M) than K other fuzzy numbers ($M_i; i = 1, 2, \dots, k$) is subdivided as follows.

$$d(M) = V(M \geq M_1, M_2, \dots, M_k) = V[(M \geq M_1), (M \geq M_2), \dots, (M \geq M_k)] \\ = \min V(M \geq M_i) i = 1, 2, \dots, k \quad (11)$$

Step 7: Normalize the weight vector

By normalizing the weight vector, the normalized weights were obtained according to the following equation.

$$W = \left[\frac{d'(A_1)}{\sum_{i=1}^n d'(A_i)}, \frac{d'(A_2)}{\sum_{i=1}^n d'(A_i)}, \dots, \frac{d'(A_n)}{\sum_{i=1}^n d'(A_i)} \right]^T \quad (12)$$

The above weights were definite (nonlinear) weights. By repeating this process, the weights of all matrices were obtained.

Step 8: Combining the weights

In the last step, the final weights were obtained by combining the weights of options and criteria.

$$\tilde{U}_i = \sum_{j=1}^n \tilde{w}_i \tilde{r}_{ij} \quad \forall i \quad (13)$$

Table 2. Random Indicators (RI) proposed by Gogus and Butcher [61]

Matrix size	1	2	3	4	5	6	7	8
RI^m	0	0	0.489	0.7937	1.072	1.1996	1.2874	1.341
RI^g	0	0	0.1796	0.2627	0.3597	0.3818	0.409	0.4164

Determining the compatibility of the answers in the FAHP method based on the Gogus and Butcher's equation

Gogus and Butcher (1998) suggested that two matrices (average numbers and the range of the fuzzy numbers) be derived from each fuzzy matrix, and then the compatibility of each matrix be calculated based on the Saati method. The steps for calculating the adaptation rate of fuzzy matrices of pairwise comparisons are as follows [60,61]:

Step 1: In the first step, the fuzzy triangular matrix was divided into two matrices. The first matrix consisted of the average numbers of triangular judgments (A^m) and the second matrix consisted of the geometric mean of the upper and lower limits of the triangular numbers (A^g).

$$A^m = [a_{ijm}]; A^g = \sqrt{a_{iju} \cdot a_{ijl}} \quad (14)$$

Step 2: The weight vector of each matrix was calculated using the Saati method, as follows:

$$w_i^m = \frac{1}{n} \sum_{j=1}^n \frac{a_{ijm}}{\sum_{i=1}^n a_{ijm}} w^m = [w_i^m] \quad (15)$$

$$w_i^g = \frac{1}{n} \sum_{j=1}^n \frac{\sqrt{a_{iju} \cdot a_{ijl}}}{\sum_{i=1}^n \sqrt{a_{iju} \cdot a_{ijl}}} w^g = [w_i^g]$$

Step 3: In the next step, the highest specific value for each matrix was calculated using the following equations:

$$\lambda_{\max}^m = \frac{1}{n} \sum_{i=1}^n \sum_{j=1}^n a_{ijm} \left(\frac{w_j^m}{w_i^m} \right) \quad (16)$$

$$\lambda_{\max}^g = \frac{1}{n} \sum_{i=1}^n \sum_{j=1}^n \sqrt{a_{iju} \cdot a_{ijl}} \left(\frac{w_j^g}{w_i^g} \right)$$

Step 4: Then, the adaption rate was calculated using the following equations:

$$CI^m = \frac{(\lambda_{\max}^m - n)}{(n - 1)}; CI^g = \frac{(\lambda_{\max}^g - n)}{(n - 1)} \quad (17)$$

Step 5: The CI index was divided by the random index (RI) to calculate the CR. If the result is lower than 0.1, the matrix was considered as compatible and usable. Saati formed 100 matrices with random numbers to obtain the RIs under the condition that the matrices were reciprocal; then, he calculated the mean and the values of incompatibility. However, since the numerical values of fuzzy comparisons are not always integers, and the geometric mean generally converts them to non-integer numbers, even if the 1 to 9 scoring was used, the RI table provided by Saati was not applicable. Thus, Gogus and Butcher regenerated a table of RIs for fuzzy pairwise comparison matrices by producing 400 random matrices, which is presented in Table 2 [61].

The average triangular fuzzy number was first generated randomly and mutually in the range of [1.9, 9] to produce random matrices. Then, the lower limit [the average value generated and 1.9] and the upper limit [1.9 and the average value generated] of each triangular number were randomly generated. Finally, the random index of each triangular number was calculated by dividing the random matrix into two matrices, namely the average and the geometric mean of the upper and lower limits. It is noteworthy that the amount of incompatibility in the RI^m column was higher than that of the RI^g , because the range of the generated random numbers for the central limit was [1.9, 9], but the range of random numbers based on the average number in the upper and

Table 3. Verbal expression and the corresponding fuzzy number for determining the importance of factors in FTOPSIS method

Code	Linguistic Value	Fuzzy Numbers(l_i, m_i, u_i)
1	Very low(VL)	(0, 0, 0.2)
2	Low(L)	(0, 0.2, 0.4)
3	Medium(M)	(0.2, 0.4, 0.6)
4	High(H)	(0.4, 0.6, 0.8)
5	Very High(VH)	(0.6, 0.8, 1)
6	Excellent(E)	(0.8, 1, 1)

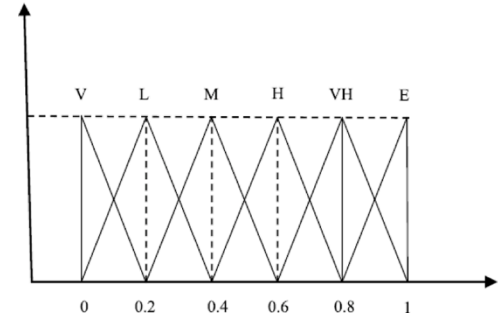


Figure 1. Verbal phrases and fuzzy numbers according to the spectrum of 6 options used in the FTOPSIS method

lower limits was smaller; therefore, there was less chance of incompatibility. Calculating the incompatibility rate for the two matrices based on the following equations, we compared the obtained values with a threshold of 0.1.

$$CR^g = \frac{CI^g}{RI^g}; CI^g = \frac{(\lambda_{\max}^g - n)}{(n - 1)} \quad (18)$$

If both of these indices were lower than 0.1, the fuzzy matrix was considered as consistent. If both were higher than 0.1, the decision-maker was asked to reconsider the proposed priorities, and if only the $CR^m(CR^g)$ was higher than 0.1, the decision-maker was asked to reconsider the intermediate values (limits) of the fuzzy judgments.

Fuzzy TOPSIS (FTOPSIS) method

Initially, Chen and Huang outlined the Technique for Order Preference by Similarities to Ideal Solution in a multi-criteria decision-making problem with n criteria and the m options in eight steps as follows [62].

Step 1: Form a fuzzy decision matrix

Depending on the number of criteria, options, and the evaluation of all options for different criteria, the decision matrix is formed as follows:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix} \quad (19)$$

It should be noted that at this stage, experts were asked to express their personal views on the importance of each criterion relative to each option or vice versa. For this purpose, the verbal expression presented in Table 3 and the fuzzy spectrum of 6 options were used.

Figure 1 shows the membership functions for verbal expressions and fuzzy numbers according to the spectrum of 6 options used in the FTOPSIS method.

If triangular fuzzy numbers are used, $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ is the function of option i ($i=1,2,\dots,m$) in relation to the j criterion ($j=1,2,\dots,n$). If the decision-making committee has k members and the fuzzy ranking of the ultimate decision-maker $\tilde{x}_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk})$ (triangular fuzzy number) is done, according to the criteria, the combined fuzzy ranking of options can be obtained based on the following equation:

$$\begin{cases} a_{ij} = \min_k \{a_{ijk}\} \\ b_{ij} = \frac{\sum_{k=1}^k b_{ijk}}{k} \\ c_{ij} = \max_k \{c_{ijk}\} \end{cases} \quad (20)$$

Step 2: Determine the weight matrix of the criteria

At this stage, the degree of importance of different criteria in decision-making was defined as the following equation:

$$\tilde{w} = [\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_n] \quad (21)$$

If triangular fuzzy numbers are used, each of the \tilde{w}_j components (weight of each criterion) is defined as $\tilde{w}_j = (\tilde{w}_{j1}, \tilde{w}_{j2}, \tilde{w}_{j3})$.

If the decision-making committee has k members, and the degree of importance for the ultimate decision-maker is $\tilde{w}_j = (\tilde{w}_{j1}, \tilde{w}_{j2}, \tilde{w}_{j3})$ (triangular fuzzy number) for $j = 1, 2, \dots, n$, the compound fuzzy ranking $\tilde{w}_j = (\tilde{w}_{j1}, \tilde{w}_{j2}, \tilde{w}_{j3})$ can be obtained from the following equations:

$$\begin{cases} w_{j1} = \min_k \{w_{jk1}\} \\ w_{j2} = \frac{\sum_{k=1}^k w_{jk2}}{k} \\ w_{j3} = \max_k \{w_{jk3}\} \end{cases} \quad (22)$$

Step 3: Non-scaling the fuzzy decision matrix

When x_{ij} is fuzzy, r_{ij} is certainly fuzzy. In order to non-scale, we used

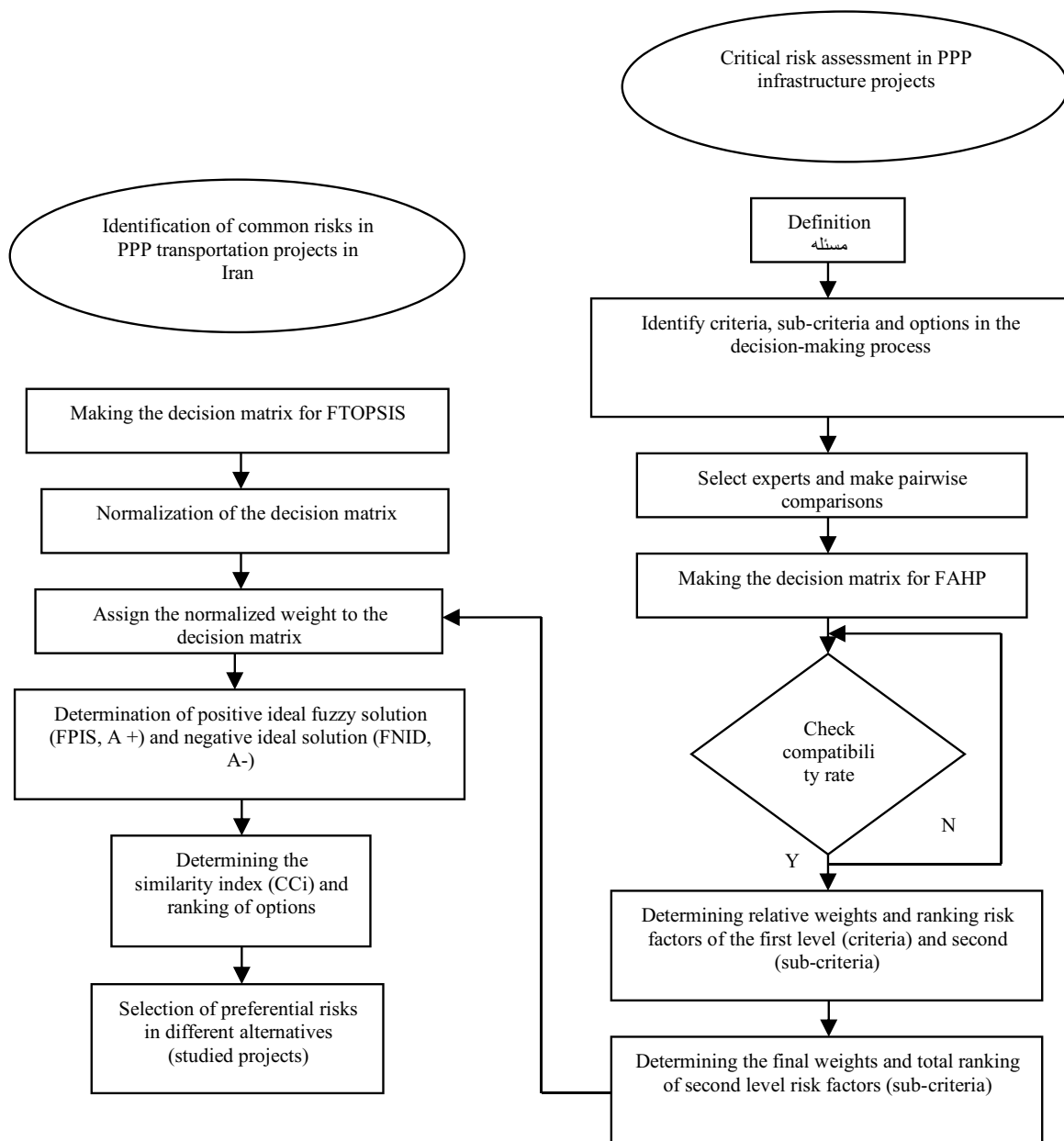


Figure 2. The structure of the fuzzy decision-making model based on the FAHP (right) and FTOPSIS (left) methods.

a linear scale transformation instead of complex calculations in the TOPSIS method to convert the scale of different criteria to a comparable scale in this step. If the fuzzy numbers are triangular, the elements of a non-scaled decision for the positive and negative criteria can be calculated using the following equation:

$$\begin{cases} \tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+} \right) c_j^+ = \max_i c_{ij} \\ \tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}^-}, \frac{a_j^-}{b_{ij}^-}, \frac{a_j^-}{a_{ij}^-} \right) a_j^- = \min_i a_{ij} \end{cases} \quad (23)$$

Therefore, the non-scale fuzzy decision matrix (R) is calculated as follows:

$$\tilde{R} = \begin{bmatrix} \tilde{r}_{11} & \dots & \tilde{r}_{1j} & \dots & \tilde{r}_{1n} \\ \vdots & & \vdots & & \vdots \\ \tilde{r}_{i1} & \dots & \tilde{r}_{ij} & \dots & \tilde{r}_{in} \\ \vdots & & \vdots & & \vdots \\ \tilde{r}_{m1} & \dots & \tilde{r}_{mj} & \dots & \tilde{r}_{mn} \end{bmatrix} \text{ or } [\tilde{r}_{ij}]_{m \times n} \begin{cases} i = 1, 2, \dots, m \\ j = 1, 2, \dots, n \end{cases} \quad (24)$$

Step 4: Determine the weighted fuzzy decision matrix

According to the weight of different criteria, the weighted fuzzy decision matrix was obtained by multiplying the degree of importance of each criterion in the non-scaled fuzzy matrix, as follows:

$$\tilde{v}_{ij} = \tilde{r}_{ij} \cdot \tilde{w}_j \quad (25)$$

which expresses the degree of importance for C_j criterion.

Therefore, the weighted fuzzy decision matrix will be calculated as follows:

$$\tilde{V} = \begin{bmatrix} \tilde{v}_{11} & \dots & \tilde{v}_{1j} & \dots & \tilde{v}_{1n} \\ \vdots & & \vdots & & \vdots \\ \tilde{v}_{i1} & \dots & \tilde{v}_{ij} & \dots & \tilde{v}_{in} \\ \vdots & & \vdots & & \vdots \\ \tilde{v}_{m1} & \dots & \tilde{v}_{mj} & \dots & \tilde{v}_{mn} \end{bmatrix} \text{ or } [\tilde{v}_{ij}]_{m \times n} \begin{cases} i = 1, 2, \dots, m \\ j = 1, 2, \dots, n \end{cases} \quad (26)$$

If the fuzzy numbers are triangular, the positive and negative criteria are, respectively:

$$\begin{aligned} \tilde{v}_{ij} = \tilde{r}_{ij} \cdot \tilde{w}_j &= \left(\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+} \right) \cdot (w_{j1}, w_{j2}, w_{j3}) = \left(\frac{a_{ij}}{c_j^+} \cdot w_{j1}, \frac{b_{ij}}{c_j^+} \cdot w_{j2}, \frac{c_{ij}}{c_j^+} \cdot w_{j3} \right) \\ \tilde{v}_{ij} = \tilde{r}_{ij} \cdot \tilde{w}_j &= \left(\frac{a_j^-}{c_{ij}^-}, \frac{a_j^-}{b_{ij}^-}, \frac{a_j^-}{a_{ij}^-} \right) \cdot (w_{j1}, w_{j2}, w_{j3}) = \left(\frac{a_j^-}{c_{ij}^-} \cdot w_{j1}, \frac{a_j^-}{b_{ij}^-} \cdot w_{j2}, \frac{a_j^-}{a_{ij}^-} \cdot w_{j3} \right) \end{aligned} \quad (27)$$

Step 5: Find the Fuzzy Positive-Ideal Solution (FPIS, A^+) and Fuzzy Negative-Ideal Solution (FNID, A^-)

The FPIS and FNID are defined as follows:

$$\begin{cases} A^+ = \left\{ \tilde{v}_1^+, \tilde{v}_2^+, \dots, \tilde{v}_n^+ \right\} \\ A^- = \left\{ \tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^- \right\} \end{cases} \quad (28)$$

Where, v_i^* is the most appropriate criterion among all options and v_i^- the least appropriate criterion among all options. These values are obtained from the following equations:

$$\begin{cases} \tilde{v}_i^* = \max_i \left\{ \tilde{v}_{ij3} \right\} \\ \tilde{v}_j^* = \min_i \left\{ \tilde{v}_{ij1} \right\} \end{cases} \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (29)$$

The options in A^* and A^- , indicate the most appropriate and the least appropriate options, respectively.

Step 6: Calculate the distance from FPIS and FNID

The distance of each option from FPIS and FNID can be calculated from the following equation:

$$\begin{cases} S_i^+ = \sum_{j=1}^n d(\tilde{v}_{ij}, \tilde{v}_j^*) \\ S_i^- = \sum_{j=1}^n d(\tilde{v}_{ij}, \tilde{v}_j^-) \end{cases} \quad i = 1, 2, \dots, m; j = 1, 2, \dots, n \quad (30)$$

$d(\dots)$ is the distance between two fuzzy numbers; if (a_1, b_1, c_1) and (a_2, b_2, c_2) are two triangular fuzzy numbers, the distance between two numbers is calculated as follows:

$$d_v(\tilde{M}_1, \tilde{M}_2) = \sqrt{\frac{1}{3} [(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2]} \quad (31)$$

Step 7: Calculate the similarity index

The similarity index is calculated using the following equation:

$$CC_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad i = 1, 2, \dots, m \quad (32)$$

Step 8: Rank the options

At this stage, options were ranked according to the similarity index, so that options with a higher similarity index would be prioritized.

Results and discussion

Given that the main purpose of the research was to evaluate and allocate risks in PPP-based transport infrastructure projects, in order to identify and analyze risks, a systematic and organized risk management approach should be used. Thus, the present study aimed to use the approach provided in the PMBOK and provide a review of the implementation of various steps in this process. Figure 2 shows the flowchart of the structure of the fuzzy decision-making model based on the combination of fuzzy multi-criteria decision-making methods.

Risk management planning

The first step in the risk management implementation process is to plan. This step leads to the successful implementation of risk management by engaging key team members and using the existing samples of risk management planning, analyzing various elements of infrastructure projects, and supporting the organization management. The present research examined the risk analysis in infrastructure projects in general and was conducted as a case study on PPP-based transport projects in Iran. Therefore, we attempted to extract the data (risks) in the analysis stage, using qualitative and quantitative methods described in the previous sections.

The purpose of risk management is to identify and analyze the risks in PPP-based infrastructure projects to develop a prioritization model and allocate the risks to the various project elements. Determining the impact of risk on a project can lead to responsive programs tailored to each risk to reduce the adverse impact on project goals. The scope of this study, as stated, was all the contract phase activities for attracting PPPs in transport projects.

The range of changes and qualitative indicators for calculating risk-based changes on each project objective is determined based on the qualitative/quantitative criterion of PMBOK risk management. Also, considering the conventional structures in projects and the close relationship between the management and technical departments of infrastructure projects studied in this research, i.e., Iran transport projects, the project contract planning, and control unit were determined as the custodian of the risk planning phase, which outlined the organization's approach in risk management in coordination with the senior management of the Ministry of Roads and Urban Development. Moreover, an expert core was formed of project managers, project planning and control managers, contract managers, procurement and purchasing managers, financial and experienced managers, and most importantly, private sector investors in financing the infrastructure projects, which

Table 4. Structure of the risk database in PPP-based transport projects in Iran and the results of the probability of occurrence, the severity of the effect and the rate of identified risks

First-level risk factors	Second-level risk factors	Reference	$RII_{Probability}$	RII_{Impact}	Probability	Impact	Risk rate	Rank
government risks (R1)	Insufficient monitoring system (R1-1)	[2,3,21]	0.58	0.49	0.48	0.23	0.113	36
	Government Intervention (R1-2)	[1,3,6,8,21,65]	0.65	0.75	0.55	0.48	0.262	19
	Government Corruption (R1-3)	[1,2,12,30]	0.64	0.81	0.54	0.54	0.290	12
	Delay in project approvals and licenses (R1-4)	[3,7,8,13]	0.71	0.77	0.61	0.50	0.302	10
financing risks (R2)	No commitment to allocate points (R1-5)	[6-8,11,25,30,34,66]	0.67	0.75	0.57	0.48	0.274	15
	Government Reliability (R1-6)	[7,8,12,14,21,23,25,65]	0.59	0.45	0.49	0.19	0.094	43
	Credit Risk (R2-1)	[1,3,7,12,19,23,24]	0.47	0.44	0.37	0.19	0.070	45
	Exchange rate fluctuations (R2-2)	[1,6,8,11,20-24]	0.72	0.81	0.62	0.54	0.332	4
	Changing Private Investors (R2-3)	[7,14,22,23,25]	0.39	0.42	0.29	0.17	0.048	46
	Non-commitment of investors (R2-4)	[7,8,14,21,23-25]	0.51	0.49	0.41	0.24	0.097	42
	Tariff change and insufficient income (R2-5)	[7,8,14,22]	0.55	0.59	0.45	0.33	0.146	33
	Inability of the investor consortium (R2-6)	[7,8,13,21,23,25,42,65]	0.68	0.66	0.58	0.39	0.227	30
	High financing costs (R2-7)	[3,7,8,11,22]	0.63	0.66	0.53	0.39	0.207	31
	Inflation risk (R2-8)	[3,7,8,11,13,21,22,30]	0.68	0.70	0.58	0.44	0.251	24
	Interest rate fluctuations (R2-9)	[6-8,11,14,22-24,30]	0.49	0.52	0.39	0.26	0.100	40
	Price change and fluctuation (additional payment) (R2-10)	[3,8,23,41]	0.73	0.80	0.63	0.53	0.330	5
	Compulsory purchase risk (R2-11)	[6-8,14,21,25,42,65,66]	0.55	0.48	0.45	0.23	0.104	38
	Market Competition (Uniqueness and Exclusiveness) (R2-12)	[7,11,21-23,26]	0.52	0.46	0.42	0.21	0.088	44
	Inappropriate change and estimation in market demand (R2-13)	[6,11,21,22,24,30,65,66]	0.67	0.73	0.57	0.46	0.264	18
construction risks (R3)	Technical Inability (R3-1)	[7,8,14,21,23]	0.51	0.50	0.41	0.24	0.099	41
	Lack of access to materials / personnel (R3-2)	[3,7,8,11,13,14,22,23,25,66]	0.68	0.68	0.58	0.41	0.240	26
	Improper estimation of construction time and delay (R3-3)	[8,14,24,25,65,66]	0.72	0.79	0.62	0.52	0.320	8
	Improper design and unapproved engineering techniques (R3-4)	[7,8,13,22,24]	0.74	0.64	0.64	0.37	0.238	27
	Land Occupation (R3-5)	[6-8,11-13,21,65]	0.47	0.37	0.37	0.12	0.045	47
	Changing the design specifications (R3-6)	[3,8,13,14,21,24,25,65]	0.74	0.80	0.64	0.53	0.337	3
	Construction Completion Risk (R3-7)	[7,8,11,22]	0.73	0.76	0.63	0.49	0.306	9
operational risks (R4)	Protection of historical and heritage objects (R3-8)	Brainstorming	0.57	0.47	0.47	0.22	0.101	39
	Increase in operating costs (R4-1)	[3,7-9,11]	0.76	0.82	0.66	0.54	0.358	2
	Performance Quality and Standards (R4-2)	[7,8,13,22,23]	0.75	0.70	0.65	0.43	0.278	14
	Improper performance and maintenance (R4-3)	[6-9,14,21,23-25,65,66]	0.74	0.78	0.64	0.51	0.325	6
	Lack of support infrastructure (R4-4)	[7,8,14,21,23]	0.72	0.69	0.62	0.42	0.261	20
political risks (R5)	Project Complexity (R4-5)	[8,14,21-23,25,65]	0.56	0.47	0.46	0.21	0.097	42
	Expropriation and nationalization (R5-1)	[6-8,14,24,25,65,66]	0.71	0.65	0.61	0.39	0.236	28
	Political / Public Opposition (R5-2)	[1,6-8,21-23]	0.79	0.69	0.69	0.42	0.290	12
	Changes in rules and regulations (R5-3)	[1-3,7,8,11,13,21-25,65]	0.70	0.75	0.60	0.47	0.285	13
	Influential political events (R5-4)	[7,9,13,14,25]	0.75	0.83	0.65	0.56	0.360	1
legal risks (R6)	Lack of political support (R5-5)	[6,21,25,65,66]	0.56	0.55	0.46	0.29	0.133	35
	Contract risk (conflicting contract) (R6-1)	[3,7,13,14,22]	0.51	0.62	0.41	0.35	0.145	34
	Inappropriate competition for tender (R6-2)	[2,13,21,22,24,65]	0.72	0.70	0.62	0.43	0.268	17
	Third Party Delay/Violation (R6-3)	[7,8,12,13,22,24]	0.70	0.72	0.60	0.45	0.270	16
	Increase in cost and time due to contract ambiguities (R6-4)	[7,8,14,23,65]	0.69	0.70	0.59	0.43	0.253	23
	Transnational Laws (R6-5)	[14,21,23,25]	0.60	0.56	0.50	0.30	0.153	32
	Lack of legal/regulatory frameworks (R6-6)	[14,21,23-25,65,66]	0.74	0.78	0.64	0.50	0.321	7
	Failure to renew resolutions (R6-7)	[7,8,14,21,25]	0.73	0.64	0.63	0.37	0.234	29
	Changes in tax regulation (R6-8)	[6-8,11,14,21,24,25,30,65,66]	0.51	0.42	0.41	0.17	0.070	45
	Force Majeure (R7-1)	[7,8,11,14,21,24,25,30,65]	0.67	0.72	0.57	0.45	0.260	21
other risks (R7)	Organizational Risks and Coordination (R7-2)	Brainstorming	0.70	0.76	0.60	0.48	0.292	11
	Cultural and Social Impacts (R7-3)	Brainstorming	0.66	0.71	0.56	0.44	0.245	25
	Environmental Risks (R7-4)	[2,7,21,24,25,65]	0.58	0.58	0.48	0.23	0.109	37
	unpredicted weather/geotechnical conditions (R7-5)	[7,8,13,30]	0.70	0.70	0.60	0.43	0.255	22

identified and analyzed the risks and the impact of risks on project goals through periodic meetings. Based on the information gathered by the researcher, the project management program, and the project's macro strategies, the team's opinions have been used as a survey to present risk response programs or revise the project management plan, if necessary.

Identifying the risks and creating the database structure

The most common risk assessment technique is based on previous research findings, intuition, personal judgments, and experience [63]. Therefore, identifying the risk factors can effectively facilitate understanding of the current risk types and guide risk management at different stages of project implementation [64]. In this step, the most important potential risks affecting PPP-based infrastructure projects were listed by

Table 5. Results of reliability assessment of research variables using Cronbach's alpha of the total questions

First-level risk factors	Number of Item	Cronbach's alpha
government risks (R1)	6	0.923
financing risks (R2)	13	0.967
construction risks (R3)	8	0.921
operational risks (R4)	5	0.969
political risks (R5)	5	0.901
legal risks (R6)	8	0.20
other risks (R7)	5	0.908

reviewing the previous studies. Delphi technique was then used by obtaining the opinions of seven experts in the field of infrastructure construction management of transport projects, in three stages as follows:

Stage 1: The list of the main risks was distributed among seven experts and specialists in the transport infrastructure projects, including the senior managers and experts in these projects, in order to express their opinions on the comprehensiveness of the identified risks presented in the revised list. Furthermore, the omitted items were added to the list at this stage. In this way, the content validity of the research questions regarding the identified risks was determined.

Stage 2: After collecting the opinions of experts, duplicate items were removed from the initial list, and some remaining risks were added based on the brainstorming method. As a result, a new list was prepared and returned to the reviewers so that team members could review the risks again.

Stage 3: In this stage, the collected opinions were examined by the researcher, and the risks were classified and separated into multiple groups. Finally, a list of different risks was prepared, and the structure of the risk database was formed based on that.

Finally, in order to track the risks and monitor the future activities related to each risk, a database of identified risks was formed in the transport infrastructure projects in Iran. This database shows the characteristics of the identified risk factors at two levels, which were gathered based on the research literature and in accordance with the different stages of the Delphi method in the previous stages. The database was consisted of a total of seven risk factors at the first level, including government risks (R1), economic and financing risks (R2), construction risks (R3), operational risks (R4), political risks (R5), legal risks (R6), and other risks (R7). A number of 6, 13, 8, 5, 5, 8, and 5 risk sub-factors were identified for each of these factors in the second level, respectively. The database structure formed for the identified risks is shown in Table 4. It should be noted that in order to facilitate the implementation of the next steps of the research, a specific symbol, namely Ri-j, was used to name the risks. According to this naming, the letter R indicates risk, i represents the first-level risk factors, and j indicates the second-level risk factors. The results of the next stages of the research are presented in the next columns.

Qualitative risk analysis

The range and the qualitative indicators for calculating the changes on each project objectives caused by the risks were determined based on

the qualitative/quantitative risk management approach of the global project management standard, which are described in detail below. In order to qualitatively analyze the various identified risks, it is necessary to determine the occurrence probability and the impact severity of each risk. According to the PMBOK standard, the impact/probability matrix was used in a new way in this study. Therefore, first, the occurrence probability and impact severity for each of the first- and second-level risks were measured according to the comments of 92 experts, using very low (1) to very high (5) linguistic expressions in accordance with the 5-point Likert scale. The Cronbach's alpha coefficient was determined for each of the first-level risk factors after obtaining the raw data from the experts' feedback to estimate the reliability of risk assessment, the results of which are presented in Table 5. The results showed that the Cronbach's alpha coefficient for each of the seven first-level risk factors was higher than 0.7. This indicated the internal compatibility of risk factors and that the reliability was acceptable.

The relative importance indices of the occurrence probability ($RII_{Probability}$) and impact severity (RII_{Impact}) of each of the second-level risks were calculated. The occurrence probability and impact severity of each risk were then calculated using the following equation by determining the relationship between the RII calculated for the occurrence probability and impact severity, and using the provided values for the two parameters according to PMBOK standard (Table 6) through linear internalization.

$$P = 0.2 \times RII_{Probability} - 0.1 \quad (33)$$

$$I = 0.1875 \times RII_{Impact} - 0.425 \quad (34)$$

Due to the independence of occurrence probability and the impact severity of each of the identified risks, it is necessary to determine the risk rate, which is comprised of the combined impact of the probability and severity of the risk. The risk rate, which is obtained using the theory of mathematical expectation ($PI = P \times I$), shows the effect of risk on the project goal, and is perceived as prioritization criteria of risks according to their importance; this way, the identified risks were classified according to the amount of PI into three ranges: critical range (higher than 0.2), the precautionary range (from 0.5 to 0.2) and the acceptable range (lower than 0.05). Table 4 presents the relative importance indices for the occurrence probability, impact severity, and the risk rate for each of the second-level risks. These results are also graphically shown in Figure 3. Based on the results, 32 risks were categorized in the critical range, 15 risks in the precautionary range, and three risks in the acceptable range. Accordingly, the initial ranking of risks based on qualitative analysis was done, and by identifying critical risks, they were used in the next cycle of risk analysis.

In order to perform a quantitative risk analysis, the first-level risk factors, and the second-level sub-factors with a critical degree of importance were investigated. These risks were considered as the first- and second-level criteria of the decision-making method, respectively. Then, using the integrated MCDM approach based on AHP and fuzzy TOPSIS, the risks in PPP-based transport projects were prioritized.

Table 6. The relationship between importance in terms of Likert scale, relative importance index (RII) and numerical indices of occurrence probability and impact severity

Probability of Occurrence				The Severity Of The Effect			
The importance	The numerical value	$RII_{Probability}$	Numerical index of probability of occurrence	The importance	The numerical value	RII_{Impact}	The numerical index of the intensity of the effect
Very Low	1	0-0.2	0.1	Very Low	1	0-0.2	0.05
Low	2	0.2-0.4	0.3	Low	2	0.2-0.4	0.1
Medium	3	0.4-0.6	0.5	Medium	3	0.4-0.6	0.2
High	4	0.6-0.8	0.7	High	4	0.6-0.8	0.4
Very High	5	0.8-1	0.9	Very High	5	0.8-1	0.8

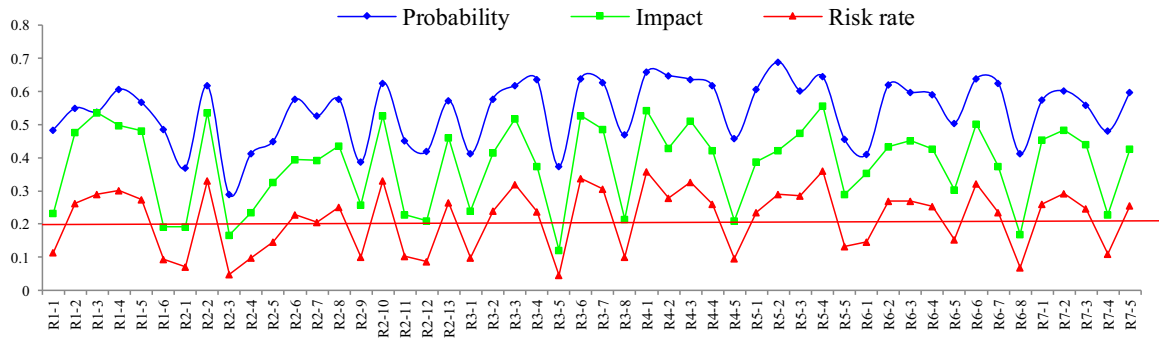


Figure 3. Results of the analysis of second-level risks identified in PPP-based projects

Quantitative risk analysis

In general, there are several ways to analyze risks quantitatively. In the present study, the survey method was used in a number of PPP-based transport projects in Iran and, FMCDM methods were applied for quantitative risk analysis. Quantitative risk assessment issues in construction projects are complex, and this assessment is associated with several uncertainties as a result of the considerable variation in the raw data from questionnaires due to the lack of information or the lack of complete knowledge of experts in the field of risk. Therefore, the factors in quantitative risk analysis should be evaluated. The fuzzy method, which is inherently an approximate approach and modeled as a conceptual method for calculating the significance of the risk effects, can more accurately determine the significance of the risk impacts with a degree of uncertainty, and the risk impacts in various projects can be estimated by combining the fuzzy analyses [67]. The nature of fuzzy logic is based on the fact that it involves not only the relative difference of risk effects but the ambiguity in some quantitative and qualitative effects simultaneously. In this logic, the effects of the human judgment under unknown circumstances can be analyzed [58]. Uncertainty can be considered as the lack of knowledge on the real value of a parameter. Also, the ability of fuzzy theory has made this method a powerful tool

regarding the complexity and inaccuracy of the data and the issues in quantitative risk analysis in real projects [68].

It is not possible to easily distinguish the importance of the risks in a PPP-based infrastructure project, and the qualitative analysis results may be flawed. Therefore, in order to present a coherent quantitative risk analysis pattern, the fuzzy integrated MCDM methods (FAHP and FTOPSIS) were used in this research. For this purpose, the critical risk factors and sub-factors in the first and second levels of qualitative analysis were considered as the criteria and sub-criteria of the decision model. Accordingly, seven main risk factors were identified at the first level as the main factors (criteria), namely the government risks (R1), economic and financing risks (R2), construction risks (R3), operational risks (R4), political risks (R5), legal risks (R6), and others risks (R7). At the next level, the sub-criteria at the second level of risk were considered as sub-factors. Accordingly, 4, 6, 5, 4, 4, 5, and 4 sub-criteria (more critical risks identified in the qualitative analysis) were considered in relation to each criterion, respectively. Finally, in the third level of the decision-making model, three examples of PPP-based transport projects in Iran were considered as alternatives in decision-making in the evaluation. It should be noted that the purpose of this model was to prioritize the most important first-level risk factors (criteria) and the second-level risk sub-factors (sub-criteria) affecting the PPP-based infrastructure

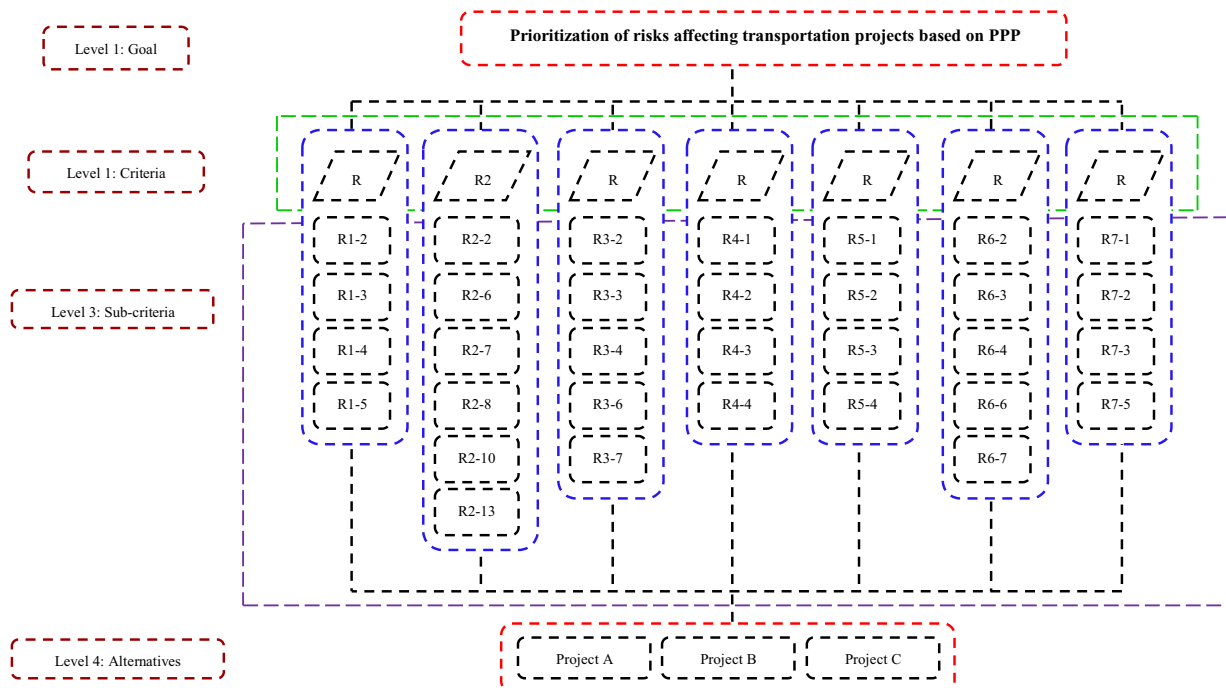


Figure 4. Decision-making hierarchical tree according to the criteria, sub-criteria, and alternatives identified in the prioritization process of risks in PPP-based transport projects in Iran

Table 7. Matrix of fuzzy pairwise comparisons of criteria (first-level risk factors) affecting PPP-based transport projects

Criteria	R1	R2	R3	R4	R5	R6	R7
R1	(1.0,1.0,1.0)	(0.16,0.23,0.33)	(0.2,0.27,0.5)	(0.2,0.27,0.5)	(0.33,0.5,1.0)	(0.25,0.33,0.5)	(0.33,1.26,3.0)
R2	(3.0,4.31,5.98)	(1.0,1.0,1.0)	(0.33,1.26,3.0)	(0.33,1.44,4.0)	(3.0,4.308,6.000)	(1.0,2.62,4.0)	(3.0,4.93,7.0)
R3	(2.0,3.63,5.0)	(0.33,0.79,3.0)	(1.0,1.0,1.0)	(1.0,1.58,3.0)	(2.0,3.63,5.0)	(1.0,2.62,4.0)	(3.0,4.93,7.0)
R4	(2.0,3.63,5.0)	(0.25,0.69,3.0)	(0.33,0.63,1.0)	(1.0,1.0,1.0)	(2.000,3.633,5.000)	(1.0,2.62,4.0)	(3.0,4.30,6.0)
R5	(1.0,2.0,3.0)	(0.16,0.23,0.33)	(0.2,0.27,0.5)	(0.2,0.27,0.5)	(1.0,1.0,1.0)	(0.2,0.5,1.0)	(0.33,1.0,3.0)
R6	(2.0,3.0,4.0)	(0.25,0.38,1.0)	(0.25,0.38,1.0)	(0.25,0.38,1.000)	(1.000,2.000,5.000)	(1.0,1.0,1.0)	(1.0,2.62,4.0)
R7	(0.33,0.79,3.0)	(0.14,0.2,0.33)	(0.14,0.2,0.33)	(0.16,0.23,0.33)	(0.333,1.000,3.003)	(0.25,0.38,1.0)	(1.0,1.0,1.0)
C.R ^m = 0.017 C.R ^s = 0.038							

projects. The second goal of the proposed model was to prioritize the preferred risks from the perspective of problem alternatives (PPP case studies) to select the common risks. It should be noted that the FAHP method was used to achieve the first goal, and the initial prioritization of the first- and second-level risks was determined. Then, by allocating the final weight obtained for the 20 preferred risks, the FTOPSIS method was used to determine the common risks in the studied projects. Table 3 presents the criteria (first-level risk factors), sub-criteria (second-level risk sub-factors), and the alternatives (PPP-based transport projects) to assess risks with fuzzy integrated decision-making methods (FAHP and FTOPSIS).

The FAHP analysis steps were described in detail in the previous section. The hierarchical tree, which was in accordance with the identified critical risks in Table 3, is shown in Figure 4. Then, after collecting the experts' initial opinions, a fuzzy pairwise comparison matrix was formed to compare the criteria and sub-criteria according to the linguistic variables. For this purpose, experts were asked to express their views on the importance of the criteria (first-level risk factors) and sub-criteria (second-level risk sub-factors) through linguistic expressions. Then, using the triangular fuzzy numbers and the arithmetic mean of the comments, a pairwise comparison matrix was prepared. It should be noted that the options studied in this study were selected as follows:

Project A (Isfahan-Shiraz Freeway)

The Isfahan-Shiraz freeway project starts from Izadkhash, Fars province, and will be constructed up to the Shiraz city with a length of 222 km in seven sections to connect Tehran to the south of Iran. The project will run on four runways and with freeway specifications. The objectives of this project include the development of the north-south transport corridor between the Caspian Sea coasts and the Persian Gulf and the important tourism, industrial, and rural highway of Tehran-Qom-Isfahan-Shiraz-Bushehr, shortening the Shiraz-Isfahan transport route to 134 km and the travel time for vehicles by about two hours, increased safety of road transport, reduced accidents, and reduced fuel consumption by about 136 million liters, as well as reduced environmental pollutants by about 5,750 tons. The initial estimate of the costs of this project with the PPP approach was 2700 billion tomans with 50% assignment share of costs to the private sector by the government and has been started since 1390. Although in the initial estimates, the time of exploitation of this project dates back to August 2017, so far, about 75% of physical progress has been made, and its operation is postponed to 2021.

Project B (Salafchegan-Arak Freeway)

Salafchegan-Arak freeway project is recognized as one of the

highways and communication corridors in Iran due to the high volume of goods and passengers for developing the Arak-Salafchegan-Qom art axis with a length of 160 km; the upgrade of this freeway is considered as a medium-term program.

Project C (Khorramabad-Arak Freeway)

The Khorramabad-Arak freeway project is the middle section of the Tehran-Imam Khomeini port highway, which is the missing link in the Persian Gulf. The total length of this freeway is 134 km in six lanes, which will run in four sections. The project goals were the 32-km reduction in the length of the Khorramabad-Arak route, the reduction of annual fuel consumption by 200 billion tomans, and the improvement of the quality of transit goods and services. The contract validity of this project is estimated at higher than 1200 billion tomans. The contract of the PPP-based project (50 percent of the costs by the government and 50 percent by the private sector) began in late 2013 with more than 80 percent of physical progress ever since, and the cost of the project has been estimated at 850 billion tomans. The operation of this project is postponed to September 2020 and has faced a delay of about two years in the process of implementation.

Comparison of first-level risk factors (criteria)

In order to determine the importance and impact of the main criteria (first-level risk factors) in the PPP-based transport projects, a pairwise comparison of seven main criteria was conducted based on the experts' initial opinions. Table 7 shows the average pairwise comparisons of the main factors (criteria). Based on the results of the pairwise comparison matrix, the priority scores of the main factors were determined as the normalized matrix, according to Table 7. It should be noted that in the pairwise comparison phase, in order to measure the compatibility level of the comparisons, the values of incompatibility rates (CR^m and CR^s) were also calculated, which are shown in Table 7. These indices indicated that the answers obtained were in line with the correct prioritization of the criteria so that the difference between the importance and preference of the parameters was significant. Given the lower than 0.1 values of the incompatibility indices, consistency can be observed between the sub-criteria and each major factor in pairwise comparisons, and the results were valid enough. Finally, the relative weight of each criterion and their initial rank were obtained according to Table 8 and Figure 5. It should be noted that the linear axis in the diagram represents the main factors (criteria), and the columnar axis represents their relative weight. Based on the results, it was observed that R2 risks with a relative score of 0.223, R3 risks with a relative score of 0.214, R4 risks with a relative score of 0.203, R6 risks with a relative score of 0.152, R5

Table 8. Normalized matrix for weight combination, degree of preference, relative weight, and final priority of the main criteria (first-level risk factors) affecting PPP-based transport projects

Criteria	R1	R2	R3	R4	R5	R6	R7	Greater ultimate degree	Relative wighted	Rank
R1	-	0.883	0.768	1	1	1	0.95	0.591	0.049	7
R2	1	-	0.889	1	1	1	1	0.715	0.223	1
R3	1	1	-	1	1	1	1	0.842	0.214	2
R4	0.998	0.879	0.763	-	1	1	0.948	0.584	0.203	3
R5	0.833	0.701	0.579	0.835	-	1	0.783	0.395	0.084	5
R6	0.428	0.27	0.151	0.43	0.644	-	0.391	0.021	0.152	4
R7	0.982	0.87	0.759	0.984	1	1	0.935	0.587	0.075	6
Total								8.115	1	7

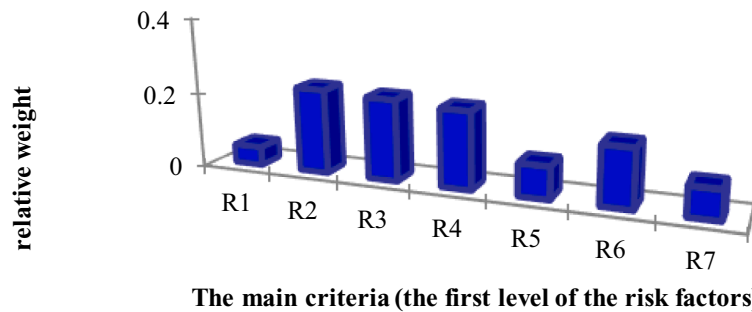


Figure 5. Final ranking results in terms of the relative weight of the impact of the main criteria (first-level risk factors) on PPP-based transport projects

Table 9. Matrix of the average fuzzy pairwise comparisons of the sub-criteria (second-level risk factors) related to the first-level risk criterion

R1	R1-2	R1-3	R1-4	R1-5		
R1-2	(1.0,1.0,1.0)	(0.25,0.55,1.0)	(0.2,0.31,1.0)	(0.25,1.25,4.0)		
R1-3	(1.0,1.818,4.0)	(1.0,1.0,1.0)	(0.25,0.43,1.0)	(0.33,1.58,5.0)		
R1-4	(1.0,3.175,5.0)	(1.0,2.28,4.0)	(1.0,1.0,1.0)	(1.0,2.71,6.0)		
R1-5	(0.25,0.79,4.0)	(0.2,0.63,3.0)	(0.16,0.36,1.0)	(1.0,1.0,1.0)		
Consistency index C.Rm =0.012 C.Rg =0.043						
R2	R2-2	R2-6	R2-7	R2-8	R2-10	R2-13
R2-2	(1.0,1.0,1.0)	(0.25,0.43,1.0)	(0.16,0.25,0.5)	(0.33,0.63,1.0)	(0.33,0.5,1.0)	(1.0,2.28,4.0)
R2-6	(0.33,0.5,1.0)	(1.0,1.0,1.0)	(0.2,0.3,0.5)	(1.0,2.28,4.0)	(1.0,2.0,3.0)	(2.0,3.9,5.98)
R2-7	(1.0,2.28,4.0)	(2.0,3.3,5.0)	(1.0,1.0,1.0)	(3.0,4.3,6.0)	(1.0,2.62,4.0)	(1.0,1.58,3.0)
R2-8	(2.0,3.63,5.0)	(0.25,0.43,1.0)	(0.16,0.23,0.33)	(1.0,1.0,1.0)	(0.25,0.43,1.0)	(1.0,2.0,3.0)
R2-10	(0.33,0.5,1.0)	(0.33,0.5,1.0)	(0.25,0.382,1.0)	(1.0,2.28,4.0)	(1.0,1.0,1.0)	(1.0,2.0,3.0)
R2-13	(0.33,1.26,3.0)	(0.25,0.43,1.0)	(0.2,0.27,0.5)	(1.0,2.0,3.0)	(0.33,0.79,3.0)	(1.0,1.0,1.0)
Consistency index C.Rm =0.028 C.Rg =0.078						
R3	R3-2	R3-3	R3-4	R3-6	R3-7	
R3-2	(1.0,1.0,1.0)	(0.25,1.1,3.0)	(0.2,0.39,1.0)	(0.25,0.43,1.0)	(0.16,0.25,0.5)	
R3-3	(0.33,0.9,4.0)	(1.0,1.0,1.0)	(0.2,0.34,1.0)	(0.16,0.25,0.5)	(0.14,0.2,0.33)	
R3-4	(1.0,2.51,5.0)	(1.0,2.88,5.0)	(1.0,1.0,1.0)	(0.33,0.5,1.0)	(0.250,0.437,1.000)	
R3-6	(1.0,2.28,4.0)	(2.0,3.9,5.98)	(1.0,2.0,3.0)	(1.0,1.0,1.0)	(0.33,0.5,1.0)	
R3-7	(2.0,3.92,5.98)	(3.0,4.95,6.99)	(1.0,2.28,4.0)	(1.0,2.0,3.0)	(1.0,1.0,1.0)	
Consistency index C.Rm =0.017 C.Rg =0.04						
R4	R4-1	R4-2	R4-3	R4-4		
R4-1	(1.0,1.0,1.0)	(0.2,0.3,0.5)	(0.33,0.5,1.0)	(0.16,0.32,1.0)		
R4-2	(2.0,3.3,5.0)	(1.0,1.0,1.0)	(1.0,2.28,4.0)	(0.25,1.1,3.0)		
R4-3	(1.0,2.0,3.0)	(0.25,0.43,1.0)	(1.0,1.0,1.0)	(0.2,0.39,1.0)		
R4-4	(1.0,3.11,5.98)	(0.33,0.9,4.0)	(1.0,2.51,5.0)	(1.0,1.0,1.0)		
Consistency index C.Rm =0.01 C.Rg =0.03						
R5	R5-1	R5-2	R5-3	R5-4		
R5-1	(1.0,1.0,1.0)	(2.0,3.3,5.0)	(1.0,2.29,4.0)	(1.0,2.62,4.0)		
R5-2	(0.2,0.3,0.5)	(1.0,1.0,1.0)	(0.25,0.43,1.0)	(0.33,0.5,1.0)		
R5-3	(0.25,0.43,1.0)	(1.0,2.28,4.0)	(1.0,1.0,1.0)	(1.0,2.0,3.0)		
R5-4	(0.25,0.38,1.0)	(1.0,2.0,3.0)	(0.33,0.5,1.0)	(1.0,1.0,1.0)		
Consistency index C.Rm =0.028 C.Rg =0.042						
Sub-criteria	R6-2	R6-3	R6-4	R6-6	R6-7	
R6-2	(1.0,1.0,1.0)	(2.0,3.0,4.0)	(0.2,0.25,0.33)	(0.25,0.33,0.5)	(0.33,0.5,1.0)	
R6-3	(0.25,0.33,0.5)	(1.0,1.0,1.0)	(0.14,0.18,0.25)	(0.16,0.23,0.33)	(0.25,0.33,0.5)	
R6-4	(3.0,4.0,5.0)	(4.0,5.31,6.99)	(1.0,1.0,1.0)	(1.0,2.62,4.0)	(2.0,3.91,6.0)	
R6-6	(2.0,3.0,4.0)	(3.003,4.310,5.988)	(0.250,0.382,1.000)	(1.0,1.0,1.0)	(1.0,2.52,5.0)	
R6-7	(1.0,2.0,3.0)	(2.0,3.0,4.0)	(0.16,0.25,0.5)	(0.2,0.39,1.0)	(1.0,1.0,1.0)	
Consistency index C.Rm =0.045 C.Rg =0.071						
R7	R7-1	R7-2	R7-3	R7-5		
R7-1	(1.0,1.0,1.0)	(0.25,0.38,1.0)	(1.0,2.62,4.0)	(1.0,2.88,5.0)		
R7-2	(1.0,2.62,4.0)	(1.0,1.0,1.0)	(3.0,4.3,6.0)	(2.0,4.48,7.0)		
R7-3	(0.25,0.38,1.0)	(0.16,0.23,0.33)	(1.0,1.0,1.0)	(0.333,1.26,3.0)		
R7-5	(0.2,0.34,1.0)	(0.14,0.22,0.5)	(0.33,0.79,3.0)	(1.0,1.0,1.0)		
Consistency index C.Rm =0.014 C.Rg =0.005						

risks with a relative score 0.084, R7 risks with a relative score of 0.075, and finally, government risks (R1) with a relative score of 0.049, were ranked from first to seventh in influencing PPP-based transport projects.

Comparison of second-level risk factors (sub-criteria)

In general, a pairwise comparison of each sub-criteria is an important step in the hierarchical analysis. Accordingly, after determining the preferred factor among the risk factors of the first-level, the sub-factor

Table 10. Normalized matrices for combining the weights of sub-criteria (second-level risk factors) related to the first-level risk criterion

R1	R1-2		R1-3		R1-4		R1-5					
R1-2	-		0.591		0.694		1					
R1-3	1		-		1		1					
R1-4	1		0.842		-		0.95					
R1-5	0.948		0.584		1		-					
R2	R2-2		R2-6		R2-7		R2-8		R2-10		R2-13	
R2-2	-		0.783		0.395		0.504		0.916		1	
R2-6	1		-		0.796		1		0.924		1	
R2-7	1		1		-		0.795		0.415		0.523	
R2-8	1		0.597		1		-		0.955		1	
R2-10	1		1		1		1		-		0.669	
R2-13	0.669		0.765		1		0.722		1		-	
R3	R3-2		R3-3		R3-4		R3-6		R3-7			
R3-2	-		1		1		0.948		0.584			
R3-3	0.676		-		1		0.783		0.395			
R3-4	0.871		0.924		-		1		0.494			
R3-6	1		1		0.763		-		1			
R3-7	1		1		1		0.759		-			
R4	R4-1		R4-2		R4-3		R4-4					
R4-1	-		0.715		0.816		1					
R4-2	1		-		0.089		1					
R4-3	1		1		-		1					
R4-4	0.395		0.504		0.916		-					
R5	R5-1		R5-2		R5-3		R5-4					
R5-1	-		1		0.994		1					
R5-2	0.765		-		1		0.829					
R5-3	1		0.424		-		1					
R5-4	0.982		1		0.917		-					
R6	R6-2		R6-3		R6-4		R6-6		R6-7			
R6-2	-		0.933		1		1		1			
R6-3	1		-		1		1		1			
R6-4	0.395		0.504		-		0.995		1			
R6-6	0.783		0.089		1		-		0.711			
R6-7	0.669		0.765		0.526		1		-			
R7	R7-1		R7-2		R7-3		R7-4					
R7-1	-		1		1		1					
R7-2	0.915		-		1		1					
R7-3	0.494		0.601		-		1					
R7-5	0.415		0.523		0.924		-					

preference among the risk factors of the second-level was determined. For this purpose, the relative weight and rank of each of the sub-criteria were determined by repeating the process performed in the previous step. Table 9 presents the results of the mean matrix of fuzzy pairwise comparisons of sub-criteria (second-level risk sub-factors) in relation to the seven criteria affecting PPP-based transport projects. Lower than 0.1 values of the non-compliance rate indices indicated that the results obtained were in line with the correct prioritization of the sub-criteria, in addition to the sufficient validity of the results. Then, by performing the relevant calculations, the normalized matrix for combining the weights of the sub-criteria (sub-factors of the second-level of risk) in each of the main criteria was determined according to Table 10.

Finally, by combining the final weights, the degree of preference and relative weight of each of the sub-criteria (second-level risk sub-factors) were calculated and ranked according to their importance and impact on PPP-based transport projects. The relative weight and the final priority of the sub-criteria for each main criterion are shown in Table 11 and Figure 6, respectively. Based on the results of pairwise comparisons of the second-level risk subfactors in government risks (Figure 6-a), the parameter of delay in project approvals and licenses (R1-4) with a weight of 0.311, and the government intervention parameter (R1-2) with a weight of 0.208, gained the highest and lowest degree of importance, respectively. In economic and financing risks (Figure 6-b), the sub-criteria of high financing cost (R2-7) and inappropriate change and estimation of market demand (R2-13), gained the highest and the

lowest degree of importance with weights of 0.309 and 0.045, respectively. In construction risks (Fig. 6-c), the construction risk sub-criteria (R3-7) and lack of access to materials/personnel (R3-2) had the highest and lowest impact on PPP projects with a weight of 0.299 and 0.116, respectively. In operational risks (Figure 6-d), performance quality and standards sub-criteria (R4-2) and the increasing operating costs (R4-1) had the highest and lowest impact with a weight of 0.323 and 0.135, respectively. In political risk (Fig. 5-e), the criteria of expropriation and nationalization (R5-1) and political/public opposition (R5-2) had the highest and lowest degree of importance with weights of 0.384 and 0.104, respectively. In legal risks (Figure 6-f), the sub-criteria of increasing cost and time due to contract ambiguities (R6-4) and the delay/violation of a third party (R6-3) had the highest and lowest impact with a weight of 0.363 and 0.034, respectively. Finally, among other criteria (Figure 6), the organizational and coordination risks (R7-2) and cultural and social effects (R3-7) had the highest and lowest impact on PPP projects with a weight of 0.223 and 0.049, respectively. Based on the results, in case of dealing with any of the first-level risks in PPP-based transport projects, the second-level risks can be prioritized according to the determined priorities.

The general ranking of sub-criteria

After separately determining the importance and initial ranking of the most important risk criteria and sub-criteria affecting PPP-based transport projects, the overall ranking of sub-criteria using the FAHP

Table 11. The degree of preference, relative weight, and the sub-criteria ranks (second-level risk factors) of the first-level risk criteria

R1	Greater ultimate degree	Relative wighted	Rank
R1-2	0.591	0.208	4
R1-3	0.715	0.257	2
R1-4	0.021	0.311	1
R1-5	0.587	0.224	3
Total	8.115	1	
R2	Greater ultimate degree	Relative wighted	Rank
R2-2	0.591	0.159	4
R2-6	0.715	0.221	2
R2-7	0.584	0.309	1
R2-8	0.395	0.088	5
R2-10	0.021	0.179	3
R2-13	0.587	0.045	6
Total	8.115	1	
R3	Greater ultimate degree	Relative wighted	Rank
R3-2	0.591	0.116	5
R3-3	0.715	0.118	4
R3-4	0.395	0.219	3
R3-6	0.021	0.249	2
R3-7	0.587	0.299	1
Total	8.115	1	
R4	Greater ultimate degree	Relative wighted	Rank
R4-1	0.591	0.135	4
R4-2	0.715	0.323	1
R4-3	0.021	0.222	3
R4-4	0.587	0.321	2
Total	8.115	1	
R5	Greater ultimate degree	Relative wighted	Rank
R5-1	0.591	0.384	1
R5-2	0.395	0.104	4
R5-3	0.021	0.296	2
R5-4	0.587	0.215	3
Total	8.115	1	
R6	Greater ultimate degree	Relative wighted	Rank
R6-2	0.591	0.109	4
R6-3	0.715	0.034	5
R6-4	0.842	0.363	1
R6-6	0.021	0.328	2
R6-7	0.587	0.166	3
Total	8.115	1	
R7	Greater ultimate degree	Relative wighted	Rank
R7-1	0.301	0.301	2
R7-2	0.409	0.409	1
R7-3	0.145	0.145	4
R7-5	0.146	0.146	3
Total	8.115	1	

method is determined in this section. This ranking was determined by multiplying the relative weight of the criteria by the relative weight of the sub-criteria, and the results can be used to select a certain number of risks with a higher degree of importance for the next steps. The absolute weight and the final ranking of the sub-criteria are presented in Table 12 and Figure 7, respectively. As an overall result of the rankings, it was observed that the risks of high financing costs (R2-7) with a final weight of 0.068, quality of performance and standards (R4-2) with a final weight of 0.0655, lack of support infrastructure (R4-4) with a final weight of 0.0651, the risk of construction completion (R3-7) with a final weight of 0.063, and the increase in cost and time due to contract ambiguities (R6-4) with a final weight of 0.055 were identified as the five most effective risk factors for PPP-based transport projects. On the other hand, the risks of Cultural and Social Impacts (R7-3) with a final weight of 0.0109, Government Corruption (R1-2) with a final weight 0.0102, Inappropriate change and estimation in market demand (R2-13) with a

Table 12. Results of the final ranking of the sub-criteria according to the final weight

Criteria	Relative weight	Sub-criteria	Relative weight	Global weight	Final Priority
R1	0.049	R1-2	0.208	0.010192	29
		R1-3	0.257	0.012593	25
		R1-4	0.311	0.015239	24
		R1-5	0.224	0.010976	26
R2	0.223	R2-2	0.159	0.035457	12
		R2-6	0.221	0.049283	8
		R2-7	0.309	0.068907	1
		R2-8	0.088	0.019624	21
		R2-10	0.179	0.039917	11
		R2-13	0.045	0.010035	30
R3	0.214	R3-2	0.116	0.024824	19
		R3-3	0.118	0.025252	16
		R3-4	0.219	0.046866	9
		R3-6	0.249	0.053286	6
		R3-7	0.299	0.063986	4
R4	0.203	R4-1	0.135	0.027405	15
		R4-2	0.323	0.065569	2
		R4-3	0.222	0.045066	10
		R4-4	0.321	0.065163	3
R5	0.084	R5-1	0.384	0.032256	13
		R5-2	0.104	0.008736	31
		R5-3	0.296	0.024864	18
		R5-4	0.215	0.01806	22
R6	0.152	R6-2	0.109	0.016568	23
		R6-3	0.034	0.005168	32
		R6-4	0.363	0.055176	5
		R6-6	0.328	0.049856	7
		R6-7	0.166	0.025232	17
R7	0.075	R7-1	0.301	0.022575	20
		R7-2	0.409	0.030675	14
		R7-3	0.145	0.010875	28
		R7-5	0.146	0.01095	27

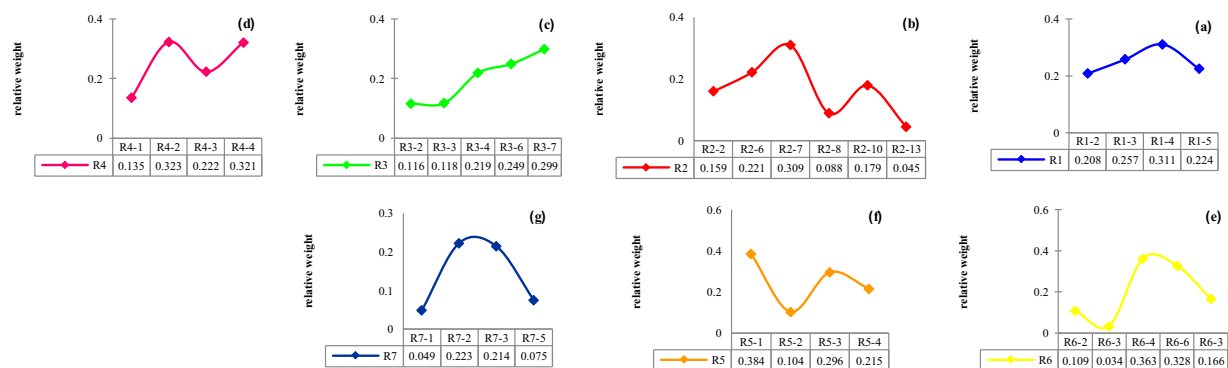


Figure 6. The degree of preference based on the sub-criteria relative weight (second-level risk factors) of (a) government risks (R1), (b) economic and financing risks (R2), (c) construction risks (R3), (d) operational risks (R4), (e) political risks (R5), (f) legal risks (R6), and (g) other risks (R7)

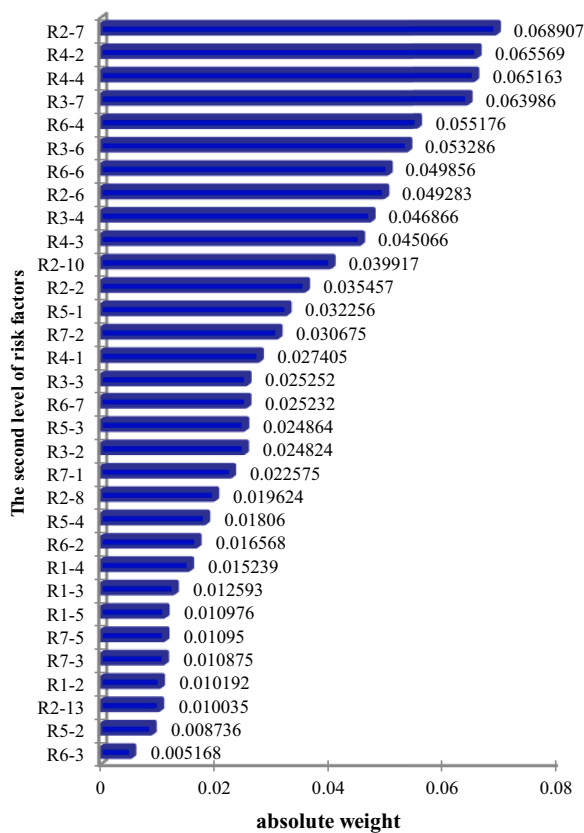


Figure 7. Prioritization of all sub-criteria based on absolute weight

Table 13. Evaluation of preferred risks identified in different PPP-based transport projects

Criteria	Sub-criteria	Risks	Ratings of Alternatives		
			Project A	Project B	Project C
R2	R2-2	C1	L	M	H
	R2-6	C2	H	M	H
	R2-7	C3	H	M	M
	R2-10	C4	VH	L	H
R3	R3-2	C5	M	H	M
	R3-3	C6	H	M	VH
	R3-4	C7	M	M	H
	R3-6	C8	VH	H	E
R4	R3-7	C9	M	L	H
	R4-1	C10	VH	M	E
	R4-2	C11	H	M	H
	R4-3	C12	H	M	M
R5	R4-4	C13	VH	L	H
	R5-1	C14	L	M	H
R6	R5-3	C15	M	H	M
	R6-4	C16	H	M	VH
	R6-6	C17	M	M	H
R7	R6-7	C18	VH	H	E
	R7-1	C19	M	L	H
	R7-2	C20	VH	M	E

final weight 0.01, Political / Public Opposition (R5-2) with a final weight of 0.0087, Third Party Delay/Violation (R6-3) with a final weight of 0.0052 were identified as five risks with the least impact on PPP-based transport projects.

Selection of preferred risks in different alternatives (studied projects)

In the previous section, the priority and impact of the first- and second-level risks on PPP-based transport projects were determined separately (i.e., in relation to each of the first-level risk factors), and generally. In order to complete the proposed model for determining the

effectiveness of these risks in real projects, the risks for different decision-making options were prioritized based on the similarity to the ideal solution. For this purpose, 20 risks with a higher degree of importance (with a total weight of more than 0.02 using FAHP method) were considered; on the other hand, three examples of PPP-based transport projects in Iran, including projects A, B, and C were selected as decision alternatives. Then, each of these projects was prioritized using the FTOPSIS method. Given that the goal is to determine the priority and impact of the preferred and identified risks on alternatives (PPP-based transport projects in Iran) in the previous stage, a fuzzy decision matrix was formed in the first stage. Therefore, the selected specialists (15 people in each project) were asked to determine the weight of the risks based on their importance through linguistic expressions. The assigned weights are shown in terms of verbal expressions in Table 13. These linguistic expressions were then converted to fuzzy numbers, and the fuzzy decision evaluation matrix was determined according to Table 14. It should be noted that the initial weight required for each of the risks at this stage is calculated from the final weights obtained using the FAHP method. Then, by performing the relevant calculations, first the fuzzy non-scale evaluation matrix and then the fuzzy weight evaluation matrix were determined by multiplying the sub-criteria weights (calculated by FAHP method) in the relevant fuzzy numbers for each of the risks in the three studied projects. After determining the fuzzy decision-making matrix, it is necessary to judge the nature of the sub-criteria for estimating the final ranking of risks in each of the studied projects and determine their proximity in terms of similarity to the ideal solution. For this purpose, first, all risks were considered as harmful parameters, and FPIS, A+, and FNID, A- were determined for all risks according to each project; the results are shown in Table 14.

Then, the distance of each of the risks from FPIS (S_i^*) and the FNID (S_i^-) was determined according to the studied projects (Table 15); the results of data sensitivity analysis regarding the distance of risks from FPIS and FNID compared to each of the studied projects are shown in Figure 8. Based on these results, the sensitivity of different risks to each project can be observed in terms of similarity to the FPIS and FNID.

Finally, the values of the similarity index (CC_i) or, in other words, the susceptibility of different decision-making options (studied projects) from the risks was calculated, and the ranking of the projects was done (Table 16). The results show that in line with the experts of the studied projects, projects A, B, and C, had a higher priority and a greater susceptibility to risks with scores of 0.433, 0.3369, and 0.283, respectively.

Based on the results of the analysis performed in this section, the priority and participation of risks and in various projects were determined. At this stage, the more critical risks were considered those with at least one of the following conditions in the studied projects:

- By decreasing the distance from the FPIS, the impact rate is higher, and the identified risk is more critical.
- By increasing the distance from FNID, the risk impact is more significant, and the identified risk is more critical.

Taking these two conditions into account, we identified the common risks in the studied projects and used the theme to provide an appropriate model for risk allocation using the fuzzy DEMATEL method (Table 17). Based on the results, four of the risks, including exchange rate fluctuations, improper performance and maintenance, expropriation and nationalization, and Lack of legal / regulatory frameworks were not highly effective in any of the studied projects and removed from the analysis process. However, sixteen of the remaining risks with a high impact in at least one or all of the studied projects were identified as final risks and considered to provide a risk allocation model between different project elements in the next step.

Table 14. Matrices of decision-making, non-scale, and fuzzy weighed evaluations, and FPIS (A +) and FNID (A-) for each of the risks compared to the various studied projects

Risks	Scorecard limits	Weights of Risks Extracted from FAHP	Ratings of Alternatives			Ratings of Alternatives (Projects)			Ratings of Alternatives (Projects)			FPIS, A ⁺	FNID, A ⁻
			A	B	C	A	B	C	A	B	C		
C1	l_i	0.0355	1	2.33	2	0.2	0.16	0.1765	0.0099	0.01	0.0087	0.0493	0.0078
	m_i	0.0355	3	4.33	3.67	0.3333	0.23	0.27	0.0164	0.01	0.01	0.0493	0.0078
	u_i	0.0355	5	6.33	5.67	1	0.43	0.50	0.0493	0.02	0.02	0.0493	0.0078
C2	l_i	0.0493	4.33	2.67	3.67	0.32	0.44	0.36	0.02	0.03	0.03	0.0689	0.022
	m_i	0.0493	6.33	4.33	5.67	0.42	0.62	0.47	0.03	0.04	0.03	0.0689	0.022
	u_i	0.0493	8.33	6	7.33	0.62	1	0.73	0.04	0.0689	0.05	0.0689	0.022
C3	l_i	0.0689	3	3.67	3	0.45	0.39	0.45	0.018	0.02	0.018	0.0399	0.0156
	m_i	0.0689	5	5.67	5	0.6	0.53	0.6	0.0239	0.02	0.0239	0.0399	0.0156
	u_i	0.0689	6.67	7.67	6.67	1.00	0.82	1.00	0.04	0.03	0.04	0.0399	0.0156
C4	l_i	0.0399	1	1.67	1.67	0.2308	0.18	0.20	0.0082	0.01	0.01	0.0356	0.0063
	m_i	0.0399	2.33	3.67	3	0.43	0.27	0.3333	0.02	0.01	0.0119	0.0356	0.0063
	u_i	0.0399	4.33	5.67	5	1.00	0.60	0.6	0.04	0.02	0.0214	0.0356	0.0063
C5	l_i	0.0248	1.33	2	2.67	0.31	0.2353	0.21	0.01	0.0058	0.01	0.0248	0.0052
	m_i	0.0248	2.67	3.67	4.33	0.50	0.36	0.31	0.01	0.01	0.01	0.0248	0.0052
	u_i	0.0248	4.33	5.67	6.33	1.00	0.67	0.50	0.02	0.02	0.01	0.0248	0.0052
C6	l_i	0.0253	3	4.33	4.33	0.4286	0.36	0.38	0.0108	0.01	0.01	0.0253	0.0091
	m_i	0.0253	5	6.33	6.33	0.6	0.47	0.47	0.0152	0.01	0.01	0.0253	0.0091
	u_i	0.0253	7	8.33	8	1	0.69	0.6923	0.0253	0.02	0.0175	0.0253	0.0091
C7	l_i	0.0467	1.33	1	1	0.23	0.2308	0.2727	0.01	0.0108	0.0127	0.0467	0.0108
	m_i	0.0467	2.67	2.33	2	0.38	0.43	0.5	0.02	0.02	0.0234	0.0467	0.0108
	u_i	0.0467	4.33	4.33	3.67	0.75	1.00	1.00	0.04	0.05	0.05	0.0467	0.0108
C8	l_i	0.0533	0.67	2	2	0.15	0.1176	0.1176	0.01	0.0063	0.0063	0.0533	0.0063
	m_i	0.0533	2.33	3.67	3.67	0.29	0.18	0.18	0.02	0.01	0.01	0.0533	0.0063
	u_i	0.0533	4.33	5.67	5.67	1.00	0.33	0.33	0.05	0.02	0.02	0.0533	0.0063
C9	l_i	0.064	1.67	1.67	2.67	0.33	0.29	0.28	0.02	0.02	0.02	0.064	0.0178
	m_i	0.064	3	3.67	4.33	0.5556	0.45	0.38	0.0356	0.03	0.02	0.064	0.0178
	u_i	0.064	5	5.67	6	1	1.00	0.625	0.064	0.06	0.04	0.064	0.0178
C10	l_i	0.0274	1	2	1.33	0.2	0.1765	0.20	0.0055	0.0048	0.01	0.0274	0.0048
	m_i	0.0274	3	3.67	3	0.3333	0.27	0.3333	0.0091	0.01	0.0091	0.0274	0.0048
	u_i	0.0274	5	5.67	5	1	0.50	0.75	0.0274	0.01	0.0206	0.0274	0.0048
C11	l_i	0.0656	2.33	2	0.33	0.37	0.3158	0.05	0.02	0.0207	0.00	0.0656	0.0035
	m_i	0.0656	4.33	3.67	1.67	0.68	0.58	0.26	0.04	0.04	0.02	0.0656	0.0035
	u_i	0.0656	6.33	5.67	3.67	1.00	0.89	0.58	0.07	0.06	0.04	0.0656	0.0035
C12	l_i	0.0451	2	3.33	3.67	0.3529	0.29	0.26	0.0159	0.01	0.01	0.0451	0.0118
	m_i	0.0451	3.67	5	5.67	0.55	0.4	0.35	0.02	0.018	0.02	0.0451	0.0118
	u_i	0.0451	5.67	7	7.67	1.00	0.6	0.55	0.05	0.0271	0.02	0.0451	0.0118
C13	l_i	0.0652	1	2	4.33	0.2	0.1765	0.13	0.013	0.0115	0.01	0.0652	0.0081
	m_i	0.0652	3	3.67	6.33	0.3333	0.27	0.16	0.0217	0.02	0.01	0.0652	0.0081
	u_i	0.0652	5	5.67	8	1	0.50	0.2308	0.0652	0.03	0.015	0.0652	0.0081
C14	l_i	0.0323	0.67	1.33	2.33	0.15	0.13	0.11	0.01	0.00	0.00	0.0323	0.0034
	m_i	0.0323	2.33	3	4.33	0.29	0.2222	0.15	0.01	0.0072	0.01	0.0323	0.0034
	u_i	0.0323	4.33	5	6.33	1.00	0.5	0.29	0.03	0.0162	0.01	0.0323	0.0034
C15	l_i	0.0249	1	0.67	1.67	0.1818	0.15	0.15	0.0045	0.00	0.00	0.0249	0.0038
	m_i	0.0249	2	2.33	2.67	0.3333	0.29	0.25	0.0083	0.01	0.01	0.0249	0.0038
	u_i	0.0249	3.67	4.33	4.33	0.67	1.00	0.40	0.02	0.02	0.01	0.0249	0.0038
C16	l_i	0.0661	3.67	4.33	7	0.50	0.44	0.3793	0.03	0.03	0.0251	0.0661	0.0251
	m_i	0.0661	5.67	6.33	8.67	0.65	0.58	0.42	0.04	0.04	0.03	0.0661	0.0251
	u_i	0.0661	7.33	8.33	9.67	1.00	0.85	0.52	0.07	0.06	0.03	0.0661	0.0251
C17	l_i	0.0499	1	2.33	0.33	0.0769	0.05	0.09	0.0038	0.00	0.00	0.0499	0.0026
	m_i	0.0499	2.33	4.33	1.67	0.14	0.08	0.20	0.01	0.00	0.01	0.0499	0.0026
	u_i	0.0499	4.33	6.33	3.67	0.33	0.14	1.00	0.02	0.01	0.05	0.0499	0.0026
C18	l_i	0.0252	0.67	0.33	0.33	0.08	0.09	0.09	0.00	0.00	0.00	0.0252	0.0019
	m_i	0.0252	2.33	1.67	1.67	0.14	0.20	0.20	0.00	0.01	0.01	0.0252	0.0019
	u_i	0.0252	4.33	3.67	3.67	0.50	1.00	1.00	0.01	0.03	0.03	0.0252	0.0019
C19	l_i	0.0226	2.33	3.33	4.33	0.37	0.33	0.29	0.01	0.01	0.01	0.0226	0.0066
	m_i	0.0226	4.33	5	6.33	0.54	0.4667	0.37	0.01	0.0105	0.01	0.0226	0.0066
	u_i	0.0226	6.33	7	8	1.00	0.7	0.5385	0.02	0.0158	0.0122	0.0226	0.0066
C20	l_i	0.031	3	3.67	2.33	0.3333	0.30	0.37	0.0103	0.01	0.01	0.031	0.0094
	m_i	0.031	5	5.67	4.33	0.4667	0.41	0.54	0.0145	0.01	0.02	0.031	0.0094
	u_i	0.031	7	7.67	6.33	0.7778	0.64	1.00	0.0241	0.02	0.03	0.031	0.0094

Step 5: Risk response planning

After the previous steps for assessing and identifying the preferred risks using qualitative and quantitative analysis and integrated MCDM methods (FAHP and FTOPSIS), this stage requires planning for responding to high-impact risks in PPP-based transport projects. In general, this process involves determining reactive measures to increase opportunities and reduce threats for achieving the project goals. One of the most important issues in this step is the assignment of responsibilities (risk allocation) to the various pillars of the project in

order to facilitate the response to the identified risks. According to Delmon Research (2015), the main actors and stakeholders in the PPP-based infrastructure projects are owners (employers), contractors, designers (consultants), grantors, suppliers, project companies, investors, multilateral and credit agencies, beneficiaries (purchaser), and project managers [69]. In the issue of risk allocation in PPP projects, each of these stakeholders can be divided into three categories, including the public sector, the private sector, and the joint sector based on a general classification [34]. Typically, the identified risks in the risk allocation studies (Zhang 2005, Wu et al. 2018) are assigned to each department

Table 15. Distance values of different decision-making options from FPIS and FNID according to the sub-criteria

Criteria	Sub-criteria	Risks	Ratings of Alternatives(Projects)			Ratings of Alternatives(Projects)		
			A	B	C	A	B	C
R2	R2-2	C1	0.0197	0.024	0.0229	0.0177	0.0089	0.0093
	R2-6	C2	0.0296	0.0363	0.0344	0.0245	0.008	0.0103
	R2-7	C3	0.0387	0.0269	0.0347	0.0124	0.0299	0.0174
	R2-10	C4	0.0157	0.0182	0.0157	0.0149	0.0103	0.0149
R3	R3-2	C5	0.0122	0.015	0.0167	0.0121	0.0069	0.0044
	R3-3	C6	0.0102	0.0129	0.0127	0.01	0.0051	0.0051
	R3-4	C7	0.0276	0.0258	0.0238	0.0145	0.0214	0.022
	R3-6	C8	0.0341	0.0423	0.0423	0.0277	0.0069	0.0069
R4	R3-7	C9	0.0296	0.033	0.0377	0.0287	0.0275	0.0134
	R4-1	C10	0.0165	0.0191	0.0169	0.0133	0.0053	0.0094
	R4-2	C11	0.0267	0.0307	0.0482	0.0448	0.0389	0.0215
	R4-3	C12	0.0206	0.0264	0.0282	0.0208	0.0096	0.0078
R5	R4-4	C13	0.0392	0.0454	0.0541	0.034	0.0153	0.0042
	R5-1	C14	0.0206	0.0236	0.0265	0.017	0.0077	0.0035
R6	R5-3	C15	0.0159	0.0159	0.0184	0.0078	0.0123	0.0038
	R6-4	C16	0.0234	0.0274	0.0371	0.0262	0.0195	0.0058
R7	R6-6	C17	0.0411	0.0454	0.0349	0.0085	0.0027	0.0276
	R6-7	C18	0.0197	0.0176	0.0176	0.0062	0.0136	0.0136
	R7-1	C19	0.0102	0.0118	0.0138	0.0098	0.0058	0.0034
	R7-2	C20	0.0158	0.0176	0.014	0.009	0.0062	0.0132

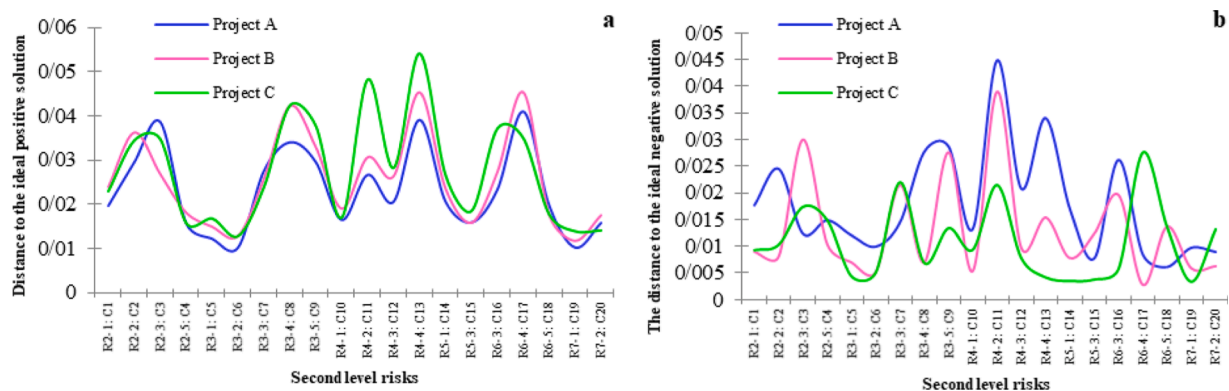


Figure 8. The final performance and sensitivity analysis of options to the sub-criteria that affect research, in terms of the distance of FPIS and FNID

Table 16. Final results of similarity to FPIS and the final ranking of different decision-making options

Alternatives	CC_i	Final rank
Project A	0.433	1
Project B	0.3369	2
Project C	0.283	3

based on expert opinions [30,43]. The results of allocating common risks in the studied projects to different pillars are presented in Table 17.

Step 6: Monitor and control the risk management process

Finally, by monitoring and controlling risks, it is necessary to follow and control the identified risks, identify new risks, ensure the implementation of risk programs, and evaluate their impact in risk control (Edition 1996). Risk is a recurring process throughout the life of PPP-based infrastructure projects.

Conclusion

In the present study, a systematic model was developed for risk assessment in PPP-based infrastructure projects. For this purpose, the most important first- and second-level risks were identified in these projects by an in-depth review of the literature. The model was then developed by conducting a case study in PPP-based freeway projects in

Iran and using the step-by-step risk management process in the PMBOK standard. In order to develop this model, it should be noted that statistical and inferential methods such as the FMCDM methods were used for qualitative and quantitative analysis, determining the importance and prioritization of the identified risks.

The results of qualitative risk analysis based on the relative importance of occurrence probability, impact severity, and risk rate for each of the second-level risks showed that a total of 32 risks were identified in the critical range (PI higher than 0.2), 15 risks in the precautionary range (PI between 0.05 to 0.2), and three risks in the acceptable range (PI lower than 0.05). Once the critical risks were identified, they were used in the next cycle of risk analysis.

The results of quantitative risk analysis by FAHP method according to the relative weight and primary rank of each criterion showed that the first-level risks including economic and financing (R2), construction (R3), operational (R4), legal (R6), political (R5), other risks (R7), and ultimately, the government risks (R1) were ranked from first to seventh in influencing PPP-based transport projects. Also, pairwise comparisons of the second-level risk factors in government risks showed that the parameters of delay in project approvals and licenses, and the government intervention parameter had gained the highest and lowest degree of importance, respectively. In economic and financing risks, the sub-criteria of high financing costs and the inappropriate change and estimation of market demand gained the highest and lowest degree of importance, respectively. In construction risks, the sub-criteria of construction completion risk and lack of access to materials/personnel gained the highest and lowest impact severity on PPP-based projects,

Table 17. Common risks with a high degree of impact in the studied projects

First level risk factors	The second level of risk factors	Common risks in the projects under study						Risk allocation
		Project A. FNID, A ⁻	FPIS, A ⁺	Project B. FNID, A ⁻	FPIS, A ⁺	Project C. FNID, A ⁻	FPIS, A ⁺	
Economic (R2)	Exchange rate fluctuations (C1)							public
	Inability of the investor consortium (C2)	☑						private
	High financing costs (C3)			☑				private
Construction Risks (R3)	Price change and fluctuation (additional payment) (C4)		☑		☑		☑	Common
	Lack of access to materials / personnel (C5)		☑		☑		☑	private
	Improper estimation of construction time and time delay (C6)		☑		☑		☑	Common
	Improper design and approved engineering techniques (C7)			☑		☑		Common
	Changing the design specifications (C8)	☑						public
Operational Risks (R4)	Construction Completion Risk (C9)	☑		☑				Common
	Increase operating costs (C10)		☑		☑		☑	private
	Performance quality and standards (C11)	☑		☑		☑		private
	Improper performance and maintenance (C12)							private
Political Risks (R5)	Lack of support infrastructure (C13)	☑						public
	Expropriation and nationalization (C14)							public
Legal Risks (R6)	Change rules and regulations (C15)		☑		☑		☑	public
	Increase in cost and time due to contractual ambiguities (C16)	☑		☑				Common
	Lack of legal / regulatory frameworks (C17)							public
Other Risks (R7)	Failure to renew resolutions (C18)				☑		☑	Common
	Force Majeure (C19)		☑		☑		☑	Common
	Organizational Risks and Coordination (C20)		☑		☑		☑	public

respectively. In operational risks, the sub-criteria of performance quality and standards, and increasing operating costs gained the highest and the lowest impact severity, respectively. In political risk, the sub-criteria of expropriation and nationalization, and political/public opposition gained the highest and lowest degree of importance, respectively. In legal risks, the sub-criteria of increasing costs and time due to contract ambiguities, and third-party delay/violations gained the highest and lowest impact severity, respectively. Finally, among the other criteria, the sub-criteria of organizational and coordination, and cultural and social effects had the highest and lowest impact on PPP-based projects, respectively. Based on these results, in case of dealing with any of the first-level risks in PPP-based transport projects, the priority of the second-level risks can be evaluated according to the set priorities. Also, as an overall result of the final ranking of the sub-criteria, it was determined that the risks of high financing costs, quality of performance and standards, lack of support infrastructure, risk of construction completion, and the increase of cost and time due to contract ambiguities are the five risks with the highest impact on projects. On the other hand, the risks of inappropriate change and estimation of market demand, force majeure, third-party delay/violation, unpredictable weather/geotechnical conditions, political / public opposition were defined as the five risks with the least impact on PPP-based transport projects, respectively. Also, the results of the similarity index or in other words, the susceptibility of different decision-making options (studied projects) from the risks were calculated, and the ranking of the projects showed that according to the experts of the studied projects, A, B, and C projects were at a higher priority and affected more by the risks.

Considering the two conditions, (1) by decreasing the distance from the FPIS, the risk impact was higher, and the identified risk was more critical, and (2) by increasing the distance from the FNID, the risk impact was higher, and the identified risk was more critical, the common risks were identified in the projects studied and used to provide an appropriate risk allocation model. Based on the results, four of the risks, including exchange rate fluctuations, improper performance and maintenance, expropriation and nationalization, and Lack of legal / regulatory frameworks were not highly effective in any of the studied projects and removed from the analysis process. However, sixteen of the remaining risks with a high impact in at least one or all of the studied projects were identified as final risks and were considered in the next step to provide a risk allocation model between different project elements.

Author statement

study conception and design: E. Jokar, B. Aminnejad, A.Lork; data collection: E. Jokar, B. Aminnejad; analysis and interpretation of results: E. Jokar, B. Aminnejad, A.Lork; draft manuscript preparation: E. Jokar, B. Aminnejad. All authors reviewed the results and approved the final version of the manuscript.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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