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Identifying the Critical Risks in Railway Projects Based on Fuzzy and Sensitivity Analysis: A Case Study of Belt and Road Projects

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Abstract: The Belt and Road Initiative (BRI) is a Chinese development strategy developed in order to establish connectivity and deepen cooperation between China and other countries, increase trade, and support the socio-economic development of vast regions. A significant number of railway projects are planned to be constructed under BRI since railways are the most efficient means of transportation. This paper investigates the critical risks in railway projects implemented under BRI. In total, 24 potential risks in BRI railway projects are identified and categorized into 6 groups. A questionnaire survey is conducted in order to collect data about the probability of risk occurrence and their impact. To identify the critical risks in railway projects, a novel method based on fuzzy and sensitivity analysis is developed and applied for risk assessment. This method uses a fuzzy synthetic evaluation approach to assess risks and sensitivity analysis as criteria for critical risk identification. The results show that the most critical risks in railway projects are changes in design, design errors, cooperation between China and BRI country, loan risk, complex geological conditions of terrain, and geopolitical risk. The theoretical contribution of this paper is a novel method which combines fuzzy and sensitivity analysis into a single approach.

Keywords: railway projects; risk assessment; risk management; fuzzy synthetic evaluation approach; sensitivity analysis; Belt and Road Initiative; Silk Road

1. Introduction

Belt and Road Initiative (BRI) is a Chinese development strategy with the focus on strengthening the connectivity and cooperation between China and BRI countries in order to sustain economic growth, create closer economic ties, deepen cooperation, and expand development of vast regions in Asia, Europe, and Africa [1]. The idea of BRI is based on the revival of the ancient Silk Road, which was once connecting the Far East with Central Asia, India, Middle East, and Europe. The Chinese government has characterized the spirit of Silk Road as "peace and cooperation, openness and inclusiveness, mutual learning, mutual benefit, and win-win results" [2]. The proposed BRI consists of two main components: the land-based "Silk Road Economic Belt" and "The 21st Century Maritime Silk Road" on sea. The Silk Road Economic Belt links China with Central Asian countries, the Middle East, West Asia, and Eastern Europe, and further spreads to West Europe. The focus of the Silk Road Economic Belt is on building economic corridors based on the existing international transport routes; keep the interrelation centers and major industrial parks. While at sea, the emphasis is opening fast, secure, and efficient transport routes connecting major seaports in Southeast Asia, South Asia, Middle East, Africa, and Europe with China. After BRI was launched by Xi Jinping, it has attracted a lot of attention and interest in the World, especially in the political and business circles. This great undertaking is beneficial for people, countries, and nations along the route. Under BRI, major seaports, railways, highways, bridges, airports, gas and oil pipelines, and industrial parks are planned to be built. However, the focus of this study is railway projects, which are planned to be constructed under BRI.

Railways are the most efficient means of transportation. The benefits of rail transport over other means of transport are cheaper than air transport, faster than sea transport, several departures per week, flexibility, standard equipment, reduced CO_2 emissions compared to air transport, sustainable, and eco-friendly. In addition, railways are one of the safest means of land transportation compared to road transportation. Furthermore, railways connect the landlocked countries in Central Asia with major seaports in South Asia, Southeast Asia, and Africa. In Asia, Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan have access to major seaports in South Asia via railway links. Similarly, landlocked Ethiopia in Africa gains access to Djibouti port through Addis Ababa–Djibouti railway. The railway projects have major impacts on the international trade and transport of passengers and goods. Therefore, the construction of railways is essential for the implementation of BRI. Similar to other infrastructure projects, railway construction projects are characterized as complex, large-scale, long period, complex ground and longitudinal site conditions, and high investment which involve numerous stakeholders [3]. Due to their unique characteristics, these projects are influenced by a significant number of risks, which could have different impacts on project goals in terms of cost overruns [4], schedule delays, failure to meet the quality standards, and safety issues. In order to identify the critical risks in BRI railway projects and successfully manage them, there is a need for risk assessment.

The current literature review reveals a significant number of studies related to opportunities and challenges in BRI from geopolitics perspective [5–7], economic perspective and international trade [8,9], energy investment [10,11], global health perspective [12], and others. However, there is a lack of studies with the focus on risk assessment and management of major construction projects that are planned to be implemented under BRI. Hence, the aims of this study are (1) to establish a risk assessment model based on fuzzy and sensitivity analysis and apply for risk assessment of railway projects; (2) to identify the critical risks in railway projects; and (3) to propose strategies for risk management.

In this paper, a novel model for risk assessment of BRI railway projects is developed based on the fuzzy synthetic evaluation approach and sensitivity analysis. Fuzzy logic is a tool for modeling approximate human reasoning and understanding of the world [13,14]. It is applied in situations involved with vagueness and imprecision associated with the development of the knowledge-based expert system. Thus, fuzzy set theory and fuzzy logic have shown as efficient tools for developing experts system for risk assessment in various engineering fields including construction engineering. For example, fuzzy-based methods are applied in the construction industry for risk assessment of Public-Private Partnership (PPP) projects [15], subway projects [16], bridges [17], pipelines [18], and others. In addition, Islam et al. (2017) have highlighted the application of fuzzy-based methods for risk assessment of buildings and infrastructure projects including roads and highways, subways, tunnels, bridges, pipelines, power generation, and transmission projects [19]. However, there is no related research that applies fuzzy-based methods for risk assessment of railway projects. The advantages of fuzzy-based methods over probabilistic approach for risk assessment are an ability to deal with vague and imprecise data [20], treat uncertainty that arises from expert's subjective judgment (lexical uncertainty) [21], treat uncertainty related to a small number of observations (limited dataset) [21], and others.

The rest of the paper is organized as follows: Section 2 provides a literature review on project risk management process. Further, Section 3 introduces the proposed methodology for risk assessment based on fuzzy and sensitivity analysis. The obtained results are presented in Section 4, while discussions and recommendations for risk management are provided in Section 5. To sum up this study, the conclusions are outlined in Section 6.

2. Literature Review

According to the Project Management Body of Knowledge (PMBOK) guide, the typical risk management process consists of six main processes: risk identification, qualitative risk analysis, quantitative risk analysis, risk response planning, risk monitoring, and risk control [22]. The initial step in the risk management process is risk identification, which detects potential sources of risks [23]. Risk identification is the process of determining potential risks, which may affect the success of the project, and documenting their characteristics [24]. There are few techniques and methods for risk identification such as brainstorming, workshops, checklist and prompt list, questionnaires and interviews, various diagramming approaches, and others [25]. Additionally, risk breakdown structure (RBS) is suitable tool to hierarchize and systematically present the potential risk in construction projects. Further, risk classification and categorization is carried out according to their characteristics and origin. The next step in risk management process is risk analysis. Risk analysis evaluates the likelihood of risk occurrences and their impacts through a qualitative, quantitative, or semi-quantitative approach [26]. The qualitative analysis evaluates the likelihood of risk occurrences and their impacts based on the subjective judgment of experts, while the quantitative analysis provides the quantitative measures of these parameters. Risk assessment is the process of prioritizing risks by evaluating and combining the likelihood of their occurrences and impacts [24]. Risk management is significant since it involves predicting the occurrence of events that could cause a negative effect on the project execution and defining proper actions to reduce the impact of these events [27,28].

2.1. Risks in BRI Railway Projects

In total, 24 risks in railway projects are identified through different literature reviews (previous journal articles, case studies, and technical reports), brainstorming, and others. Further, risk factors were grouped into risk categories according to their origin and characteristics. Risk factors and categories are listed in Table 1. Risks were classified into six different categories: BRI, external factors, environment, design process, construction process, and human resource.

Table 1. Risk in railway projects implemented under BRI.

ID	Risk Categories	Risk Factors	Sources
R1	C1: BRI	Geopolitical risk	[6,7,29,30]
R2		Loan risk	[31]
R3		Cooperation between China and BRI country	[10,29]
R4	C2: External factors	Economic risk	[28,32–34]
R5		Political risk (change of the government)	[28,32–36]
R6		Law risk	[32,34,36]
R7		Cultural and social differences	[32,33,35–39]
R8		Weather	[32–36]
R9	C3: Environment	Soil pollution and site contamination	[28,35,38–41]
R10		Noise and vibrations	[28,42–45]
R11		Complex geological conditions of terrain	[32–34,45,46]
R12	C4: Design process	Design errors	[28,32–34]
R13		Changes in design of railway route	[28,34,45,46]
R14	C5: Construction process	Poor site organization and management	[36]
R15		Failure of equipment	[34,36]
R16		Lack of availability of equipment	[33,36]
R17		Delay of equipment delivery	[36]
R18		Poor quality of materials	[32–34,36]
R19		Delay of supply rail tracks and other materials	[32,33,36]
R20		Lack of quality control of construction works	[4,32]
R21	C6: Human resource	Lack of labour	[32,33,36]
R22		Poor planning and management	[33,35]
R23		Poor team communication	[32,36]
R24		Accident occurrence and lack of safety	[28,34,35]

The first category consists of risks related to BRI Policy: geopolitical risk, loan risk, and cooperation between China and BRI country. Risks related to BRI Policy are outside of the project, thus their influence is uncontrollable. The New Silk Road is a diplomatic approach by China in order to establish a new economic and political order in East Asia and West Asia [30]. It has the tendency to change the geopolitics in different regions of the world [6,29]. Hence, the BRI is influenced by serious geopolitical risk which could affect the realization of the construction projects. The geopolitical risks in BRI projects arise from: (1) countries located in complex geopolitical regions, where political, religious, and ethnic conflicts are common, such as Afghanistan and Pakistan; and (2) the New Silk Road and the 21st Century Maritime Silk Road present a threat to economies of certain countries, such as the USA, Japan, and India. For instance, Chinese development, economic growth and greater influence on the Eurasia continent will put the United States outside of the Asian's market [7]. From the USA point of view, BRI is related to "new international order," "new economic model," and "new civilization exchange" [7]. The majority of BRI countries are developing countries, which have insufficient funds for large-scale and complex railway projects. Hence, loans from special banks are provided to the governments of BRI countries in order to finance their BRI project. Special banks and funds are established for the needs of BRI. These banks are Asian Infrastructure Investment Bank with the capital base of US$100 billion [47–49], Silk Road Fund with the capital base of US$40 billion [47,49], and The Export-Import Bank of China [49,50]. Gaining the loan for construction of BRI project from the Chinese bank represents loan risk. Loans for railway projects and other BRI projects can be approved or denied depending on BRI country's ability to return loan [31]. Thus, some countries are at higher risk depending on their current number of creditors. For instance, Greece is evaluated as a high-risk score since it has other creditors. Also, procedures for obtaining loan and loan effectiveness are included in loan risk. Compared to the traditional international construction projects, BRI projects are the product of the diplomatic relation and bilateral partnership between the Chinese government and the government of BRI country. Firstly, the country decides to accept Chinese proposal to join BRI and sign an agreement. Hence, risks that can influence the execution of the BRI project in the host country are related to diplomatic relations between China and the BRI country. If some issues or misunderstanding appear in cooperation between China and the BRI member country, it can lead to the interruption of the project.

External factors are the second category that consists of risks outside of the project. Similar to the risks related to BRI, this risk category is less controllable. This category includes economic risk, political risk, law risk, cultural and social differences, and weather. The economic risk appears due to inflation, interest rate fluctuation, variation in the currency exchange rate, taxes, and increase of the price of construction materials, equipment and labor, funding shortage, cash flow imbalance, lack of financial allocation, and others. The currency exchange rate is a significant economic factor for BRI projects since the Chinese contractor is working in a foreign country, which has its local currency. In addition, some materials and equipment for the requirements of the project are imported from China. The loss due to currency exchange could increase the cost of the project. Law and regulations risk is associated with the law background of the country. In some countries, laws are complex, unclear, incoherent, changeable, and open to interpretation. Law issues appear due to changes in laws and regulations and of planning and construction, contractual matter, human rights, complex approval and permit procedures, legal disputes, export/import restrictions, breach of contracts by participants, and others. Contract negotiations and project approval can be lengthy, and resulted in project delays. In addition, some clauses in contracts could be risky to manage and could cause conflicts in contract forms and documents. Political risks are related to the political situation of the country, political stability, political changes, government effectiveness, the inconsistency of government policy, sovereignty, war, corruption, bribes, and bureaucracy and excessive procedures. Contractors for BRI railway projects are large-scale Chinese corporations such as China Railway Group Limited, China Railway Construction Corporation Limited, China Railway Engineering Corporation, and others. They are working on the construction of railway projects in BRI countries with different social, cultural, and religious background from China. Thus, BRI projects include stakeholders from different social, cultural, and religious backgrounds. Accordingly, risks related to the cultural and social differences in BRI railway projects should be considered in this study. The cultural difference was one of the major issues that affected the management of international projects in the past [37]. Also, the language barrier as a social factor between different stakeholders appears in cross-cultural communication, and it could cause misunderstandings during the project implementation and have major impacts on the project goals. In the previous international projects related to PPP, it was observed that differences between the Asian and Western cultures were likely to result in management issues, conflicts, misunderstandings, and disputes [38,39,41]. Chinese culture is one of the oldest cultures in the World with its specific and unique characteristics, which is mainly based on Confucian–Taoist–Buddhist philosophies [51]. However, the cultural and social background of China and Southeast Asian countries are relatively similar due to their geographical locations and mutual history [52]. To conclude, the cultural dimension is very important for the implementation of BRI railway projects. Construction of railways is an outdoor activity that is influenced by weather conditions to a great extent. The critical weather conditions are related to storms, heavy rainfalls, or heavy snow in some countries of BRI during the construction process. On the other hand, hot weather could also influence the progression of the construction of railways. The speed of construction depends on weather conditions. BRI projects are located in different geographical positions with diverse climates, from a cold climate with long winter period in Russia, northern China, Kazakhstan, and other central Asian countries to warm and humid tropical climate in South and Southeast Asia, Middle East, and African countries. Workers must be prepared and ready to work in specific weather conditions, as well as to use specific procedures for construction works. In the case of the critical weather conditions, some equipment and materials can be destroyed, damage to the structure could be caused, and the productivity of labor and equipment could be decreased.

In the third category, environmental risks are considered. Environmental risks on construction sites are soil pollution and site contamination, noise and vibrations, and complex geological conditions of terrain. Construction works on railway projects are outside activities. The waste produced by these activities can pollute the soil and ground waters near the construction site. Usually, causes of soil and water pollution at the construction site are erosion, earthworks, storm water runoff, sediment, lack enforcement, compaction, waiting time and delay during earthwork and site development, and others [40]. Construction sites are prone to oil, fuel, and chemical spills as a consequence of operating heavy machines, which can lead to soil and groundwater contamination [53,54]. During the construction, some construction operations and machines generate loud sound and produce noise and vibrations [43]. Noise is a pollutant with a negative impact on the workers, neighborhood, and living environment. In addition, one of the reasons for cost overruns in Chongqing–Lichuan Railway Development projects financed by the Asian Development Bank was due to noise abatement measures, which caused an increase of 36% [45]. From the geotechnical engineer's point of view, geotechnical and geological conditions of terrain are uncertain [55]. Hence, the geotechnical site characterization is an important part of every major infrastructure project such as a railway. In the previous projects, complicated geotechnical measures involving wall rock tunneling caused cost overruns in the Chongqing–Lichuan Railway Development project [45]. Complex topography in Yichang–Wanzhou Railway Development project in China required modification to the original design in order to cope with the terrain, and it simultaneously caused cost overrun and schedule delay in the project [46].

During the design process, infrastructure projects are exposed to design errors and changes in design. Generally, changes in the design of railway projects occur due to topographical complexity, increased tunnels and bridges on the route, increased size and capacity of passenger's stations, traffic signalization, and others. The other reason for changes in design and design errors are insufficient investigation of the geological and geotechnical conditions of terrain or bad soil conditions for laying the tracks.

The fifth category of risks is related to the construction process and it consists of risks related to the construction site, construction materials, equipment, and quality of construction works. These risks are poor site organization and management, failure of equipment, availability of equipment, delay of equipment delivery, poor quality of materials, delay in supplying rail tracks and other materials, and lack of quality control of construction works. Equipment and materials are essential for the construction process; hence, the availability, functionality of equipment, and delivery on time is important for the successful completion of railway projects. Railway construction process can be very complex in nature and require special equipment for these operations. In some cases, advanced technology is needed for completing these complex operations. Since some of BRI countries are undeveloped and there is a lack of accessible equipment, the availability of equipment is one of the potential risks. Chinese contractor needs to import this equipment from China, and import procedures can be lengthy and cause delays in equipment delivery. The last group of risks is connected with human resources and management of the project. In this group, the lack of labor, poor planning and management by project manager, poor team communication, accident occurrence, and lack of safety measures on the site are analyzed in order to efficiently manage the project. Some countries experience a shortage of skilled labor in the market, and unskilled workers could cause defects in construction works. Import of skilled workers results in the rise of project costs. During the construction work, construction workers are exposed to various types of injury-inducing hazards and unsafe work environment due to poor safety management, which could result in an accident [56,57]. In order to avoid accidents, the site manager should appropriately plan the work in advance, and labors should use personal protection devices.

2.2. Methods for Risks Assessment of Construction Projects

The current literature review reveals that different methods were used for risk assessment and ranking of construction projects. Generally, these methods can be divided into two groups: qualitative and quantitative methods. Qualitative methods were less applied for risk assessment, while quantitative methods were commonly used in risk assessment procedures. Risks were assessed and ranked in a descriptive manner by the qualitative approach. Some of the applications of qualitative approach for risk assessments were in risk assessment of construction projects in Poland [58], drilling projects [59], large projects [60], risk assessment of construction companies [61], and others. Quantitative methods for risk assessment and ranking were relative importance index, probabilistic and statistical approach, analytical hierarchical process (AHP), fuzzy analysis, Bayesian network, and others. Relative importance index and probabilistic and statistical approach were the most common quantitative methods used for estimating risks. Relative importance index is a widely used metric to estimate risk as the product of the likelihood of risk occurrence and risk impact. This method was used for identifying the critical risks in different countries and regions, such as critical risks in public–private partnership projects in Greece [62], Arabian Gulf region [63], risk assessment of subway in Nanjing, China [64], the key risk in Australia [65], and others. Some of the applications of the probabilistic and statistical approach for risk assessment in the construction industry were tunnel construction risk assessment [66], assessment of critical success factors in Malaysian construction projects [67], critical tasks and aspects in nuclear construction projects [68], and others. AHP is an efficient method for solving multi-criteria decision-making problem. A decision problem is decomposed into a hierarchical breakdown structure with a goal, factors, and sub-factors. The weights between the factors and sub-factors are estimated by a system of pairwise comparison. Further, AHP is used for risk assessment of cross-sea route project in China [69], risk and opportunity assessment of international projects [70], prioritization of rural roads [71], and others. Fuzzy analysis as a suitable tool for risk assessment that enables experts to express their subjective judgment in the form of linguistic variables is used for risk assessment and ranking in the construction industry. Fuzzy analysis for risk assessment in the construction industry was initially applied for modeling risk management process based on the UK context [72] and construction project risk assessment in London [73]. Bayesian networks are also used for risk assessment in the construction industry but not often as other methods due to computational complexity. Some of the applications of Bayesian network were construction contract risk assessment [74], risk analysis of gas field development projects [75], fall risk evaluation of steel construction projects [76], and others.

3. Methodology

3.1. Data Collection

A questionnaire was designed and a survey was conducted to evaluate risks from Table 1. The first part of the questionnaire was related to the educational background and working experience of respondents. While the second part of the questionnaire was related to the risk analysis. Respondents were asked to evaluate the probability of risk occurrence and the impact of risks on their railway projects. Overall, the questionnaire included 24 risks associated with railway projects. This questionnaire was distributed to construction practitioners and experts in Chinese contractor companies ensuring that they were working on BRI railway projects. The respondents were employees in Chinese companies with multi-cultural working experience. They were contacted through Chinese social networks QQ and WeChat, and professional social network LinkedIn. In total, 39 valid responses were collected from companies which were constructing railway projects under BRI. The respondent's educational background and working experience are listed in Table 2. It can be observed that the majority of respondents (56%) have a bachelor's degree and less than 5 years of working experience (54%). Even though the sample size is limited (only 39 responses), risk analysis can be carried out as the central limit theorem is true for a sample size greater than 30 [77,78].

Table 2. Respondent's profile.

Educational Background		Working Experience	
College degree	5	Less than 5 years	21
Bachelor's degree	22	5–10 years	9
Master's degree	12	10–15 years	5
PhD degree	0	15–20 years	3
		More than 20 years	1

3.2. Fuzzy Synthetic Evaluation Method for Risk Assessment

The fuzzy synthetic evaluation method was developed for risk assessment of railway projects. The first step in the fuzzy synthetic evaluation process was to define the set of basic criteria or factors and a set of alternatives. In this model, the set of basic criteria/factors were risk factors and the set of alternatives presented the potential values of the probability of risk occurrence (P) and impact of risks (I). Based on the number of the potential values for P and I, a 5-point linguistic scale is selected with the corresponding definitions of possible values for P and I, as described in Table 3; Table 4. For each risk factor, P and I values were collected through a questionnaire survey.

Table 3. Linguistic definition of the probability of risk occurrence [79].

Probability of Occurrence	Description
Very low	Event is highly unlikely to occur.
Low	Event is unlikely to occur.
Moderate	Event may occur.
High	Event is expected to occur.
Very high	Event will certainly occur.

Table 4. Linguistic definition of risk impact [79].

Risk Impact	Description
Very low	Cost and time overrun is less than 1%; project scope or quality change is not noticeable.
Low	Cost and time overrun is between 1% and 4%; few areas of project scope or quality are affected.
Moderate	Cost and time overrun is between 4% and 7%; major areas of project scope or quality are affected.
High	Cost and time overrun is between 7% and 10%; changes in project scope or quality are unacceptable.
Very high	Cost and time overrun is more than 10%; project scope or quality does not meet business expectations.

The fuzzy synthetic evaluation method for risk assessment of railway projects consists of three steps which are as follows:

Step 1. Risk assessment of risk factors:

Using the collected values of P for risk factors, the evaluation matrix R is formed. The element r_{ij} of evaluation matrix R presents the degree that the alternative a_j satisfies the risk factor i. In case of geopolitical risk (R1), 12 respondents (32%) evaluated P as very low, 6 respondents (15%) as low, 15 respondents (38%) as a moderate, 4 respondents (10%) as high, and 2 respondents (5%) *as very high*. According to the collected data, the membership function of P for geopolitical risk is given as follows:

$$\left(R_1^P\right)_{1x5} = (0.32,\ 0.15,\ 0.38,\ 0.1,\ 0.05) \tag{1}$$

Similarly, the impact of risk factors is evaluated and evaluation matrix R for I is given as:

$$\left(R_i^I\right)_{1x5} = \left(r_{i1}^I,\ r_{i2}^I,\ r_{i3}^I,\ r_{i4}^I,\ r_{i5}^I\right) \tag{2}$$

For each alternative in set, a corresponding weight is given: $s_j = \{1,\ 2,\ 3,\ 4,\ 5\}$. Further, P and I of risk factors are calculated using the following equation:

$$P_i = \sum_{i=1}^{5} s_j \times r_{ij}^P \tag{3}$$

$$I_i = \sum_{i=1}^{5} s_j \times r_{ij}^I \tag{4}$$

In order to rank risks, the risk score (SC) is assessed as the product of P and I according to the following formula:

$$SC_i = \sqrt{P_i \times I_i} \tag{5}$$

Step 2. Risk assessment of categories:

After P, I, and SC are estimated for each risk factor, the next step is to evaluate SC of risk categories. Firstly, the weight of each risk factor in each risk category is determined. The weights assigned to P of risk factor i are estimated as:

$$w_i^P = \frac{P_i}{\sum_{i=1}^{k} P_i} \tag{6}$$

where, k is the number of risk factors within the risk category.

Similarly, the weights are assigned to I for each risk factor. The risk evaluation matrix for risk category D is a product of the fuzzy composition of the weight vector W and the evaluation matrix R. Further, membership functions for P of risk category t are calculated based on the equation:

$$d_{t,j}^{P} = \sum_{i=1}^{k} w_i^P \times r_{ij}^P \tag{7}$$

$$(D_t^P)_{1\text{x}5} = (W_i^P)_{1\text{x}k} \times (R_i^P)_{k\text{x}5} = \left(d_{t1}^P,\ d_{t2}^P,\ d_{t3}^P,\ d_{t4}^P,\ d_{t5}^P\right) \tag{8}$$

Correspondingly, the membership function for I of risk category t and matrix D is evaluated. Similar to the risk factors, P, I, and SC of risk categories are calculated:

$$P_{C_t} = \sum_{i=1}^{5} s_j \times d_{tj}^P \tag{9}$$

$$P_{C_t} = \sum_{i=1}^{5} s_j \times d_{tj}^P \tag{10}$$

$$SC_{C_t} = \sqrt{P_{C_t} \times I_{C_t}} \tag{11}$$

Step 3. Overall project risk:

P, I, and SC of overall project risk were estimated as a product of the weight vector of risk categories and evaluation matrix. The weights of P for each risk categories are estimated by the following equations:

$$w_{C_t}^P = \frac{P_{C_t}}{\sum_{t=1}^{l} P_{C_t}} \tag{12}$$

where, l is the number of risk categories and $\left(\sum_{i=1}^{k} P_i\right)_t$ is the sum of P for each risk factor in risk category C_t. In the same way, the weights of I for each risk categories are measured.

Then, the membership functions of P and I for overall project risk are established according to these equations:

$$d_j^P = \sum_{t=1}^{l} w_{C_t}^P \times d_{t,j}^P \tag{13}$$

$$\left(D^P\right)_{1x5} = (W_C^P)_{1xl} \times (D_C^P)_{lx5} = \left(d_1^P,\ d_2^P,\ d_3^P,\ d_4^P,\ d_5^P\right) \tag{14}$$

provided those membership functions of P, I, and SC for the overall project risk are assessed with the following equations, respectively:

$$P = \sum_{i=1}^{5} s_j \times d_j^P \tag{15}$$

$$I = \sum_{i=1}^{5} s_j \times d_j^I \tag{16}$$

$$SC = \sqrt{P \times I} \tag{17}$$

3.3. Sensitivity Analysis

Sensitivity analysis is used as a criterion to identify the most critical risks in railway projects in order to provide information to project managers. The overall project risk is the function of the probability of risk factors and their impacts $SC(P_1,\ I_1, \ldots P_{24},\ I_{24})$, as described in the previous section. To identify the critical risks that mostly contribute to the increase of the overall project risk, the probability of risk occurrence and impact of risk for each risk factor was increased and the overall risk was estimated [80,81]. Firstly, the overall project risk $SC(P_1, I_1, \ldots P_{24}, I_{24})$ was assessed with the initial values using the procedure described in the previous section. Further, the membership functions for the probability of risk and risk impact were increased with small value $\delta > 0$ for each risk indicator separately, and the procedure was applied to assess the overall project risk $SC(P_1, I_1, \ldots P_k + \delta, I_k + \delta, \ldots P_{24}, I_{24})$. Hence, the procedure was repeated 24 times for each risk factor. The difference of overall risk for each risk factor is estimated according to the following equation:

$$\Delta_i = \frac{SC(P_1, I_1, \ldots P_k + \delta, I_k + \delta, \ldots P_{24}, I_{24}) - SC(P_1, I_1, \ldots P_{24}, I_{24})}{\delta} \tag{18}$$

4. Results

P, I, and SC for risk factors are calculated according to Equations (1)–(5). The results for risk factors are obtained in Table 5. The example of the procedure was demonstrated for risk R1: geopolitical risk. According to the collected data, the membership function for P is:

$$(R_1^P)_{1x5} = (0.32,\ 0.15,\ 0.38,\ 0.1,\ 0.05)$$

While, the membership function for I is:

$$(R_1^I)_{1x5} = (0.21,\ 0.36,\ 0.28,\ 0.15,\ 0.00)$$

Using the Equation (3), P for geopolitical risk is estimated:

$$P_1 = \sum_{i=1}^{5} s_j \times r_{1j}^P = 1 \times 0.32 + 2 \times 0.15 + 3 \times 0.38 + 4 \times 0.10 + 5 \times 0.05 = 2.41$$

Table 5. Probability, impact, risk score, and weights of risk factors.

ID	Probability			Impact			SC
	Membership Function	Val.	W	Membership Function	Val.	W	
R1	(0.32, 0.15, 0.38, 0.10, 0.05)	2.41	0.29	(0.21, 0.36, 0.28, 0.15, 0.00)	2.37	0.31	2.39
R2	(0.15, 0.18, 0.44, 0.13, 0.10)	2.85	0.35	(0.18, 0.33, 0.33, 0.13, 0.03)	2.50	0.33	2.68
R3	(0.15, 0.23, 0.29, 0.21, 0.12)	2.92	0.36	(0.09, 0.38, 0.29, 0.21, 0.03)	2.71	0.36	2.81
R4	(0.26, 0.20, 0.18, 0.26, 0.10)	2.74	0.20	(0.10, 0.36, 0.33, 0.21, 0)	2.65	0.20	2.70
R5	(0.20, 0.21, 0.36, 0.15, 0.08)	2.70	0.19	(0.13, 0.36, 0.23, 0.15, 0.13)	2.79	0.21	2.74
R6	(0.20, 0.31, 0.23, 0.18, 0.08)	2.63	0.19	(0.15, 0.23, 0.41, 0.15, 0.05)	2.69	0.20	2.65
R7	(0.15, 0.18, 0.32, 0.20, 0.15)	3.02	0.22	(0.09, 0.32, 0.30, 0.26, 0.03)	2.82	0.21	2.92
R8	(0.21, 0.20, 0.36, 0.13, 0.10)	2.71	0.20	(0.13, 0.36, 0.36, 0.10, 0.05)	2.58	0.19	2.64
R9	(0.18, 0.36, 0.38, 0.05, 0.03)	2.39	0.33	(0.20, 0.33, 0.41, 0.03, 0.03)	2.36	0.32	2.37
R10	(0.18, 0.43, 0.31, 0.08, 0)	2.29	0.31	(0.18, 0.46, 0.28, 0.08, 0)	2.26	0.31	2.27
R11	(0.10, 0.44, 0.20, 0.23, 0.03)	2.65	0.36	(0.10, 0.38, 0.26, 0.26, 0)	2.68	0.37	2.67
R12	(0.18, 0.38, 0.26, 0.13, 0.05)	2.49	0.50	(0.18, 0.38, 0.23, 0.18, 0.03)	2.49	0.53	2.49
R13	(0.11, 0.39, 0.37, 0.13, 0)	2.53	0.50	(0.18, 0.47, 0.26, 0.08, 0)	2.24	0.47	2.38
R14	(0.20, 0.44, 0.13, 0.15, 0.08)	2.46	0.13	(0.20, 0.31, 0.28, 0.15, 0.05)	2.54	0.13	2.50
R15	(0.18, 0.38, 0.26, 0.08, 0.10)	2.54	0.14	(0.10, 0.41, 0.28, 0.08, 0.13)	2.72	0.15	2.63
R16	(0.15, 0.49, 0.18, 0.10, 0.08)	2.46	0.13	(0.13, 0.36, 0.28, 0.18, 0.05)	2.67	0.14	2.56
R17	(0.08, 0.43, 0.23, 0.07, 0.18)	2.85	0.16	(0.13, 0.36, 0.20, 0.18, 0.13)	2.82	0.15	2.83
R18	(0.21, 0.28, 0.38, 0.10, 0.03)	2.46	0.14	(0.15, 0.41, 0.23, 0.13, 0.08)	2.56	0.13	2.52
R19	(0.05, 0.28, 0.33, 0.18, 0.16)	3.10	0.18	(0.15, 0.21, 0.31, 0.18, 0.15)	2.97	0.16	3.03
R20	(0.21, 0.46, 0.28, 0, 0.05)	2.23	0.12	(0.15, 0.44, 0.28, 0.08, 0.05)	2.43	0.13	2.33
R21	(0.20, 0.54, 0.20, 0.03, 0.03)	2.13	0.23	(0.20, 0.38, 0.28, 0.08, 0.05)	2.38	0.23	2.25
R22	(0.23, 0.33, 0.31, 0.08, 0.05)	2.38	0.26	(0.18, 0.36, 0.23, 0.10, 0.13)	2.64	0.26	2.51
R23	(0.13, 0.46, 0.20, 0.15, 0.05)	2.54	0.27	(0.13, 0.26, 0.36, 0.15, 0.10)	2.85	0.27	2.69
R24	(0.28, 0.41, 0.21, 0.05, 0.05)	2.18	0.24	(0.23, 0.33, 0.23, 0.10, 0.10)	2.51	0.24	2.34

Similarly, I for geopolitical risk is estimated according to Equation (4):

$$I_1 = \sum_{i=1}^{5} s_j \times r_{1j}^{I} = 1 \times 0.21 + 2 \times 0.36 + 3 \times 0.28 + 4 \times 0.15 + 5 \times 0.00 = 2.37$$

Finally, RC risk score is calculated based on Equation (5):

$$RC_1 = \sqrt{P_1 \times I_1} = \sqrt{2.41 \times 2.37} = 2.39$$

Further, P, I, and RC for risk categories were estimated. The procedure was demonstrated for risk category C1: BRI. This risk category consisted of three risks—R1, geopolitical risk; R2, loan risk; and R3, diplomatic and bilateral relations between China and BRI country. Firstly, the weight for each risk factor was determined. The weight of P of geopolitical risk in BRI risk category is estimated based on Equation (6):

$$w_1^P = \frac{P_1}{\sum_{i=1}^{3} P_i} = \frac{2.41}{2.41 + 2.85 + 2.92} = 0.29$$

Similarly, other weights for other two risk factors for P are estimated. Hence, the weight vector of P for BRI risk category is:

$$W_1^P = (0.29,\ 0.35,\ 0.36)$$

Further, membership functions for P of BRI risk category is calculated based on Equations (7) and (8):

$$(D_1^P)_{1x5} = (W_1^P)_{1x3} \times (R_1^P)_{3x5} = [0.29,\ 0.35,\ 0.36] \times \begin{bmatrix} 0.32 & 0.15 & 0.38 & 0.10 & 0.05 \\ 0.15 & 0.18 & 0.44 & 0.13 & 0.10 \\ 0.15 & 0.23 & 0.29 & 0.21 & 0.12 \end{bmatrix}$$
$$= (0.20,\ 0.19,\ 0.37,\ 0.15,\ 0.09)$$

Subsequently, the membership functions for P and I of other risk categories are estimated. P, I, and RC of risk category are calculated based on Equations (9–11). For instance, P for BRI risk category is:

$$P_{C_1} = \sum_{i=1}^{5} s_j \times d_{1j}^{P} = 1 \times 0.20 + 2 \times 0.19 + 3 \times 0.37 + 4 \times 0.15 + 5 \times 0.09 = 2.74$$

$$I_{C_1} = \sum_{i=1}^{5} s_j \times d_{1j}^{I} = 1 \times 0.16 + 2 \times 0.36 + 3 \times 0.30 + 4 \times 0.16 + 5 \times 0.02 = 2.52$$

$$SC_{C_1} = \sqrt{P_{C_1} \times I_{C_1}} = \sqrt{2.74 \times 2.52} = 2.63$$

Further, P, I, and RC are determined for each risk category separately, and the results are given in Table 6.

Table 6. Probability, impact, risk score, and weights of risk category.

ID	Probability			Impact			*SC*
	Membership Function	**Val.**	***W***	**Membership Function**	**Val.**	***W***	
C1	(0.20, 0.19, 0.37, 0.15, 0.09)	2.74	0.18	(0.16, 0.36, 0.30, 0.16, 0.02)	2.52	0.16	2.63
C2	(0.20, 0.22, 0.29, 0.18, 0.11)	2.78	0.18	(0.12, 0.33, 0.33, 0.18, 0.05)	2.74	0.19	2.76
C3	(0.15, 0.41, 0.29, 0.12, 0.02)	2.42	0.16	(0.16, 0.39, 0.31, 0.13, 0.01)	2.44	0.16	2.43
C4	(0.15, 0.38, 0.32, 0.13, 0.02)	2.49	0.16	(0.18, 0.43, 0.24, 0.13, 0.02)	2.38	0.15	2.42
C5	(0.15, 0.39, 0.26, 0.10, 0.10)	2.61	0.17	(0.14, 0.35, 0.26, 0.14, 0.09)	2.63	0.17	2.62
C6	(0.21, 0.43, 0.23, 0.08, 0.05)	2.33	0.15	(0.18, 0.33, 0.28, 0.11, 0.10)	2.62	0.17	2.47

In order to assess the overall project risk, the weights of each risk category is determined as specified in Table 6. For instance, the weight of BRI risk category is obtained using Equation (12):

$$w^P_{C_1} = \frac{P_{C_1}}{\sum_{t=1}^{I} P_{C_t}} = \frac{2.74}{2.74 + 2.78 + 2.42 + 2.49 + 2.61 + 2.33} = 0.18$$

Similarly, weights for other risk categories are obtained for P and I. Hence, the weight vector of P for overall risk is:

$$W^P_C = (0.18,\ 0.18,\ 0.16,\ 0.16,\ 0.17,\ 0.15)$$

The weight vector of I for overall risk is:

$$W^I_C = (0.16,\ 0.19,\ 0.16,\ 0.15,\ 0.17,\ 0.17)$$

The membership function for P of overall risk is evaluated following Equations (13) and (14):

$$\left(D^P\right)_{1x5} = (W^P_C)_{1x6} \times (D^P_C)_{6x5} = [0.18,\ 0.18,\ 0.16,\ 0.16,\ 0.17,\ 0.15]\ x \begin{bmatrix} 0.2 & 0.19 & 0.37 & 0.15 & 0.09 \\ 0.2 & 0.22 & 0.29 & 0.18 & 0.11 \\ 0.15 & 0.41 & 0.29 & 0.12 & 0.02 \\ 0.15 & 0.38 & 0.32 & 0.13 & 0.02 \\ 0.15 & 0.39 & 0.26 & 0.10 & 0.10 \\ 0.21 & 0.43 & 0.23 & 0.08 & 0.05 \end{bmatrix} = [\ 0.18,\ 0.33,\ 0.29,\ 0.13,\ 0.07]$$

Likewise, the membership function for I of overall risk is estimated:

$$\left(D^I\right)_{1x5} = (W^I_C)_{1x6} \times (D^I_C)_{6x5} = [0.16,\ 0.36,\ 0.29,\ 0.14,\ 0.05]$$

Finally, P, I, and SC of overall project risk are calculated:

$$P = \sum_{i=1}^{5} s_j \times d^P_j = 1 \times 0.18 + 2 \times 0.33 + 3 \times 0.29 + 4 \times 0.13 + 5 \times 0.07 = 2.58$$

$$I = \sum_{i=1}^{5} s_j \times d^I_j = 1 \times 0.16 + 2 \times 0.36 + 3 \times 0.29 + 4 \times 0.14 + 5 \times 0.05 = 2.56$$

$$SC = \sqrt{P \times I} = \sqrt{2.58 \times 2.56} = 2.57$$

The overall risk of railway projects implemented under BRI is 2.57. The linguistic terms mapped to 2.00 and 3.00 are "low" and "moderate", respectively. The value of 2.57 is nearer to 3.00 than 2.00; thus, the risk of railway projects implemented under BRI is considered as "moderate".

Further, sensitivity analysis is carried out and the differences in the overall project risk before and after the increase of the probability of risk and impact for each risk factor are provided in Table 7.

Table 7. Sensitivity analysis for risk factors.

ID	ΔR
R1	0.1511
R2	0.1906
R3	0.2103
R4	0.1123
R5	0.1162
R6	0.1091
R7	0.1314
R8	0.1082
R9	0.1448
R10	0.1323
R11	0.1812
R12	0.2467
R13	0.2203
R14	0.0674
R15	0.0755
R16	0.0715
R17	0.0860
R18	0.0690
R19	0.0994
R20	0.0580
R21	0.0920
R22	0.1144
R23	0.1276
R24	0.0981

5. Discussions and Recommendations for Risk Management of the Critical Risks

According to sensitivity analysis, the most critical risks contribute to the highest increase of the overall risk (a risk with the highest ΔR in Table 7). These risks are changes in design of railway route, design errors, cooperation between China and BRI country, loan risk, complex geological conditions of terrain, and geopolitical risk. Changes in design of railway route and design errors belong to design process risk category; hence, design process risk category is the most critical risk category. Further, cooperation between China and BRI country and loan risk belong to BRI Policy risk category, and this risk category is ranked on the second place. On the other hand, the least critical risks are lack of quality control of construction works, poor quality of materials, poor site organization and management, lack of availability of equipment, and failure of equipment. All these risks belong to construction process risk category and this category is the least critical risk category.

Changes in design of railway route (ΔR = 0.2467) is the most significant risk, since it contributes mostly to the enhancement of total project risk. The changes in design of railway route occur due to insufficient investigation of geological and geotechnical characteristics of soil and terrain, bad rock conditions, and other factors. Also, adding additional components on the routes such as bridges, tunnels, or passengers stations causes changes in design. In order to reduce changes in design process, adequate investigation about the geotechnical characteristics of soil is required during the feasibility study. Also, the position of bridges and tunnels on the route, as well as the capacity of passenger's stations should be determined in the initial stage of project.

Design errors (ΔR = 0.2203) is positioned on the second place, which is also related to design process. Design errors could occur due to the lack of experience of designers, insufficient investigation of terrain and soil layers, as well as the capacity of stations and others. Hence, the feasibility study is an important stage in project lifecycle and risk management process. During feasibility study, the detailed investigation of geotechnical conditions of soil and geological characteristics of soil layers should be conducted in order to avoid any design errors. Also, design process should be carried out by experienced railway engineers.

Cooperation between China and BRI country (ΔR = 0.2103) is highly ranked on the third place; however it is the most important risk from the BRI policy risk category. The cooperative, diplomatic, and bilateral relations between the Chinese government and the government of host country is important for initiating and successful completion of BRI projects, since the contract of BRI railway project is based on their agreement. If there are some changes in the contract about the cooperation or breach of the bilateral relations between the two countries, it can disrupt the completion of BRI project in the host country. In order to avoid this risk, it is important to maintain good relations between two countries and their governments.

Loan risk (ΔR = 0.1906) is the fourth ranked risk among the critical risks, and it is the second critical risk from BRI policy risk category. Since the majority of BRI countries are undeveloped or developing countries with the lack of funding, loans are necessary for investment in railway infrastructure projects. Without the loans provided by Chinese banks, the construction of the majority of BRI projects is impossible. The important question that rises is how these countries are going to pay back credits. One of the possible methods and suggestions by Chinese investors is that the infrastructure project is owned by the Chinese government for a certain period of time. After the expiration period, the ownership will be returned to the local government.

Complex geological conditions of terrain (ΔR = 0.1812) contributes mostly to the increase of the total risk from the group of risks related to environment. This risk occurs due to the insufficient investigation of the geological conditions of terrain, the geotechnical differences between the detailed design and actual survey, rock conditions, landslides during the excavation process, and others. Due to this risk, changes in design are required. Further, complex geological and geotechnical conditions of terrain have influenced the execution of the majority of railway projects in China in the past [82]. To avoid or reduce this risk, a detailed analysis of soil and soil layer, as well as underground water is essential before starting the construction process.

Geopolitical risk (ΔR = 0.1511) is the sixth ranked critical risk which belongs to the BRI policy risk category. Since BRI policy is a geopolitical and geo-economics project with the tendency to change the current geopolitical scene in the World, it is influenced with the serious geopolitical risk. The USA and Japan could interpret BRI Policy as a threat to their economy. Further, it can cause disputes or even wars between countries. Also, this risk is uncontrollable and it is out of control of Chinese contractors or investors. Hence, there are no particular measures to avoid or reduce this risk. However, to avoid this risk, one of the Chinese strategies is to promote BRI project as "win–win" policy and to maintain a good relations with other countries and nations.

6. Conclusions

Railway projects implemented under BRI are of international importance not only for China but for all countries on the Silk Road railway route. Railway transportation is the most suitable and efficient means of transport in BRI, since it is cheaper than air transport, eco-friendly, and faster than sea transport. However, the construction of railways is exposed to several risks that represent a threat for successful implementation of the project in terms of cost, time, quality, and safety. Therefore, there is a need for effective risk assessment of BRI railway projects in order to identify the critical risks and successfully manage them. Compared to the traditional railway projects, BRI railway projects are exposed to additional risks related to BRI Policy—geopolitical risk, loan risk, and cooperation between China and BRI country. Overall, 24 different risks which can influence railway projects performance are identified and categorized into six categories. Further, the fuzzy synthetic evaluation method with the aid of sensitivity analysis is developed in order to assess these risks and overall project risk. The proposed method based on fuzzy and sensitivity analysis has shown as an efficient, reliable, and practical tool for risk assessment since it enables to assess risks on three different levels, risk factors, risk categories, and overall project risk; the lexical uncertainty and uncertainty due to the lack of data are included and considered in the assessment process. The findings show that the critical risks are changes in the design of railway route, design errors, cooperation between China and BRI country, loan risk, complex geological conditions of terrain, and geopolitical risk. Further, the most critical risk categories are related to design process (changes in the design of railway route and design errors) and BRI Policy (cooperation between China and BRI country, loan risk and geopolitical risks). Some of the recommendations to reduce design process risks is to engage experience railway designers and to conduct a detailed investigation of the geological and geotechnical conditions of terrain and soil layers characteristics. Risks related to BRI Policy are less controllable since they depend on external factors. However, China as BRI founder should establish and maintain good relations with other countries whether they belong to BRI or not. On the other hand, the least critical risks are related to the construction process. The overall project risk of railway projects is estimated as "moderate". The following information is significant for Chinese contractors who are participating in the railway projects. Also, the critical risks are important for future investors, enterprises and companies, governments, international organizations and other stakeholders who are planning to develop business under BRI.

Some of the limitations of this study are: (1). a lack of data (only 39 responses); (2). the number of countries which joined BRI is constantly expanding; and other. There are indicators that more countries will join the initiative in the future. Besides the current three continents (Asia, Europe and Africa), it is planned that countries from South America join the Initiative.

The suggestions for further research on BRI projects are risk assessment of highway projects, fixed links (bridges and tunnels), and ports and other types of infrastructure. Also, the critical risks in BRI projects can be analyzed for the different geographical region since BRI is spreading in Asia, Africa, and Europe. There is a difference between the key risk for different regions in Asia (East Asia, Central Asia, South Asia, and Southeast Asia), Europe (East Europe, Central Europe, and others), and Africa (West Africa, North Africa, and others) due to a diverse social, political, cultural, and religious background of countries and their geographical locations.

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