Risk management of PPP project in the preparation stage based on Fault Tree Analysis

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Abstract. The risk management of PPP(Public Private Partnership) project can improve the level of risk control between government departments and private investors, so as to make more beneficial decisions, reduce investment losses and achieve mutual benefit as well. Therefore, this paper takes the PPP project preparation stage venture as the research object to identify and confirm four types of risks. At the same time, fault tree analysis(FTA) is used to evaluate the risk factors that belong to different parts, and quantify the influencing degree of risk impact on the basis of risk identification. In addition, it determines the importance order of risk factors by calculating unit structure importance on PPP project preparation stage. The result shows that accuracy of government decision-making, rationality of private investors funds allocation and instability of market returns are the main factors to generate the shared risk on the project.

1. Introduction

The rational assessment of shared risk about the public-private partnership project (hereinafter referred to as "PPP project") is the basis of risk-response and risk-allocation mechanism[1]. The PPP project has a significant impact on regional economic and social development. At the same time, it is also the primary means of government to guide private investment. Due to the internal and external factors, PPP project involves many risks, which mainly involves risk losses, considerable uncertainties and increased risk events by the main investment part[2]. Therefore, it is necessary to identify the risk factors, improve the effectiveness of risk management, grasp the key points of risk management, and allocate resources rationally to reduce risk losses in the pre-project preparation stage. Besides, fault tree analysis (hereinafter referred to as "FTA") is a tree describing directed logic of accident and a logical deductive analysis tool, which is used to analyze the phenomenon, cause and result about accident, so as to find out the measures to prevent the accidents[3]. Consequently, in this paper, FTA method is used to analyze and assess the risk factors of PPP project in the preparation stage.

2. Literature review

At present, there are two main kinds of risk-sharing methods for PPP projects: one is to confirm the risk-sharing ratio of each project through questionnaire and expert interview statistics. The tendency of risk is reflected by comparing the mean. The other is to establish mathematical models to seek the optimal solution of risk-sharing so as to determine the number of key risk-sharing between government and private sector. Consequently, there are both advantages and disadvantages of two methods. The former is easy to operate, but it can not define the specific commitment number of shared risk in the government sector and private sector. While the latter can determine the amount of

shared risk quantitatively. However, the model building process is complicated. What's more, most cases need to discard some conditions, and it is different from the real PPP project. Thus, the conclusions of reliability should be verified[4]. In addition, Thomas et al. proposed a fuzzy fault framework tree and Delphi method on the basis of risk probability and impact assessment, which included the process of key risk modeling and expert judgment system in the general case[5]. Besides, Zhang and Zou developed fuzzy analytic hierarchy process (AHP) model to evaluate the risk environment of joint venture.

However, as an emerging model, it appears to have many problems about PPP mode in China, such as delaying approvals, financing problems, lacking of market returns, project uniqueness, legal change, government credit and other risks[7]. Due to lacking of operational experience in the government and the private sector in PPP project, lots of projects failed to be identified and evaluated effectively[8]. Consequently, it is essential for government sectors and private investors to use scientific tools to assess the risk of PPP project and to provide a scientific basis for decision-making in the pre-preparation phase. Therefore, the purpose of this paper is to identify and assess the risks in PPP projects from the four perspectives of government sectors, private investors, macroeconomics and external environment. Moreover, this paper focus on finding out the main causes that lead to the occurrence of PPP projects so as to reduce the risk probability of different subjects and make risk assessment more closer to reality on the basis of uncertainty conditions.

3. The risk analysis process of PPP project
From a practical point of view, PPP project risk includes the probability of events and the seriousness of consequences. Thus, the analysis process can be divided into risk identification, risk estimation and risk assessment.

3.1. Risk identification
Risk identification, namely, identify all factors that may affect the progress of project to classify statistically and propose risk list. Hence, risk factors can be defined by checklist method and expert survey methods[9]. According to *PPP research report in 2016,* it pointed out that China has implemented more than 8,000 PPP projects, which involve water plants, power plants, bridges, tunnels, roads transportation, hospitals, sewage disposal and other fields[10]. As shown in Table 1, it summarizes the representative PPP projects and major risk factors for failure.

Table 1. PPP project problems and major risk factors for failure

Project / Risk	Government decision-making mistakes	Public object	Government credit	Force majeure	Insufficient market returns	Project uniqueness	Changes in market demand	Charges change
Jiangsu sewage treatment plant			√	√				
Shanghai Dachang Water Plant								
Beijing tenth water plant	√	√						
Hunan power plant			√	√				
Qingdao Veolia Sewage Treatment Project	√		√					
Hangzhou Bay Bridge					√	√	√	
Lianjiang Sino-French Water Supply Plant	√		√					
Fujian's Quanzhou Erythrina Bridge					√	√	√	
Tangxun Lake Sewage Treatment Plant								
Yan'an East Road Tunnel								√
Shenyang ninth water plant			√					

Project							
Beijing-Beijing Highway				√	√	√	
Beijing Metro Line 4		√	√	√			
National Stadium (Bird's Nest)		√	√	√			
Chongqing Water Group Project	√	√	√				
Beijing Subway Olympic Line BT Project	√	√					
Nanjing Metro Line 2 BT Project							
Guangzhou Guanghe hospital		√	√	√			
Shantou Chaonan People 's Hospital							
Beijing New Milestone Cancer Hospital		√	√	√			
Guangxi Laibin B Power Plant		√		√	√		
Beijing Yizhuang gas BOT project							
Hubei Shiyan City bus company project	√	√	√	√		√	

Source: PPP Study 2016

From the statistics of the reasons for failure, a half of the PPP project failures are related to the lack of government credit, insufficient market returns, public opposition, market demand changes and project uniqueness. They account for a high proportion, so special attention should be paid to such issues in PPP cooperation projects.

3.2. Risk Estimation

Identified risk factors may determine the number and probability of risk losses and it is necessary to find out the relation among them. the probability and the magnitude of loss to determine the degree of correlation is essential in the risk assessment. There are a lot of methods of risk estimation, such as planning evaluation technology(PERT), analytic hierarchy process(AHP) and fuzzy comprehensive evaluation, etc., which are analyzed the risk of PPP project from possibility of occurrence, severity of impact and controllable degree on the preparation phase[11].

3.3. Risk assessment

According to the estimation results, the appropriate methods are used to evaluate the risk factors of PPP projects and to determine the importance of factors and the level of risk, which can summarize the results of qualitative analysis so as to propose risk management recommendations for government departments and private investors to develop PPP risk management strategy in the project preparatory stage.

4. The construction of fault tree for PPP project

Bell Labs applied the method of Fault Tree Analysis (FTA) to militia missile launch control system and the research made great success in 1961. It is a method for reliability, security analysis and risk evaluation of large complex systems. At present, FTA has been widely used in aerospace, nuclear, electronics, machinery, chemical, mining and other fields[13-15]. On the whole, the FTA method not only can link the relevant factors of system failure analysis, but also can find the system fault spectrum and weak links easily. What's more, the system failure probability and other reliability parameters can be determined quantitatively in order to provide quantitative data to assess and improve the reliability of system. The basic steps of FTA method are shown in Figure1.
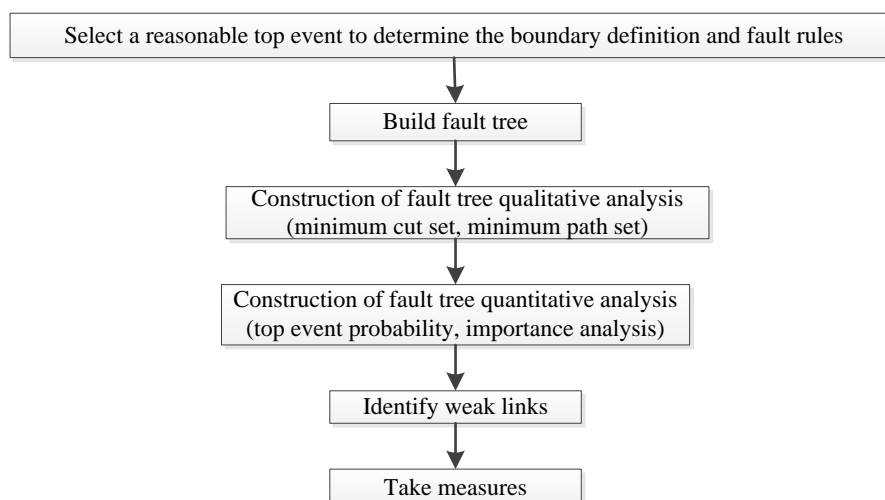
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┌─────────────────────────────────────────────────────────────────────┐
│   Select a reasonable top event to determine the boundary definition and fault rules   │
└─────────────────────────────────────────────────────────────────────┘
                                    │
                                    ▼
                    ┌───────────────────────────┐
                    │      Build fault tree      │
                    └───────────────────────────┘
                                    │
                                    ▼
            ┌───────────────────────────────────────────┐
            │   Construction of fault tree qualitative analysis   │
            │      (minimum cut set, minimum path set)    │
            └───────────────────────────────────────────┘
                                    │
                                    ▼
            ┌───────────────────────────────────────────┐
            │  Construction of fault tree quantitative analysis  │
            │    (top event probability, importance analysis)   │
            └───────────────────────────────────────────┘
                                    │
                                    ▼
                    ┌───────────────────────────┐
                    │     Identify weak links    │
                    └───────────────────────────┘
                                    │
                                    ▼
                    ┌───────────────────────────┐
                    │        Take measures       │
                    └───────────────────────────┘
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Figure 1. The basic steps of FTA method

5. The case study of PPP project

5.1. Project Overview

Yinxiang River Cultural Tourism Zone is located in the south of Shigu Town, Weibin District, Baoji City, Shaanxi Province. It has a total planned area of 67 square kilometers. Additionally, the planning area about the first centralized control area of Yinxiang River (hereinafter referred to as "Yinxiang river treatment area") is 9 square kilometers, of which construction area is 758 acres. Yinxiang river control area of 9 square kilometers is the scope of project. On the whole, the construction of project is divided into three parts, including infrastructure and public facilities construction (about RMB 1.272 billion), franchise facilities construction (about RMB 116 million), land acquisition and resettlement house construction (about RMB 1.141 billion). In addition, the initial investment is estimated about RMB 2.529 billion and its total construction period is 5 years. Besides, the project is started in 2016 and should be put into use in 2020.

5.2. The identification and analysis of project risk factors

Based on the long-term stability of cooperative relation between government and private investors, taking the risk management ability, project return mechanism and market risk management ability into account, it should be allocated the risk reasonably between government and social investors.

Firstly, due to land acquisition and demolition, the residents of resettlement, and archaeological heritage protection risk in the development process, the government departments is responsible for pre-formalities and administrative approval risks for the construction projects.

Secondly, the private investors are mainly responsible for operation risk and financial risks of the project, such as rising interest rates or financing costs, broken capital chain, construction timing less than expected, insufficient operating income and other risks.

Finally, the risk of force majeure should be shared by the two parties. At the same time, policy and legal risks, which is beyond the scope of government controllable legal changes and policy changes risk, should be shared by the two parties as well.

5.3. The construction of fault tree

There are many risks in PPP project. In the process of risk identification, the risk factors of whole system can be identified and decomposed one by one on the basis of project cycle, so that the network analysis and calculation can be carried out smoothly. And then, the risk factors that can be eliminated by general measures should be removed. According to the basic idea and principle of fault tree rendering, a part of the fault tree is shown in Figure 2. Especially, the fault tree consists of 13

intermediate events, 23 basic events, 8 logical OR gates and 6 logical AND gates in table 2. Based on the above risk estimation results, the risk of Yinxiang River PPP project was analyzed with Free FTA software in the project preparation phase.
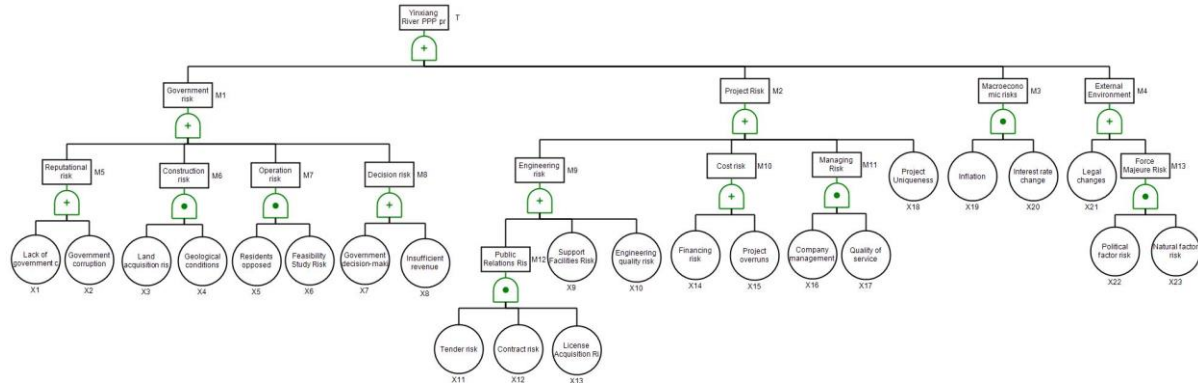

Figure 2. The fault tree analysis of PPP project for Yinxiang River

Table 2. The event table of PPP project for Yinxiang River

Notation	The event name	Notation	The event name
T	Yinxiang River PPP project failure	X_6	Feasibility study risk
M_1	Government risks	X_7	Decision-making mistakes
M_2	Project risks	X_8	Insufficient revenue
M_3	Macroeconomic risks	X_9	Supporting facilities
M_4	External environmental risks	X_{10}	Project quality problem
M_5	Reputational risk	X_{11}	Tender risk
M_6	Construction risk	X_{12}	Contract risk
M_7	Operational risk	X_{13}	License acquisition risk
M_8	Decision risk	X_{14}	Financing risk
M_9	Engineering risk	X_{15}	Project overruns
M_{10}	Financial risk	X_{16}	Company management risk
M_{11}	Managing risk	X_{17}	Quality of service
M_{12}	Public relations risk	X_{18}	Project uniqueness risk
M_{13}	Force majeure risk	X_{19}	Inflation
X_1	Lack of government credit	X_{20}	Interest rate change
X_2	Government corruption	X_{21}	Legal changes
X_3	Land acquisition risk	X_{22}	Political factor risk
X_4	Geological risk	X_{23}	Natural factor risk
X_5	Residents opposed		

5.4. Qualitative analysis of fault tree

5.4.1. Minimum cut sets. A cut set is a subset of the set that satisfies the following conditions in the bottom events of fault tree:

The subset is assumed to be $\{X_{i1}, X_{i2}, X_{i3}, ..., X_{ik}\}$, i = 1,2,…,K (K is the number of cut sets), and the top event T must occur when all the bottom events contained in the subset are occurred. However, if

the cut set that contains the bottom event is arbitrarily removed so that it does not become cut sets, namely, such cut set is a minimum cut set.

According to the fault tree, the minimum cut set can be obtained by Boolean algebra method.

$$T = M_1 + M_2 + M_3 + M_4$$
$$= M_5 + M_6 + M_7 + M_8 + M_9 + M_{10} + M_{11} + X_{18} + X_{19} + X_{20} + M_{13} + X_{21}$$
$$= X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_9 X_{10} M_{12} + X_{14} + X_{15} + X_{16}$$
$$+ X_{17} + X_{18} + X_{19} + X_{20} + X_{21} + X_{21} M_{13}$$
$$= X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_9 X_{10} X_{11} + X_9 X_{10} X_{12}$$
$$+ X_9 X_{10} X_{13} + ... + X_{14} + X_{15} + X_{16} + X_{17} + X_{18} + X_{19} + X_{20} + X_{21} + X_{21} X_{22} + X_{21} X_{23}$$

From the above results, we can get the conclusion that the top event is the union of n = 94 intersection, which is the minimum cut set of the fault tree, corresponding to the 23 fault occurrence patterns of the top event.

5.4.2. Minimum path set. The minimum path set of the fault tree is solved by the method to find the minimum cut set of the dual tree. Moreover, the minimum path set is solved by using the properties of dual system. There are three minimum path sets in the fault tree, and there are three paths in which the top event does not occur. Therefore, three kinds of processing schemes can be developed to make ensure that the top event does not occur.

5.4.3. The structure importance of the bottom event. The magnitude of importance about element is called the structural importance of element in the fault tree structure. Beside, the structural importance is independent of the probability about element. The formula is

$$I_{\phi(i)} = 1 - \prod_{x_i \in k_j} \left[1 - \frac{1}{2^{N_j} - 1} \right] \qquad (1)$$

Where, k_j is j the minimum cut set; $N_j (j \in k_j)$ is the bottom event i that at the bottom event of the minimum cutset k_j; for the bottom event i, $x_i \in k_j$ is the smallest cutset j; and then, $I_{\phi(i)}$ is the structural importance coefficient for the bottom event i.

The minimum cut set of the fault tree about PPP project failure has been determined, then the structural importance coefficient of the bottom event can be calculated according to Equation. (1). Besides, the importance of the structure is also calculated. And then, it can be sorted according to the size of coefficient about the structure importance. The coefficient is greater, the top event has a greater impact on the bottom event .

The structural importance of calculation results is:
$$I(X_{21}) = I(X_{18}) = I(X_{15}) = I(X_{14}) = I(X_{10}) = I(X_9) = I(X_8) = I(X_7) = I(X_2) = I(X_1) >$$
$$I(X_{23}) = I(X_{22}) = I(X_{20}) = I(X_{19}) = I(X_{17}) = I(X_{16}) = I(X_6) = I(X_5) = I(X_4) = I(X_3) >$$
$$I(X_{13}) = I(X_{12}) = I(X_{11})$$

The fault tree is composed of 23 bottom events. By analyzing the importance degree of the bottom event structure, we can find the bottom events clearly, which are more important in the system. Additionally, we can conclude that the structural importance values of X_1, X_2, X_7, X_8, X_9, X_{10}, X_{14}, X_{15}, X_{18} and X_{21} are equal by analyzing its distribution results. Thus, these bottom events have the greatest impact on the top event. The structural importance of X_3, X_4, X_5, X_6, X_{16}, X_{17}, X_{19}, X_{20}, X_{22}, X_{23} is greater, so these events have a greater impact on the top event. Therefore, it's necessary to strengthen the early warning and management of risk in M_1, M_2 and M_4 so as to avoid the maximum risk in the preparatory stage of PPP project.

5.5. Quantitative analysis of fault tree

5.5.1. The probability of the bottom event. Based on the collected cases to estimate the occurrence

probability of the bottom events, the risks of PPP projects are decomposed into the event levels, and then the probability of the bottom events is calculated[16]. According to the calculation results, it can be concluded that the occurrence probability of the largest is $X_8 = 0.1600$, $X_3 = X_5 = X_9 = 0.0500$, and the smallest is $X_1 = X_2 = X_4 = X_{21} = X_{22} = X_{23} = 0.0010$ in the 23 base events.

5.5.2 The probability of the top event. The occurrence probability of fault tree, whose the top event is P (T) = 0.2378, is calculated by using the "down method". According to the calculation of intermediate event and top event probability, we can get the conclusion that the first level intermediate event, which has the greatest impact on the top event, is M_1 (the sum of occurrence probability about "government risk" is 0.2800). In addition, the second-floor event with the greatest impact on M_1 is X_2 ("government decision error" occurs with a probability of 0.0314). Therefore, it is necessary to be controlled to "OR" connection the events with high occurrence probability. Furthermore, reducing the occurrence probability of the top event is possible, which can be controlled the bottom event about X_3 (lack of government credit), X_6 (project non-uniqueness), X_{10} (insufficient market return) and X_{11} (market demand change).

5.5.3 The probabilistic importance of the bottom event. Based on the probability importance analysis of the bottom events, we can see that the probability of X_8 (income insufficiency) and X_9 (supporting facility risk) is the largest. When the above 23 bottom events occur, they have the greatest impact on the top event. At the same time, these bottom events are connected with the top event by "OR gate". Consequently, the change of probability about the bottom event has great influence on the top event. Therefore, the risk warning should be taken into account seriously to ensure that the occurrence probability of the top event is the least during the project implementation. However, the bottom event for "AND" connection is exactly opposite. The higher the probability of the bottom event, the lower the importance of probability. Therefore, it should focus on the occurrence probability of the smallest "AND" connection bottom event so as to avoid the top event effectively.

As the occurrence probability of the top event about Yinxiang River PPP project is large, the probability of adjustment event is P (T) = 0.1347. Table 3 shows the probability of improved bottom event and its importance ranking.

Table 3. The Ranking of Probabilistic Importance for the bottom Event

Bottom event notation	Probability importance	Bottom event notation	Probability importance
X_8	0.9615000	X_4	0.0087000
X_9	0.8741000	X_{19}	0.0026000
X_{14}	0.8723000	X_{20}	0.0024000
X_{15}	0.8723000	X_{16}	0.0009000
X_{10}	0.8697000	X_{17}	0.0009000
X_{18}	0.8697000	X_{22}	0.0009000
X_7	0.8662000	X_{23}	0.0009000
X_{21}	0.8662000	X_3	0.0004000
X_1	0.8658000	X_{11}	0.0000009
X_2	0.8657000	X_{12}	0.0000009
X_5	0.0104000	X_{13}	0.0000009
X_6	0.0087000		

5.5.4. The ratio of income to investment. To reduce the occurrence probability of risk events, namely, is to reduce the incidence of the top events in the Yinxiang River PPP project, then the relative

reduction in the probability of the top event is income. Hence, the ratio of income to investment is:

$$r = \frac{|\Delta Q / Q|}{investment}$$

(2)

In the equation, Q is probability of the top event, which is the difference about occurrence probability between the improved top event and the original top event [15].

According to the analysis, it can be seen that the probability importance and structure importance of X_8 (income insufficiency) is large. After the fault tree risk controlling, the probability decreases from 0.1600 to 0.1200. In brief, the probability of the improved top event is 0.1347, and the probability of the initial event is 0.2378. Besides, the initial estimate of investment is about 2.529 RMB billion, which is calculated by equation (2):

$$r = \frac{(0.2378 - 0.1347) / 0.1347}{25.29} = 0.0172$$

That is, compared to the original probability of X_8, the risk is reduced.

In short, on the basis of the existing cases, the mean value method was used to analyze the two important degrees of the bottom events comprehensively. To sort the importance of event, the conclusions can be drawn that the bottom events that have the greatest impact on the top events are X_8, X_9, X_{10}, X_{14}, X_{15}, X_{18}, which have higher probability and structure importance, that is, insufficient government revenue, supporting facilities, engineering quality problems and project unique risks have a great impact on Yinxiang River PPP project. Therefore, the necessary measures should be taken to reduce the probability of occurrence.

6. Control measures for risk management of PPP project

The basic principle of risk control measures about Yinxiang River PPP project is taken as the project risk contingency plan, which can reduce the adverse impact of the risk effectively on the project, so as to decrease the basic risk events fundamentally. Table 4 shows that probability of the bottom event and risk control measures for risk reduction of Yinxiang River PPP project.

Table 4. The risk-controlling measures of PPP Project for Yinxiang River

Bottom event notation	Risk control measures
X_1、X_2、X_4	Establish supervisal mechanism, sign the government default agreement, and strengthen geological survey in the early stage of project
X_3、X_5、X_9	Soothe emotions and give a certain amount of subsidy policy, and do a good job overall scheduling equipment
X_6	Increase expert assessment efforts
X_8	Increase the fee items
X_{10}	Control the quality of critical project review strictly
X_7、X_{11}、X_{12}、X_{13}	Grasp the macroeconomic factors, study the government documents in detail and maintain good public relations
X_{14}、X_{15}	Plan the project funds rationally, and control the expenditure strictly
X_{16}、X_{17}	Strengthen the management level of private investors and establish detailed rules and regulations
X_{18}	Sign liquidated damages agreement
X_{19}、X_{20}	Reserve profit margins

7. Conclusion

In this paper, the risk of PPP project is taken as the research object, and then the risk identification is

carried out though building the fault tree in the preparation stage. Moreover, the four types of risk sharing are also confirmed. At the same time, the risk factors of different subjects are evaluated on the basis of risk identification, and the degree of risk influence is quantified to determine the importance order of risk factors, which have an influence on PPP project in the preparation stage. These results point out that the accuracy of government decision-making, the rationality of private investors' fund allocation and the instability of market return are the main factors that generate the shared risk about project. Secondly, the risk of project incompletion, insufficient facilities, financing and projects non-uniqueness, to some extent, will hinder the smooth implementation of PPP projects and there is a great deal of uncertainty. Finally, external environmental factors, such as legal change and force majeure risk, are less likely to occur in the preparation phase of PPP project.

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