Research on the risk of Metro PPP projects based on DEMATEL-ANP

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ABSTRACT: The risk of metro PPP project has the characteristics of complexity and diversity, and the introduction of social capital in the project further aggravates the complexity of metro PPP project. Based on the particularity of metro PPP projects, this paper identifies 27 indicators suitable for the risk research of such projects; the internal relationship between risk indicators is established by using Decision Making Trial and Evaluation Laboratory (DEMATEL), the weight of risk indicators is determined by using analytic network process (ANP), and a risk research model based on ANP is proposed; the risk of metro PPP project is realized according to typical case. The results show that policy is the indicator with both the highest centrality and influence, while geological conditions is the indicator with the highest causality, and the most easily affected factor is construction cost; construction cost and project overdue are the most important indicators among the 27 indicators.

1. INSTRUCTION

According to statistics, in 2022, the national general public budget revenue was 20,470.3billion yuan, and the national general public budget expenditure was 26,060.9 billion yuan. Among them, with the implementation of "The Belt and Road Initiative" strategy, the proportion of transportation infrastructure project expenditure in general public budget expenditure increased by 22.3% year-on-year, to 676.6 billion yuan, accounting for 5.48%, which brought some pressure to the national finance. PPP (Public-Private Partnership) model can make full use of social capital to participate in the public service field, and escort the smooth implementation of the project [1]. Different from western developed countries, the main force of social capital of PPP projects in China is state-owned enterprises. According to statistics, as of August 2020, the turnover of PPP projects with social capital of central enterprises or local state-owned enterprises accounted for 74.75% of the total turnover of PPP projects, especially the PPP projects of transportation infrastructure, which have the characteristics of large investment and long construction period. The PPP model has the characteristics of numerous project participants and difficult financing, so the risk research of metro PPP projects is particularly important.

How to reasonably manage the risks of metro PPP projects is the most important task for project managers to prevent risks [2]. Li Jinghua and Li Qiming, 2007 discussed the economic risks of the Beijing Metro Line 4 are analyzed in detail [3]. Yin Yilin and Yin Xiaolu, 2013 divided the risk of Beijing Metro Line 4 into five main types: political risk, economic risk, environmental risk, construction risk and operation risk, and analyzed the difficulties and basic procedures of risk sharing of Beijing Metro Line 4, get the results of risk sharing, and conduct quantitative analysis and verification [4]. Zhou Shengshi et al. 2019 analyanalyzed the risks and causes restricting the implementation of subway PPP projects from three aspects of the government, the contractor and the banking institution, by establishing the multi-party dynamic game sharing model, the multi-subject risk sharing structure combination is selected on the basis of the risk-return theory [5]. Cui Xiaoyan et al. 2019 explained the main risks facing the project, including credit risks, construction risks, income risks, uncontrollable risks, legal policies, approval and decision-making risks, based on Qingdao Metro Line 1 project [6].

At present, scholars at home and abroad are rich in PPP project risk research methods, mainly including AHP (Analytic Hierchy process), fuzzy integral, system dynamics, BP (BackPropa-gation), neural network and other methods. Zhao Hui and Wang Xueqing, 2010 improved BP neural network based on genetic algorithm, and applied it to the financing risk research of expressway PPP project [7]. Among the above research methods, except system dynamics, the interaction between risks is not studied from the perspective of system, so the construction of system dynamics model is rough [8].

Based on the related literature, this paper gives full play to the advantages of DEMATEL, and then determines the index weight by ANP method, and puts forward a risk research model based on ANP. Then, using the above model, the risk assessment of PPP project of Hohhot metro is carried out, which provides a basis for risk management of metro PPP project.

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2. OVERVIEW OF PPP MODE

2.1. Definition of PPP mode

PPP is a project mode in which the public sector and the private sector jointly invest in infrastructure and public goods or services. So far, the PPP model has not yet formed a unified and clear definition. There are many PPP models in the world. The earliest thought is that public-private partnership refers to the government, enterprises, the third sector and individual citizens. In pursuit of social needs, scholars and institutions of the World Bank, Asian Development Bank and the United Nations Institute for Training and Research have put forward various PPP models, each with its own characteristics.

2.2. Advantages of PPP mode

PPP model introduces the market mechanism into the investment and financing of infrastructure and public goods or services, and has many unique advantages. Not all urban infrastructure projects can be commercialized. The government doesn't think that operating infrastructure through the market mechanism is the same as withdrawing from all investment fields. In the process of infrastructure marketization, the government must continue to invest a certain amount of money in infrastructure. For the government, the investment in PPP projects is smaller than that in the past, and the difference between them is the income of the government adopting PPP [9].

2.3. Application areas of PPP mode

According to the notice of the Ministry of Finance, the PPP mode is applicable to infrastructure and public service projects with large investment scale, long-term stable demand, flexible price adjustment mechanism and high degree of marketization [10]. Relevant departments at all levels should give priority to projects with stable cash flow and transparent price mechanism. At present, PPP projects promoted by the Ministry of Finance are more inclined to operate projects [11].

According to the National Development and Reform Commission's "Guidelines for Cooperation between Government and Social Capital" No. 20182524, the PPP model is mainly applicable to public service and infrastructure projects in charge of the government, and is suitable for market-oriented operation. Municipal facilities, transportation facilities such as roads, railways, airports and urban rail transit, public service projects, and water conservancy projects can implement PPP mode of resource, environment and ecological protection [12]. For new municipal projects and new urbanization pilot projects in various regions, priority should be given to the construction of PPP mode.

3. CONSTRUCTION OF RISK INDEX SYSTEM FOR METRO PPP PROJECT

Compared with the general infrastructure projects, the metro projects themselves have the characteristics of large upfront investment, complex technology and long project time span. metro PPP projects are also faced with potential risks brought by PPP mode.

According to the characteristics of metro PPP projects, combined with literature review, through expert discussion, this paper preliminarily determined 36 indicators suitable for metro PPP project risk research, discriminated the probability and impact of risks, and determined 27 indicators for metro PPP project risk research. It can be seen that the introduction of PPP mode makes metro projects face more political and legal, markets, construction, operational and natural risks.

In the research, based on the index division of Xie 2020 [13], fully combined with the characteristics of the research index, the risk index system of metro PPP project risk is constructed, as shown in Table 1.

Table 1. Risk index system of Metro PPP project.

R1	Political and Legal Risks	R2	Market Risk	R3	Construction Risk	R4	Operational Risk	R5	Natural Risk
R11	Project approval	R21	Inflation	R31	Project quality	R41	Operating cost	R51	Geological conditions
R12	Government credit	R22	Interest rate	R32	Engineering change	R42	Insufficient operating income	R52	Climatic conditions
R13	Corruption	R23	Market demand	R33	Construction cost	R43	Charge change	R53	Force majeure
R14	Policy	R24	Pricing	R34	Project overdue	R44	Operation safety		
R15	Contract document	R25	Market competition	R35	Supporting facilities	R45	Operational management		
R16	Taxation			R36	Construction safety	R46	Project residual value		
				R37	Construction technique				

4. RISK RESEARCH MODEL OF METRO PPP PROJECT

4.1. DEMATEL model

DEMATEL model was first proposed by scholars Gabus and Fon-tela to solve complex problems. It is a method of factor analysis based on matrix and the graph theory. Through the relationship and direct influence matrix of each factor in the system, we can judge the influence degree and influence degree of each factor, thus judging the importance of each factor, The specific steps are as follows:

(1) Analyze the correlation degree of risk indicators of 27 identified metro PPP projects, and determine the direct relationship matrix M of risk indicators.

(2) The matrix of direct influence relation is unified, and then the direct influence matrix D is obtained.

$$D = M/K \quad (1)$$

(3) On the basis of matrix D, the comprehensive influence matrix T is calculated.

$$T = D\,(I\ - D) - 1 \quad (2)$$

(4) Determine the model threshold λ. In this paper, the valve value is taken as the average value to determine the dependence and the feedback relationship between risk indicators, and the NRM (Network Relationship Model) and the causality diagram are constructed [15].

(5) $\lambda = \mu T$ (3)

In the formula: μT represents the average of values in the comprehensive influence matrix T.

4.2. ANP model

The ANP model is put forward by Professor Saaty. AHP overcomes the boundaries such as the independence of elements in the model and the absence of feedback, and increases the comparison of indirect advantages among elements, making it suitable for the interaction among elements in complex environments. The specific steps are as follows [14]:

(1) according to the internal relationship of risk indicators in DEMATEL model, the ANP network hierarchy of risk indicators for metro PPP projects is determined.

(2) Calculate the unweighted hypermatrix W. Let the column vectors in the matrix (Wij) respectively correspond to the influence degree of Cj on Ci in the control layer, then W is:

$$W = \begin{matrix} W11\ W12\ \ldots\ W1N \\ W21\ W22\ \ldots\ W2N \\ WN1\ WN2\ \ldots\ WNN \end{matrix} \quad (4)$$

(3) Calculate the weighting matrix U, whose element u_{ij} is the weight.

(4) Calculate the weighted hypermatrix W.

$$W = (W_{ij}) \quad (5)$$

$$W_{ij} = u_{ij} \times W_{ij} \quad (6)$$

Where: i = 1,2,…N; j = 1,2,…N.

(5) Calculate the limit hypermatrix W∞.

$$W\infty = \lim t\to\infty (W)t \quad (7)$$

5. EMPIRICAL ANALYSIS.

On the basis of the risk research index system and ANP risk research model constructed in the previous part, taking the Hohhot Metro PPP project as an example, this paper makes a risk study on it.

5.1. Determine the impact of risk indicators.

By analyzing the internal relations of risk indicators, the correlation matrix of risk evaluation indicators was obtained by using the five-level scale 0,1,2,3,4, and the scores of experts. Then, according to the DEMATEL method, the comprehensive impact matrix T is obtained, as shown in table 2, the degree of centrality and cause of risks is shown in figure1, the degree of influence-influenced of risks is shown in figure2.

Table 2 the comprehensive impact matrix T of the first-level risk indicators.

	R1	R2	R3	R4	R5
R1	0.057805	0.044084	0.090909	0.100654	0.225535
R2	0.070594	0.288655	0.000000	0.225535	0.000000
R3	0.608345	0.565765	0.454545	0.000000	0.673811
R4	0.263256	0.101496	0.454545	0.673811	0.100654
R5	0.000000	0.000000	0.000000	0.000000	0.000000

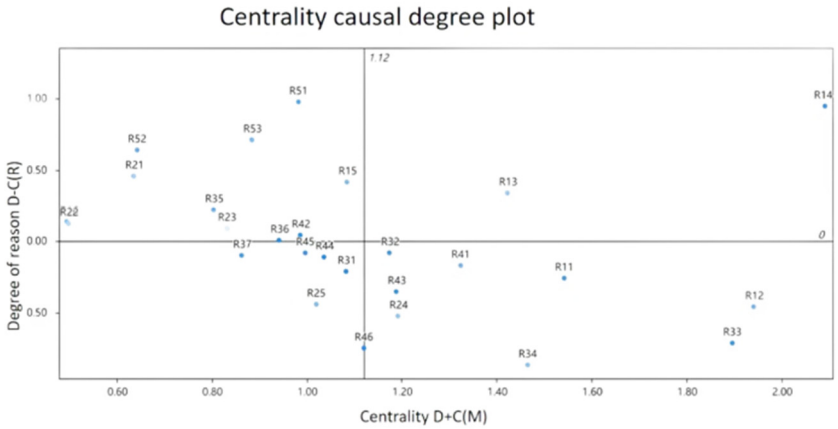

Figure1 the degree of centrality and cause of risks

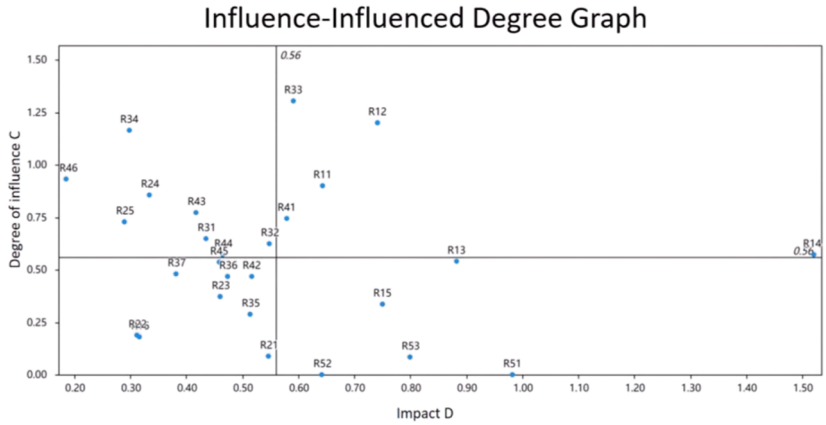

Figure2 the degree of influence-influenced of risks

5.2. Calculate the weight of risk indicators

Based on ANP method, ANP model is determined by DEMATEL according to the relationship structure, as shown in Figure 3. Firstly, the risk indicators are compared. According to the relationship between the risk indicators, different comparison matrices can be formed. Table 3 to Table 7 shows the comparison of related risk indicators based on R1 to R5 respectively. Secondly, all secondary risk indicators in each major risk indicators are paired and compared. In addition, it is necessary to check its consistency during the whole calculation process. The specific consistency CR is a measure of consistency. When Cr≤0.10, it has strong consistency. In this study, Cr is less than 0.10, which meets the requirements.

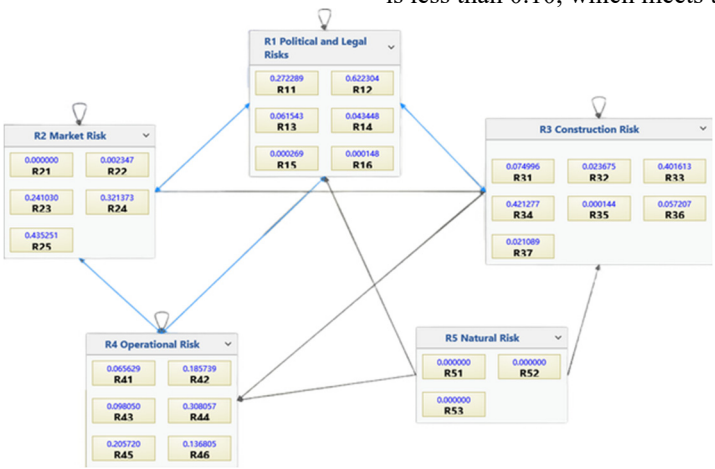

Figure3 the ANP model

Through further analysis of various risk indicators, it can be seen from Table 3 that R3 is the most important index under R1 with weight of 0.61; in Table 4, R3 is still the most important index under R2 with weight of 0.57; in Table 5, R4 is the most important index under R3 with weight of 0.45, beside itself; in Table 6, R4 itself is the most important index under R4 with weight of 0.67; and in Table 7, R3 is still the most important index under R5 with weight of 0.67.

Table 3 R1 Judgment Matrix of Level 1 risk indicators under Criteria

	R1	R2	R3	R4	Weight
R1	1	1	1/8	1/7	0.06
R2	1	1	1/6	1/4	0.07
R3	8	6	1	4	0.61
R4	7	4	1/4	1	0.26
CR: 0.07; λmax: 4.19					

Table 4 R2 Judgment Matrix of Level 1 risk indicators under Criteria

	R1	R2	R3	R4	Weight
R1	1	1/7	1/9	1/3	0.04
R2	7	1	1/3	4	0.29
R3	9	3	1	5	0.57
R4	3	1/4	1/5	1	0.10
CR: 0.05; λmax: 4.13					

Table 5 R3 Judgment Matrix of Level 1 risk indicators under Criteria

	R1	R3	R4	Weight
R1	1	1/5	1/5	0.09
R3	5	1	1	0.45
R4	5	1	1	0.45
CR: 0; λmax: 3.0				

Table 6 R4 Judgment Matrix of Level 1 risk indicators under Criteria

	R1	R2	R4	Weight
R1	1	1/3	1/5	0.10
R2	3	1	1/4	0.23
R4	5	4	1	0.67
CR: 0.08; λmax: 3.09				

Table 7 R5 Judgment Matrix of Level 1 risk indicators under Criteria

	R1	R3	R4	Weight
R1	1	1/4	3	0.23
R3	4	1	5	0.67
R4	1/3	1/5	1	0.10
CR: 0.08; λmax: 3.09				

The limit hyper-matrix is obtained by calculating the risk research index matrix. And output the final risk research index weight ranking through Super Decision software (Table 8).

Table 8 Weight of risk indicators

Indicator	Weight	Accumulative Weight
R11	0.031031	0.031031
R12	0.070919	0.10195
R13	0.007014	0.108964
R14	0.004951	0.113915
R15	0.000031	0.113946
R16	0.000017	0.113963
R21	0.000000	0.113963
R22	0.000070	0.114033
R23	0.007179	0.121212
R24	0.009572	0.130784
R25	0.012964	0.143748
R31	0.056014	0.199762
R32	0.017683	0.217445
R33	0.299964	0.517409
R34	0.314651	0.83206
R35	0.000107	0.832167
R36	0.042728	0.874895
R37	0.015751	0.890646
R41	0.007177	0.897823
R42	0.020311	0.918134
R43	0.010722	0.928856
R44	0.033687	0.962543
R45	0.022496	0.985039
R46	0.014960	0.999999

5.3. Analysis of results

DEMATEL analysis shows that policy is the indicator with both the highest centrality and influence, while geological conditions is the indicator with the highest

causality, and the most easily affected factor is construction cost.

According to ANP analysis, construction cost and project overdue are the most important indicators. Therefore, in order to successfully manage risks, participants in metro PPP projects must combine the characteristics of indicators and the weight of indicators to prevent risks.

6. CONCLUSION

As the important position of metro PPP project in PPP field and the complex risks of the project itself, it is necessary to discuss the major risks faced in every stage of the project. According to literature, this study determines 27 risk indicators of metro PPP projects from five aspects. Taking the Hohhot Metro PPP project as an example, this paper puts forward a proposal that DEMATEL method is used to establish the internal relations among the risk indicators, ANP method is used to determine the weights, and ANP risk research model is used to study the risks.

The research shows that ANP method can provide managers with two effective types of information: the causal relationship between risk indicators and the weight of risk indicators. Causality summarizes the influence of risk indicators, the degree of influence and influenced. The weight of the risk indicators reflects the important risks that should be dealt with in the risk management of metro PPP projects.

As a scientific and effective method to promote new risk research, ANP will help project decision makers to fully and clearly understand the internal relationship between research indicators and the importance of risk indicators, and ensure the effective supply of resources. It is beneficial to project risk managers to make an appropriate response to potential risks of the project, and avoid or reduce the occurrence level of related risks. This is very important for the risk management of metro PPP projects.

FUNDINGS

This work was sponsored in part by Research Program of science and technology at Universities of Inner Mongolia Autonomous Region（NJSY21159）and 2021 Innovation Launch Support Program for Students Returning From Overseas Study of Inner Mongolia Autonomous Region (15).

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