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The control mode study of PPP project financing management information system

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Abstract
In recent years, public–private partnership (PPP) mode has been developed greatly in China's infrastructure and public services, which can effectively solve the financial difficulties of local governments. This article selects the residual value risk (RVR) as an important index in the risk control of PPP project and constructs and verifies the pre-optimization method of RVR. A method is presented to control and optimize RVR before the risk occurs. The vulnerability as the breakthrough point of RVR beforehand control through DRCM sensitivity analysis is carried out on the effect of the beforehand control of RVR; then, using the optimal control theory to design RVR beforehand control of optimization process, the correctness and validity of the method are verified by an example.

Keywords The PPP project · Financing management · The information system

1 Introduction

Public–private partnership (PPP) projects, namely government and social capital cooperation. The Treasury defines it as: "In the field of infrastructure and public services, government and social capital to establish a cooperative relationship based on contract, aims to use market mechanism to allocate risk, the supply of public products and services to improve the quantity, quality and efficiency" (Bodiako et al. 2017; Cui et al. 2018; Tariq and Zhang 2020). Specifically, the PPP model as Build–Operate–Transfer (BOT), Build–Own–Operate (BOO), Build–Lease–Operate–Transfer (BLOT), Design–Build–Operate (DBO), Transfer–Operate–Transfer (TOT) and Private–Finance–Initiative (PFI), and a series of specific financing model of the overall concept. It represents the social capital and the government different degree and different ways of cooperation and focuses on the introduction of social capital investment—construction—operation in infrastructure projects, emphasis on a "win–win" situation of mutual benefit. Its applications range from traditional industries such as roads, bridges, rail transit, gas, water supply, sewage treatment and garbage collection to prisons, schools, hospitals, defense, aerospace and other fields (Xu and Bureau 2016). The earliest application of PPP in China is the BOT project of *Shenzhen Shajiao B power plant*, and its successful experience has made it a preliminary recognition in China. Subsequently, PPP mode has been tried in various fields, and its specific content is also promoted to TOT, BOO, BOOT and other forms. But it is still concentrated in areas such as toll roads, water utilities, urban gas and waste disposal (Min-Rong et al. 2017; Cheng et al. 2021; Zhang 2019; Li et al. 2019). With the acceleration of urbanization in China, the demand for infrastructure in cities is increasing, and local governments are facing huge financial pressure in infrastructure investment and financing (Wei 2016). At the same time, the state council's opinion on strengthening the management of local government debt issued by the state council in 2014 made it clear that: *Strengthen the government or the debt supervision, divest the financing function of the financing platform company, and bring the stock debt into the budget management*. Therefore, local government in China is facing huge pressure, and the financial situation is not optimistic. Strengthen the regulation of the government contingent liabilities, stripping the financing platform company

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government financing function, the stock of debt should be brought into the budget management“. With PPP mode to introduce social capital into infrastructure construction and operation has become an inevitable trend (Tang et al. 2015; Maier et al. 2021; Geng et al. 2020).

Traditional project financing mainly includes direct financing, project company financing, leveraged lease financing, facility use agreement financing, product payment financing, etc., with the continuous development of project financing theoretical research and practical application; a series of new project financing methods have emerged. PPP emphasizes the complementarity of advantages, risk sharing and benefit sharing. The BOOT project company has both management right and ownership. The government allows the project company to mortgage the project assets to the bank for financing purposes within a certain range and period of time, so as to obtain more favorable loan conditions, so as to reduce the product/service price of the project. The PPP model is mainly used in the construction of public infrastructure (Zhang et al. 2019). The implementation of PPP projects in the financial management system can solve the shortcomings of low financing efficiency of government departments in organizing the construction of social public infrastructure. At the same time, compared with the traditional single management mode, the PPP mode can effectively save costs. This paper uses surplus value as an evaluation index, constructs and validates the pre-optimization method of surplus value risk and conducts the optimization process of RVR pre-control based on DRCM sensitivity analysis.

2 State of the art

At present, there is not much research on the residual risk of PPP projects at home and abroad. Some scholars only mention the concept of residual value risk in the PPP literature. The scholars point out that the value of the residual risk of PPP project depends on the value of the project assets at the end of the franchise period. Whether the residual risk can be controlled well depends on whether there is a competitive market. They study the risk sharing of PPP/PFI project in the UK and define the residual risk as intermediate level risk (Zhou 2017). Some scholars describe the risk of residual value as: In the contract period of PPP project, due to poor management, the risk of residual value may occur, which is subordinate to the risk of asset ownership. The scholars mentioned that the asset salvage value stipulated in the final project contract may not be consistent with the market value of the asset, so the government of the asset owner should bear the risk of asset impairment (Srivastava 2017). Scholars attributed the reasons why some countries have not yet begun to apply PPP mechanisms to social infrastructures into three categories: the lack of clear legislation, uncertainty of risk allocation and financial feasibility. And aims to identify the risk allocation for the development of a public school in Colombia by interviews with experts from the academia, public sector and private sector (Sastoque et al. 2016). An ontology-based approach is proposed to analyze the RVR in PPPs, which is a framework addressing the vulnerability and a knowledge-based modeling for RVR management. The RVR ontology model is composed of class of project, risk, and vulnerability, as well as taxonomy of risk factors for risk sources (RS), risk events (RE), risk consequences (RC), exposure (V1), resilience (V2) and sensitivity (V3). Meanwhile, different relationships among taxonomies, classes and individuals are expressed in model (Yuan et al. 2018).

In addition, some scholars have conducted targeted researches on the residual risk of PPP projects, mainly focusing on the concept, connotation, identification and evaluation of residual risk. Through the literature research, the definition and connotation of the residual value risk of PPP project are defined, and some suggestions are put forward by analyzing the standard contract model of the existing PPP model at home and abroad.

3 Methodology

3.1 Structural equation model

Some scholars have proposed the residual risk path model of PPP project including risk source, risk event and risk result and further studied the connotation of residual value risk of PPP project. On the basis of analyzing the connotation of residual value, the evaluation model of residual value risk of PPP project was constructed by Bayesian network (Lu and Wang 2016). Through investigation and analysis, the connotation and influencing factors of residual value risk of PPP project are analyzed, and the evaluation model of residual value risk is constructed by using the structural equation model. The structural equation model (SEM) is a very general linear statistical modeling method. It integrates the multiple regression analysis, path analysis, simultaneous equation and confirmatory factor analysis and other statistical techniques that can use statistical hypothesis test of the method, analyzed about the phenomena of inner structure theory. The variables involved in SEM can be divided into two categories: explicit and latent variables. Explicit variables are variables that can be directly observed and measured, and also called observed variables; a latent variable is a variable that cannot be observed directly, but it can be measured indirectly by an explicit variable. From the angle of variable generation, the variables of SEM can be divided into exogenous variables and endogenous variables. Exogenous variables are not affected by other variables in the model, which is equivalent to the concept of independent variables. The endogenous variables are affected by other variables in the model, which are equivalent to the concept of dependent variables. To sum up, SEM has four variables: exogenous explicit variables, endogenous explicit variables, exogenous latent variables and endogenous latent variables. From the model structure, SEM can be divided into two parts: measurement equation and structural equation. The measurement equation is used to describe the relationship between explicit and latent variables, usually as follows:

$$X = \Lambda_x \xi + \delta \quad (1)$$

$$Y = \Lambda_x \eta + \varepsilon \quad (2)$$

In the formula, X is the vector of exogenous explicit variables; Y is the vector of endogenous explicit variables; Λ_x is the factor loading matrix of exogenous variables on exogenous latent variables; and Λ_y is the factor loading matrix on the endogenous variables. δ is the error term of exogenous variable X, and ε is the error term for the endogenous explicit variable Y. The structural equation mainly describes the relationship between latent variables and is usually expressed as follows:

$$\eta = B\eta + \Gamma\xi + \zeta \quad (3)$$

In the formula, η is the endogenous latent variable; ξ is an exogenous latent variable; B is the relationship between endogenous latent variables; Γ is the influence of exogenous latent variables on endogenous latent variables; and ζ is the residual term of the structural equation, which reflects the part that η fails to be explained in the equation.

3.2 The risk flow evaluation model algorithm of PPP project

Risk by the above flow, the definition of the PPP project risk conduction involves four major risk flow, respectively, for the system flow (R_s), stage risk flow (R_p), the construction phase (R_c) and operation phase flow risk (R_o). Each risk flow is formed by a complex, dynamic interaction of the associated risk variables. As mentioned above, the advantages of SEM to multicollinearity provide an opportunity for us to analyze the formation mechanism of risk flow. Through SEM modeling, the dynamic, strongly correlated and nonlinear internal structure approximation of the risk flow is simulated as static and linear SEM measurement equation, which can be used to evaluate the risk flow. Therefore, the risk flow evaluation model (RFEM) can be constructed in the form of SEM measurement equation (type 1 and 2):

$$\begin{cases} R_s = a_s \times \tau_s^T \\ R_p = a_p \times \tau_p^T \\ R_c = a_c \times \tau_c^T \\ R_o = a_o \times \tau_o^T \end{cases} \quad (4)$$

It can be seen that the path coefficient not only represents the factor load of explicit variables on latent variables, but also can be understood as the contribution of risk variables to the risk flow. Combined with a questionnaire survey on the importance of precursory risk statistics and path coefficient of parameter estimation, which identify each risk flow variables of key risks. Then simplify the RFEM as further simplified process in Table 1.

In Table 1, the risk variables of "mean < 3.30" and "path coefficient < 0.400" are also satisfied. Foreign exchange risk, according to the results of Rs, the Rp force majeure risks, Rll organization risk and environment risk because of its mean and path coefficient are low and knocked out, the risk of other variables, as a key risk is preserved. Although the "importance" and path coefficient of average represented by the "contribution" are important criteria that can be used as a screening of variables, but the path coefficient is more suitable for the calculation of RFEM regression coefficient. The reason is that SEM can effectively remove autocorrelation and purify measurement error and guarantee the independence of risk variables, thus ensuring the accuracy and objectivity of regression coefficient solution. The magnitude of the risk flow is linearly dependent on the size of each key risk variable, and the risk flow can be quickly solved by a given key risk variable. Therefore, RFEM based on SEM is a simple, fast and effective method, which can be used to evaluate the risk flow formed by various risk clusters in PPP project risk conduction network.

3.3 DRCM quantitative model analysis algorithm.

According to the effect of risk transmission in the above article, in the risk conduction network of PPP project, the same node may be impacted by multiple risks simultaneously. These risks are not simple parallel superposition, but the strong or weak effect of risk. Each node of the PPP project's risk conduction network has basically taken a risk. Therefore, it is necessary to analyze the formation mechanism of risk and disaster and form a quantitative analytic function. The Copula function proposed by scholars in 1959 created the conditions for the analysis of the disaster function C (s). The Copula function allows for the flexible construction of multiple distributions with different edge distributions and different related structures, without the limitation of traditional joint normal distribution. According to the Sklar theorem, set $F(x_1, x_2, \ldots, x_n)$ is

Table 1 The simplification of RFEM

Risk flow	Risk variable	Mean value	Mean value < 3.30	Path coefficient	Path coefficient < 0.400	Disposal results	Retention path coefficient normalized value
Rs	R1	3.66		0.684		Retain	0.130
	R2	3.08	√	0.560		Retain	0.106
	R3	3.82		0.742		Retain	0.141
	R4	3.21	√	0.421		Retain	0.080
	R5	2.93	√	0.333	√	Delete	
	R6	3.28	√	0: 566		Retain	0.108
	R7	3.23	√	0.594		Retain	0.113
	R8	3.65		0.589		Retain	0.112
	R9	3.05	√	0.256	√	Delete	
	R10	3.62		0.624		Retain	0.119
	R11	3.19	√	0.313	√	Delete	
	R12	3.49		0.479		Retain	0.091

a N-dimensional joint distribution function. Its marginal distribution function is $F(x_1), F(x_2), \ldots, F(x_n)$, so F has a unique Copula function:

$$F(x_1, x_2, \ldots, x_n) = C(F(x_1), F(x_2), \ldots, F(x_n)) \tag{5}$$

For the risk conduction network of PPP project, the risk state S (S) can also be written as the function of Copula:

$$F(R_1(s_1), R_2(s_2), \ldots, R_n(s_n))(F(R_1(s_1), R_2(s_2), \ldots, R_n(s_n))) = C(RC_1(s_1), RC_2(s_2), \ldots, RC_n(s_n)) \tag{6}$$

In the formula, $R_i(S_i)$ is the various risk events of the occurrence of disaster; $RC_i(S_i)$ is the risk result of risk event: $1 \leq i \leq n$. According to the diffusion effect of risk conduction, risk diffusion has a selective mechanism in the risk transmission network of PPP projects. In the process of spreading risk, the risk transmission process is usually spread by the risk of the largest correlation degree, weak risk tolerance and poor risk tolerance. Among them, risk tolerance is also called risk tolerance, which refers to the acceptability of differences in the realization of enterprise goals, and the tolerable limit of differences in the realization of related goals set on the basis of risk preference. The greater risk tolerance indicates that the company has a strong ability to withstand risks, and the usual daily countermeasures can be taken for small risks within the tolerance range. Risk tolerance is relatively weak or poor, indicating that the company's ability to withstand risks is weak or poor. This selective mechanism is identified and filtered through vulnerability. Suppose one of the PPP project risk conduction network risk spread has n nodes to the edge, after each to the edge of the vulnerability of $V_i(t), i \in 1, 2, 3, \ldots, n$, then can be built on the basis of the principle of risk spread diffusion function density function $D_i(t)$:

$$D_i(t) = \frac{V_i(t)}{\sum_{i=1}^{n} V_i(t)}, i \in 1, 2, \ldots, n \tag{7}$$

The diffusion function $D_i(s)$ is the integral of the density function in time domain s, which is:

$$D_i(s) = \frac{\int_0^s V_i(t)dt}{\sum_{i=1}^{n} \int_0^s V_i(t)dt}, i \in 1, 2, \ldots, n \tag{8}$$

It can be seen that the diffusion function is always aimed at the specific risk transmission process, and the risk state of the risk diffusion node will give priority to the weak link of the flow of risk transmission network. In the case that the node risk state is known, the risk flow to the edge of each strip is completely solved by the diffusion function. And diffusion function is determined by the vulnerability state-space description, therefore, by means of the fragility of the regulation and control, can influence the spread of the node state of risk, which regulates the flow of risk conduction network risk and traffic.

4 Result analysis and discussion

This paper preliminarily preprocesses the collected data sets, including filling in missing values, deleting outliers, the rationality of detected data and so on.

After the initial setup and variable assignment of the SD model are completed, the model is checked and corrected. In this article, the simulation experiment of DRCM is carried out with Vensim software, and the simulation results of RVR of the tunnel project are shown in Fig. 1.

Through Fig. 1, we can know that RVR shows an obvious upward trend over time during the whole life cycle of the project; the rise of RVR has slowed over time. It is known from the foreword that the rising trend of RVR is the accumulation of various risk events of PPP projects. The slowdown of the rising trend is due to the role of risk control measures, namely the RVR is finally effectively controlled with the continuous implementation and control of various control measures. It can be seen that the simulation results are in accordance with the objective facts of the tunnel project, and the correctness of the construction of the DRCM model is well verified, which reflects the change rule of RVR in the dynamic regulation. At the same time, the simulation results also show the risk results of each risk transmission process of the tunnel project, namely the risk evolution curve of each node and the directed edge of the risk transmission network, as shown in Fig. 2.

The model structure of RVR hierarchical control system mainly involves two important modules: RVR dynamic regulation module and optimal control module, respectively. Among them, the simulation of RVR dynamic regulation module is implemented based on the SD simulation platform Vensim, while the simulation of the optimal control module is completed by using the dynamic programming solver of Excel. In order to verify the correctness and convergence of RVR hierarchical control system, the optimal control scheme under various scenarios is investigated, respectively (the optimal solution for the dynamic programming of the target function), and the results are shown in Table 2.

It can be seen from Table 1 that no matter what kind of situation, the only optimal solution can be obtained through RVR hierarchical control system, and the convergence of the model is verified. At the same time, under the premise of the total cost, the optimal control scheme of various scenarios is very different: In the case of the government-led scenario, M3 and M4 are the most heavily controlled; in the context of social capital, M4 and M3 have the most control. In the situation of the two sides, M3 and M4 are the most heavily controlled; it is also the most powerful (but different proportion) of M3 and from under shared scenario. According to Table 2, the optimal solution in the same controlling the main body of control measures, the government can get west tunnel project, respectively, all kinds of situations and the controlling of social capital, the result as shown in Table 3. Through comparative analysis of government and social capital intensity, it is not difficult to find: As far as it is concerned, the intensity of the control of the two parties is positively correlated with the cost of control. In terms of the mutual ratio, except for the government-led situation, the ratio of the two parties under

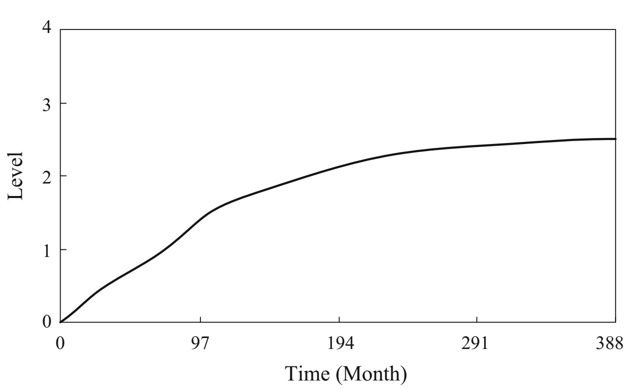

Fig. 1 The simulation results of RVR in WHT

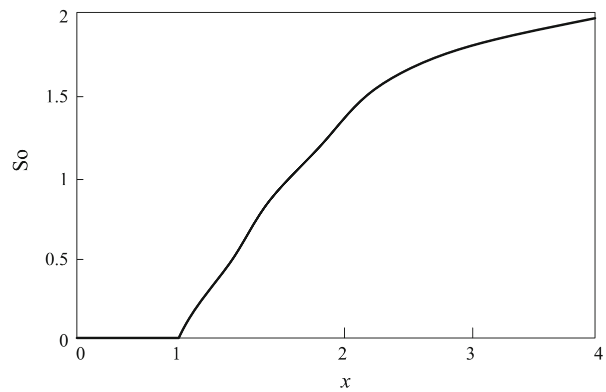

Fig. 2 The simulation results of the risk conduction network of the West tunnel project

Table 2 The optimal solution of risk control scheme under every scenario in WHT

Scene	M1	M2	M3	M4	M5
$M_1 = M_2 = \cdots = M_n$	1.86	1.86	1.86	1.86	1.86
$\omega_q = 10, \omega_p = 5$	0.27	0.21	7.30	4.84	1.60
$\omega_q = 5, \omega_p = 10$	0.22	0.18	3.72	6.25	4.87
$\omega_q = 7.5, \omega_p = 7.5$	0.42	0.26	7.14	4.85	3.40
$\omega_q + \omega_p = 15$	0.34	0.24	6.33	5.37	3.54

Table 3 The comparison of control strength between public and private sectors in WHT

Scene	$\sum_{i=1}^{p} M_i$	$\sum_{j=1}^{q} M_j$	$\sum_{i=1}^{p} M_i / \sum_{j=1}^{q} M_j$	Min (RVR)
$M_1 = M_2 = \cdots = M_n$	7.43	13.00	0.57	2.7777
$\omega_q = 10, \omega_p = 5$	14.79	6.77	2.18	2.2077
$\omega_q = 5, \omega_p = 10$	7.35	13.70	0.54	2.071
$\omega_q = 7.5, \omega_p = 7.5$	11.05	10.34	1.07	2.062
$\omega_q + \omega_p = 15$	10.13	11.25	0.90	2.053

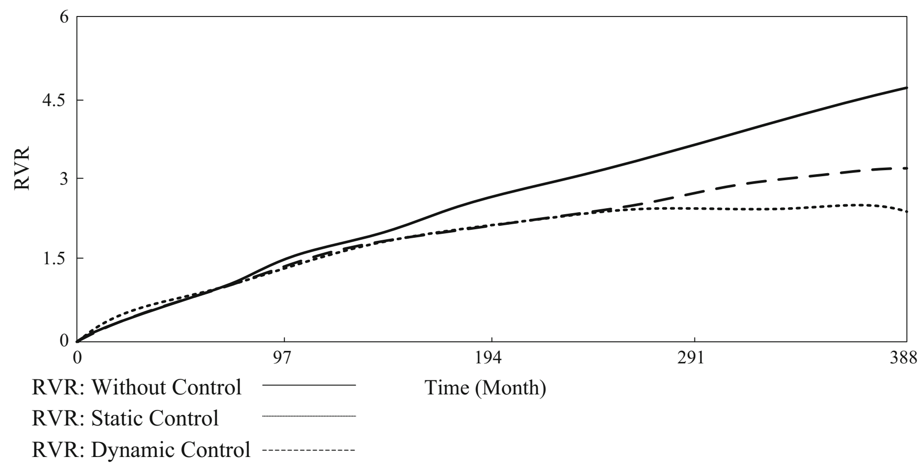

Fig. 3 The contrast curve of RVR under three risk control methods

other scenarios is basically less than 1. The control measures of social capital are generally larger, which is related to the control measures adopted by the social capital of the tunnel. In terms of the optimization effect, the optimization effect is the best when the two sides exert a balanced control. This indicates that the risk control of PPP project requires both parties to participate in and play their respective strengths, which can provide the decision-making basis for the design of PPP project risk-sharing mechanism (Fig. 3).

To sum up, the reliability, validity, generality, correctness and convergence of RVR-layered hierarchical control system constructed in this article are verified by example simulation. The system optimization control of RVR has significant effect, enables decision makers to calmly deal with all kinds of optimal decision problem under the actual situation, the risk of the optimal control scheme for policymakers to provide quantitative basis, which is also reasonable for the PPP project risk-sharing mechanism is designed to provide decision support. In addition, the optimized control system also has a simple input and output interface and extremely fast operation efficiency, which can facilitate the decision maker to adjust the control strategy timely after the risk occurs. To sum up, through the analysis of the above, we can deduce the PPP project risk transmission network, which the formation mechanism of the complex RVR, relatively simple is mapping to the risk of a universal transmission network. This can clearly reflect how the risk is ultimately formed by conduction, coupling and diffusion. At the same time, the mapped risk conduction network has better controllability, and it is easier to control the conduction process than the risk itself.

5 Conclusion

Through the detailed literature, the current research status of PPP mode, PPP project residual value risk (RVR), PPP project risk management, etc., is summarized and reviewed. Then, the research idea of risk control of general engineering project is borrowed, and the risk conduction network of PPP project is constructed and verified. Then, based on the analysis of the risk conduction effect of PPP project, the causal conduction network of the risk conduction network of PPP project is deduced. And by constructing the structural equation model for causal testing, the results show that the model parameter estimation results are ideal, the model and data are fitted with higher fitting degree, and the causal hypothesis is basically correct. Based on the empirical analysis results of RVR simulation in what, risk conduction network simulation of West tunnel project and RVR comparison curve under three risk control methods. The parameter estimation results of SEM model can also provide quantitative explanation for the transmission relationship between risks: The PPP project risk can be constructed using a path coefficient and flow evaluation model (RFEM), and its function is use SEM to remove autocorrelation and purify the advantage of measuring error, easy and quickly to solve internal dynamic complex formed by the risk of cluster risk flow; the influence coefficient Y can be used to solve the transformation degree between the risk flow and provide the quantitative basis for the accurate construction of the correlation model. In the future, we will continuously optimize and improve the current model and compare it with more models.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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