Private Partner Selection of PPP Model for Rural Infrastructure Based on Grey Cluster Theory

Limei Liang, Lin Shen, Yabei Cui and Hongjie Liu

***Abstract*—**To overcome the shortcoming of analytic hierarchy process (AHP) and fuzzy theory in the private partner selection of public-private-partnership (PPP) model for rural infrastructure, a private partner selection method is presented based on grey cluster theory. The method can reflect the ability of private partners in an objective manner, which make the decision more objectively and accuracy. At first, this paper constructed evaluation index system of private partners of PPP model for rural infrastructure and built a selection model combined AHP and gray clustering method. Then this paper took water supply project in H city as the example to verify the applicability and feasibility of the model. The results showed that the critical factors were relevant experience and fund position of private enterprises, then the technological and managerial levels of the private enterprises. In view of analysis results, this paper offered suggestions such as innovation of financing channels, completion of rural financial system and supervisory system to secure the interests of farmers.

***Keywords*—**PPP model, grey cluster theory, rural infrastructure, private partner selection.

I. INTRODUCTION

RURAL infrastructure is the general term for public services that provide to develop rural production and ensure farmers' lives. They are the basis for the development of various undertakings in the rural production and living, and the organic composition of rural economic system. On the one hand, due to the infrastructure of non-competitive and non-exclusive quasi-public goods attribute, we generally use government-led investment construction mechanism in a long time. On the other hand, owing to the limited sources of government special fund and the single channel, the current rural infrastructure has some problems such as lagging behind and supply structural imbalances. It seriously restricts the integration of the Beijing-Tianjin-Hebei region. In order to change supply situation effectively, we must explore various supply modes actively. Since the third plenary session of the 18th, the government and social capital cooperation (Public Private Partnership, the PPP) mode gradually rise. PPP model through franchising and equity transfer of property rights to establish a partnership between the government and the private capital. These ways have many characteristics, such as benefit-sharing and risk-sharing. Choosing private partners scientifically and making the partnership stable continuously are the key to the success of the PPP mode.

About the exploration of the private partner selection problem in the PPP project, the research of scholars at home and abroad concentrate mainly on two directions. One is the existing problems and experience summarized in practical operation. The study explored the dilemma associated with the adoption of PPP as a mechanism for the provision of regional transport infrastructure in Africa, and analyzed the factors affecting projects operation [1]. Scholars summed advantages of applying PPP model to urban sewage treatment projects, and the main issues that affect urban sewage treatment from the perspectives of government, enterprises, intermediary agencies, and public groups [2]. Another one is the decision-making index system of building and decision-making method of choice. Document frequency analysis and questionnaire methods are generally used to determine the private partner selection based on the index system of the PPP project and select the appropriate method to make decisions. The common methods include analytic hierarchy process(AHP) [3]-[5], fuzzy analytic hierarchy process (FAHP) [6]-[7], data envelopment analysis [8] and the analytic network process(ANP) [9] in selection method. Some scholars proposed other methods. C. Prakash and M.K. Barua constructed a combined model based on Fuzzy Analytic Hierarchy Process (FAHP) for ranking of selection criteria and Vlsekriterijumska Optimizacija I Kompromisno Resenje for the final selection [10]. B. Huang et al. used a chaotic particle swarm optimization algorithm to solve the multi-criterion partner selection problem [11].

On the private partner selection decision, due to asymmetric information, the details of private companies cannot be accurately understood by government departments. Most metrics, those cannot get accurate data, only can describe qualitatively and quantitatively by experts with traditional method. And then human subjective factors have a great influence on the selection results, which greatly reduce the accuracy and reliability of the selection results. The grey system theory focuses on solving the uncertainty problems such

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as "small sample" and "poor information" that analytic hierarchy process and fuzzy theory are hard to solve. Compared with traditional method, a AHP-grey clustering model combined AHP and grey clustering methods in this paper. It can greatly eliminate the impact of two selection methods on the results. This selection model can not only reflect the decision makers' wishes, but also avoid the subjective arbitrariness, which make the result more scientific and reasonable.

II. Research Methods and Data Sources

A. Research Methods

Using grey clustering method, the construction of private partner selection model for rural infrastructure projects under the PPP pattern, provides a reference for government decision-making. Model building process has two steps.

The first step is to construct the evaluation index system of the private partners. On the basis of the literature, combining the operation process of multiple PPP project, we can organize the private partner selection index which affects the construction effect of rural infrastructure projects. These indicators are respectively from six aspects including the perspective of financial, technical, management, relevant experience, reputation and security environmental protection to choose. Make a summary of it, we can build the private partner selection index system of the PPP mode. The system consists of six indicators and 20 secondary indicators, as shown in Fig.1.

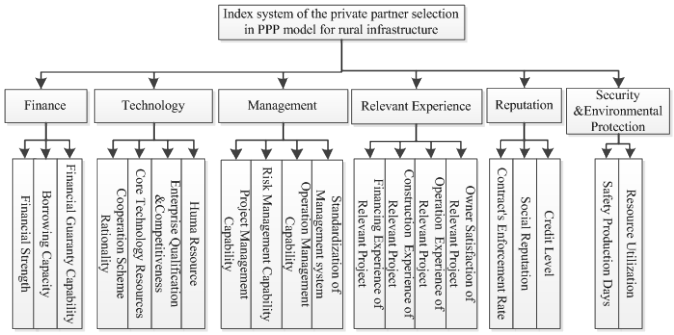

Fig. 1. Index system for private partner selection in PPP model

The second step is to construct the private partner selection model in PPP mode based on grey clustering theory. The basic idea of the grey system theory is to construct an original matrix using limited data. And through the transformation and whitening of the original matrix information, the characteristics of the selected objects are analyzed through information analysis. Grey cluster is an important branch in the theory of grey system, mainly according to the albino number of the evaluation index, then the composite effect is calculated and the type of the evaluated object is determined. The analysis method of grey cluster possesses the advantages of simple and the objective result, helping to improve decision-making scientific and accurate.

In the model, the target layer represents the problem to be solved. That is to choose the appropriate private partners, expressed in *P*. The second layer as the criterion layer $P_i=(p_1, p_2, ..., p_i)$, i represents different level of evaluation index. The third layer is the index layer $P_{ij}=(p_{i1}, p_{i2}, ..., p_{ij})$, and j stands for the number of secondary indexes subordinate to the ith primary index. The fourth layer for solution, represents different options, that is different private investment enterprise. Concrete implementation steps are as follows:

By using Delphi expert investigation method and combining hierarchy comprehensive evaluation method, the judgment matrix is constructed. The relative importance of the indices is determined by using the Satty scale method. After a single hierarchy, hierarchy total and consistency test, we can determine the weights of criteria layer weight $A_i=(a_1, a_2, ..., a_i)$ and index layer $A_{ij}=(a_{i1}, a_{i2}, ..., a_{ij})$.

We organize *s* experts to rate private investment enterprises according to the grading standard on a scale of 0 to 5. The higher the expert's satisfaction, the closer the score is to 5 points, otherwise the closer to 0. In this way we can conclude the sample matrix D.

$$D=\begin{bmatrix} d_{111} & d_{112} & \cdots & d_{11s} \\ d_{121} & d_{122} & \cdots & d_{12s} \\ \cdots & \cdots & \cdots & \cdots \\ d_{ij1} & d_{ij2} & \cdots & d_{ijs} \end{bmatrix}$$

When choosing a private investment enterprise, the number of grey type e is 5, which represents "excellent", "good", "moderate", "qualified" and "unqualified". And corresponding white weight function is $f_1(x)$, $f_2(x)$,..., $f_5(x)$:

$$f_1(x)=\begin{cases} \frac{1}{5}x & 0\le x<5 \\ 1 & x\ge 5 \end{cases}$$

$$f_2(x)=\begin{cases} \frac{1}{4}x & 0\le x<4 \\ 5-x & 4\le x\le 5 \end{cases}$$

$$f_3(x)=\begin{cases} \frac{1}{3}x & 0\le x<3 \\ \frac{1}{2}(5-x) & 3\le x\le 5 \end{cases} \quad (1)$$

$$f_4(x)=\begin{cases} \frac{1}{2}x & 0\le x<2 \\ \frac{1}{3}(5-x) & 2\le x\le 5 \end{cases}$$

$$f_5(x)=\begin{cases} 1 & 0\le x<1 \\ \frac{1}{4}(5-x) & 1\le x\le 5 \end{cases}$$

The clustering coefficient indicates that the evaluation sample belongs to the degree of different clustering. For example, for the child rule layer $P_{\bar{ij}}$, the evaluation sample belongs to the coefficient of group *e* and the coefficient is x_{ije}. Equation (2) is used to calculate x_{ije}.

$$x_{ije} = \sum_{k=1}^{s} f_e\left(d_{ijk}\right) \quad (2)$$

For the criterion layer P_i, the total grey evaluation of the sample is recorded by x_{ij}. Equation (3) is used to calculate x_{ij}.

$$x_{ij} = \sum_{e=1}^{5} x_{ije} \quad (3)$$

The grey evaluation power is recorded as r_{ije}. Equation (4) is used to calculate r_{ije}.

$$r_{ije} = \frac{x_{ije}}{x_{ij}} \quad (4)$$

For each evaluation index p_{ij}, evaluation objects belonging to the evaluation rights of various grey classes jointly constitute grey evaluation weight vector, which is written as r_{ij}, having $r_{ij} = (r_{ij1}, r_{ij2}, r_{ij3}, r_{ij4}, r_{ij5})$. Grey evaluation weight vectors constitute index layer grey evaluation weight matrix R_i after comprehensive summary.

$$R_i = \begin{bmatrix} r_{i1} \\ r_{i2} \\ \vdots \\ r_{ij} \end{bmatrix} = \begin{bmatrix} r_{i11} & r_{i12} & \cdots & r_{i15} \\ r_{i21} & r_{i22} & \cdots & r_{i25} \\ \cdots & \cdots & \cdots & \cdots \\ r_{ij1} & r_{ij2} & \cdots & r_{ij5} \end{bmatrix}$$

B_i represents the evaluation result of the criterion layer, and A_{ij} represents the index layer weight matrix. Equation (5) is used to calculate B_i.

$$B_i = A_{ij}^T \times R_i = \begin{pmatrix} b_{i1} & b_{i2} & b_{i3} & b_{i4} & b_{i5} \end{pmatrix} \quad (5)$$

Then we assign values to all grey classes, such as the first grey ("excellent") value is d_1, and the second grey ("good") value is d_2, ..., and the fifth grey class ("unqualified") is d_5. The evaluation grade vector $D = (d_1, d_2, d_3, d_4, d_5)$ of each grey class. Equation (6) is to calculate the comprehensive evaluation value of the evaluator, and the *S* value is the grey evaluation result of the subject.

$$S = B \times D^T \quad (6)$$

Similarly, the scores of other private investment enterprises can be gotten, and the highest score is the optimal decision.

B. Data Sources

Institute with data are from the H city urban and rural water supply project. This project construction and operations adopts the PPP mode, and its total investment is 690 million yuan. Government departments choose the private investment enterprise by using the public bidding way. After qualification examination and comparative screening, three private investment enterprises -company A, B, and C- enter the final selection stage. Government organizes five experts who have full experience in PPP project review to score three private enterprises from the perspective of finance, technology, management, relevant experience, reputation and security environmental protection.

Table 1 Index weight, sample matrix and weighting vector of grey cluster

The target layer	Criteri-on layer weight	Index layer weight	The sample matrix					The gray evaluation weight vector				
The PPP model of rural infrastructure projects the private partner selection index system	0.201	0.093	5	4.5	4.5	4.5	4.5	0.525	0.228	0.114	0.076	0.057
		0.062	4.5	4.5	4	4.5	3.5	0.353	0.283	0.168	0.112	0.084
		0.046	4	4.5	4.5	4.5	4	0.371	0.301	0.151	0.101	0.076
	0.192	0.081	4	3.5	3.5	3.5	3.5	0.230	0.286	0.223	0.149	0.112
		0.044	5	4.5	5	5	4.5	0.697	0.146	0.073	0.048	0.036
		0.044	4.5	4.5	4.5	4	3	0.335	0.266	0.184	0.123	0.092
		0.023	3	4	4	3.5	4	0.241	0.301	0.211	0.141	0.106
	0.177	0.071	3.5	3	3	3.5	3	0.189	0.236	0.265	0.177	0.133
		0.047	2.5	2	2.5	2.5	1.5	0.150	0.165	0.220	0.255	0.210
		0.035	3.5	4	4	4	3.5	0.252	0.316	0.199	0.133	0.100
		0.024	2.5	2.5	3	2.5	3	0.156	0.196	0.260	0.222	0.166
	0.228	0.047	3	2.5	2.5	2	2.5	0.146	0.183	0.244	0.244	0.183
		0.05	4.5	4.5	4.5	4.5	4.5	0.464	0.257	0.129	0.086	0.064
		0.05	2.5	3	3	2.5	2	0.148	0.185	0.270	0.227	0.170
		0.08	3.5	4	4	3.5	3	0.230	0.286	0.223	0.149	0.112
	0.115	0.038	3	3.5	3	3	2.5	0.175	0.218	0.267	0.194	0.146
		0.038	4	4	4.5	4.5	3.5	0.319	0.301	0.175	0.117	0.088
		0.038	4	5	5	4	4.5	0.464	0.257	0.129	0.086	0.064
	0.087	0.052	4.5	4.5	5	4.5	5	0601	0.191	0.096	0.064	0.048
		0.035	5	4	4.5	4	4.5	0.413	0.282	0.141	0.094	0.070

III. Results and Analysis

A. Model Operation Results

The index weight is determined by using AHP method, and the results are shown in table 1.

Based on the information that provided by the private investment enterprise and the understanding of the situation, experts according to the evaluation index system rate three companies. And then we can get the sample matrix D. Based on the albino weight function, grey evaluation weight vector can be calculated. In the case of A company, the sample matrix and grey evaluation weight vector as shown in table 1.

By making comprehensive evaluation on the first level evaluation index, we can get:

$$B_1 = a_{1j} \times R_1 = (0.436,\ 0.262,\ 0.139,\ 0.093,\ 0.070).$$

The same goes for B2, B3, B4, B5, and B6. Then we can get the grey evaluation weight matrix R as follows.

$$R = \begin{bmatrix} 0.436 & 0.262 & 0.139 & 0.093 & 0.070 \\ 0.361 & 0.252 & 0.179 & 0.119 & 0.089 \\ 0.187 & 0.228 & 0.239 & 0.195 & 0.151 \\ 0.253 & 0.238 & 0.213 & 0.169 & 0.127 \\ 0.319 & 0.251 & 0.194 & 0.135 & 0.101 \\ 0.526 & 0.228 & 0.114 & 0.076 & 0.056 \end{bmatrix}$$

The comprehensive evaluation result of private investment enterprises is:

$$B = A_i^T \times R = (0.332 \quad 0.244 \quad 0.185 \quad 0.136 \quad 0.103).$$

Comprehensive evaluation is: $S = B \times C^T$ =3.566. So, the overall score of A company is 3.566. In the same way, the comprehensive score of company B was 4.159, and the combined score of C was 3.907. Choose the company that has the highest score according to the principle of choice.

B. References Operation Result Analysis

The weight of the primary index is as follow: financial (0.201), technology (0.192), management (0.177), related experience (0.228), reputation (0.115) and security& environmental Protection (0.087). When choosing a private partner, firstly, we focused on whether the private sector has the participation experience and the strength of its financial strength. Secondly, we focused on whether the private enterprise has the corresponding technology and whether it has strong management ability and perfect management system.

According to the weight, the top ten of the secondary indexes are: financial strength, cooperation scheme rationality, the owner satisfaction of relevant project, project management capability, borrowing capability, safety production days, construction experience of relevant project, operating experience of relevant project, financing experience of relevant project and risk management capability.

Financial perspective focuses on the financial strength and borrowing capability of private enterprises. The investment of rural infrastructure projects is large, and the payback period is long. when choosing the private enterprise, a partner with large funds and strong financing ability can effectively promote the project operation and greatly reduce the risks to both cooperation parties.

Technology perspective focuses on the rationality of the cooperation schemes proposed by private enterprises. Cooperation scheme expatiates each other's rights and responsibilities in the public-private partnership model, including cooperation mode, the cooperation term, income distribution scheme and fee pricing standard of operation periods, etc. This is the PPP mode huge guarantee of success.

Management perspective focuses on project management and risk management ability of private enterprise. The infrastructure project has some characteristics, such as high cost, long investment period, high quality requirements and many stakeholders. It involves multiple links such as scope management, integration management, communication management and project management. In the process of construction and operation, there are many uncertainties and risks, which require the private enterprise to have a strong risk management capability.

Related experience perspective focuses on private enterprise project financing, construction, operation experience and the satisfaction of owner. According to the theory of behavioral science, a private enterprise which has successful PPP project experience and can be recognized by the owners, will also have a better performance in subsequent cooperation.

Security environmental protection perspective focuses on safety production days of private enterprises. Rural infrastructure project is closely related to the interests of the peasants. Safety accidents are not trivial. The safety accident rate of private enterprises is a potential safety hazard for the cooperation between the two sides. Therefore, the number of days of safe production is also one of the important factors to focus on when choosing a private partner.

The score of company A is 3.566, company B is 4.159, and company C is 3.907. According to the evaluation results of grey cluster model, company B is the most suitable partner. And the final bid is indeed B company, which confirms the feasibility of this model. The financial strength of company B is the strongest among the three companies, and it has many experience in infrastructure project construction and PPP project cooperation. It further verifies the accuracy of the index system: relevant project experience and financial capability are the key factors which affect the selection of private partner of PPP projects. Private enterprises have accumulated a great deal of experience in the investment, construction and operation of similar projects, which is an important guarantee for the success of their cooperation. And the strong financial strength can ensure that the infrastructure projects have sufficient source of funds in the construction process and the later operation stage, effectively reducing the risk of cooperation failure.

IV. Conclusion and Discussion

Based on the characteristics of PPP mode of rural

infrastructure construction project, this paper constructs a private partner evaluation index system. Using the grey clustering method, the information asymmetry between government departments and private partners is effectively solved, and the private partner selection model is created. The feasibility and applicability of the model are verified through an example of urban and rural water supply projects in H city.

The results show that:

1) Whether the private sector has the participation experience and the strength of its financial strength are the key factors deciding the selection of private enterprise, followed by whether the private enterprise has the corresponding technology and whether it has strong management ability and perfect management system.
2) The private partner selection model in PPP model based on grey clustering theory, systematically considers the association among various factors in the evaluation index system. By making a connection on the research and analyze through the known information, the result shows that computing method is simple, evaluation process is scientific and evaluation result is reasonable. Those can solve some problems effectively including the small sample size and limited information. When choosing private enterprises, it can improve the scientific nature and accuracy of decision-making and reduce the PPP project risk of default in the process of public-private partnerships. It can also put forward rationalization proposal to help government departments make choices and decisions.

The introduction of private capital is the only way to solve the limited source of government funds and invest in structural imbalances in the construction of rural infrastructure. In order to further encourage private capital to participate in the construction and operation of rural infrastructure projects, we should strengthen the following areas:

1) Broadening the financing channel and optimizing the investment structure. We will increase publicity and encourage private enterprises participation. We can attract private enterprises through institutional innovation, financial subsidies and tax breaks, actively mobilize social investment and ease government financial pressure.
2) Improving the rural financial system and giving play to the power of credit. We will encourage the development of new rural financial institutions, and form rural financial organizations with complete functions, orderly competition and diversified services. We will direct bank loans, insurance funds, social security fund and housing funds to invest in rural infrastructure in the form of loans.
3) Improving the PPP supervision system and protecting the interests of farmers. We will improve the relevant legal system of the PPP project, the risk prevention mechanism and supervision mechanism. It forms the supervisory mechanism, which is jointly attended by government regulators, investors, social public, experts and media. Finally, we can create a good operating environment.

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