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RESEARCH ON THE BI-LEVEL PROGRAMMING OF UNDERGROUND LOGISTICS PROJECT BASED ON PUBLIC-PRIVATE PARTNERSHIP MODE

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Abstract. *With the expansion of Chinese cities, the urban population sharply increases and urban traffic congestion is becoming more and more serious, causing the efficiency decline and cost increase of urban logistics, which greatly influenced the healthy development of the city logistics. This paper draws lessons from the ideas of the developed countries to solve the problem of urban logistics by means of underground logistics, and puts forward the method of constructing the underground logistics system by using the new Public-Private Partnership (PPP) mode. Based on this, the paper includes three aspects. First, analyze the exiting researches of capital and risk assumptions in urban underground logistics construction. Then combining with risk preference game model and PPP mode of highway project operational cost model, quantify the bi-level programming model, so that the proportion of project investment and risk can be rationalized. Finally, the plant growth simulation algorithm was used to analyze an actual case. The optimal investment and risk proportions were calculated through the model, and the government's public finance expenditure was the least and the private department's net profit was the largest.*

Keywords: Underground logistics, PPP mode, Bi-level programming

1. **Introduction.** Chinese cities are in the period of modernization with intelligence, green, low-carbon and intensive construction. With the acceleration of the process of urbanization, the popularization of e-commerce, and the increasingly obstructed urban traffic, the issue of transport has become the core of urban modernization. The fast and efficient truck freight not only consumes a lot of fuel and causes air pollution, but also has higher and higher logistics costs. In response to the above problems, the underground logistics transportation model has arisen. However, underground logistics systems have large investments, high costs, and long payback periods, making it difficult for government to support them independently. Therefore, the PPP mode will be used to give full play to the advantages of the professional expertise of private enterprises and provide strong financial support for the construction of new-type urban underground logistics in China.

PPP refers to the relationship of mutual cooperation between the public department (government) and the private department based on the construction and operation of a specific public infrastructure project. The two sides strive for "benefit sharing, risk sharing, full cooperation" to ensure the successful completion of the project. In 1992, the United Kingdom took the lead in putting forward the PFI mode [1], the predecessor of the PPP mode. Subsequently, Chile, Portugal, the United States, Japan and other countries

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have introduced PPP mode. It can be seen from the cases study of various countries that the key of PPP mode lies in the reasonable investment proportion and risk allocation in the early stage of the project.

On the investment ratio, as early as the 1970s, Kim studied the problem of debt capacity and optimal capital structure when firms suffered bankruptcy costs and corporate income taxes [2]. In the 1990s, Hart et al. created models for the costs and benefits of prison privatization based on the advantages of private investors in improving service quality and reducing project costs [3]. In the 21st century, Bakatjan et al. combined the financial model with the linear programming model to create a model from the perspective of the maximum project owner's return on the project to determine the optimal capital structure for the decision makers [4]. Sun et al. built a model based on game theory pricing and project optimal ownership structure for the construction and operation of expressways under the PPP model [5]. Liu et al. took into consideration of the traffic saturation period and franchise period of the PPP expressway project to construct a decision model for the investment ratio and franchise period of public-private partnerships to maximize social and private benefits [6].

At present, many scholars have studied the proportion of project risk, which can be divided into two categories: first, qualitative analysis methods such as questionnaire surveys and case studies; second, quantitative analysis methods of projects. Bing et al. proposed to explore the preferences of risk allocation through questionnaire surveys [7]. Jin and Zhang drew on the theory of TCE (Transaction Cost Economics) to establish, train, validate, and test Artificial Neural Network (ANN) models for risk allocation decisions in PPP projects [8]. Khazaeni et al. transformed knowledge and expert experience into quantitative analysis based on fuzzy logic, and proposed a fuzzy adaptive decision model for selecting equilibrium risk allocation [9]. Wang et al. adopted a cooperative game approach to construct a game model based on different risk preference coefficients [10]. He and Zhao built an optimal cooperative game model based on the risk appetite of the government and private groups, so that the risk can be transferred between the two parties and the overall risk of the project can be reduced [11].

Some scholars also discuss investment and risk at the same time. Zhang pointed out the current status of risk and uncertainty factors and proposed to overcome the limitations of traditional financial analysis techniques by improving financial engineering techniques [12]. Sundararajan and Tseng developed a dynamic capital structure approach to consider the impact of performance risk on project value under uncertainty [13]. He and Fu established the best investment proportion model for public-private partnership investment, and based on the comprehensive evaluation method, the public and private parties' risk sharing ratio and income distribution ratio were given [14].

However, most of the existing studies have presented independent research systems or qualitative analysis of the impact of risk on investment. In view of this, this paper establishes a bi-level programming model to quantitatively study the impact relationship and specific ratio between PPP project investment and risk, and provides reliable theoretical and data support for the PPP mode of underground logistics projects.

2. **Research Question.** The problem of the bi-level programming model was first proposed by the American mathematicians Candler and Norton in 1977 [15]. Both the upper and lower layers have objective functions and constraints and interact with each other. The bi-level programming is a special multi-level programming and has been applied in many fields such as transportation, management, and engineering design. Stackelberg model is a specific model for the management application of bi-level programming.

The research on the bi-level programming of the underground logistics project PPP mode involves both government and private department investment, risks and benefits. Therefore, this research regards the minimum government's public finance expenditure and the maximum private department's net profit as the upper and lower targets, and the ratio of investment and risk as the decision variables. Construct a bi-level programming model of the PPP mode and solve the model.

For the underground logistics project of the PPP mode, due to the complexity of the environment leading to too many influencing factors, this paper makes the following assumptions for modeling.

1) Although it is very important to select a private company that meets the requirements in terms of quality, this is determined by the results of project bids and is not covered here. Therefore, assume that a suitable private company has been found.

2) In this paper, the government's control of the project investment ratio is set as the government's decision-making variable, and the proportion of the private company's risk allocation is taken as the decision-making variable of the private enterprise.

3) The government is responsible for policies, laws, and minimum demand risks. Private companies are responsible for business risks such as project design, construction, operation, and maintenance. This paper only examines the proportion of both departments' commitments in natural disasters and other force majeure risks.

4) In order to facilitate the construction of the model, this paper does not consider the conversion cost, the total funds of the PPP project given, and does not consider the government's follow-up subsidies.

5) In order to simplify the model, this paper only focuses on the bi-level programming model of the underground logistics project PPP mode consisting of a single public department and a single private department.

3. **Methodology.** In the PPP mode underground logistics project, government's public finance expenditure includes project investment and force majeure risk expenses, and private department's net profit refers to the difference between operating income and project investment, force majeure risk expenses, and operation and maintenance expenses.

Assume that the total project funds is C, the franchise period $T = t_1$ (construction period) $+\ t_2$ (operating period), the expected investment return rate of the private department is π, the government allows the private department to achieve a maximum return rate of 50%, and the risk to undertake the effort is b. The ratio of investment and risk allocation between the government and the private department is shown below.

For project investment, it is divided into two parts: government and private department. Set $f_i(\rho)$, then $f_i(\rho) = \rho_i \cdot C$, $i = 1, 2$, that is, project investment is a function of investment ratio ρ_i, and $\rho_1 + \rho_2 = 1$.

Table 1. Proportion of public and private parties in project investment and risk allocation

Ratio	Government	Private
Investment	ρ_1	ρ_2
Risk	θ_1	θ_2

Assume that the force majeure risk cost factor is ϕ_j ($\phi_j > 0$), which is shared by the government and the private department. If $h_j(\theta)$ is set, then $h_j(\theta) = \phi_j \cdot b \cdot \theta_j$, $j = 1, 2$ [10], that is, the project risk cost is a function of risk proportion θ_j, and $\theta_1 + \theta_2 = 1$.

Under normal circumstances, the higher the construction cost of urban rail projects is, the more emphasis will be placed on project operations and maintenance, and the cost will increase. In addition, the greater the degree of importance attached to the project by private company is, the greater the proportion of input is, and the more the increase in the cost of operating and maintaining the project is. Therefore, we can draw $(dv)/(dC) > 0$, $(dv)/(d\rho_2) > 0$, and it is assumed that the project operation and maintenance cost [6] is

$v = C^{k_1} \cdot \rho_2^{k_2}$ $(k_1, k_2 > 0)$, which is undertaken by the private department and is a function of the private department investment ratio ρ_2.

Taking account of the actual situation of Chinese economic development and subway passenger flow, gross sales will vary with ticket price and passenger flows, and passenger flows will continue to increase over time. This research assumes that the passenger flow is $q = r + w \cdot \sqrt{t}$ $(r, w > 0)$ and the operating income is $I = \int i \cdot (r + w \cdot \sqrt{t})dt$.

In this PPP mode underground logistics project, the public department (government), as the leading party, project investment and force majeure risk costs are the basis for the private department to reduce costs. The government has a dominant position, has control over the proportion of project investment and risk, and the private department has the right to share. However, the proportion of shares cannot be determined by itself, but rather by the government. The private department can rationally adjust its own decisions based on government decisions to achieve its own optimal interests. The government guides the private department through supervision and control and seeks to minimize its own public finance expenditure.

The government project investment is

$$f_1(\rho) = C \cdot \rho_1 = C \cdot \rho \tag{1}$$

The cost of the force majeure risk of government is

$$h_1(\theta) = \phi_1 \cdot b \cdot \theta_1 = \phi_1 \cdot b \cdot (1 - \theta) \tag{2}$$

The government's total public finance expenditure for this project is

$$L_1 = f_1(\rho) + h_1(\theta) = C \cdot \rho + \phi_1 \cdot b \cdot (1 - \theta) \tag{3}$$

The private department project investment is

$$f_2(\rho) = C \cdot \rho_2 = C \cdot (1 - \rho) \tag{4}$$

The cost of the force majeure risk of the private department is

$$h_2(\theta) = \phi_2 \cdot b \cdot \theta_2 = \phi_2 \cdot b \cdot \theta \tag{5}$$

The total gross sales of the private department is

$$I = \int i \cdot (r + w \cdot \sqrt{t})dt \tag{6}$$

The cost of operation and maintenance of the private department is

$$v = C^{k_1} \cdot \rho_2^{k_2} = C^{k_1} \cdot (1 - \rho)^{k_2} \tag{7}$$

The net profit of the private department for the project is

$$\begin{aligned} L_2 = & -f_2(\rho) - h_2(\theta) + I - v = -C \cdot (1 - \rho) - \phi_2 \cdot b \cdot \theta \\ & + \int i \cdot (r + w \cdot \sqrt{t})dt - C^{k_1} \cdot (1 - \rho)^{k_2} \end{aligned} \tag{8}$$

Thus, the bi-level programming model is shown as follows:
Upper level: The government has the smallest total public finance expenditure for this project.

$$\begin{array}{ll} \min & L_1 = C \cdot \rho + \phi_1 \cdot b \cdot (1 - \theta) \\ \text{s.t.} & 0 < \rho < 1, \ 0 < \theta < 1 \end{array} \tag{9}$$

Lower level: The private department has the maximum net profit.

$$\begin{array}{ll} \max & L_2 = -C \cdot (1 - \rho) - \phi_2 \cdot b \cdot \theta + \int i \cdot (r + w \cdot \sqrt{t})dt - C^{k_1} \cdot (1 - \rho)^{k_2} \\ \text{s.t.} & C \cdot (1 - \rho) \cdot (1 + \pi) < L_2 < C \cdot (1 - \rho) \cdot (1 + 50\%) \end{array} \tag{10}$$

4. **Case and Results.** A subway project adopts the PPP mode with a total investment of $C = 153$ (million yuan) and is responsible for A and B (A is the public department and B is the private department). The construction period of the project is 5 years. After the completion of the project, B is responsible for operation and management, facility maintenance and other specific work, franchise period of 30 years. Ticket price $i = 2$ (yuan). Due to the project expansion after 5 years, the passenger flows function coefficients are $r_1 = 50$, $r_2 = 100$, $w = 25$, and one year according to 365 days. The risk-taking cost $b = 50$ (million yuan), the government risk-taking effort cost coefficient $\phi_1 = 5$, the private department risk-taking effort cost coefficient $\phi_2 = 8$, the project operation and maintenance cost function coefficients $k_1 = k_2 = 0.5$, the expected rate of return on investment of the private department $\pi = 10\%$. The bi-level programming model is

$$\begin{aligned}
\text{Upper level:}\quad & \min \quad L_1 = 153{,}000{,}000 \cdot \rho + 250{,}000{,}000 \cdot (1-\theta) \\
& \text{s.t.} \quad 0 < \rho < 1,\ 0 < \theta < 1 \\
\text{Lower level:}\quad & \max \quad L_2 = -153{,}000{,}000 \cdot (1-\rho) - 400{,}000{,}000 \cdot \theta \\
& \qquad + 365 \cdot \int 2 \cdot (50 + 25 \cdot \sqrt{t})dt + 365 \cdot \int 2 \cdot (100 + 25 \cdot \sqrt{t})dt \\
& \qquad -153{,}000{,}000^{0.5} \cdot (1-\rho)^{0.5} \\
& \text{s.t.} \quad 168{,}300{,}000 \cdot (1-\rho) < L_2 < 229{,}500{,}000 \cdot (1-\rho)
\end{aligned}$$

Li et al. proposed PGSA in 2005 [16]. Since the algorithm was put forward, it has been widely applied and expanded in the fields of management, power, water conservancy, and nuclear industry. This paper uses PGSA to solve the PPP mode of underground logistics bi-level programming model. The solution of the bi-level programming model is detailed in [17-20]. Through the above references, it is concluded that PGSA has computational accuracy and stability in solving the bi-level programming model. Due to space issues, this paper does not elaborate it. The introduction of PGSA in the PPP mode underground logistics project is as Figure 1.

Through calculation, an optimal solution is obtained: $\rho = 0.63$, $\theta = 0.438$, that is, government investment accounts for 63%, and the private department risk allocation accounts for 43.8%, government public finance expenditure is 2,366,400 billion and private department net profit is 845,510 billion.

The proportion of government funding is negatively correlated with private department risk allocation. Therefore, a reasonable investment and risk ratio should be set up to achieve a "win-win" model between the government and the private department. This model will be of important reference value for the government and the private department in the PPP mode of underground logistics projects.

5. **Conclusion.** The underground logistics project of the PPP mode is conducted between the government and the private department during the game process. In the game process, the proportion of participants' investment and risk allocation directly affects the members' own interests, which reflects the value of cooperation and competition. This paper constructed an optimization model of the ratio of investment and risk allocation and used plant growth simulated algorithms to analyze potential investment and risk bearing combinations among partners. What is more, the model constructed in this paper is based on some assumptions, and there are some limitations and deficiencies. In the future, we will further study the impact of government follow-up subsidies on the proportion of investment and risk-taking.

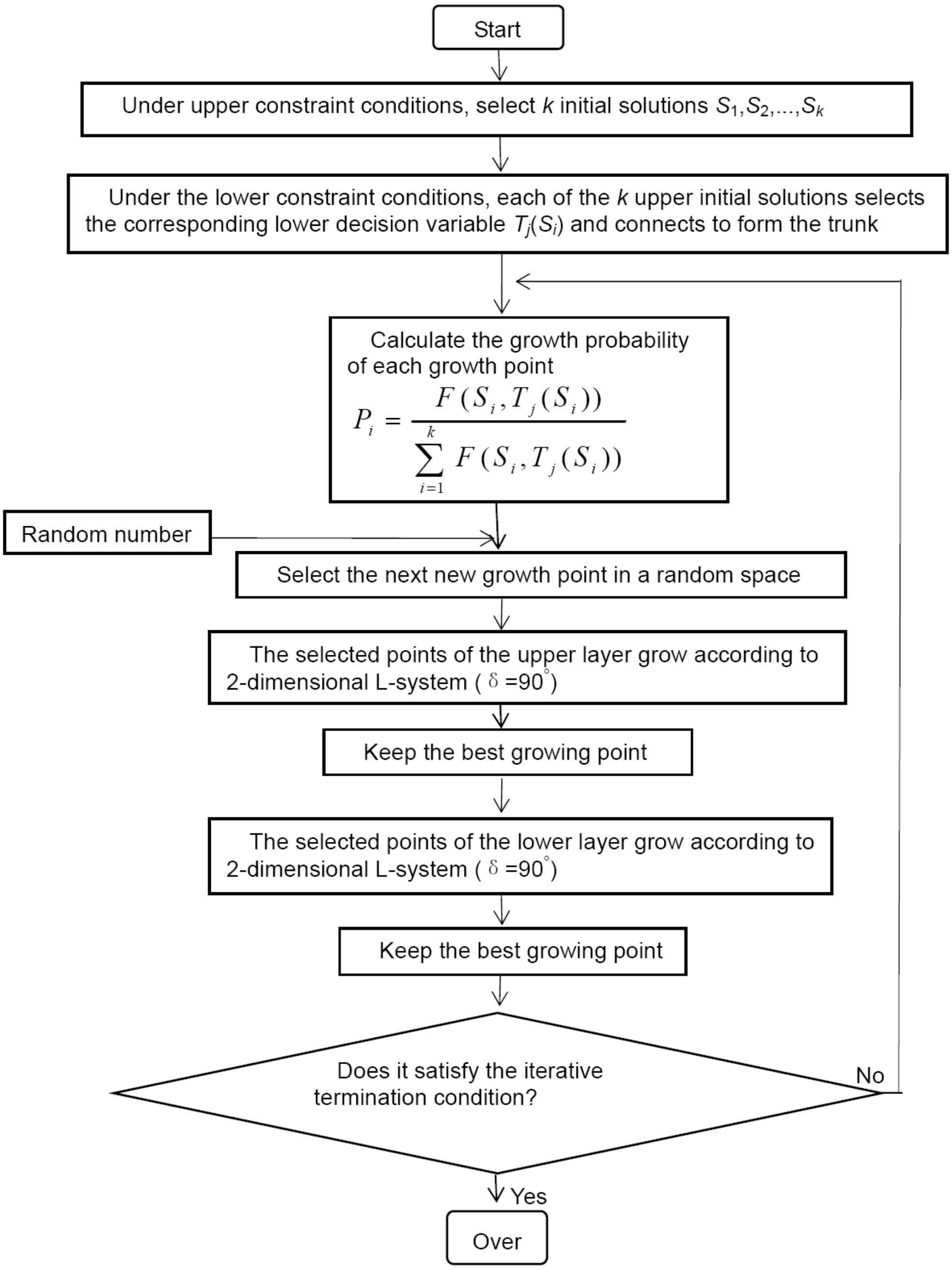

Figure 1. Flow chart

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