Risk Analysis in Construction Stage of Urban Rail Transit

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Abstract: The paper analyses three kinds of packing methods of urban rail transit construction project; Summarizes the main work of preparation stage, financing stage, construction stage and operation stage in urban rail transit project ; Concludes the key risk points of each construction unit. At the same time, according to the analytic hierarchy process model, the paper calculates the weights and importance scores of risk factors in the construction stage. The main risk sources and risk level of construction phase are identified and analysed, lastly the consistency of the results is tested.

1 INTRODUCTION

Urban rail transit project risk identification contains many factors and a variety of response measures, this article focuses on the urban rail transit construction phase of risk identification and response measures. Prerequisites for risk identification include the packing method of construction project, main stages and key tasks of urban rail transit, and the division of organization among the participating units.

2 RISK PREREQUISITES OF URBAN RAIL TRANSIT CONSTRUCTION PHASE

2.1 Packing Method of Urban Rail Transit Construction Project

The way of packing of the project has great influence on the management organization and construction progress. It is one of the prerequisites for risk identification in the construction phase of the urban rail transit project.

From the perspective of urban rail transit construction, there are three types of packing methods commonly used in the project.

Table 1: The main types of packing methods and typical applications

Types of packing	Typical applications
Non-sunken capital investment project model	Beijing Metro Line 4, Beijing Metro Line 14, Beijing Metro Line 16, Hangzhou Metro Line 1 and Hangzhou Metro Line 5
The overall investment and financing project model	Urumqi Line 2, Beijing New Airport Line, Hohhot Line 1 and Line 2, Chengdu New Airport Line
Overall construction + land development model	Shenzhen Metro Line 4, Shenzhen Metro Line 6, Foshan Metro Line 2

The first is the type of non-sunken capital investment project model, it’s sunk capital part of the investment is capital investment by the government, non-sunken part is that the social capital investment. Belonging to sunk capital part in Urban rail transit project is civil engineering construction, and belonging to non-sunken part is the mechanical and electrical equipment project (Qingwu, Zhao, 2014). Civil engineering construction is partly funded by the government and construction. By means of bidding, the electromechanical equipment is invested and constructed by a project company jointly set up by social capital and the government. After the completion of the construction, the project company is responsible for the operation of the project routes and is rewarded through the revenue during the

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operation period (mainly the ticket revenue and government subsidies).

The second type is the overall investment and financing mode of construction projects, that is, the government selects one social capital company and the designated government company to set up the project company by means of bidding. The project company is responsible for the investment and construction of the project as a whole (including civil engineering, mechanical and electrical equipment) . After the completion of the project, the project company is responsible for the operation of the line and is rewarded with revenue during the operation period (major ticketing revenue and government subsidies).

Table 2: The main tasks of urban rail transit construction phase and division of responsibilities

Main tasks	The division of responsibilities				
	Owners of units	Design unit	Supervision unit	Construction unit	Supplier unit
Line design	Make a demand	Implement	-	-	-
Model selection of vehicles	Organization	Design	Consultation	-	Coordination
Land demolition	Organization	Coordination	Check	Implement	-
The line and station construction	Check	Design alteration	Supervision	Organization	-
Equipment procurement	Organization	Coordination	Check	-	Production
Design contact	Organization	In charge	Check	Coordination	Coordination
Model machine production	Check	In charge	Supervision	-	Organization
Leave-factory check and acceptance	Check	In charge	Supervision	Coordination	Organization
Equipment installation	Check	Guidance	Supervision	Implement	Coordination
Equipment debugging	Organization	Guidance	Check	Implement	Coordination
Final acceptance	Organization	Coordination	Implement	Coordination	Coordination

The third type is to build the overall construction + land development model. That is, the government selects the social capital through competitive bidding and sets up the project company with the government appointed company. The project company is not only responsible for the investment and construction of the project as a whole , and also get the development rights along the land line. After the completion of the project, the project company is rewarded mainly through the ticketing revenue, advertising revenue and land development income during the operation period.

Typical applications about three types of packing methods are shown in table 1.

2.2 Urban rail transit construction phase division and key work

No matter what type of urban rail transit construction mode, the construction generally can be divided into four stages: the preparation stage, financing stage, the construction phase and the operation phase (General Administration of Quality Supervision, 2013). To grasp the division of these phases and the key tasks they include is of great significance to the identification of urban rail transit construction phase risks. The main work of each phase is shown in figure 1.

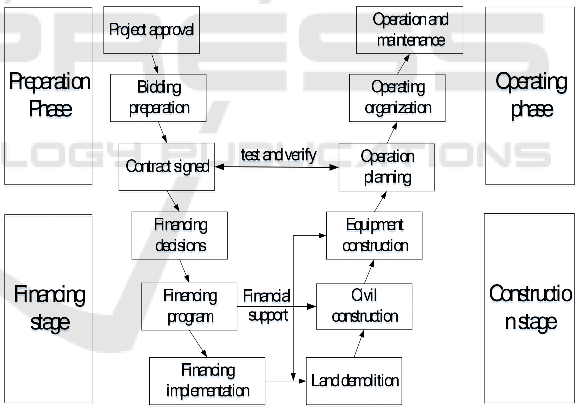

Figure 1: The V diagram of the main works about four stages in the urban rail transit projects

2.3 The Main Work of Urban Rail Transit Construction and Division of Responsibilities

Many articles have been written on the risk analysis during the preparation stage and the financing stage of urban rail transit projects, which will not be repeated here. This article focuses on the analysis of the major risks in the construction phase. One of the important prerequisites for risk identification is to analyse the main tasks in the construction phase

(Yanjun, Xiao, 2014) and the division of responsibilities between the participating units, as shown in table 2.

3 IDENTIFICATION OF MAIN RISKS IN URBAN RAIL TRANSIT CONSTRUCTION STAGE

The risks of urban rail transit construction stage mainly include construction conventional risk, technology risk, management risk, interface risk, political risk, financial risk and legal risk (Hetai, Sheng, 2015). See table 3 for details.

Table 3: Risk identification in construction stage of urban rail transit

Risk classification	Risk factor
Construction conventional risk	The land demolition and compensation(m_1), The increase in finance costs(m_2), Protection of the archaeological relics, Construction force majeure
Technology risk	Improper design(m_3), Improper construction technology(m_4), Improper protective measures, Improper product protection, Harsh construction environment
Management risk	The construction time delay(m_5), The risk of quality control, Safety risk control, Cost overruns
Interface risk	Imported equipment control(m_6), Transfer of existing complex facilities(m_7), No cooperation between departments, System interface mismatch
Political risk	The negative behaviour of government(m_{10}), The local partner unreliability, The government nonpayment
Financial risk	Inflation(m_{11}); interest rate(m_{12}), Rate of foreign exchange
legal risk	Default of contractor(m_8), Standard Specification update(m_9), The bankruptcy of item company, The contract dispute, arbitration, ambiguity

4 THE RISK LEVEL CALCULATION OF CONSTRUCTION RISK FACTORS

The risk level of risk factors can be calculated using analytic hierarchy process (AHP) model. Firstly, experts were invited to score the weight and the importance of the risk factors separately. Then, the weight and the importance of the risk factors were normalized according to the AHP model, and the consistency of the results was verified. Finally, according to the results of the example to determine the level of risk factors.

4.1 Calculation of risk factor weight value ω_i

4.1.1 Construct a comparison matrix

Suppose n risk factors in the construction phase are $C_1, C_2, \cdots, C_n$ and weight of every factor importance is $\omega_1, \omega_2 \cdots, \omega_n$. For any two factors C_i and C_j, let a_{ij} denote the ratio of C_i to C_j (Zhonggeng, Han, 2009), get:

$$a_{ij} = \frac{\omega_i}{\omega_j} (i, j = 1, 2, \cdots, n) \qquad (1)$$

Construct a comparison matrix $A = (a_{ij})_{n\times n}$, get:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & a_{ij} & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \qquad (2)$$

And:

$$A = \begin{bmatrix} \frac{\omega_1}{\omega_1} & \frac{\omega_1}{\omega_2} & \cdots & \frac{\omega_1}{\omega_n} \\ \frac{\omega_2}{\omega_1} & \frac{\omega_2}{\omega_2} & \cdots & \frac{\omega_2}{\omega_2} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\omega_n}{\omega_1} & \frac{\omega_n}{\omega_2} & \cdots & \frac{\omega_n}{\omega_n} \end{bmatrix} \qquad (3)$$

Obviously the matrix is a positive reciprocal matrix, get:

$$a_{ij}>0,\ a_{ij}=\frac{1}{a_{ij}},\ a_{ij}=1\ (i,\ j=1,2,\cdots,\ n) \quad (4)$$

4.1.2 Determination of relative weight vector ω_i

Assume the weight vector is ω_i, According to formula 3, get

$$A=(\omega_1,\omega_2,\ldots,\ \omega_n)^T(\frac{1}{\omega_1},\frac{1}{\omega_2},\cdots,\frac{1}{\omega_n}) \quad (5)$$

$$A\ (\omega_1,\omega_2,\ldots,\ \omega_n)^T=(\omega_1,\omega_2,\ldots,\ \omega_n)^T(\frac{1}{\omega_1},\frac{1}{\omega_2},\cdots,\frac{1}{\omega_n})(\omega_1,\omega_2,\ldots,\ \omega_n)^T$$

$$A\ (\omega_1,\omega_2,\ldots,\ \omega_n)^T=nW \quad (6)$$

This shows that $(\omega_1,\omega_2\ldots,\ \omega_n)^T$ is the eigenvector of matrix A, and n is the eigenvalue.

According to formula 3, A is a positive reciprocal matrix, the knowledge of linear algebra shows that the positive reciprocal matrix has a property $\lambda_{max}=n$, so:

$$A\ (\omega_1,\omega_2,\ldots,\ \omega_n)^T=\lambda_{max}(\omega_1,\omega_2,\ldots,\ \omega_n)^T \quad (7)$$

$(\omega_1,\omega_2\cdots,\ \omega_n)^T$ is the eigenvector corresponding to λ_{max}.

4.2 Calculation of importance value y_i of risk factors

According to the five Likert Scale (Weiya, Hao, 2012), the importance of risk factors is scored, and the importance of the risk factors given by the experts is k, as shown in table 4.

Table 4: K scores and their meanings

k	Likert scale score meaning
1	"Very unimportant"
2	" Unimportant"
3	"Generally important"
4	"Important"
5	"Very important"

Then, use weighted average method to calculate the y_i values about importance of the risk factor , the formula is as follows:

$$y_i=\frac{\sum_{k=1}^{5}k\times n_k}{5} \quad (8)$$

Where y_i is the average of the i number risk factor importance; n_k is the number of experts with the marking score of k.

4.3 Calculation of risk factor value s_i

Based on the results of the previous two steps, the weight vector ω_i and the importance vector y_i are multiplied together to obtain the risk factor risk degree s_i, the formula is as follows:

$$s_i=\omega_i\times y_i \quad (9)$$

4.4 Consistency test of the result calculation

Under normal circumstances, the judgment matrix obtained may not be the same. However, in practice, it is not absolutely necessary that the coherence be absolutely established, and only require a general agreement. This can be judged by the consistency indicator.

(1) Consistency Indicator CI

$$CI=\frac{\lambda_{max}-n}{n-1} \quad (10)$$

(2) Random Consistency Indicator RI. Generally use the table 5 given value

Table 5: Relationship values between n and RI

n	1	2	3	4	5	6	7
RI	0	0	0.58	0.90	1.12	1.24	1.32

(3) Consistency Ratio Indicator CR

$$CR=\frac{CI}{RI} \quad (11)$$

When CR <0.1, it is acceptable to consider the consistency of the matrix. And get:

$$\lambda_{max}\approx\frac{1}{n}\sum_{k=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n}a_{kj}}(i=1,2,\cdots,n) \quad (12)$$

5 CASE ANALYSIS OF RISK FACTORS

(1) From table 3, 12 risk factors(m_1~m_{12}) are initially selected as samples, 6 experts give the weight value of risk factors (ω_1~ω_6) , and calculate its average value ϖ , the results in table 6.

Table 6: Expert scoring table of weights of risk factors

Risk factor	ϖ	ω_1	ω_2	ω_3	ω_4	ω_5	ω_6
m_1	11.9	10	12.5	15	10	10.5	13
m_2	9.3	8.3	10	12.5	6.7	10	8.3
m_3	9.9	12.5	11.7	10	7.5	10	7.5
m_4	11.3	12.5	10	10	9.2	9.2	16.7
m_5	7.5	6.7	6.7	10	8.3	6.7	6.7
m_6	7.2	6.7	6.7	8.3	6.7	8.3	6.7
m_7	7.4	8.3	5.8	8.3	6.7	6.7	8.3
m_8	6.6	5	9.2	4.2	8.3	6.7	6
m_9	9	10	10	5.8	10	8.3	10
m_{10}	7.7	10	7.5	5.8	6.7	9.2	6.7
m_{11}	6.5	8.3	5	5	8.3	7.5	5
m_{12}	5.6	1.7	5	5	9.2	7.5	5

According to formula 3, using the average value ϖ of the weights given in table 6, a comparison matrix is constructed:

$$A=\begin{bmatrix} \frac{\omega_1}{\omega_1} & \frac{\omega_1}{\omega_2} & \cdots & \frac{\omega_1}{\omega_n} \\ \frac{\omega_2}{\omega_1} & \frac{\omega_2}{\omega_2} & \cdots & \frac{\omega_2}{\omega_2} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\omega_n}{\omega_1} & \frac{\omega_n}{\omega_2} & \cdots & \frac{\omega_n}{\omega_n} \end{bmatrix}=\begin{bmatrix} \frac{11.9}{11.9} & \frac{11.9}{9.3} & \cdots & \frac{11.9}{5.6} \\ \frac{9.3}{11.9} & \frac{9.3}{9.3} & \cdots & \frac{9.3}{5.6} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{5.6}{11.9} & \frac{5.6}{9.3} & \cdots & \frac{5.6}{5.6} \end{bmatrix}$$

The largest eigenvalue of A is （according to MATLAB software calculation）：

$$\lambda_{\max} \approx 12.0000000000000002$$

and get the corresponding eigenvector is：

$$(\omega_1, \omega_2, \cdots, \omega_{12})^T = (0.12, 0.09, \cdots, 0.06)^T,$$

Detailed ω_i in $(\omega_1, \omega_2, \cdots, \omega_{12})^T$ is show in table 8.

(2) 6 experts give the importance value of risk factors ($y_1 \sim y_6$), and calculate its average value $\overline{y}$, the results in table 7.

(3) According to formula 9, ω_i multiplies $\overline{y}_i$ to obtain the level of the risk factor s_i. The calculation results are shown in table 8, and the level of the risk factor can be seen in figure 2.

As show in figure2, these factors have very high risk level, they are the land demolition and compensation (m_1), improper construction technology (m_4), improper design (m_3), the construction time delay (m_5), transfer of existing complex facilities (m_7) , which are the need to focus on prevention and control in construction stage.

Table 7: Expert scoring table on the importance of risk factors

Risk factor	$\overline{y}_i$	y_1	y_2	y_3	y_4	y_5	y_6
m_1	4	1	5	5	5	5	3
m_2	1.67	1	2	1	2	2	2
m_3	2.17	4	1	3	2	1	2
m_4	3.33	4	2	3	3	3	5
m_5	2.33	5	2	1	2	2	2
m_6	1.17	1	1	1	1	1	2
m_7	2.67	3	3	3	2	2	3
m_8	2.17	5	3	1	1	2	1
m_9	1.83	1	2	1	3	1	3
m_{10}	2.17	5	3	2	1	1	1
m_{11}	1.17	2	1	1	1	1	1
m_{12}	1.17	2	1	1	1	1	1

Table 8: The level of risk factor value

Risk factor	ω_i	$\overline{y}_i$	s_i	The level of Risk factor value
m_1	0.12	4	0.48	Very high
m_2	0.09	1.67	0.15	Low
m_3	0.10	2.17	0.22	High
m_4	0.11	3.33	0.37	Very high
m_5	0.08	2.33	0.19	High
m_6	0.07	1.17	0.09	Low
m_7	0.07	2.67	0.19	High
m_8	0.07	2.17	0.16	General
m_9	0.09	1.83	0.16	General
m_{10}	0.08	2.17	0.18	General
m_{11}	0.07	1.17	0.09	Low
m_{12}	0.06	1.17	0.07	Low

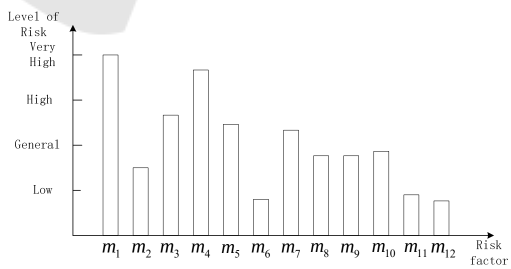

Figure 2: Risk level of risk factor in construction stage

(4) According to the formula 11, do the consistency test, have:

$$CR = \frac{CI}{RI} = \frac{\lambda_{\max} - n}{RI(n-1)} < 0.1$$

among them:

$$\mathrm{RI} = 1.24, \mathrm{n} = 12, \lambda_{\max} \approx 12.0000000000000002$$

Because CR<0.1, the result of this judgment is acceptable.

6 CONCLUSION

(1) The paper analyzes the preconditions of risk analysis in urban rail transit and points out the main work and division of responsibilities between preparation stage, financing stage, construction stage and operation stage.

(2) This paper analyzes various risks of urban rail transit construction, including construction conventional risk, management risk, technology risk, interface risk, political risk, financial risk and legal risk.

(3) This paper adopts AHP model to calculate the degree of risk of each risk factor in the construction stage and points out that the most important risk factors are the land demolition and compensation, improper construction technology, improper design, the construction time delay, transfer of existing complex facilities. Finally, the consistency of the calculated data is tested to ensure the reliability of calculation.

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