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Research on Influencing Factors and Control Measures of Construction Cost Overrun in China's Expressway Projects

Shiwei Chen, Fujian University of Technology, China, & Lulea University of Technology, Sweden

Xingyue Fan, Fujian University of Technology, China

Binqing Cai, Fujian University of Technology, China*

ABSTRACT

In China, the expressways have been built a lot over the past decade. The construction of the expressway suffers from usual cost overrun. There are many factors of different stakeholders influencing the construction cost of expressways, and it is difficult to control all of them. Therefore, it is necessary to identify the key factors causing expressway construction cost overrun and take corresponding cost control measures. In this article, decision-making trial and evaluation laboratory (DEMATEL), interpretative structural modeling method (ISM) and system dynamics (SD) are integrated as DEMATEL-ISM-SD method to identify the key driving factors of expressway construction cost overrun and simulate the interactions of these factors to find the cost control measures. A case in China has been selected as an example to demonstrate how to use the proposed method. As a result, six key factors from different stakeholders are found. Then, six corresponding measures are put forward. This study can provide guidance for expressway construction cost control.

KEYWORDS

Construction cost overrun, DEMATEL, Expressway, ISM, SD

INTRODUCTION

With its rapid development over the decades, China has developed a growing demand for fast transportation, particularly for expressways, a type of wide road among or within cities that allows for fast driving. The Chinese government has proposed a series of policies that promotes the development of expressways. From the *Outline of Building a Strong Transportation Country* to the *National Comprehensive Three-dimensional Transportation Network Plan*, the development goal of fully building an expressway transportation system that satisfies the needs of people and industries was proposed. In October 2022, the 20th National Congress of the Communist Party of China was held and again emphasized the need to accelerate the construction of expressways in China.

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*Corresponding Author

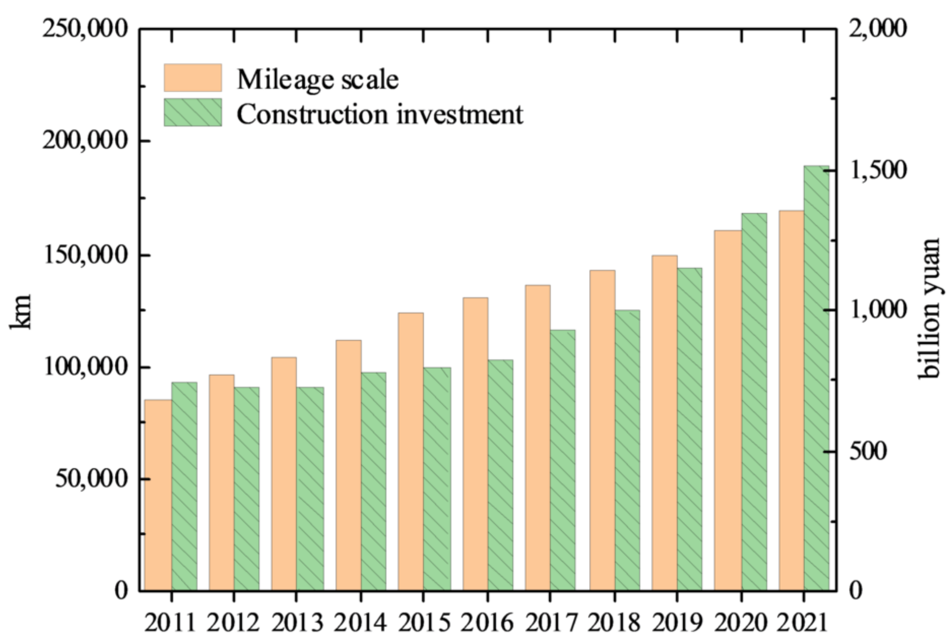
Under the great promotion by the government, a large number of expressways have been built in China for the past ten years. According to the statistics of the Ministry of Transport of the People's Republic of China (2021), the mileage scale and construction investment of expressways increased year by year from 2011 to 2021, as shown in Figure 1. By 2021, the mileage of expressways was 169,100 kilometers, and the total construction investment of expressways was 1515.1 billion yuan.

However, in the great amount of expressway projects in China, there has been found a frequent phenomenon of cost overrun, also known as the "three excesses problems"(Huang, 2011). Since the investment and construction quantity of expressways are very big, the cost overrun can cause severe problems to the civil engineering industry. Therefore, it is necessary and urgent for the personnel in the civil engineering industry and managers of expressway projects to know the influencing factors that cause the cost overrun and take according cost control measures.

Determining how to accurately identify the key influencing factors of expressway construction cost overruns and formulate effective cost control measures is an important issue for construction-related research and practices. For example, Feng et al. (2020) used the risk decomposition structure method to construct a cost risk control index system for East African expressway construction. Mathew et al. (2021) used 118 expressway projects as objects and established a structural equation model to explore the impact relationship and path of project characteristics, project complexity, and delivery risk on project cost growth. Phuong et al. (2020) combined fuzzy set theory and fuzzy clustering analysis and investigated the cost situation of expressway projects under different construction delivery modes based on project characteristics, project complexity, and delivery risk.

Although there has been much research focusing on cost overrun of projects, only a few studies explore the cost overrun of expressway construction in China. These have not explored the issue from a multiple-stakeholders' perspective. Since the natural environment at the construction sites and the stakeholders in China are different from those in other countries, it is necessary to conduct a systematic analysis for such problems existing in China. In addition, the key influencing factors are usually found through the qualitive analysis based on subjective opinions from expert interviews. A quantitative analysis based on interactions among influencing factors of cost overrun is still missed.

Figure 1. Mileage scale and construction investment of China's expressways in 2011-2021



Such lack in quantitative analysis negatively affects the accuracy of the analysis of key influencing factors of cost overrun.

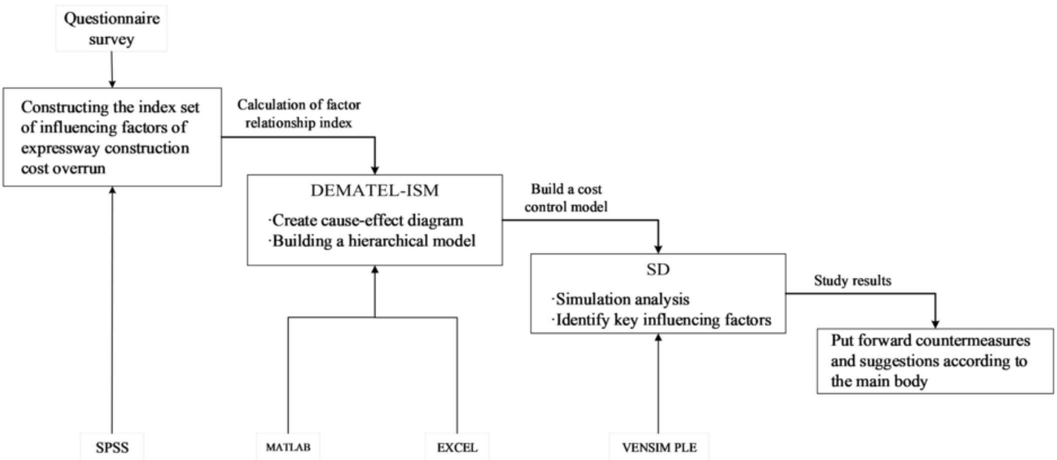
This paper aims to cover the above gaps. This paper combines the Decision-Making Trial and Evaluation Laboratory (DEMATEL), Interpretative Structural Modeling Method (ISM), and System Dynamics (SD) together as the DEMATEL-ISM-SD method to find out the key influencing factors in China's expressway projects from a multiple-stakeholders' perspective. DEMATEL and ISM are used to analyze the interactions among influencing factors of cost overrun in a qualitive way. SD is used to conduct a quantitative analysis for interactions among influencing factors of cost overrun based on the results of DEMATEL and ISM. After the analysis of DEMATEL-ISM-SD, some countermeasures for the cost overrun for different stakeholders in China's expressway projects are put forward. The found countermeasures can provide guidance for different stakeholders of China's expressway projects in cost management practice. The proposed DEMATEL-ISM-SD method can provide a new way to find key influencing factors of cost overrun in expressway projects.

RESEARCH METHOD

DEMATEL is a system of science methodology. By using graph theory and matrix tools, the cause-effect logical relationships and importance between factors in a system can be determined. Solving complex problems and identifying key elements in the system can also be simplified. This method has been widely used in business management, project management, new media development, information technology development, and ecological civilization construction (Hsu, 2013; Zhang, 2019), but it alone cannot simplify the system structure. Interpretative Structural Modeling Method (ISM) is a structural analysis method, which uses directed diagrams to analyze the hierarchical structure of elements in a complex system, simplify its complex relationships, and clearly and intuitively reflect the relationship between elements (Attri et al., 2013), which can effectively make up for the shortcomings of DEMATEL that cannot simplify the system structure. However, the DEMATEL-ISM method can only qualitatively determine the key elements in the system, and it is difficult to reflect the degree of interaction between the influencing factors in the complex system. System Dynamics (SD) is a method that combines system science theory and computer simulation to study the structure and function of complex systems (Zhu et al., 2022). SD can link the factors within the system structure for dynamic analysis, clarify the interrelationship between the factors of the system in the form of feedback loop, and quantitatively reflect the degree of influence between factors (Huang et al., 2020; Shih et al., 2014), which can make up for the shortcomings of the DEMATEL-ISM method that cannot quantitatively analyze the degree of influence between factors. Therefore, this study proposes a method that integrates the DEMATEL, the ISM, and the SD to analyze the factors and control measures of the cost overrun in expressway construction. DEMATEL can determine the causal logic relationships among factors and their importance in the system, but cannot analyze the mechanisms of the interactions among influencing factors. To overcome this limitation, ISM is used to simplify complex relationships and identify the relationships among factors. SD can quantitatively analyze the internal factors of the system and conduct dynamic analysis by linking various factors with feedback loops and equations to determine the specific degree of influence among system factors.

The framework of the proposed method is shown in Figure 2 and described as follows: Firstly, the factors influencing the cost overrun of expressway construction are identified through questionnaires and literature review. Secondly, the DEMATEL-ISM method is used to establish a hierarchical structure model of the influencing factors and to identify the key factors and their causal relationships. Thirdly, based on the results of DEMATEL-ISM, a SD model is constructed to simulate and analyze the key influencing factors of expressway construction cost. Finally, cost control measures are proposed for expressway construction cost control based on the simulation results.

Figure 2. Methodology framework



DEMATEL-ISM METHOD FOR IDENTIFYING KEY INFLUENCING FACTORS

Identifying the Factors That Influence the Construction Cost of Expressways

The factors are collected from literature, including Lei et al. (2010), Qiu et al. (2009) and Susanti et al. (2021), as shown in Table 1. Then, a questionnaire survey was designed to understand the occurrence probability of each influencing factor and the degree of influence on the project cost from the employees of various stakeholders who have been engaged in expressway construction for a long time in Fujian Province, and to identify the factors affecting the cost from various stakeholders for the construction related employees in Fujian Province. The questionnaire was divided into two parts. The survey objects are the staff engaged in expressway construction at present, and are mostly employees engaged in construction-related units in Fujian Province. The online survey mode was adopted, and 303 questionnaires were sent out, 290 of which are valid questionnaires, among which the construction unit accounts for 65.58%, the construction unit accounts for 17.49%, the design unit accounts for 6.27%, and other units account for 10.57%. The first part of the survey was to analyze the basic situation of the respondents. The purpose of this part was to have a more comprehensive understanding of the working conditions and nature of each interviewee. Six questions are set up for the survey: gender, age, education level, working years, the nature of the post, and the type of work unit. In the second part, according to the influencing factors of project cost overrun, the probability of factors and the degree of influencing project cost are investigated from four aspects: the owner, the designer, the contractor, and the construction external conditions. This part identifies the influencing factors of project cost from the owner, contractor, and other aspects, among which there are seven factors related to the owner, five factors related to the designer, eleven factors related to the contractor, and five factors related to other aspects, such as government and market.

This paper uses SPSS26.0 to test the reliability and validity of the questionnaire data. The reliability coefficient is Cronbach α coefficient. The greater the reliability coefficient is, the higher the internal consistency is, and the more reliable the results of the questionnaire survey are. Usually, the value of Cronbach's α coefficient is between 0 and 1. If the α coefficient does not exceed 0.6, it is generally considered that the internal consistency reliability is insufficient and should be improved; 0.7-0.8 indicates a comparable reliability. The reliability of the scale is very good when it reaches 0.8-0.9 (Chai, 2010). Validity analysis through the KMO value and Bartlett sphericity test value to judge, KMO value greater than 0.6, significance value less than 0.05 to prove that the questionnaire has a good degree of validity and accuracy, can be carried out after the work of modeling analysis.

Results of the Cronbach α coefficients were 0.971 and 0.972 respectively, both above 0.9, which indicated that the results obtained by this questionnaire had high reliability and validity. The obtained KMO values were 0.963 and 0.965, respectively, both greater than 0.6, and the significance value in the Bartlett sphericity test was 0.000, less than 0.05. Thus, indicating that the item design of this questionnaire was reasonable, and the questionnaire had high validity and accuracy.

The collected questionnaire data is calculated to analyze the probability of each influencing factor and the average value of the influence degree on the construction cost overrun. Then, the risk degree of each influencing factor according to the results of the two types of data are calculated and used to divide all the collected influencing factors into high, medium, and low risk degrees, as shown in Table 2 (Chen et al., 2011). In the questionnaire, the expert may be uncertain and hesitant about the level of risk for some factors (Zuo et al., 2019; Zuo et al., 2020). Inspired by Yu et al. (2021) and Wan et al. (2013), the analysis of the questionnaire in this paper is conducted based on the Fuzzy theory. In combination with the actual project situation, the influencing factors with low risk are not analyzed in depth in this study. In actual management, managers should take reasonable precautions against them. This questionnaire identified fifteen influencing factors, and constructed the index set of influencing factors of highway construction cost overrun in Fujian Province, and explained the factors through the expert interview.

IDENTIFYING CAUSAL RELATIONSHIPS USING DEMATEL-ISM

DEMATEL-Based Four-Degrees Calculation

(1) Build directly affects the matrix. Using the method of expert scoring, ten experts (including owners, contractors, designers, and university teachers) were selected to quantitatively score the interrelationship between the identified factors and judge the degree of direct relationship between the fifteen factors, which was expressed by the numbers 0, 1, 2, 3, and 4 (0-no influence between the two factors; 1-the influence relationship between the two factors is weak; 2- the influence relationship between the two factors is general; 3-strong influence relationship between the two factors; 4-the relationship between the two factors is very strong (Uygun et al., 2015)). After sorting out the scoring results, the average score value is taken as the degree of direct influence of the corresponding factors, so as to construct the direct impact matrix $X = \left(x_{ij}\right)_{n*n}$, (See Table 3).

(2) Normalization directly affects the matrix. Using Formula (1), the sum of the values of each row in X is found and the maximum value of the sum of each row is taken. Each element in X is divided by the maximum value for normalization to obtain the normalized impact matrix $Y = \left(y_{ij}\right)_{n*n}$.

$$Y = \frac{1}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} x_{ij}} X \tag{1}$$

(3) Calculate the combined impact matrix. The inverse of the difference between the identity matrix and the normalized influence matrix is found by Formula (2) and multiplied by the normalized influence matrix to obtain the comprehensive impact matrix G, where is the identity matrix E.

$$G = \left(Y + Y^1 + Y^2 + Y^3 + \ldots + Y^n\right) = \sum_{n=1}^{\infty} Y^n = Y * \left(E - Y\right)^{-1} \tag{2}$$

Table 1. Index system a of influencing factors of expressway construction cost overrun

Main Body (Level 1 Index B)	Cost Influencing Factors (Secondary Index C)	Factor Meaning
Proprietor B1	Land acquisition and demolition takes too much time C1	The cost of land removal compensation and the loss of too much time for land acquisition and removal due to insufficient communication and other reasons affect the project progress
	Lack of investment decision-making ability C2	When estimating the project, the natural and social conditions of the construction area are not fully considered, and the feasibility analysis is insufficient
Designer B2	Insufficient preliminary investigation C3	The results of the investigation deviate from the actual situation
	Frequent design changes C4	Frequent design changes due to unexpected ground conditions, unrealistic requirements, inadequate planning, and poor design
	Improper selection of construction design scheme C5	Selection of design schemes such as bridge length, tunnel length, bridge-tunnel ratio, and construction route
	The coordination ability of the designer is insufficient C6	Insufficient information transmission, communication, and coordination with the owner and the contractor
Contractor B3	Low price due to bidding competition C7	The bid price is too low, even lower than the cost price, increasing the risk of project construction cost
	Improper selection of construction scheme C8	The construction technology level and environmental impact were not fully considered when selecting the construction scheme, and the best construction scheme was not selected
	Poor management professionalism C9	The management personnel have weak professional knowledge or lack of experience in expressway project management, and lack of mastery and application of advanced management theory
	Inadequate material control C10	Control of material procurement, transportation, and storage
	Poor quality subcontractors and suppliers C11	Management level and credit status of subcontractors and suppliers
	Insufficient coordination capacity of the contractor C12	Insufficient information transmission, communication, and coordination with the owner and the designer
External factors B4	Unpredictable site conditions C13	Unpredictable climatic conditions, geological conditions, geological disasters, etc.
	Emergencies during construction C14	Reports or complaints from the masses, excavation of underground cultural relics, etc.
	Policy implications C15	Impact of national policies on land, financial budget, taxation, environmental protection and safety, and relevant requirements of local government

(4) “Four degrees” calculation. The impact degree D_i was obtained by summing up the values in each row of the matrix. The affected degree F_i was obtained by summing up the values in each column of the matrix. The centricity M_i of each influencing factor is obtained by adding D_i and F_i, and the causality degree of each influencing factor is N_i by subtracting D_i and F_i. If $N_i > 0$, the factor is considered a causal factor, and if $N_i < 0$, the factor is considered a resulting factor (Wang et al., 2021). The results of the four-degree calculation are shown in Table 4. Based on the centrality and cause degrees of each factor, a cause-result diagram of the factors affecting the overruns in expressway construction costs was created, as shown in Table 3.

Table 2. Risk degree of influencing factors according to the questionnaire

Influencing Factors	Frequency Index	Impact Index	Degree of Risk
Excessive time lost in land acquisition and demolition affects project progress	0.6234	0.6208	high
Inadequate investment decision making capacity	0.4017	0.4300	medium
Lack of preliminary survey	0.4868	0.5323	high
Frequent design changes	0.4967	0.5317	high
Improper selection of construction design solutions	0.3944	0.4531	medium
Inadequate design-side coordination	0.4498	0.4954	medium
Tender competition leads to low prices	0.5614	0.5871	high
Improper selection of construction solutions	0.3983	0.4465	medium
Poor professionalism of management staff	0.3944	0.4314	medium
Insufficient material control	0.3614	0.4023	medium
Inferior subcontractors and suppliers	0.4036	0.4815	medium
Inadequate contractor coordination	0.3535	0.4058	medium
Unpredictable site conditions	0.4135	0.4624	medium
Policy Impact	0.3766	0.4399	medium
Unforeseen events during construction	0.3726	0.4083	medium

Table 3. Direct impact matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	0	3	1	2	1	2	1	0	0	0	0	2	1	2	2
C2	3	0	2	2	3	3	3	3	2	2	2	3	2	0	0
C3	3	1	0	3	3	0	2	2	0	3	2	0	2	0	2
C4	0	0	1	0	2	2	1	2	0	2	0	2	1	1	1
C5	2	2	1	1	0	1	0	2	0	1	1	1	1	0	0
C6	2	0	1	2	2	0	0	1	0	1	1	0	1	2	0
C7	0	1	0	0	0	1	0	3	1	3	3	1	1	1	0
C8	0	1	0	0	2	1	2	0	1	1	0	1	1	0	0
C9	1	0	0	0	0	3	1	2	0	2	3	3	2	3	0
C10	0	2	0	0	2	0	1	1	0	0	0	0	2	0	0
C11	0	1	0	0	0	3	2	2	2	2	0	3	0	2	0
C12	2	0	1	2	2	0	0	1	2	1	1	0	1	2	0
C13	2	0	1	1	1	1	0	1	0	0	1	1	0	1	0
C14	2	0	0	0	1	1	0	0	0	0	0	1	0	0	2
C15	3	1	0	0	0	2	1	0	0	0	2	2	0	2	0

(5) Plot the cause-effect diagram. In order to visually show the influence of each influencing factor in the system on the expressway construction cost, the cause-result diagram of the influencing

Table 4. Results of the "four degrees"

Factors	Degree of Influencing	Degree of Being Influenced	Degree of Centrality		Degree of Reason
	D_i	F_i	M_i	ranking	N_i
C1	1.1556	1.2501	2.4057	2	-0.0944
C2	1.9264	0.8205	2.7469	1	1.1060
C3	1.4582	0.5496	2.0078	7	0.9087
C4	0.9026	0.8672	1.7698	10	0.0353
C5	0.8953	1.2620	2.1573	4	-0.3668
C6	0.8065	1.2490	2.0555	5	-0.4426
C7	0.9259	0.8744	1.8004	9	0.0516
C8	0.6572	1.2673	1.9245	8	-0.6101
C9	1.1873	0.5396	1.7269	11	0.6477
C10	0.5509	1.1220	1.6729	12	-0.5712
C11	1.0586	0.9537	2.0123	6	0.1049
C12	0.9523	1.2490	2.2013	3	-0.2967
C13	0.6499	0.9694	1.6194	13	-0.3195
C14	0.4563	1.0211	1.4775	14	-0.5648
C15	0.8622	0.4503	1.3125	15	0.4119

factors of expressway construction cost is drawn according to the index values of the centrality and causal degree of each factor in the calculation result, as shown in Figure 3.

Constructing a Multi-Level Hierarchical Interpretive Structure Model for Factors

(1) Determine the overall impact matrix. The overall influence matrix H is obtained by adding the comprehensive influence matrix G and the identity matrix E using the Formula (3).

$$H = G + E \tag{3}$$

(2) Determine the reachability matrix. The reachability matrix represents the relationship between the fifteen factors. By using Formula (4), a threshold λ is introduced to process the elements in H to obtain a reachability matrix $K\left(K = \left[k_{ij}\right]_{n*n}\right)$. In the reachability matrix, 1 indicates a strong relationship between two factors, and 0 indicates a weak relationship between two factors (Wang et al., 2018).

By introducing a threshold of λ, the relationship between factors with weak influence can be deleted, simplifying the hierarchical structure and making the structure more concise (Zhou & Zhang, 2008). Threshold λ is determined by taking the average of the values in the overall impact matrix (Shakeri & Khalilzadeh, 2020). In this study, the average of the values in the overall impact matrix is calculated to be 0.13, threshold $\lambda = 0.13$. The reachable matrix K of the factors affecting the construction cost of expressway is obtained by using Formula (4), as shown in Table 5.

Figure 3. Cause-result chart of influencing factors of expressway construction cost overrun

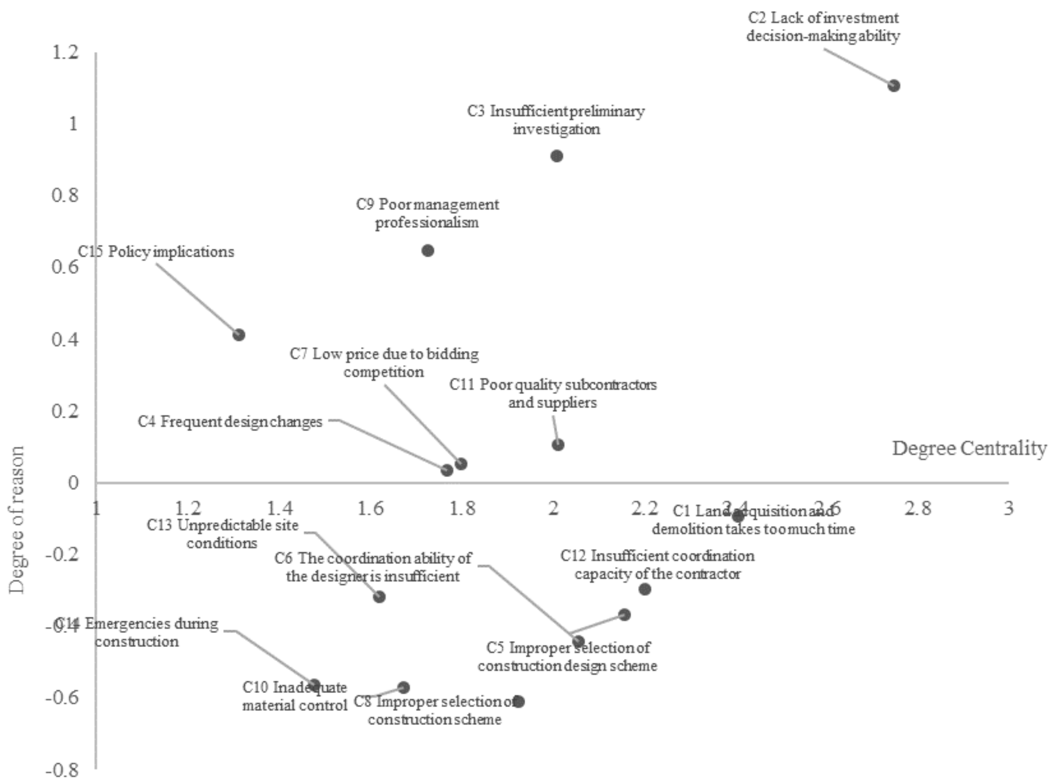


Table 5. Reachability matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
C2	1	1	0	1	1	1	1	1	0	1	0	1	1	0	0
C3	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0
C4	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1
C5	0	0	1	1	1	1	0	0	0	0	0	1	0	0	0
C6	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
C7	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
C8	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
C9	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0
C10	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1
C11	0	0	0	1	0	1	0	0	0	0	1	1	0	0	0
C12	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
C13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
C14	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
C15	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1

$$k_{ij} = \begin{cases} 1, h_{ij} \geq \lambda(i, j = 1, 2, \ldots, n) \\ 0, h_{ij} < \lambda(i, j = 1, 2, \ldots, n) \end{cases} \tag{4}$$

(3) Building a Hierarchical Model. According to the reachable matrix K, the reachable set and the prior set are identified, and the fifteen identified factors affecting the construction cost of expressways are classified. The reachable set refers to a set of all elements whose element value is 1 in the row corresponding to the factor C_i in the reachable matrix K, as shown in Formula (5). The leading set refers to a set of all elements in the reachability matrix K, where the column factor value corresponding to the factor C_i is 1, as shown in the Formula (6). If the reachable set and the preceding set satisfy the Formula (7), all the influencing factors of the highest level (L1) can be obtained, and then the row and column of the L1 level element are deleted and the above operation is performed until all factors are stratified (Zhang et al., 2015).The division results of each element are shown in Table 6. According to the hierarchical results, the hierarchical diagram is drawn, and finally the multi-level hierarchical interpretation structure model of the influencing factors of expressway construction cost is obtained, as shown in Figure 4.

$$R(C_i) = \left\{C_j \in C \middle| r_{ij} = 1\right\} \tag{5}$$

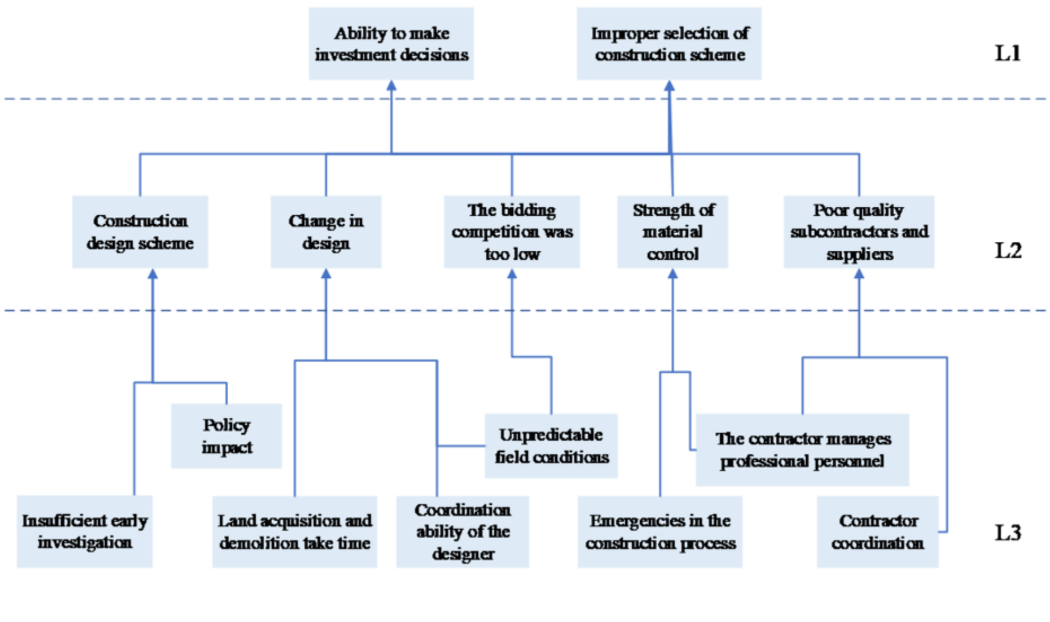
$$A(C_i) = \left\{C_j \in C \middle| r_{ji} = 1\right\} \tag{6}$$

$$R(C_i) \cap A(C_i) = R(C_i) \tag{7}$$

Table 6. Hierarchical results of influencing factors of expressway construction cost overrun

C_i	**Reachable Set** $R(C_i)$	**Precedence Set** $A(C_i)$	**Intersection** $R(C_i) \cap A(C_i)$	**Level**
1	1,15	1,2,15	1	L 3
2	1,2,4,5,6,7,8,10,12,13	2,8	2,8	L 1
3	3,4,5,10	3,5	3,5	L 3
4	4,5,11	2,4,5,11	4,5,11	L 2
5	3,5,6,12	2,3,5	3,5	L 2
6	5,6	2,6,11	6	L 3
7	7,10	2,7,10	7,10	L 2
8	2,8	2,8	2,8	L 1
9	9,10,11,12	9,12	9,12	L 3
10	7,10,13,15	2,3,7,9,10	10	L 2
11	6,11,12	9,111,14	11	L 2
12	9,12	2,9,11,12	9	L 3
13	13	2,10,13	13	L 3
14	11,14	14	14	L 3
15	1,15	1,4,10,15	1,15	L 3

Figure 4. Hierarchical structure model of influencing factors of expressway construction cost overrun



In order to reduce the complexity of the system and ensure the operation effect of the system, according to the hierarchical structure model and the calculation results of DEMATEL, the influencing factors of the construction cost of expressway in Fujian Province are divided into three types: endogenous factors, exogenous factors, and negligible factors. The three types of factors can be used as the system boundary of the system dynamics model. Endogenous factors include labor cost, material cost, machinery cost, construction rate, etc. Exogenous factors include construction technology level, construction technology, land acquisition and relocation time, management level, etc. Negligible factors include policy influence, unforeseen field conditions, etc. The system boundary is divided to provide a basis for subsequent research.

A SYSTEM DYNAMICS MODEL

A Cost Control Model for Expressway Construction

After identifying the key factors causing cost overruns in expressway construction using the DEMATEL-ISM method and developing a hierarchical structure model, a SD model was constructed to control the construction cost of expressways. The model simulates the dynamic impact of the key factors on cost overruns and provides recommendations for cost control. Based on the results of the DEMATEL-ISM calculation, a simulation model for cost control in expressway construction was established. The main equations of the model are presented in Table 7 (due to space limitations, auxiliary variable formulas are not included), and the system flowchart is shown in Figure 5.

Model Simulation and Analysis

Simulation Scenario Settings

In this study, six independent variables are selected for simulation based on their high centrality ranking, their classification in levels L1 and L2, and their relevance within the system boundary. These variables include bidding price, frequency of design changes, management level, land acquisition

Table 7. Description of main equations

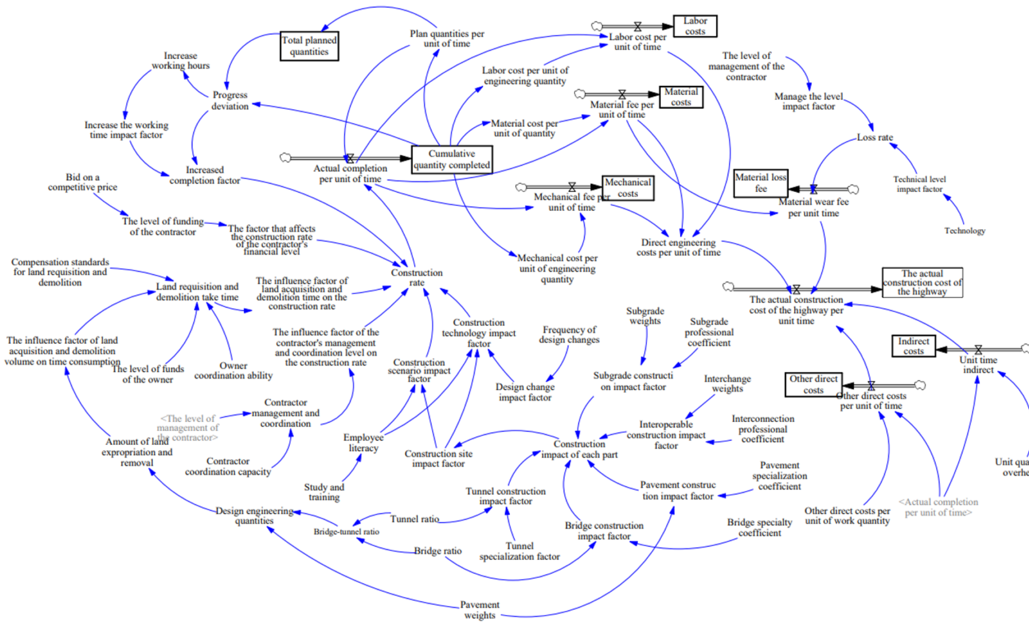
Variable	Name	Unit	Variable Equations
Level variable	Cumulative quantity completed	m	INTEG(Actual completion per unit of time,0)
	The actual construction cost of the expressway	Million yuan	INTEG(The actual construction cost of the expressway per unit time,0)
Rate variable	Actual completion per unit of time	m	construction rate * plan quantities per unit of time
	Plan quantities per unit of time	m	IF THEN ELSE(cumulative quantity completed <=329.54,25.35,IF THEN ELSE(cumulative quantity completed <=5898.58,91.29,IF THEN ELSE(cumulative quantity completed <=6755.84,65.94,IF THEN ELSE(cumulative quantity completed <=6790,34.11,0))))
	The actual construction cost of the expressway per unit time	Million yuan	Direct engineering costs per unit of time + Unit time indirect + Other direct costs per unit of time + Material wear fee per unit time
Auxiliary variables	The actual construction cost of the expressway per unit time	Million yuan	Direct engineering costs per unit of time + Unit time indirect + Other direct costs per unit of time + Material wear fee per unit time
	Technology level impact factor	Dmnl	WITH LOOKUP (Technology level, ([(0,0)- (10,10)], (0.5,0.45), (0.6,0.35), (0.65,0.3), (0.7,0.25), (0.75,0.2), (0.8,0.15), (0.85,0.1), (0.9,0.05), (0.95,0.03), (1,0)))
	Construction speed	Dmnl	(0.2397 × contractor's funding level on construction rate impact factor + 0.3405 × impact factor of land acquisition and demolition time on construction rate + 0.1366 × construction technology impact factor + 0.1789 × contractor management and coordination level influence factor on construction rate + 0.1043 × construction program impact factor) × completion factor after increase
	Management level impact factor	Dmnl	WITH LOOKUP (Contractor management level, ([(0,0)-(10,10)], (0.5,0.45), (0.6,0.35), (0.7,0.25), (0.8,0.15), (0.9,0.05), (1,0)))
	Design change impact factor	Dmnl	WITH LOOKUP (Frequency of design changes, ([(0,0)-(10,10)], (0,1),(0.2,0.9), (0.4,0.8), (0.6,0.7), (0.8,0.6), (1,0.5)))
	Contractor funding level	Dmnl	WITH LOOKUP (Bidding competition price, ([(0,0)-(10,10)], (0.5,0.5), (0.6,0.6), (0.7,0.7), (0.8,0.8), (0.9,0.9) ,(1,1)))

and demolition time, bridge-tunnel ratio, and contractor coordination ability. Expert interviews were conducted to set the ranges of values for each variable. Land acquisition and demolition time, bridge-tunnel ratio, and frequency of design changes range from 0 to 1, while management level, bidding price, and contractor coordination ability range from 0.5 to 1. A value closer to 1 indicates a longer land acquisition and demolition time, a higher bridge-tunnel ratio, a higher frequency of design changes, a higher management level, a higher contractor coordination ability, or a higher bidding price. Conversely, a value further away from 1 indicates a shorter land acquisition and demolition time, a lower bridge-tunnel ratio, a lower frequency of design changes, a lower management level, a lower contractor coordination ability, or a lower bidding price.

Simulation Results and Analysis

This article conducts simulation analysis on six key factors, including the frequency of design changes, bidding price, management level, land acquisition and demolition time, bridge-tunnel ratio, and contractor coordination ability. The simulation results are shown in Figure 6, where Scenario 1

Figure 5. SD model for expressway construction cost control



is set as the baseline representing the actual situation. When one factor changes, the values of other factors remain the same as in the baseline scenario.

An analysis of the maximum and minimum fluctuations of the expressway construction cost under different scenarios shows that the actual construction cost of the expressway increases as land acquisition and demolition time, bridge-tunnel ratio, and frequency of design changes increase, and as management level, bidding price, contractor coordination ability, and bridge-tunnel ratio decrease. The order of the magnitude of change from small to large is: contractor coordination ability (11.37%), land acquisition and demolition time (13.62%), frequency of design changes (15.78%), bidding price (16.76%), bridge-tunnel ratio (24.87%), and management level (25.03%).

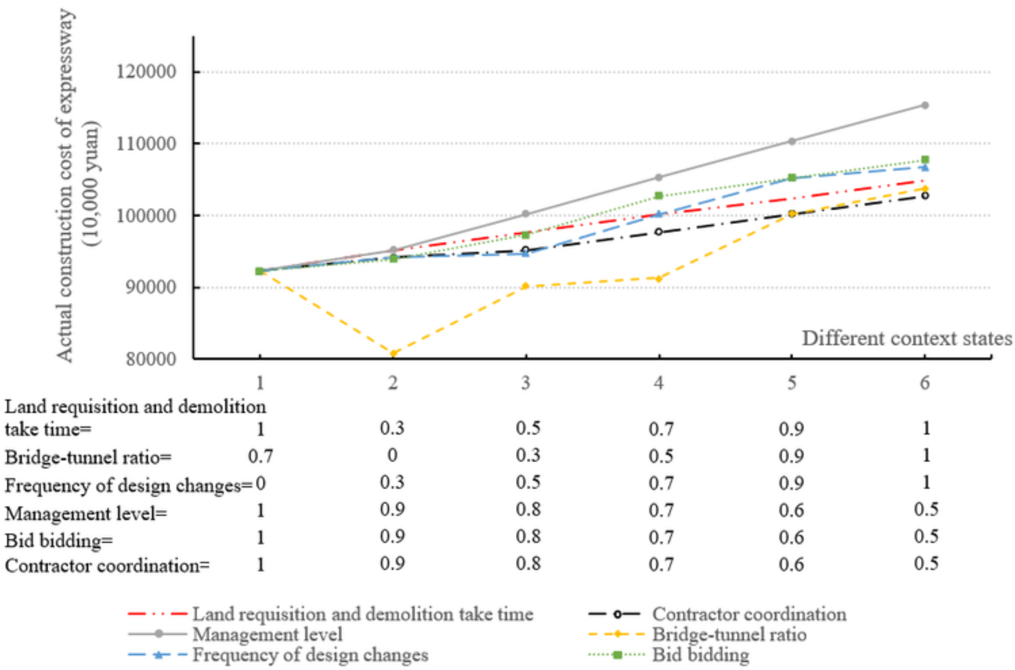
The results indicate that among the six influencing factors, the bridge-tunnel ratio and management level have a greater impact on the construction cost of the expressway, followed by bidding price and frequency of design changes. The impact of land acquisition and demolition time and contractor coordination ability on the construction cost of the expressway is relatively small, but should not be ignored. From the perspective of the various stakeholders, the factors related to contractors and designers have a greater overall impact on the actual construction cost of the expressway, while the factors related to the owner have a lower overall impact on the construction cost of the expressway.

CONTROL MEASURES FOR EACH STAKEHOLDER

Based on the results of the analysis of the identified influencing factors and their impact levels, control measures are proposed from the perspective of each party:

(1) The contractor should focus on improving their own management and coordination level, and make a reasonable bid during the tender process. The management level of the contractor has the greatest impact on construction costs and needs to be improved urgently. One of the main reasons for the low construction management level is the fragmentation and extensive nature of

Figure 6. Simulation result diagram



traditional manual management. To solve this problem, contractors can respond to the national direction of intelligent construction, introduce digital technology to monitor the project process in real time, and improve cost control accuracy and efficiency. Secondly, the bid price also has a certain impact on construction costs and should be acknowledged by contractors. Therefore, the contractor should conduct a comprehensive risk assessment of the project, based on the design and technical information in the bidding documents, before tendering and make a reasonable bid. At the same time, they should refuse malicious bidding and excessive price reduction. In addition, to improve the contractor's coordination ability, companies should strengthen their employees' communication awareness, promote communication and coordination within the project, between the company and the project, and between companies, and build a project information exchange platform to achieve information and resource sharing.

(2) The design party should control the bridge-tunnel ratio and reduce design changes. The bridge-tunnel ratio has a great impact on construction costs. From the perspective of construction costs, the design party should control the bridge-tunnel ratio as much as possible, if it is not necessary. A full survey should be conducted before design, the best route should be selected, and the bridge-tunnel ratio should be optimized. On the other hand, the design party should try to avoid design changes. A design management team can be established to discuss high-quality design schemes, use information technology for 3D design modeling and review, promptly discover and handle problems, and reduce design changes caused by human error.

(3) The owner should strengthen land acquisition and demolition management. Lengthy land acquisition and demolition times also have a certain impact on construction costs. Therefore, the owner should understand the current policies and market conditions in advance, plan the land acquisition and demolition compensation amount reasonably, accurately calculate the land acquisition and demolition costs, and explore more effective land acquisition and demolition

plans. At the same time, complete on-site data should be collected, and detailed surveys of the construction site should be conducted to improve the efficiency of land acquisition and demolition.

CONCLUSION

China's expressway development has grown rapidly, and the phenomenon of cost overruns in expressway construction is common. Although there has been much research on cost control, few have focused on expressways in China and lack of systematic analysis and effective control strategy on the interaction between the influencing factors of expressway construction cost. Due to insufficient analysis of the factors affecting expressway construction costs in China, cost overruns in expressway construction occur frequently.

In order to fill this research gap, this study proposed a coupling DEMATEL-ISM-SD method of expressway construction cost control, based on the proposed method, to analyze the causes of expressway construction cost overrun and the interaction between the influencing factors of stakeholders and the particular factors that impact the expressway construction cost; the findings of this study also provide a reference for related industries of scientific cost control.

The results show that the ratio of bridges and tunnels and management level have a greater impact on expressway construction costs, followed by bidding competitiveness and design change frequency, while the time-consuming land acquisition and demolition and the coordination ability of contractors have a relatively small impact, but should not be ignored. From the perspective of various stakeholders, the factors related to contractors and designers have a greater overall impact on the actual construction costs of expressways, while the factors related to owners have a lower overall impact. This indicates that in expressway construction, attention should be focused on the role of contractors and designers in controlling costs, and different control measures should be adopted according to the different interests of stakeholders for multi-party cooperation in cost control. Specific control measures include: contractors should pay attention to their own management and coordination level and make reasonable bids when bidding; designers should control the ratio of bridges and tunnels and reduce design changes; and owners should strengthen land acquisition and demolition management. This study can provide a more reliable basis for project managers of expressway construction to develop effective cost control measures and provide new ideas and measures for active cost control.

However, this study also has some shortcomings. This study only identifies the key influencing factors of expressway construction cost from the perspective of the three important participants, namely, the owner, the contractor, and the designer, and does not stand in the perspective of all participants. Therefore, the identified key influencing factors are not comprehensive enough. In the future, all participants in expressway construction should further identify the key factors of expressway construction cost comprehensively.

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COMPETING INTERESTS

The authors of this publication declare there are no competing interests.

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APPENDIX 1

Survey on the Factors Influencing Cost Overruns in Fujian Expressway Construction Projects

Dear Sir/Madam:

Hello, thank you for filling out this questionnaire in your busy schedule. The purpose of this questionnaire is to understand the risk factors affecting the cost of expressway construction projects in Fujian Province. This questionnaire is anonymous, the results obtained are for academic research only, all data are strictly confidential. The questionnaire takes about 5 minutes to fill in, please feel free to provide your answers.

PART I. BASIC INFORMATION

1. Gender:
2. Age:☐Under 25 ☐26-35 ☐36-45 ☐46-55 ☐55 and above
3. Academic qualifications:
☐Junior college and below ☐Undergraduate ☐Master ☐Doctor
4. Your working years in the construction industry:
☐Under 5 years ☐6-10 years ☐ 11-15 years ☐ 16-20 years ☐ more than 20 years
5. What is the nature of your job:
☐Management staff (project or department manager, deputy manager, chief engineer category)
☐Technical staff (e.g. civil engineers, construction workers, safety officers, surveyors)
☐Other professional staff (designers, contract administrators, information clerks, cost engineers)
6. Type of work unit:
☐Construction unit ☐Construction unit ☐Supervisory unit ☐Design Unit ☐Survey unit ☐Other

Part II. Probability and Impact of Risk Factors

This section focuses on assessing the probability and impact of risk factors. Please fill in your answers in the Table A1. Probability refers to the level of likelihood that a risk will occur. Impact refers to the effect on the project objectives once the risk event occurs. Probability and impact are each divided into five components, with a score to determine the magnitude of the probability of occurrence and the level of impact. The probability of occurrence and the degree of impact to the project cost are divided into five levels: very low, low, medium, high, and very high.

Table A1. Questionnaire of influencing factors

Risk Category	Very Low	Low	Medium	High	Very High
Owner's Side					
1. Excessive time lost in land acquisition and demolition affects project progress					
Probability of occurrence					
Impact on project costs					
2. Delayed payment by the owner					
Probability of occurrence					
Impact on project costs					
3. Inadequate regulation					
Probability of occurrence					
Impact on project costs					
4. Unreasonable schedule requirements					
Probability of occurrence					
Impact on project costs					
5. Inadequate investment decision making capacity					
Probability of occurrence					
Impact on project costs					
6. Unclear contract provisions					
Probability of occurrence					
Impact on project costs					
7. Inadequate owner coordination					
Probability of occurrence					
Impact on project costs					
Design Institute					
8. Lack of preliminary survey					
Probability of occurrence					
Impact on project costs					
9. Frequent design changes					
Probability of occurrence					
Impact on project costs					
10. Improper selection of construction design solutions					
Probability of occurrence					
Impact on project costs					
11. Inadequate design-side coordination					
Probability of occurrence					
Impact on project costs					
12. Lack of timely delivery of drawings					
Probability of occurrence					
Impact on project costs					

continued on following page

Table A1. Continued

Risk Category	Very Low	Low	Medium	High	Very High
Contractor					
13. Tender competition leads to low prices					
Probability of occurrence					
Impact on project costs					
14. Improper selection of construction solutions					
Probability of occurrence					
Impact on project costs					
15. Unreasonable construction organization structure setting					
Probability of occurrence					
Impact on project costs					
16. Poor professionalism of management staff					
Probability of occurrence					
Impact on project costs					
17. Insufficient proficiency of employees					
Probability of occurrence					
Impact on project costs					
18. Improper material selection					
Probability of occurrence					
Impact on project costs					
19. Insufficient material control					
Probability of occurrence					
Impact on project costs					
20. Improper selection of construction machinery (including sources, models, quantities, etc.)					
Probability of occurrence					
Impact on project costs					
21. Mechanical use in poor condition					
Probability of occurrence					
Impact on project costs					
22. Inferior subcontractors and suppliers					
Probability of occurrence					
Impact on project costs					
23. Inadequate contractor coordination					
Probability of occurrence					
Impact on project costs					
External Conditions of Construction					
24. Unpredictable site conditions					
Probability of occurrence					
Impact on project costs					

continued on following page

Table A1. Continued

Risk Category	Very Low	Low	Medium	High	Very High
25. Inflation					
Probability of occurrence					
Impact on project costs					
26. Material price fluctuations (information prices in various regions and the impact of market, environmental, and other requirements on prices)					
Probability of occurrence					
Impact on project costs					
27. Unforeseen events during construction					
Probability of occurrence					
Impact on project costs					

Shiwei Chen is a Lecturer working in Fujian University of Technology, China. He has his Ph.D. degree from Harbin Institute of Technology, Chnia. His research focuses on sustainable construction method and intelligent technology-based project management.

Xingyue Fan is a postgraduate student at the School of Civil Engineering, Fujian University of Technology, China. Her research focuses on construction cost control and project management.

Binqing Cai is a professor at Fujian University of Technology, China. She has her Ph.D degree from Fuzhou University, China. Her research focuses on social network analysis in construction enterprises and project management.