Research on the Derivative Rule and Estimation Methods of Intelligent High-Speed Railway Investment Estimation

Yang Meng, Chuncheng Meng, Xiaochen Duan*
College of Management, Shijiazhuang Tiedao University, Shijiazhuang, Hebei 050043, China

***Abstract*—Taking the investment estimation of intelligent construction of high-speed railway as the research object, based on the historical data of investment of similar high-speed railway projects, this paper builds an explanatory structure model, establishes an system dynamic (SD) model of investment estimation of intelligent construction of high-speed railway, and puts forward suggestions for supplementing the labor value theory and improving the value-added tax. The paper carries out in-depth research and analysis in the following aspects: 1) the list of influencing factors for investment estimation of intelligent construction of high-speed railway in the feasibility study stage is constructed, and the interpretative structural model (ISM) is constructed to sort out the relationship between the influencing factors; 2) the SD model of intelligent construction cost estimation of high-speed railway is established to improve the accuracy of investment estimation of intelligent high-speed railway construction; 3) put forward suggestions and schemes for improving investment estimation content of intelligent construction of high-speed railway under high intelligence; 4) improve and supplement the labor value theory and the value-added tax base.**

Keywords—High-speed railway; intelligent construction; investment estimation; interpretative structural model; system dynamics

I. INTRODUCTION

The level of intelligence in the future will largely affect the competitiveness of countries in the field of high-speed railroads, which brings pressure on the intelligent transformation of China’s high-speed railroads while providing a huge opportunity for development. However, with the rapid development of high-speed railway construction under high intelligence, the human labor required in the construction process of high-speed railway is becoming less and less, and “machine instead of human” is becoming more and more common at the construction site; in the near future, less humanized and unmanned will become the mainstream of high-speed railway engineering construction [1]. The corresponding content and method of investment estimation of high-speed railway construction under high intelligence are only suitable for the low and medium intelligence level. With the enhancement of intelligence, the labor cost and management cost are greatly reduced and the robot cost increases, i.e., the content and structure of investment estimation is undergoing a fundamental change. The value-added tax (VAT) calculation theory based on the labor theory of value, where human labor creates new value, is under attack. Therefore, it is important to analyze and study the characteristics of the factors influencing the investment estimation of intelligent construction of high-speed railways and their mechanism of action, construct an investment estimation system for intelligent construction of high-speed railways based on system dynamics, establish a case empirical system to accompany the system for empirical analysis, and propose improvements to the labor value theory and VAT billing base.

With France, Germany and Japan as the prominent examples, all countries in the world have launched research on intelligent railroad construction [2]. German railroads aim to achieve information management and widely promote building information modeling (BIM) technology. In 2014, it proposed to apply 5D BIM technology to the whole process management of German railroad construction and started the intelligent change with the iTWO 5D BIM platforms, such as Bahnhof Horrem station, Rastatter tunnel, Filstal bridge, etc [3, 4]. France, one of the traditional railroad powers, now also places the development of railroad information technology in its development strategy, for example, the digital French railway strategy officially launched in 2015, which strives to focus on the construction of Internet for railroad stations, trains, and road networks and plans to build a railroad system with convenient transportation, strong competitiveness, and close relevance to future transportation from 2031 to 2040 [5, 6]. The United Kingdom expects significant cost reductions in digital signaling, intelligent infrastructure and train control after 2027 and takes applications of intelligent technologies as a daily means of operating the railway network [7]. Japan has taken the lead in the development of intelligence in the field of construction and has started the construction of intelligent coverage of public works management ten years ago to successfully realize the paperlessness of all information in the whole life cycle of construction, which has greatly improved the efficiency of construction and also reduced construction costs [8].

In recent years, Chinese scholars have carried out many research works on the application of system dynamics in the field of engineering construction. Zhou constructed a model of project cost management system based on system dynamics to realize the dynamic evaluation of project costs [9]. Yue uses the system dynamics method to build the project quality system model to realize the quality management of construction projects [10]. Mao constructed a system dynamics model based on the framework of “BIM-cooperative subject”, pointed out the importance and relationship of relevant influencing factors, and guided the development direction for proposing the strategy of synergy effect of cooperative subject [11]. Gao constructed a risk model for engineering projects based on system dynamics theory and verified it with petroleum projects, which provides a development direction for engineering project risk management [12]. By establishing a system dynamics model for resource allocation of engineering projects, Zhong et al. proposed that the resource allocation strategy should be formulated based on the matching between the characteristics of project operation mode and multiple resources [13]. Based on the system dynamics model, Liu et al. studied the relationship between engineering schedule and cost management [14]. Chen et al. constructed a system dynamics model to study the logical relationship between the factors influencing the cost of prefabricated building and selected rational measures to optimize the cost, improving the current situation of cost management of prefabricated construction projects [15].

In summary, many scholars have used system dynamics to study engineering investment estimation, but most of the studies focus on tunnel investment, component cost, or estimation of part of the cost of the overall project such as material cost, and the system dynamics-based intelligent construction investment estimation for high-speed railway is currently not reported in the literature. This paper explored the method of intelligent construction investment estimation for high-speed railways, identified the factors influencing intelligent construction investment estimation for high-speed railways, constructed an interpretative structural model (ISM) model to explore the interactions between the factors, and built a system dynamic (SD) model. Moreover, SD, scenario simulation, and case inference were used to study the trend of various cost changes of intelligent construction of high-speed railway under high intelligence (70-100%). According to the evolution trend, the corresponding investment estimation cost content and rate improvement methods were proposed to provide academic theoretical basis and support for the investment estimation decision of high-speed railway under high intelligence.

This paper took the intelligent construction investment estimation of high-speed railway as the research subject, constructed the ISM to sort out the relationship of influencing factors of intelligent construction investment estimation of high-speed railway; on this basis, the SD model of intelligent construction investment estimation of high-speed railway was constructed to achieve high-precision estimation; finally, intelligent construction cost correction scheme and tax rate increase correction scheme were proposed under high intelligence (70%-100%).

II. RELATED BASIC THEORIES

A. Interpretative Structural Model Theory

The interpretative structural model (ISM) often presents the results of analytic hierarchy process in a skeleton diagram, which clearly and intuitively illustrates the role of every element in the interaction relationship, and it shows obvious advantages in sorting out the complex, multi-layered factor relationship [16]. Considering the intelligent construction investment estimation of high-speed railway as a whole, the ISM can quickly sort out the relationship between its influencing factors and thus find the key influencing factors. The specific steps are shown below.

Firstly, the correlation relationship between factors is determined, and an adjacency matrix is constructed. The interaction relationship between influencing factors is analyzed. If factor S_i has influence on factor S_j, then it is stipulated that there is a direct influence relationship between them; otherwise, it is considered that there is no direct influence relationship between them.

The next step is to determine the recursive relationship between factors in two steps. The first step is to calculate the reachable matrix, and the other step is to determine the level division of different factors.

1) Find the reachable matrix. A reachable matrix describes the extent to which the factors can be reached after a certain length of pathway between them through the matrix form, which often requires the indirect role of intermediate factors. Boolean matrix operation rules make the following provision:

when $(A+I)^{K-1} \neq (A+I)^{K} = (A+I)^{K+1}$, $(A+I)^{K-1}$ is the desired reachable matrix M.

2) Divide the hierarchical structure. Based on the obtained reachable matrix M, the reachable set and the prior set of the factors are obtained, and the influencing factors are divided into different hierarchies. $R(S_i)$ represents the reachable set, which is the set of all factors that can be reached from S_i, i.e., the set of factors that can be directly influenced by S_i; $A(S_i)$ represents the prior set, which is the set of all factors that can reach S_i, i.e., the set of factors that have direct influence on it. Based on this, the intersection set $C(S_i)$ of the them is obtained.

When the reachable set and the intersection set contain exactly the same influencing factors, they are classified as influencing factors at the same layer. Based on this, the rows and columns where such factors are located are removed, and the remaining influencing factors are classified again by the above method, and so on until all factors are stratified.

B. System Dynamics Model

SD is a highly dynamic scientific method of analysis based on the whole process of a system [17], which can solve complex and nonlinear systemic problems. The main parameters of the model are divided into four categories: constants, initial values, linear functions, and table functions.

1) Estimation of the constants and initial values with the GM(1,1) model.

Step 1: calculate the cumulative generation sequence.

$$x^{(1)}(k)=\sum_{i=1}^{k} x^{(0)}(i) \quad , k=1, 2, \dots, n \quad (1)$$

Step 2: find the mean series.

$$z^{(1)}(k)=\frac{x^{(1)}(k)+x^{(1)}(k+1)}{2} \quad , \; k=1,2,\dots,n\text{-}1 \quad (2)$$

Step 3: calculate intermediate parameters *C, D, E, F*.

$$C=\sum_{k=2}^{n} z^{(1)}(k)\,,\ D=\sum_{k=2}^{n} x^{(0)}(k)\,,\ E=\sum_{k=2}^{n} z^{(1)}(k) * x^{(0)}(k)\,,\ F=\sum_{k=2}^{n} z^{(1)}(k)^2 . \tag{3}$$

Step 4: development coefficient a and grey action quantity coefficient *b*.

$$a=\frac{CD-(n-1)E}{(n-1)F-C^2}\,, \tag{4}$$

$$b=\frac{DF-CE}{(n-1)F-C^2}\,. \tag{5}$$

2) Estimation of the values of the factors of the linear functional relationship.

Step 1: determine the subjective weights using the G1 method.

It is assumed that the impact evaluation index system for investment estimation of high-speed railway construction projects has n evaluation indexes, $\{x_1, x_2, x_3, ..., x_n\}$ and w_i is the subjective weight of the i-th indicator. The expert survey method determines that these n elements have the following relationships:

$$x_1 \geq x_2 \geq x_3 \geq \cdots \geq x_n\,. \tag{6}$$

The ratio of the importance degree of evaluation indicator x_{i-1} to x_i is w_{i-1} / w_i, denoted as:

$$r_i=\frac{w_{i-1}}{w_i}(k=n,n-1,\ldots,3,2). \tag{7}$$

Then, the subjective weights are calculated:

$$w_n=(1+\sum_{i=2}^{n}(\prod_{k=i}^{n} r_k)^{-1}\,, \tag{8}$$

$$w_{i-1}=r_i w_i(k=n,n-1,\ldots,3,2)\,. \tag{9}$$

Step 2: the entropy method is used to determine the objective weight.

The characteristic weight of the i-th expert under the j-th indicator is calculated:

$$p_{ij}=\frac{x_j}{\sum_{i=1}^{m} x_{ij}}\,. \tag{10}$$

Step 3: the comprehensive weighting method determines the final weight.

The subjective weight is p_j, and the objective weight is $\mathrm{q_j}$.

$$k_1=\frac{\sum_{i=1}^{n}\sum_{j=1}^{m} p_j x_{i_j}}{\sqrt{(\sum_{i=1}^{n}\sum_{j=1}^{m} p_j x_{i_j})^2+(\sum_{i=1}^{n}\sum_{j=1}^{m} q_j x_{i_j})^2}} \tag{11}$$

$$k_2=\frac{\sum_{i=1}^{n}\sum_{j=1}^{m} q_j x_{i_j}}{\sqrt{(\sum_{i=1}^{n}\sum_{j=1}^{m} p_j x_{i_j})^2+(\sum_{i=1}^{n}\sum_{j=1}^{m} q_j x_{i_j})^2}} \tag{12}$$

The weight coefficient is substituted into the formula:

$$w_j=k_1 p_j+k_2 q_j\,. \tag{13}$$

The final weight is obtained.

3) Estimation of the values of the factors of the table function relationship.

In the whole system flow chart, there is not only a linear function relationship between the factors, but also a table function relationship, for example, the relationship between material dynamic management capability and management intelligence level and the relationship between material dynamic management capability and material unit price influence factor.

III. MODEL CONSTRUCTION

A. Construction Ideas

The intelligent construction system of high-speed railway is a dynamic and complex large system, involving many influencing factors, and the influencing factors are complex, stochastic, dynamic, and coupled, making the intelligent construction investment of high-speed railway show time-series non-linear dependent variable characteristics, such as non-linear, stochastic, dynamic, changeable, and prominent. Moreover, the intelligent construction system of high-speed railway in China is at the world leading level, so there are less historical data to draw on. For these reasons, this thesis used structural explanatory equations, historical data, literature questionnaires, and expert interviews to mine the factors influencing the intelligent construction investment of high-speed railways, used case inference and SD methods to analyze the evolutionary trends and derived mechanisms of the intelligent construction investment estimation, and constructed the corresponding investment estimation prediction and improvement model to effectively improve the accuracy and reliability of the intelligent construction investment estimation.

B. Model Composition

1) Influencing factor structure explanatory equation identification module.

a) Preliminary identification based on literature analysis method: We obtained more than 200 papers by searching the keywords of “intelligent high-speed railway”, “intelligent construction”, “investment estimation factors”, and “investment estimation index”. Twenty-three papers that cover a wide range of factors and were included in recent time were screened according to the criteria of citation frequency and the grade of journals and selected as the basis for identification to summarize the influencing factors of investment estimation of intelligent construction of high-speed railways.

b) Additional identification based on the case study method: To supplement the impact of intelligence on investment estimation, this paper took Beijing-Zhangjiakou and Beijing-Xiongan high-speed railways and three typical intelligent construction projects with large difficulties in the Zhengzhou-Wanzhou high-speed railway as examples to sort out the influencing factors of high-speed railway investment estimation.

c) List of factors influencing investment estimation for intelligent construction of high-speed railways: According to the feedback results of the expert pilot survey, the initial set of influencing factors was determined. Seventeen influencing factors were finally determined after questionnaire survey and analyzing and processing the data with SPSS software, including labor, material and machine costs, management costs, design depth, management efficiency, degree of economic development in the region, traditional construction machine configuration, intelligent robot configuration, construction site management level, dynamic material management capability, professional quality of management personnel, project complexity, resource allocation efficiency, intelligent degree of geological exploration, intelligent degree of construction, degree of equipment mechanization, information construction level, and intelligent degree of management.

2) Analysis of the evolutionary trend and derivative mechanism of the impact of influencing factors on investment Intelligent construction investment estimation for high-speed railways was viewed as a holistic system in which every influencing factor interacts with each other. A matrix was constructed for the influencing factors of the intelligent high-speed highway construction investment estimation using an ISM algorithm to quickly sorted out the direct or indirect relationships between the influencing factors [18].

a) Determine the correlation between factors and construct the adjacency matrix: The influencing factors were considered as a system consisting of 17 elements. An adjacency matrix was constructed: $A=[a_{ij}]17\times17$, where a_{ij} indicates the interaction relationship between the influencing factors. The value of a_{ij} was 1 when S_i had a direct influence on factor S_j; the value of a_{ij} was 0 when factor S_i did not have a direct influence on factor S_j; the cells on the diagonal of factor S_i were all recorded as 0.

b) Determine the recursive relationship between factors.

Step 1: Based on MATLAB platform, final reachable matrix M was calculated.

Step 2: A hierarchical structure division table of the factors influencing the investment estimation of intelligent construction of high-speed railways was sorted out, as shown in Table I.

c) Construction of an ISM: The influence factor structure was drawn according to the reachable set, antecedent set, and factor hierarchy decomposition results, as shown in Fig. 1.

3) Investment estimation module based on case inference and SD: System dynamics analysis was considered based on the complex factors and the nonlinear and changeable characteristics of the estimation process.

a) Construction of cause-and-effect diagram of intelligent construction investment estimation system for high-speed railways.

Based on the influence paths obtained from the ISM, the study analyzed the cause-effect relationship, the overall and local feedback mechanism of the system, and the feedback loops in the system for the intelligent construction investment estimation system of high-speed railways and further clarified the polarity of the variables in the system and their mutual influence. The system feedback relationship is shown in Fig. 2.

b) The overall flow chart of the intelligent construction investment estimation system of high-speed railways.

A model flow diagram was established as shown in Fig. 3 by taking the investment estimation cost of intelligent construction of high-speed railways, labor cost, material cost, construction machine use cost, robot cost, enterprise management cost, equipment purchase cost, and the estimated investment cost at the project proposal stage as state variables and taking changes in labor cost, material cost, construction machine use cost, robot cost and enterprise management cost and willingness to invest as rate variables.

4) Trend analysis module for the evolution of investment estimation based on case inference and SD.

On the basis of the above model, the evolution trend of investment estimation was analyzed by inputting 50%, 60%, 70%, 80%, 90%, and 100% intelligence levels.

5) Improvement module for investment estimation derivative mechanism and estimation method.

Based on the above trends of investment estimation evolution, the corresponding derivative mechanisms and laws were deduced, and suggestions for improving labor value theory and the current investment estimation preparation methods were proposed.

TABLE I. RESULTS OF THE HIERARCHICAL DIVISION OF KEY INFLUENCING FACTORS

Levels	**Factors**
Level 1 (direct apparent influencing factors)	Labor, material and machine costs; management cost
Level 2 (indirect influencing factors)	Project complexity; resource allocation efficiency; professional quality of management staff; management efficiency; degree of economic development in the region; material dynamic management capacity
Level 3 (indirect influencing factors)	Design depth; intelligent robot configuration; construction site management level; traditional construction equipment configuration; information management level
Level 4 (decisive influencing factor)	Intelligent degree of geological exploration; intelligent degree of construction; degree of equipment mechanization; intelligent degree of management

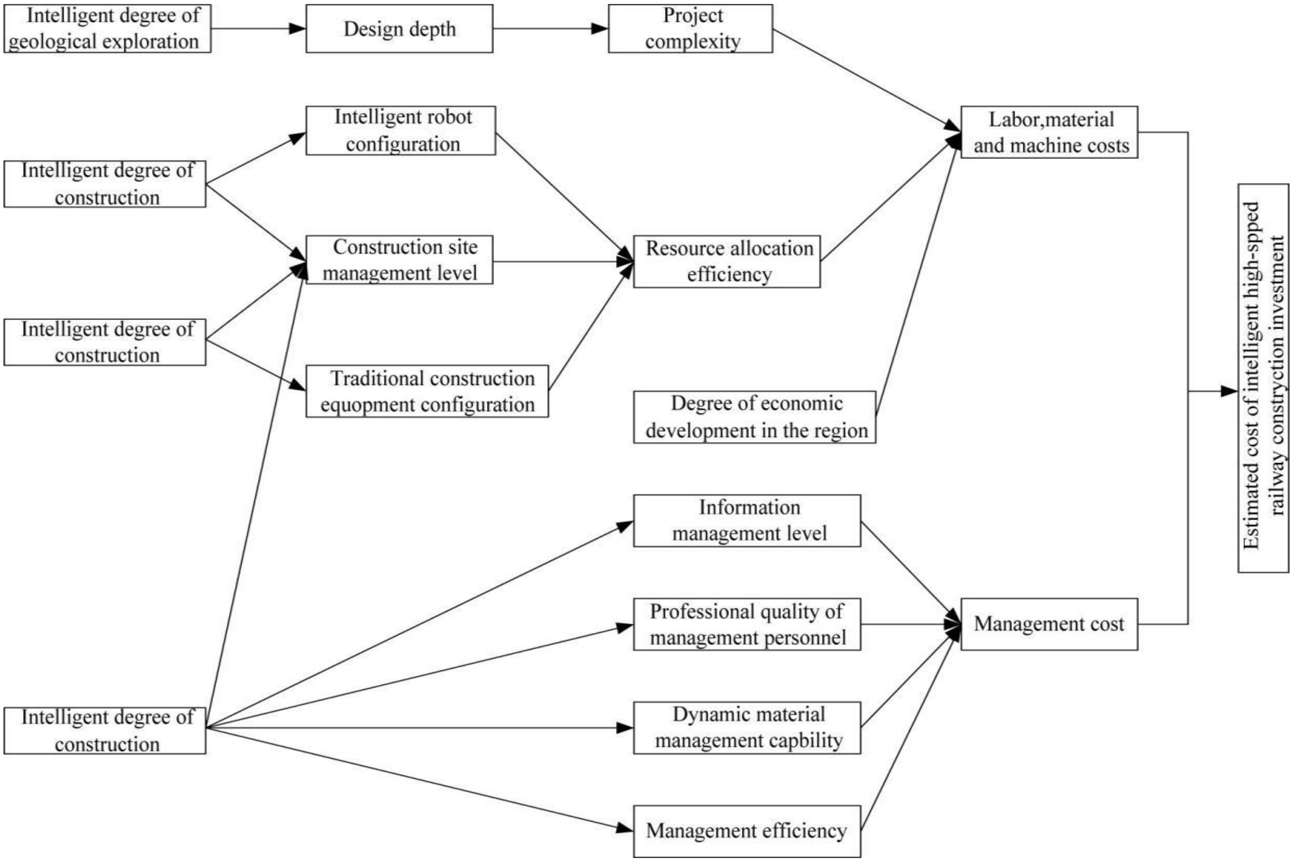

Fig. 1. The ISM of factors influencing investment estimation for intelligent construction of high-speed railways.

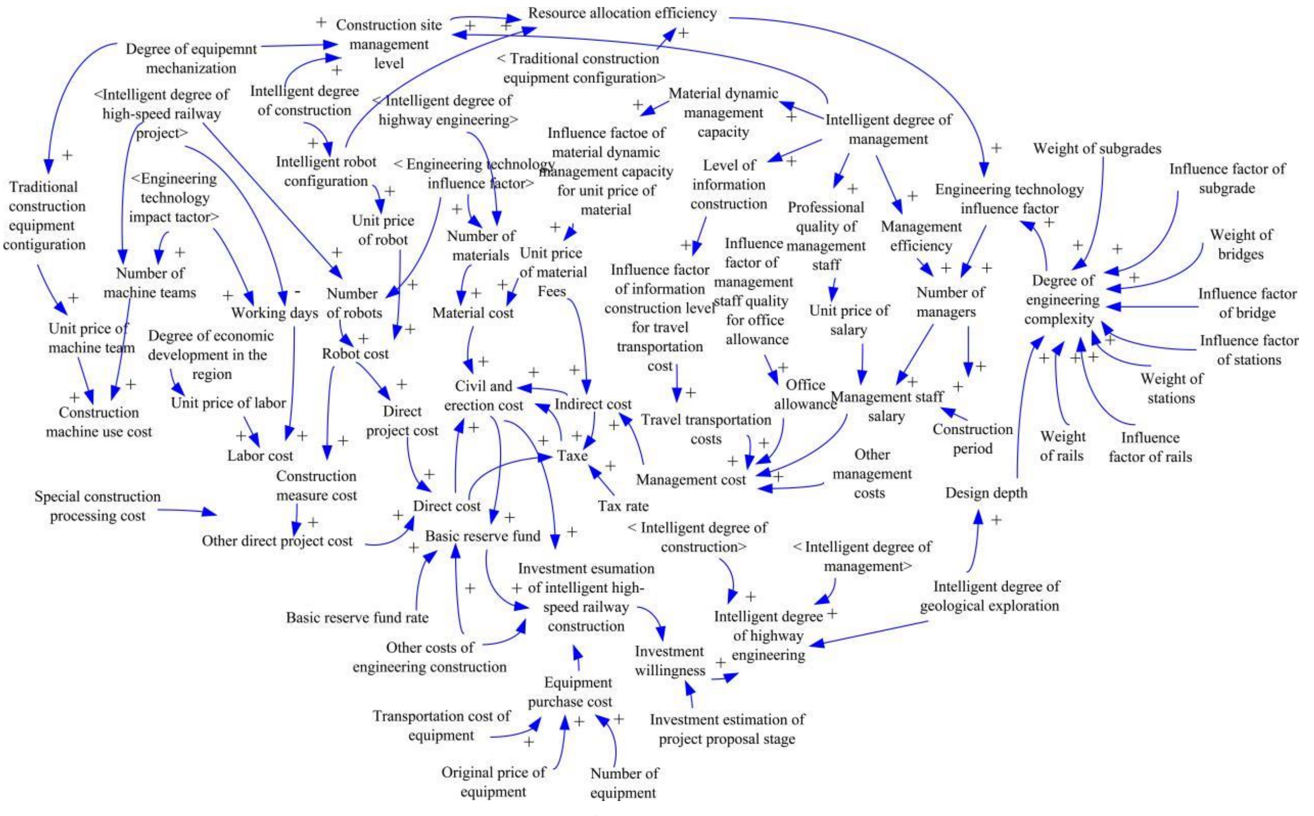

Fig. 2. System feedback relationship diagram.

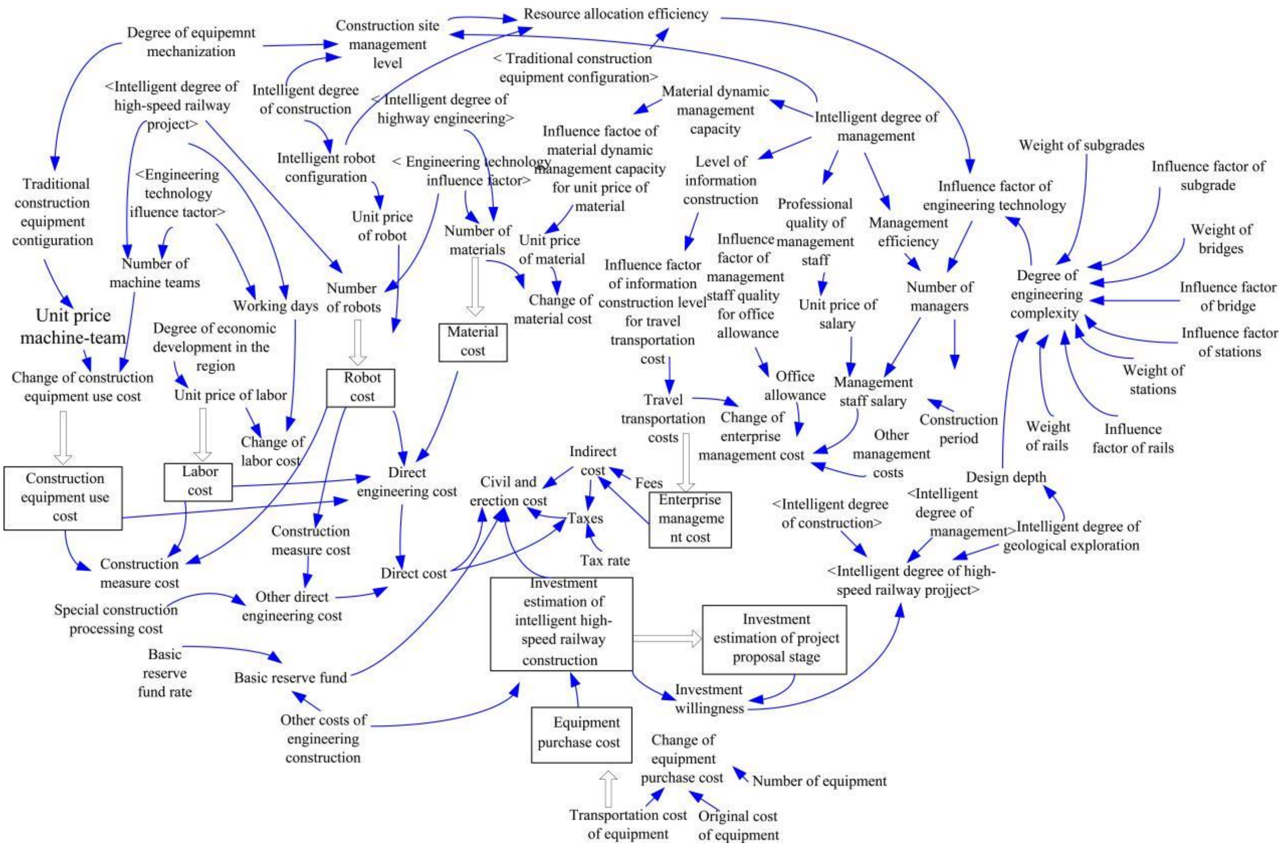

Fig. 3. Model flow diagram.

IV. MODEL APPLICATION (INTRODUCTION TO PROJECT COMPLEXITY)

Models were applied in the construction of a high-speed train (HST) project, which started in 2019, with a bridge-tunnel ratio of 94%. It was constructed by mature tunnel intelligent construction technology and is a highly intelligent high-speed railway construction project. System dynamics analysis was applicable due to its complex factors and the non-linear and changeable characteristics of the estimation process. Simulations were performed based on the constructed SD model. The main parameters and equations were set, including constants, initial values, linear functions, and table functions.

A. *Estimation of Constants and Initial Values*

With the extension of the construction period, the costs showed exponential situation growth, and the data involved were poorly available. The above characteristics indicated that it was reasonable to adopt the GM(1,1) model. This paper only shows the prediction of other costs of engineering construction, as shown in Table II, and the remaining costs were predicted in the same way.

The grading ratio test values were all within the standard range interval [0.672,1.501], which met the requirement of the construction of the GM(1,1) model. The results obtained according to equations 4 and 5 are shown in Table III, and test difference ratio $C = 0.0027 <= 0.35$, i.e., the accuracy of the constructed model met the requirement, so other costs spent in engineering construction was predicted using the model, as shown in Table IV.

TABLE II. GRADING RATIO VALUES UNDER THE GM(1,1) MODEL

Case	Original value	Grading ratio λ	Original value + translation conversion shift value (shift = 0)	Converted grading ratio λ
1	402.868	-	402.868	-
2	393.157	1.025	393.157	1.025
3	385.965	1.029	385.965	1.029
4	387.421	0.996	387.421	0.996

Note: λ = data in the previous period/data in the current period

TABLE III. THE RESULTS OF GM(1,1) MODEL CONSTRUCTION

Development factor a	Grey action quantity b	Posterior test difference ratio c
-0.0110	377.2902	0.0027

TABLE IV. PREDICTIVE VALUES OF OTHER COSTS OF ENGINEERING CONSTRUCTION

Serial number	Original value	Predicted value
1	402.868	402.868
2	393.157	393.157
3	385.965	385.965
4	387.421	387.421
Backward one period	-	393.123
Backward two periods	-	392.441
Backward three periods	-	410.041
Backward four periods	-	405.263

B. Estimation of the Values of Factors of the Linear Functional Relationship

Taking the construction site management level as an example, its subtrees were the degree of management intelligence, the degree of construction intelligence, and the degree of equipment mechanization. The subjective and objective weights were calculated by the comprehensive weighting method by taking these subtrees as the boundary point.

Step 1: determine the subjective weights using the G1 method.

Suppose that x_1, x_2, and x_3 are the degree of management intelligence, the degree of construction intelligence, and the degree of equipment mechanization, respectively; experts believed that these three elements had the following relationship: $x_1 \geq x_2 \geq x_3$, and $r_2 = \frac{w_1^*}{w_2^*} = 1.2$, $r3 = \frac{w_2^*}{w_3^*} = 1.2$, $r_2 \cdot r_3 = 1.44$, $r_3 = 1.2$, $\sum_{k=2}^{3}(\prod_{i=k}^{3} r_i) = 2.64$.

According to Equations 7, 8, and 9, $w_1 = 0.33$, $w_2 = 0.396$, and $w_3 = 0.275$.

Step 2: Determine objective weights by the entropy method.

The scores given by experts are shown in Table V.

TABLE V. SCORES GIVEN BY EXPERTS

Factors	**Expert 1**	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**
Degree of management intelligence	0.2	0.2	0.1	0.2	0.2
Degree of construction intelligence	0.3	0.2	0.3	0.3	0.2
Degree of equipment mechanization	0.4	0.4	0.3	0.3	0.4

The calculation results of equation 10 are shown in Table VI.

TABLE VI. FEATURE WEIGHT

j	p_{ij}					e_j	g_j	w_j
1	0.222	0.222	0.111	0.222	0.111	1.581	0.581	0.327
2	0.231	0.154	0.231	0.231	0.154	1.591	0.591	0.334
3	0.222	0.222	0.167	0.167	0.222	1.6	0.6	0.338

Step 3: determine the final weights using the comprehensive weighting method.

According to equations (11) and (12), $k_1 = 0.669$, $k_2 = 0.715$. The final weights were calculated using equation (13). After normalization, $w_1 = 0.328$, $w_2 = 0.365$, and $w_3 = 0.307$, i.e., construction site management level = 0.328 * the degree of management intelligence + 0.365 * the degree of construction intelligence + 0.307 * the degree of equipment mechanization.

C. Estimation of the Values of Factors of the Table Function Relationship

It was assumed that the data on the degree of management intelligence were accurate; the dynamic management capability of materials would be improved as the degree of management intelligence increased. The corresponding table function was established according to the statistical law, as shown in Table VII.

TABLE VII. TABLE FUNCTION RELATIONSHIP

Management intelligence degree	0	0.1	0.2	0.3
Material dynamic management capability	0.73	0.78	0.83	0.89

The material dynamic management capability = WITH LOOKUP (the degree of management intelligence) Lookup([(0,0)-(1,1)], (0,0.73), (0.1,0.78), (0.2,0.83), (0.3,0.89)).

Resource allocation efficiency and management efficiency were represented by linear functions and table functions. The model constructed in this paper successfully passed the structure, assignment, and unit consistency tests.

D. Model Simulation and Result Analysis

Simulation settings were performed in Vensim software to simulate the intelligent construction investment estimation results of the XC section of the HST high-speed railway. The comparison between the results and the actual data of the project suggested that the error between the estimated cost of the intelligent construction investment of high-speed railway in the first year simulated by the system and the actual value was 4.62%; the error between the two-year cumulative investment estimation and the actual investment was 1.83%. This suggested that the accuracy met the requirements, and the model simulation results could be considered to be in line with the reality.

The experimental results of the SD model proposed in this paper were compared with the experimental results of other high-speed railway intelligent construction investment estimation models that can be found in the related literature, i.e., the grey-wolf optimizer-support vector machine (GWO-SVM) estimation model [19] and the improved back-propagation neural network (BPNN) prediction model [20], and the specific data are shown in Table VIII. The error rate in Table VIII is the error between the two-year cumulative investment estimation and the actual investment, and it was seen that the error rate of this model was 1.83%, which was smaller other estimation models. It verified the accuracy of the SD model in the field of investment estimation for intelligent construction of high-speed railway.

TABLE VIII. THE EXPERIMENTAL RESULTS OF DIFFERENT ESTIMATION MODELS

Model	**Error rate**
The SD model	1.83%
GWO-SVM estimation model	3.14%
The improved BPNN prediction model	3.23%

V. SCENARIO SIMULATION OF THE EVOLUTIONARY TREND OF THE ESTIMATED COST OF HIGH-SPEED RAILWAY INVESTMENT UNDER HIGH INTELLIGENCE

The investment cost was simulated by taking the degree of management intelligence as an example to review the composition of the investment estimation content of the intelligent construction of high-speed railways. Intelligent management refers to the management of the whole process of construction with the help of information management system in the process of high-speed railway construction management. As the degree of intelligent management increases, fewer managers are required, and corporate overheads are reduced. Comprehensive intelligence degree of the high-speed railway project = IF THEN ELSE (investment willingness <= 0.45, 0.65 × the intelligent degree of geological exploration + 0.2 × the intelligent degree of construction + 0.15 × the intelligent degree of management, 0.3 × the intelligent degree of geological exploration + 0.35 × the intelligent degree of construction + 0.35 × the intelligent degree of management).

The relationship between investment costs and the change of comprehensive intelligence degree of high-speed railway project is shown in Table IX. The labor cost and management cost decreased with the improvement of the intelligence degree, while the robot cost increased significantly, as shown in Fig. 4 and 5. This deviated from the content of traditional railroad investment estimation, so the estimation content and taxable base need to be improved.

TABLE IX. VARIATIONS OF DIFFERENT COSTS WITH THE IMPROVEMENT OF THE COMPREHENSIVE INTELLIGENCE OF HIGH-SPEED RAILWAY PROJECT

Degree of intelligence	Labor cost	Material cost	Construction machine use cost	Robotic cost	Management cost	Profit	Tax
50%	2210.45	15746.13	2746.83	2.29	63.07	1453.81	2444.48
60%	1822.25	14849.78	2471.82	13.13	50.44	1344.52	2260.71
70%	1515.99	14216.74	2236.55	18.71	40.15	1261.97	2121.91
80%	1145.99	13036.42	1850.11	25.68	31.10	1126.25	1893.71
90%	457.54	12065.18	1554.47	224.97	20.57	1002.59	1685.78
100%	0	11406.18	1065.27	492.93	9.70	908.19	1527.05

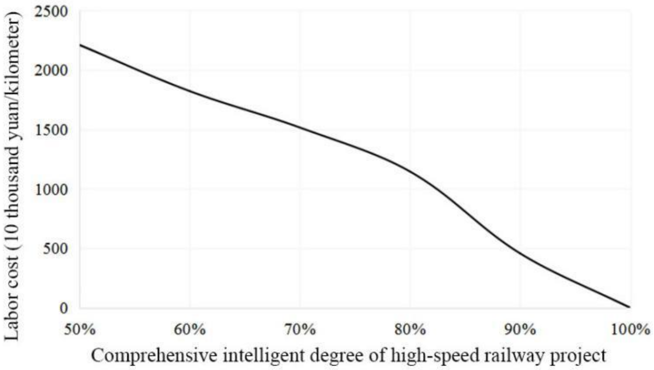

Fig. 4. Trend graph of labor cost change.

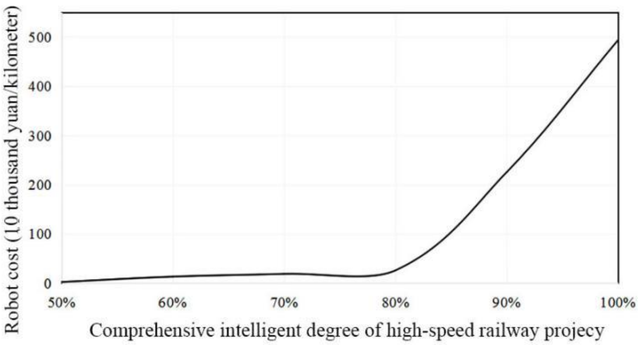

Fig. 5. Trend graph of robot cost change.

VI. STUDY ON THE DERIVATION MECHANISM OF HIGH-SPEED RAILWAY INVESTMENT ESTIMATION UNDER HIGH INTELLIGENCE

At present, the theoretical basis of high-speed railway intelligent construction investment estimation is labor value theory, and machines and robots are only materialized labor, which is only transfer value; the calculation method theoretically takes the increased value of labor cost, management cost, and depreciation cost as the profit and tax billing base, but actually the profit and tax are calculated based on the cost excluding tax. Therefore, under 70-100% high intelligence, the estimated cost and calculation method of intelligent construction investment of high-speed railways need to be revised. Based on this, this paper proposed the amendment of intelligent civil and erection costs and the amendment of tax rate increase.

A. *Intelligent Civil and Erection Cost Content Amendment*

The cost components and content of intelligent civil and erection costs under high intelligence were adjusted using value theory, system theory and artificial intelligence. The specific elaboration is shown below.

1) *Material cost:* With the deepening of construction site intelligence, the dynamic management ability of materials is improved, and thus the material cost is reduced.

2) *Construction machine use cost:* Traditional construction machines are replaced by intelligent equipment such as robots on a large scale to significantly reduce construction machine use cost.

3) *Robot cost:* A new item of “robot cost” was created, mainly for robot depreciation, while construction equipment use cost becomes the cost of using traditional equipment.

4) *Enterprise management cost:* With the continuous improvement of the degree of intelligence, enterprise management cost is greatly reduced; when complete intelligent is realized, enterprise management cost will include the senior management salary.

5) *Profits and taxes:* In the case of complete intelligence, there are few labor and management costs. If the robots are still regarded the transfer value of physical labor and excluded from the VAT base, it will seriously affect the profits of enterprises and VAT, resulting in a significant reduction in profits and value added of enterprises.

B. *Rate Increase Amendment*

With the development of intelligent production, robots, like people, are a source of surplus value creation. If the rate is not changed, it will seriously affect the profits of enterprises and taxes such as VAT, which will affect the national tax revenue. Therefore, the tax rate should be increased, and profits and VAT should be calculated according to the current cost excluding tax.

C. *Improvements and Supplements to the Labor Theory of Value*

1) Analysis of unmanned construction value sources: The overall value (W) of a conventional railroad investment should be expressed as: $W = \mathrm{C} + \mathrm{V} + \mathrm{M}$, where C denotes constant capital, V denotes variable capital, and M is surplus value. Due to intelligence and unmanned construction, the robot's production is a mature production chain. In the production process, the means of production (C') and the mental and physical labor of scientists and workers (V') are all necessary and are also the source of surplus value (M'), and at this moment the value of the robot is: $W' = C' + V' + M'$. Then, the value generated by the intelligent high-speed railway can be written as: $W = W' + C_2 = C' + V' + M' + C_2$. Based on this, when the intelligent construction of the high-speed railway is carried out, the cost of purchasing robots already includes the mental labor of the scientists and the physical labor of the workers who produce these robots.

2) Changes to the labor value theory brought about by the fully intelligent construction of high-speed railways: The only source of surplus value is still labor, but the source of labor has changed to labor and robot capital, which is the inevitable result of the rapid development of intelligence. With the development of intelligent technology, the demand for labor is getting lower and lower, and it may even produce the phenomenon of creating robots through the labor of robots in the future. Nevertheless, it is undeniable that although human labor creation is no longer reflected in every production line, the source of surplus value creation is still human, and human and human labor must be the source of value creation, which is an indispensable condition for the creation of artificial intelligence robots.

VII. CONCLUSION

This paper briefly introduced the ISM and the SD model. The relationship between the factors affecting the intelligent construction investment estimation of high-speed railway was sorted through the ISM model, and the SD prediction and improvement model was constructed for the intelligent construction investment estimation of high-speed railway. Simulation experiments were carried out in the construction of HST high-speed railway. It was found that the error between the first-year estimated cost of intelligent construction investment in system simulation and the actual value was 4.62%; the error between the two-year cumulative investment estimate and the actual investment was 1.83%. The results prove that the SD model has high accuracy and is feasible in the investment estimation of intelligent construction of high-speed railway.

ACKNOWLEDGMENTS

This study was supported by Hebei Natural Science Foundation: Research on 3D Nonlinear Intelligent Estimation Method of Investment and Operation Income of High Speed Railway (G2019210226).

REFERENCES

[1] S. M. Tian, W. Wang, C. Y. Yang, Y. Liu, N. Y. Wang, K. J. Wang, Z. F. Ma, and G. Lu, "40 year development and Prospect of railway tunnels in China," Tunn. Constr., vol. 41, pp. 1903-1930, 2021.

[2] K. F. Wang, R. Hao, W. L. Lu, and H. L. Wang, "Research and application of intelligent construction technology in railway engineering construction," China Railw., pp. 45-50, 2019.

[3] Deutsche Bahn-Digital Transformation and Long-term Challenges. 2018.

[4] P. Li, S. Shao, R. Xue, and X. D. Zhang, "Research on the development trend of digitalization and intellectualization of foreign railways," China Railw., pp. 25-31, 2019.

[5] European Commission. Road map to a Single European Transport Area Towards a competitive and resource efficient transport system. (2011-03-28) [2018-10-24].

[6] The European Rail Research Advisory Council. Rail route 2050: The Sustainable Backbone of the Single European Transport Area. (2011) [2018-10-24].

[7] European Commission. Horizon 2020 Work Programme 2016—2017 Smart, green and integrated transport. EU, 2015.

[8] East Japan Railway Company. The Mid-to-Long-term Vision for Technological Innovation. (2016) [2018-11-06].

[9] L. Zhou, "Construction of engineering cost model based on system dynamics," Build. Technol. Dev., vol. 48, pp. 121-123, 2021.

[10] X. Q. Mao, Wei. Li, and C. H. Mao, "System dynamics analysis on the promotion path of multi-agent synergy effect of engineering construction under BIM," J. Civ. Eng. Manag., vol. 37, pp. 80-85, 2020.

[11] S. L. Yue, and W. Zhang, "Research on construction project quality management based on system dynamics," Sci. Technol. Econ. Market, pp. 97-98, 2020.

[12] J. Gao, and X. T. Wu, "Risk evolution evaluation of engineering projects based on system dynamics model," Stat. Decis. Making, vol. 36, pp. 185-188, 2020.

[13] Y. Zhong, Z. G. Chen, and Z. Zhou, "Research on resource allocation model and strategy of large-scale construction projects -- modeling and simulation based on system dynamics," China Manage. Sci., vol. 24, pp. 125-132, 2016.

[14] J. K. Liu, and W. J. Yang, "Research on cost schedule control of construction projects based on system dynamics," Constr. Technol., vol. 45, pp. 95-99 + 128, 2016.

[15] Y. Chen, Y. Wang, and L. Jia, "Research on cost control of prefabricated buildings based on system dynamics," Value Eng., vol. 36, pp. 1-5, 2017.

[16] A. Akintoye, "Analysis of factors influencing project cost estimating practice," Constr. Manag. Econ., vol. 18, pp. 77-89, 2000.

[17] W. Duan, Y. Qi, F. Gong, and D. S. Xu, "A review of research on the combination of system dynamics and economic management theories and methods," Stat. Decis. Making, vol. 38, pp. 41-46, 2022.

[18] B. Jia, "Research on risk management of SH key engineering projects based on interpretive structural model,"Jinan: Shandong University, 2020.

[19] X. Chen, “Investment probabilistic interval estimation for construction project using the hybrid model of SVR and GWO,” J. Constr. Eng. M., vol. 147, pp. 1-13, 2021.

[20] B. Wang, “Discussion on the prediction of engineering cost based on improved BP neural network algorithm,” J. Intell. Fuzzy Syst., vol. 37, pp. 6091-6098, 2019.