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Research article

Research on investment evaluation of highway projects based on system dynamics model

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Abstract: Aiming at the deficiencies presented by the traditional methods of highway project investment evaluation, the proposed highway investment evaluation method was based on system dynamics. First, we constructed an evaluation index system from profitability, solvency, and risk resistance and clarified the positive and negative causality within the investment evaluation system of highway projects; second, we determined the boundaries of the system dynamics model and divided it into six sub-systems, namely, income, cash flow, investment evaluation, profit, cost, investment and financing, and liabilities; and then, we established the system dynamics model of highway investment evaluation based on the sub-systems. The model made up for the limitations of the traditional discounted cash flow method; finally, taking the China's Yunnan Province an Expressway project as an example, using VENSIM software simulation, we get the evaluation results of the system dynamics model and make a comparative analysis with the discounted cash flow method, which showed that the calculation inaccuracies of the NPV and other financial indicators were in a reasonable range, and the evaluation method had strong operability and practicability. The system dynamics investment evaluation model provided a systematic, intuitive, whole-process investment evaluation method, which provided a theoretical basis for the analysis and decision-making of the investment effect of highway projects.

Keywords: transportation economics; investment appraisal; system dynamics; highways; discounted cash flow approach
Mathematics Subject Classification: 91-10

1. Introduction

According to the 2022 Transportation Industry Development Statistics Bulletin [1], by the end of 2022, the annual investment in highway fixed assets was completed at RMB 2852.7 billion, an increase of 9.7% over the previous year. However, the national toll highway revenue and expenditure gap is increasing year by year, and the gap reached 627.880 billion yuan in 2021. Most provinces across the country have the dilemma of having difficulty repaying loans to maintain highway operation and maintenance, or the remaining funds after revenue is used for loan repayment cannot cover daily operation costs and taxes [2]. Assessing the reasonableness of capital investment in highway projects, evaluating their potential for reliable returns, and identifying future financial risks are crucial aspects to focus on during the pre-project stage [3]. Therefore, finding a scientific and reliable investment evaluation method is of utmost importance [4].

The discounted cash flow (DCF) method is the most applied approach for evaluating investments in construction projects across China. This method, however, often lacks the flexibility required for complex, large-scale projects. Numerous scholars have sought to address these limitations: Machiels et al. [5] and others the application of real options theory to better suit the evaluation of large-scale projects; Cai and Zhou [6] and colleagues incorporated real options theory to study revenue adjustment methods for PPP mode toll roads in response to CPI changes; Wang et al. [7] and others constructed a financial risk evaluation model for large-scale projects based on hierarchical analysis and feed-forward neural network to create a large-scale project financial risk evaluation model; Li [8] designed a comprehensive line solution chart based on the relationships between investment evaluation indicators to assess various investment programs; and Liu et al. [9] and others developed formulas for interval number type investment indices in order to enhance the applicability of traditional evaluation metrics.

The study of system dynamics in project investment evaluation is an emerging and dynamic research area. Shepherd [10] has conducted a thorough analysis of the applications of system dynamics in the transportation sector, delineating 12 distinct advantages of this modeling approach in the field. Furthermore, Liu et al. [11] and collaborators have developed a system dynamics model for evaluating project operation risks, identifying critical indicators that impact project operational risk. Additionally, Zhao et al. [12] and colleagues have devised a system dynamics model specifically tailored for assessing the value-for-money of Public-Private Partnership (PPP) projects. Moreover, Xue et al. [13] and team have created a comprehensive system dynamics model to gauge project performance by considering project inputs, risks, and benefits. In the domain of project investment evaluation, system dynamics offers a comprehensive and systematic methodology, providing valuable insights for in-depth analysis and decision-making.

In response, this paper introduces a new method for evaluating highway project investments based on system dynamics. This approach addresses the limitations of the traditional DCF method, particularly its application to the investment evaluation of construction highway projects. By employing system dynamics, our method provides a more direct reflection of both the dynamic aspects of projects and their evaluation indices, demonstrating strong applicability and relevance to real-world scenarios.

Typically, research on investment evaluation of construction projects tends to focus on specific stages of the project life cycle or on particular aspects of investment evaluation. This approach often overlooks the holistic and systematic nature of investment evaluation [14]. Recognizing this gap, we leveraged traditional investment evaluation experience and integrates system dynamics theory. We have developed a system dynamics investment evaluation model that uses profitability, solvency, and risk resistance as key analytical indices to evaluate highway construction projects [15]. Utilizing VENSIM software, we conducted example simulations and analyses, drawing conclusions that illustrate the model's effectiveness. This method not only addresses the limitations of the traditional discounted cash flow approach but also provides a deeper understanding of how various factors interact within a project, enhancing the overall evaluation process.

Generally speaking, investment evaluation of construction projects by researchers often focuses on specific stages or aspects, overlooking the holistic and systematic nature of such assessments. To address this gap, we integrate the experience of traditional investment evaluation with the theory of system dynamics. We construct a comprehensive system dynamics investment evaluation model specifically tailored for highway construction projects. This model considers profitability, solvency, and risk-resistant ability as the primary analytical indexes for investment evaluation. Through the use of VENSIM software, we conduct example simulations, analyses, and draw conclusions. This approach enables a more thorough and nuanced understanding of the investment landscape, ensuring that evaluations are not only comprehensive but also capable of providing reliable insights for decision-makers in the construction industry.

2. Construction of system dynamics model

2.1. Applicability analysis

The discounted cash flow method, real option method, and hierarchical analysis method are three commonly used methods in highway investment evaluation.

(1) Discounted cash flow method

The idea of the discounted cash flow method is to predict the cash flow of the project in the future calculation period and convert it to the present value at a certain discount rate. However, in highway investment evaluation, this method lacks flexibility and response to unknown risks.

(2) Real options method

The real options approach recognizes that real investments also have the right to choose or abandon investments similar to financial options and that investing in a project is equivalent to purchasing an option. For projects with a long duration and a high level of uncertainty, the uncertainty is difficult to quantify, resulting in a large estimation inaccuracy.

The value of the project investment in the real options method is expressed as:

$$\mathrm{ENPV} = \mathrm{NPV} + \mathrm{C} \tag{2.1}$$

where ENPV is the project investment value; NPV is the project net present value; and C is the project option value.

The real options pricing model is calculated as follows:

$$\begin{cases} \mathrm{C} = \mathrm{N}(\mathrm{d}_1)\mathrm{S} - \mathrm{N}(\mathrm{d}_2)\mathrm{K}e^{-\mathrm{rt}} \\ \mathrm{d}_1 = \frac{\ln(\mathrm{S}/\mathrm{K}) + (\mathrm{r} + \frac{1}{2}\sigma^2)\mathrm{t}}{\sigma\sqrt{\mathrm{t}}} \\ \mathrm{d}_2 = \mathrm{d}_1 - \sigma\sqrt{\mathrm{t}} \end{cases} \tag{2.2}$$

where C is the option value; $N(d_1)$ are $N(d_2)$ are the cumulative standard normal distribution probabilities of d_1 and d_2, respectively; S is the price of the underlying asset of the project investment, i.e., the discounted value of the project's expected cash flow; K is the cost of the project investment; σ is the volatility of the price of the underlying asset, i.e., the volatility of the project's value; t is the effective life of the option; r is the risk-free interest rate.

(3) Hierarchical analysis

Hierarchical analysis solves multi-objective, hierarchical decision-making problems by quantifying the complex decision-making thought processes of project investors [16]. However, this method has a fixed choice of programs and lacks flexibility.

The Hierarchical Analysis Judgment Matrix is calculated as follows:

$$\begin{cases} \bar{a}_{ij} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \\ w_i = \frac{1}{n}\sum_{j=1}^{n} \bar{a}_{ij} \\ \lambda_{max} = \sum_{i=1}^{n} \frac{\sum_{j=1}^{n} a_{ij} w_j}{n w_i} \end{cases}. \tag{2.3}$$

(4) System dynamics simulation method

Compared with the above-mentioned three methods, the system dynamics simulation method has some unique advantages. The advantages of using system dynamics are particularly evident in the application of highway project investment evaluation.

System dynamics has the following characteristics. First, it is suitable for dealing with long periods of complex system problems [17]. By employing various function expressions, system dynamics can simulate the complex, non-linear relationships among cash flow, material flow, and information flow in each period of a highway project. This approach helps to overcome the limitations of traditional investment appraisal methods [18]; second, the simulation can conveniently and dynamically carry out the multifactorial financial sensitivity analysis, to realize the objective evaluation of the uncertain factors. Finally, the system dynamics is suitable for dealing with system problems with insufficient data [19]. In highway projects, the selection of certain parameters can be subjective. However, the model is based on multiple feedback loops within the system and analyzes the causal relationships among its elements. This approach allows the model to maintain consistent operating results even when parameters are within a certain range of inaccuracy.

2.2. Selection of evaluation indicators

Evaluation indicators are selected from three aspects: Favorability, feasibility, and achievability to create the evaluation indicator system, as shown in Table 2.1.

Table 2.1. Highway project investment evaluation index system.

Objective layer	Segmentation layer	Evaluation indicators
Investment appraisal of highway projects	Profitability Evaluation	Net financial present value (NPV)
		Internal rate of return
		Dynamic payback period
		Total investment return
		Return on assets
		Net capitalization margin
	Solvency Evaluation	Debt service coverage
		Interest provision ratio
	Evaluation of Risk Resistance	Gearing

2.3. Modeling

2.3.1. Determination of system boundaries and subsystem delineation

Although different highway construction projects have certain differences in construction scale, capital investment, and financing mode, some common structures can be summarized in investment evaluation. On this basis, with reference to the relevant provisions within the Methods and Parameters for Economic Evaluation of Highway Construction Projects [20], the system boundaries are determined, and the six subsystems are divided into six major subsystems: Investment, financing and liabilities subsystem; income subsystem; cost subsystem; profit subsystem; cash flow subsystem; and investment evaluation subsystem.

2.3.2. System architecture

Based on the analysis of highway project environment and investment evaluation elements, the internal feedback mechanism of each subsystem and the positive and negative correlation between subsystems and the whole are clarified, and a causal feedback diagram is constructed, as shown in Figure 2.1.

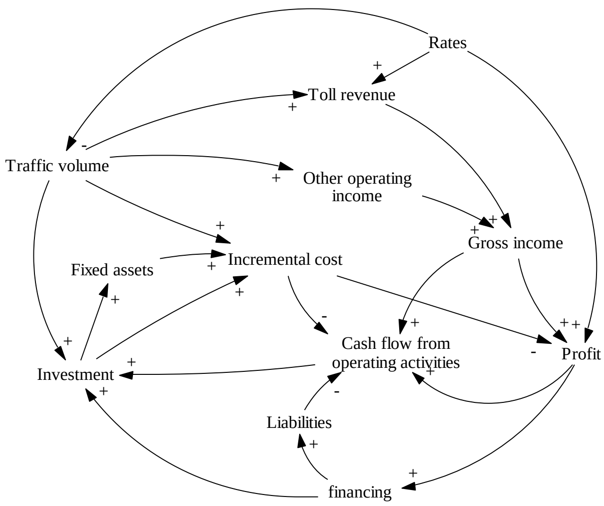

Figure 2.1. Causal feedback loops for major factors.

2.3.3. Dynamics model of highway investment evaluation system

By clarifying the system boundary, dividing the subsystems, and analyzing the overall structure of the system, the dynamics model of the highway project investment evaluation system is constructed as shown in Figure 2.2.

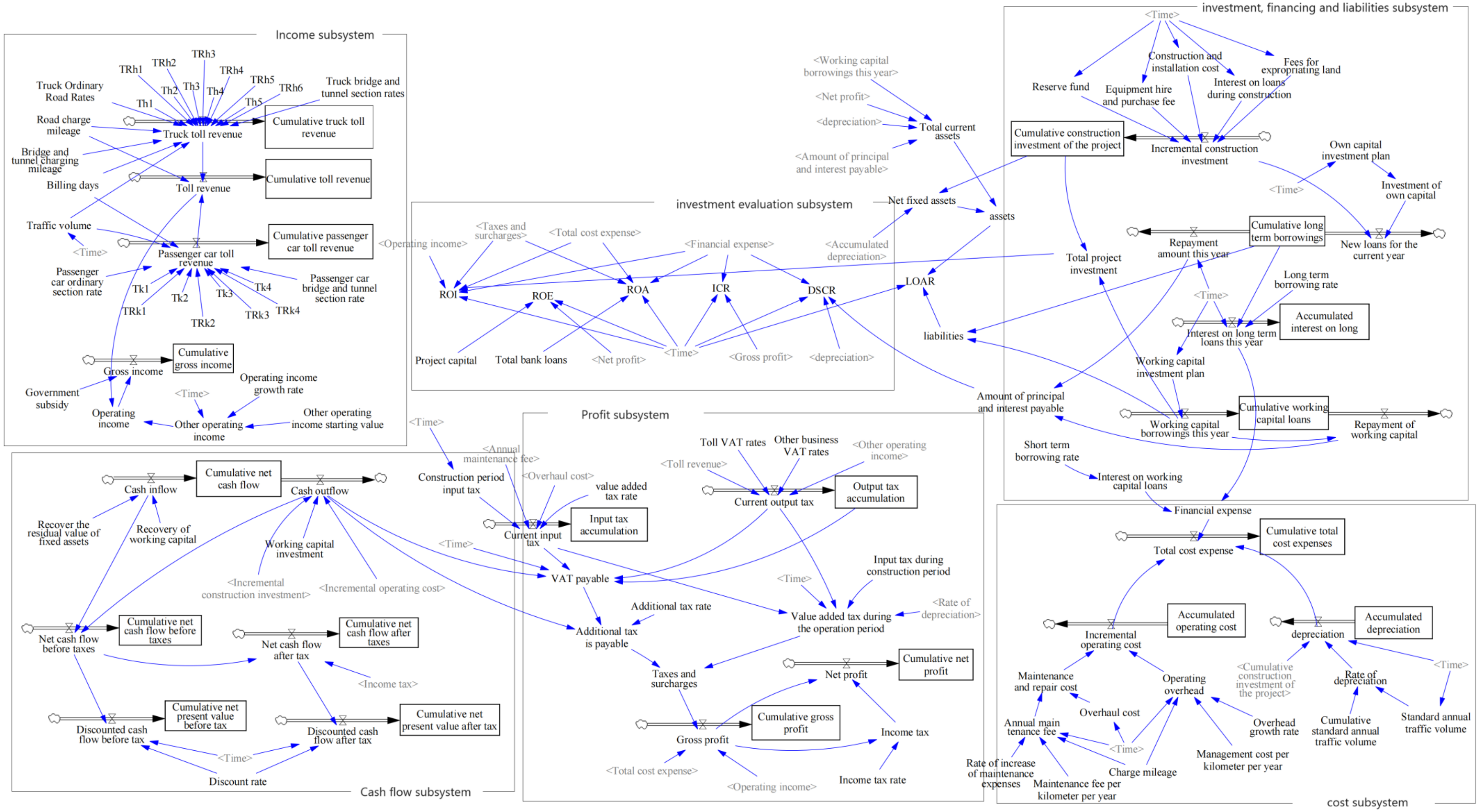

Figure 2.2. Flow chart of the investment appraisal system for highway projects.

In order to present the relationship between variables in quantitative form, DYNAMO editing language is used for the definition of system variable equations, and then the example is simulated and examined by VENSIM software. Table 2.2 displays the key functions involved.

Table 2.2. DYNAMO functions utilized in the model.

Function type	DYNAMO language	Note
integral function (math.)	INTEG({variable},{initial})	Integration overflow velocity variables
rounding function (math.)	INTEGER({x})	For parameter rounding
Select function	IF THEN ELSE({cond},{ontrue},{onfalse})	Indicates conditional selection
table function	WITH LOOK UP(Time,{data})	Non-linear data output
delay function	DELAY1I({in},{dtime},{init})	Delayed Data Entry

3. Empirical and simulation analysis

3.1. Research target

An Expressway Project in Yunnan Province is the subject of study, according to the Engineering Feasibility Study Report of the Expressway Project, the toll mileage of this road section is 65.625 kilometers, of which 42.307 kilometers are ordinary tolled sections and 23.318 kilometers are bridge and tunnel tolled sections, and the total amount of investment is 1,031,066,000 yuan, including social capital, government subsidies, and commercial loans, and the construction period of 3 years opened to traffic in 2023.

In this study, the basic assumptions of the highway investment evaluation system dynamics model are as follows:

(1) There is no big fluctuation in the socio-political and economic environment during the concession operation period of the project.

(2) According to the holiday toll-free policy, the number of toll collection days per year during the operation period is calculated as 345 days.

(3) The investment in fixed assets is equal and occurs only during the construction period. It is assumed that the project will reach the estimated operation level after completion, and the trial operation period is not considered.

(4) Revenue from the project's operating activities is calculated only for the main business revenue, i.e., toll revenue, and other operating revenues are estimated according to the initial valuation and a certain growth rate.

(5) According to the characteristics of the main business income form of the highway, the accounts receivable and credit sales are not considered for the time being, and the operating income is calculated according to the current sales income.

(6) Only corporate income tax, value-added tax, and taxes and surcharges are considered for the project's taxable expenses.

(7) The bank's long-term loan interest rate and working capital borrowing interest rate are fixed. According to the bank's regulations related to infrastructure project loans, the project's long-term borrowing adopts the fixed repayment method and the repayment period is 25 years.

(8) The project is not a Public-Private-Partnership project, and direct government funding

subsidies are not considered in the investment appraisal for the time being, and the preferential interest rate of the policy support section is reflected.

3.2. Data description

3.2.1. Calculation of key variables

(1) Traffic volume

The results of the traffic volume forecast are shown in Table 3.1, and the data are from the Public Works Report. According to the forecast year difference of the predicted traffic volume, calculate the average value of the difference and take the difference year by year to estimate the standard traffic volume in each year.

Table 3.1. Traffic volume prediction results of the project (pcu/d).

Roadway Section	Year				
	2020	2025	2030	2040	2050
Average	7556	11252	15764	23393	29924

(2) Operating costs

Operating costs mostly include operation and management fees, daily maintenance fees, and overhaul costs. The operation and management costs mostly cover the operation and management costs of the operating company and road management. Daily maintenance costs cover the costs of facilities and greening maintenance along the routes and daily maintenance of roads. The overhaul cost is the regular maintenance of road facilities carried out to ensure the service level of the roads, generally every ten years for a period of two years. According to the Statistical Bulletin of Operational Highways in Yunnan Province 2016−2019, the operation and management fee and daily maintenance fee of the Project are taken at RMB 339,100/km and RMB 324,400/km per year. Since the completion of the project, the road and related facilities will be overhauled in 2031 to 2032, 2041 to 2042, and 2051 to 2052, with each overhaul lasting two years, and the three overhaul costs are RMB 81,250,000/year, RMB 114,062,500/year, and RMB 146,875,000/year, respectively. All the above costs take into account the average annual growth rate.

$$C = \sum_{t=1}^{n} C_1 \cdot L \cdot (1 + l_1)^{t-1} + \sum_{t=1}^{n} C_2 \cdot L \cdot (1 + l_2)^{t-1} + C_3$$

where C is the total operating cost; C_1 is the operating and management cost per unit kilometer; l_1 is the growth rate of the operating and management fee; C_2 is the daily maintenance cost per unit kilometer; l_2 is the growth rate of the daily maintenance fee; C_3 is the cost of overhaul; t is the operating year; and L is the toll mileage.

(3) Depreciation of fixed assets

According to the specific conditions of the expressway project, the total investment of the project will be depreciated as a whole when calculating the depreciation of fixed assets. In order to reasonably reflect the highway depletion and the profit situation of the project, the traffic flow depreciation method is adopted to calculate the depreciation rate by the proportion of the annual standard traffic volume to the total standard traffic volume during the operation period, and the calculation formulas are as follows:

$$\text{Annual depreciation} = \frac{\text{Annual standard traffic volume}}{\text{Total standard traffic volume during the operational period}} \times \text{Original value of fixed assets}$$

(4) Finance costs

The costs incurred by the enterprise to raise funds are referred to as finance costs, i.e., interest expenses and related handling fees, etc. Construction projects commonly use the debt service method for equal debt service, the formula is presented as follows:

$$A = I_c \times \frac{i(1+i)^n}{(1+i)^n - 1}$$

where A is the annual debt service amount; I_c is the borrowing balance at the beginning of the starting year of repayment; i is the annual interest rate; and n is the scheduled repayment period.

3.2.2. Constant parameter values

In order to reduce the impact of parameter fluctuations on the simulation of the system dynamics model, the parameters with insignificant fluctuations with time and external environmental changes are set as constants by taking the average value, and the major constant parameters involved in this project are shown in Table 3.2.

Table 3.2. Main parameters involved in the project.

Parameter name	Parameter value
Truck general road rate	0.45Yuan/ton-kilometer
Truck bridge and tunnel section rates	1.15Yuan/ton-kilometer
Passenger car general roadway rates	0.50Yuan/ton-kilometer
Passenger Car Bridge and Tunnel Section Rates	1.40Yuan/ton-kilometer
Percentage of buses in class I (Tk1)	47.58%
Percentage of buses in category II (Tk2)	1.61%
Percentage of buses in three categories (Tk3)	2.62%
Percentage of buses in four categories (Tk4)	0.89%
Percentage of goods vehicles in class I (Th1)	20.14%
Percentage of goods vehicles in class II (Th2)	9.35%
Percentage of goods vehicles in three categories (Th3)	3.55%
Percentage of trucks in four categories (Th4)	4.00%
Percentage of trucks in five categories (Th5)	0.83%
Percentage of Class VI trucks (Th6)	9.43%
Billing factor for category I buses (TRk1)	1.00
Billing factor for category II buses (TRk2)	1.80
Billing factor for category III buses (TRk3)	2.50
Billing factor for bus category IV (TRk4)	4.50
Truckload category I billing factor (TRh1)	1.00
Truckload Rating Factor for Truck Class II (TRh2)	3.50
Truckload Rating Factor for Truck Class III (TRh3)	5.10
Truck type IV billing factor (TRh4)	5.80

Continued on next page

Parameter name	Parameter value
Truck type V billing factor (TRh5)	6.20
Truck type VI billing factor (TRh6)	6.80
Other operating income growth rate	3.00%
Growth rate of maintenance fees	2.00%
Management fee growth rate	2.00%
Discount rate (after tax)	4.50%
VAT rate	9.00%
Other business VAT rates	6.00%
Surtax rates	12.00%
Income tax rate	25.00%
Interest rates on long-term loans	4.65%
Interest rate on current borrowings	3.85%

3.3. Analysis of system dynamics simulation results

Based on the calculation of variables and parameter values in the previous section, an example simulation is carried out using VENSIM software. The following results are obtained:

Figures 3.1 and 3.2 focus on the revenue subsystem, while Figures 3.4−3.6 focus on the cost subsystem. Figure 3.7 focuses on the profit subsystem, while Figures 3.8−3.10 analyze the cash flow subsystem. Finally, Figures 3.11−3.14 focus on the investment appraisal subsystem.

3.3.1. Analysis of investment appraisal results

(1) Analysis of major factors in investment appraisal

1) Toll revenue is shown in Figure 3.1

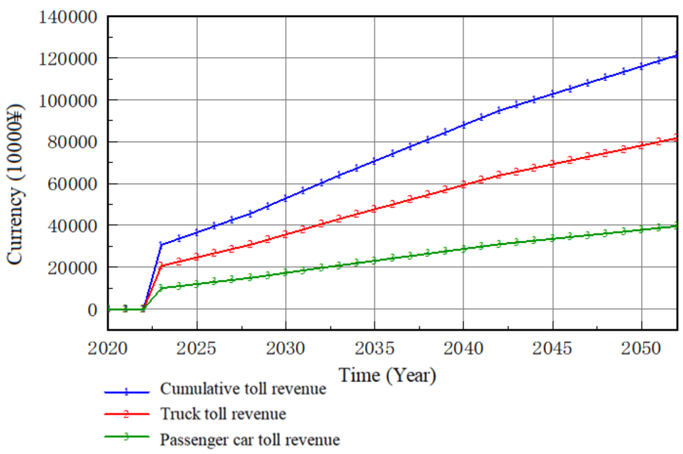

Figure 3.1. Project toll revenue simulation.

2) Total revenue is shown in Figure 3.2.

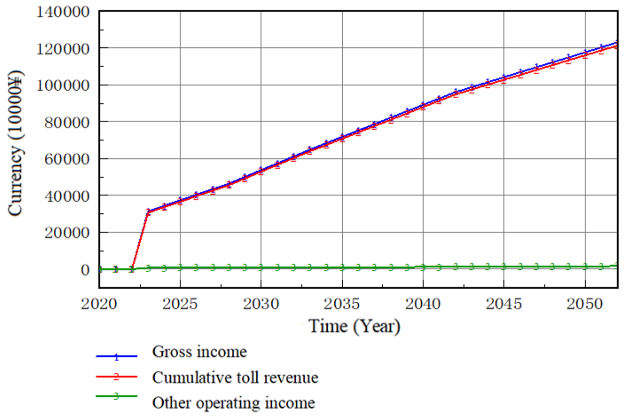

Figure 3.2. Simulation of total project income.

3) Operating costs are shown in Figure 3.3.

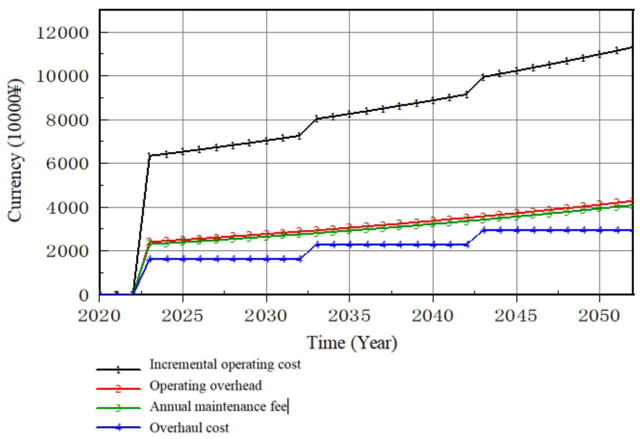

Figure 3.3. Simulation of project operating costs.

4) Finance costs, as shown in Figure 3.4.

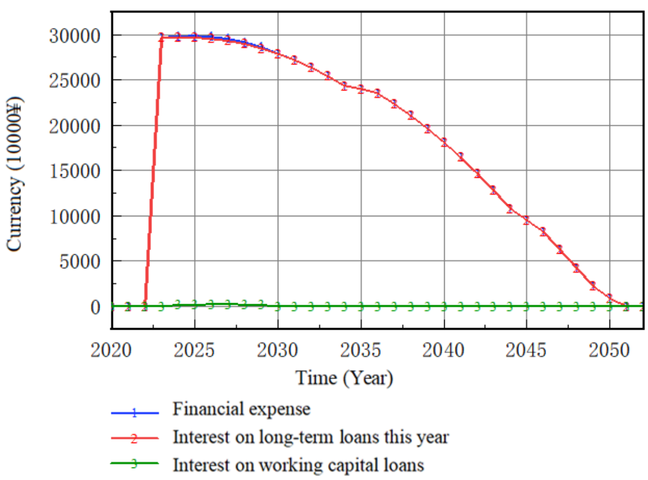

Figure 3.4. Simulation of project financial costs.

5) The total cost is shown in Figure 3.5.

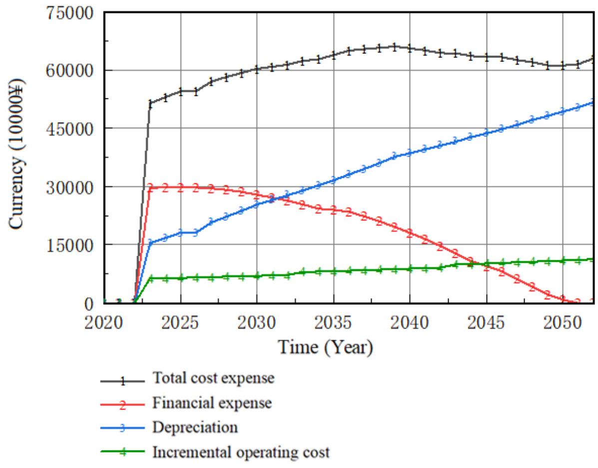

Figure 3.5. Simulation of total project costs and expenses.

6) Net profit is shown in Figures 3.6 and 3.7.

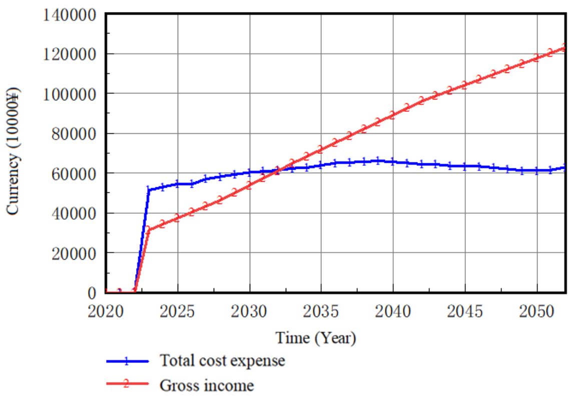

Figure 3.6. Total project costs and expenses vs. total revenue.

7) The profit subsystem simulation results are shown in Figure 3.7.

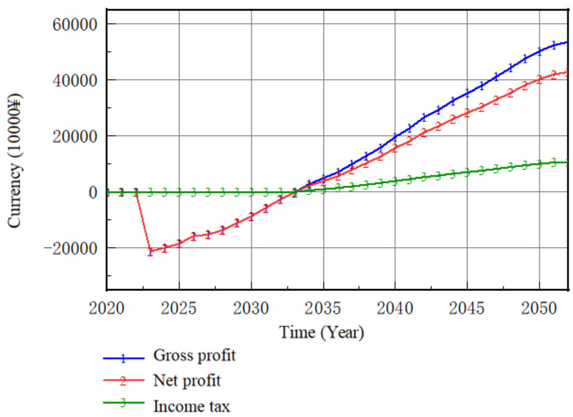

Figure 3.7. Simulation of project net profit.

8) After-tax net cash flow is shown in Figures 3.8 and 3.9.

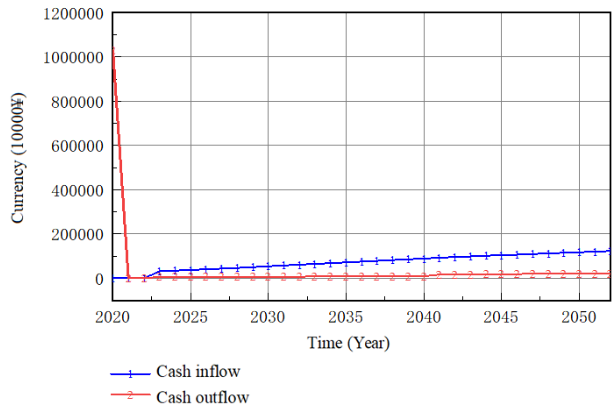

Figure 3.8. Simulation of project cash inflows and outflows.

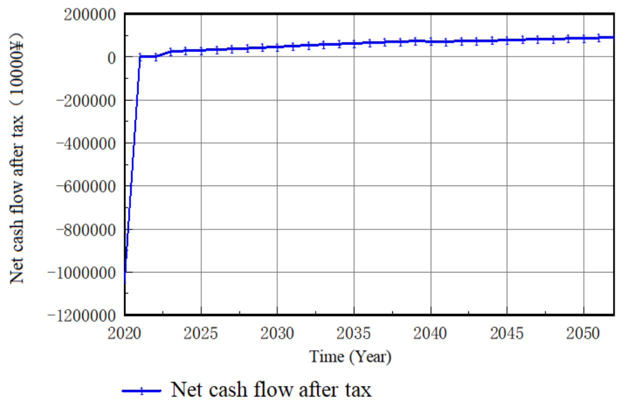

Figure 3.9. Project net cash flow after tax.

(2) Analysis of investment appraisal profitability indicators

1) NPV is shown in Figure 3.10.

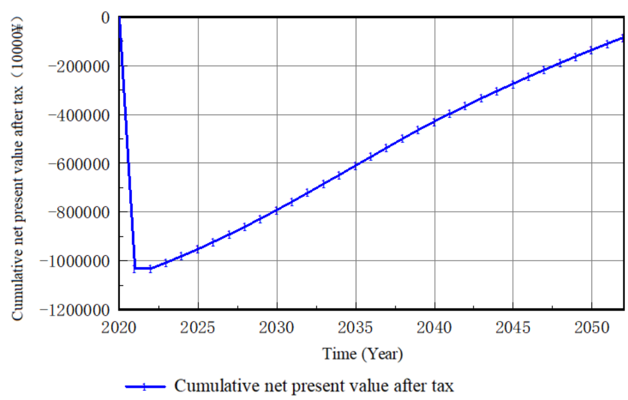

Figure 3.10. Simulation of the cumulative after-tax net present value of the project.

2) The simulation curves of ROI on total investment, ROE on net capitalization, and ROA on return on assets are shown in Figure 3.11.

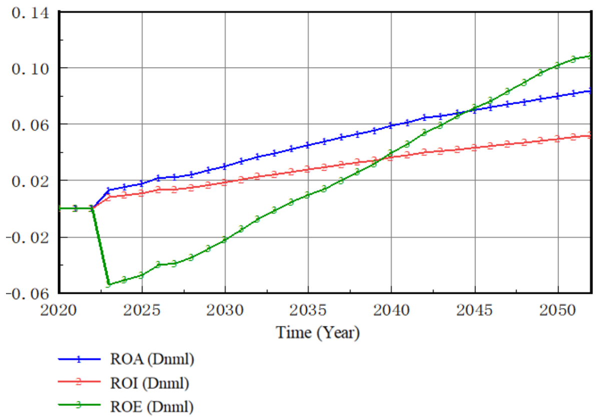

Figure 3.11. Simulation of project ROA, ROI, and ROE.

(3) Analysis of solvency indicators for investment appraisal

1) Interest Provision Ratio ICR is shown in Figure 3.12.

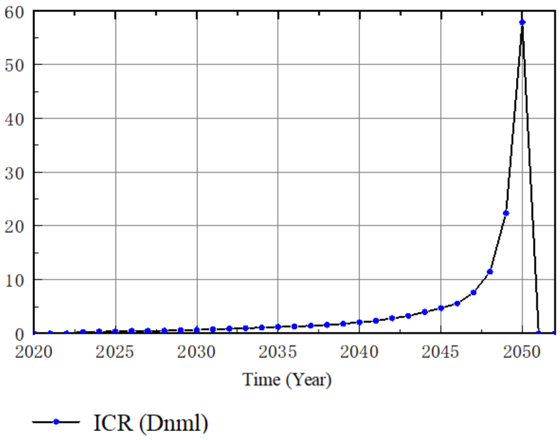

Figure 3.12. Project ICR simulation.

2) Debt service provision ratio DSCR is shown in Figure 3.13.

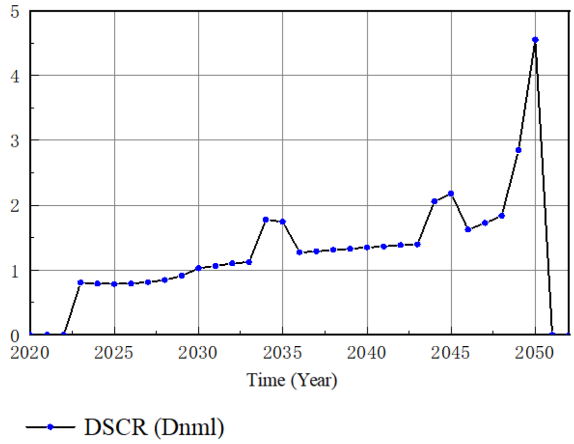

Figure 3.13. Project DSCR simulation.

(4) Analysis of risk resilience indicators

The gearing ratio (LOAR) is shown in Figure 3.14.

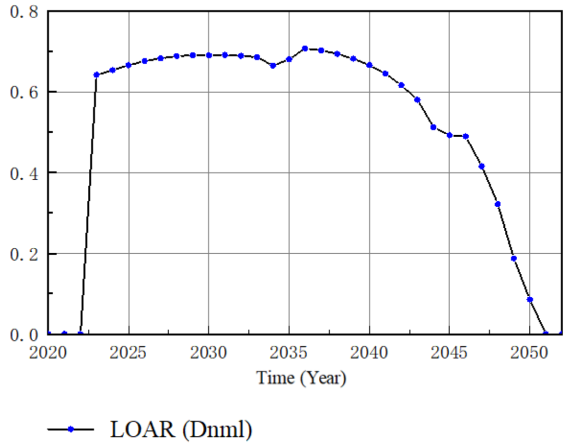

Figure 3.14. Project LOAR simulation.

Analyzing the simulation results yields the following conclusions.

(1) Trucks accounted for a higher percentage of toll revenues, ending the period with revenues of RMB817.34 million and an annual increase of RMB203.640 million, higher than bus revenues of RMB396.06 million and an annual increase of RMB9.8680 million for buses. Both contribute to the total toll revenue annual change of RMB 30,232,200,000.

(2) Total project revenue at the end of the operating period was RMB123,056,000, of which RMB121,340,000 was toll revenue and RMB17,160,000 was other operating revenue.

(3) Operating costs increase yearly, fluctuating every ten years due to overhaul costs, peaking at RMB113 million in the ending year.

(4) The long-term borrowing during the construction period will be repaid in 26 years starting from 2025, with the interest paid as usual. Before 2034, the repayment capacity of the project is weak and the decreasing trend of the finance cost is gentle. After that, the project's operation cost is stable, the repayment ability is improved, the decreasing trend of finance cost is significant, and the debt repayment will be completed by 2050.

(5) During the operating period, the total cost of the project increases annually, peaking at RMB660.62 million in 2039. Due to the negative growth of finance costs, the decrease after 2035 is greater than the increment of depreciation and operating costs, and the total cost decreases year by year from 2038. By 2050, finance charges stabilize, and total costs increase slightly due to depreciation and operating costs.

(6) The project is profitable from 2032 onwards, with revenues exceeding costs and the difference widening each year to a profit of RMB534.63 million at the end of the period.

(7) After 2032, the project is profitable, income tax increases with profits, and net profit increases year by year. In the last year of the concession period, the net profit reaches RMB427.7 million.

(8) After the operation period in 2023, the difference between cash inflows and cash outflows gradually increases. During the construction period in 2021−2022, the net cash flow is 0. During the operation period, the project's net cash flow grew gently, from RMB248.1 million to RMB885.45 million. Therefore, the project's net cash flow reached its lowest peak at the beginning of the construction period in 2020.

(9) The calculation of the discount rate shows that the net benefit of the project is not

enough to cover the cost of construction. ROE and ROI grow slowly and have low values during the operation period. ROI fails to reach the benchmark rate of return of the project in the first and middle periods of the operation period, which indicates that the project profitability is weak and there is financial risk.

(10) In the early years of operation, project profits are not sufficient to cover finance costs, resulting in slow growth in the interest provision ratio. By 2032, the project profit will turn positive and grow year by year, which can be used to pay interest. By 2040, the ICR will reach the benchmark value of 2, which meets the requirement of interest repayment capacity. Thereafter, ICR growth accelerates, peaking at 57 in 2050.

(11) Since 2038, the project DSCR has reached the benchmark value of 1.3, with a clear growth trend. Debt repayment capacity is good, and by 2047 when the repayment of long-term borrowing enters the end of the repayment period, the DSCR growth trend is similar to that of ICR, and the DSCR reaches a peak of 4.50 in the last year of the repayment period.

(12) Since the project has been in operation, the LOAR fluctuates between 60% and 75%, peaking at 71% in 2036, which is a high proportion of debt capital and high risk. However, after 2042, the LOAR decreases year by year, reducing the risk, and is less than 40% after 2047 until the loan is repaid.

In summary, the project has a negative after-tax net present value at the end of the operation period, the internal rate of return is lower than the benchmark, the payback period is overdue, and the net profit margin on capital, return on assets and total return on investment are lower than the industry benchmark. Therefore, the project is unable to realize profit and recover all investment during the operation period and does not have investment feasibility. Furthermore, the project's solvency is weak, the interest provision ratio needs to reach the standard by 2040, and the debt level is high in the first and middle part of the operation period, so investors are facing greater financial risks. In addition, the project's risk-resistant ability is also weak, with the highest gearing ratio of 71%, which will not meet the industry standard until after 2042, and the first 20 years of the operation period will be highly indebted.

3.3.2. Sensitivity analysis

(1) Sensitivity analysis of toll revenue

Figure 3.15 shows a one-factor sensitivity analysis of toll revenues.

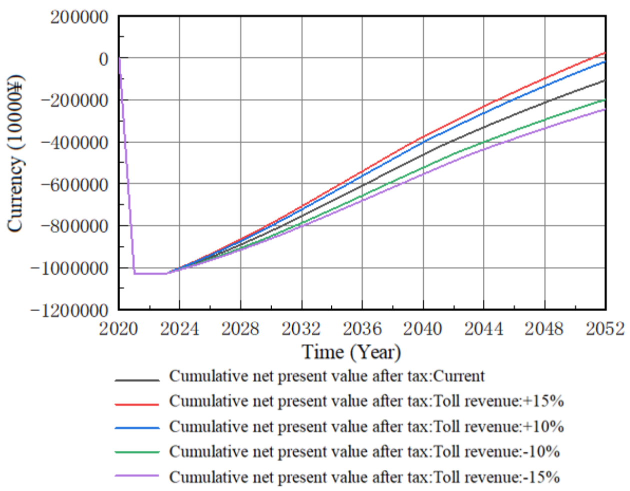

Figure 3.15. Sensitivity analysis of toll revenue.

(2) Sensitivity analysis of operating costs

Figure 3.16 shows a one-factor sensitivity analysis of operating costs.

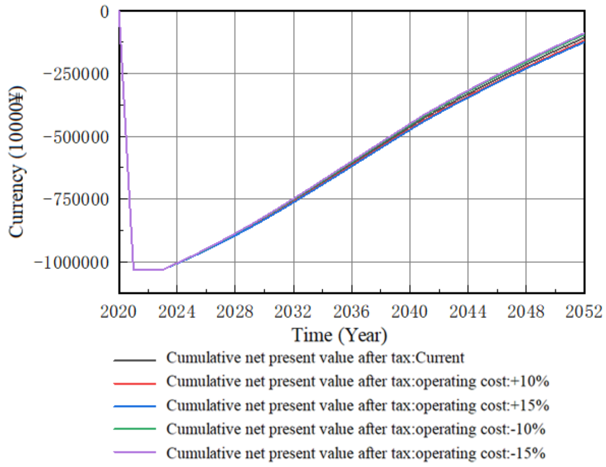

Figure 3.16. Operating cost sensitivity analysis.

(3) Mixed-factor sensitivity analysis

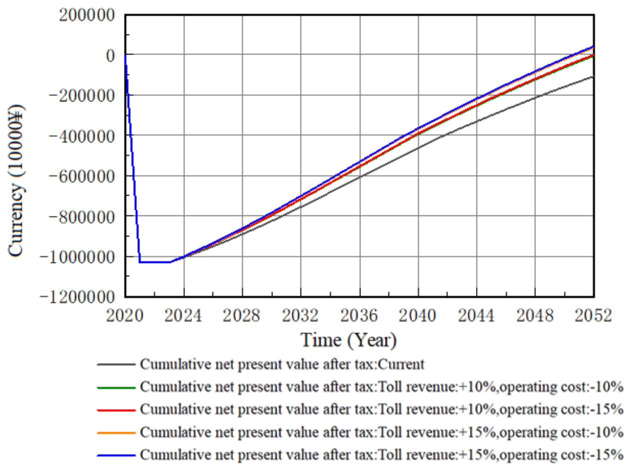

Figure 3.17. Mixed-factor sensitivity analysis.

Figure 3.15 shows that the project has a positive NPV and an IRR greater than the benchmark rate of return of 4.71% only when the toll revenue increases by 15%. Toll revenues are sensitive to NPV and IRR and therefore their impact should be emphasized in operations.

Figure 3.16 shows that operating costs are negatively correlated with NPV, with little effect in the initial period and slight variations in the middle and late periods. In all cases, the project fails to recover its full investment over the operating period.

Figure 3.17 presents a mixed-factor sensitivity analysis showing the impact of simultaneous changes in toll revenues and operating costs on the project evaluation indicators. Of the four combinations, a 15% increase in toll revenues and a 15% decrease in operating costs results in the largest project NPV, which recovers the full investment in 2050. In the other combinations, the project also recovers its full investment at the end of the operating period or slightly later, and in only one case does it fail to do so.

Table 3.3 shows that the greater the change in toll revenue, the greater the project IRR. Within the same range of change, the sensitivity of toll revenue to project investment evaluation indicators is stronger. In addition, the project's investment recovery is overly dependent on toll revenues, indicating that the project's revenue composition is limited and its capacity to withstand financial risks is weak.

Table 3.3. Changes in indicators related to the sensitivity analysis of the mixing factors.

Estimation norm	Mixed-factor sensitivity analysis					
	Toll revenue operating cost	+10% -10%	+10% -15%	+15% -10%	+15% -15%	starting value
After-tax cumulative net present value (RMB million)	/	-2261	6514	43327	48781	-88928
After-tax internal rate of return	/	4.48%	4.52%	4.79%	4.83%	3.82%

(4) Extension of fee year analysis

Using the system dynamics model simulation, the project is projected to extend the tolling year by 4 years. The model predicts that the project will reach saturation traffic volume in 2054. From Figure 3.18 simulation results show that after extending the toll life, the project recovers all the investment in 2056, with a net present value of 93.63 million yuan and an internal rate of return of 4.53%. The simulation values are basically consistent with the calculation results, and the model can be used for policy analysis to provide support for the long-term benefit equilibrium.

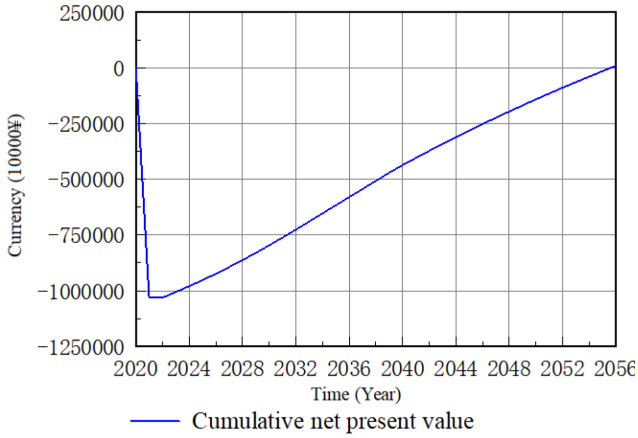

Figure 3.18. Cumulative NPV simulation for extended toll periods.

3.4. Investment appraisal cash flow statement

Table 3.4. Project cash flow statement.

Unit: ¥10, 000

Project period	vintages	cash inflow （CI）	Toll revenue （TR）	Other operating income (OBI)	Recovery of liquidity （ROI）	cash outflow （CO）	Project investment (PI)	Liquidity investment （LI）	Cash operating costs (COC)	Taxes and surcharges (TS)	Net cash flows (NCF)	Cumulative net cash flows (CNCF)	earnings before interest and tax (EBIT)	taxable income (TI)	Adjustment of income tax (AIT)	Net cash flow after tax (NCFAT)	Cumulative net cash flow after tax (CNCFAT)	Cumulative net present value after tax (CNPVAT)
construction period	2020	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
	2021	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
	2022	/	/	/	/	1031066	/	/	/	/	-1031066	-1031066	/	/	/	-1031066	-1031066	/
operational period	2023	31369	30641	728	/	6338	/	/	6338	/	25031	-1006035	-21173	/	/	25031	-1006035	-1006035
	2024	34390	33640	750	/	6432	/	/	6432	/	27958	-978077	-19978	/	/	27958	-978077	-979281
	2025	37409	36636	773	/	6529	/	/	6529	/	30880	-947197	-18365	/	/	30880	-947197	-951003
	2026	40431	39635	796	/	6627	/	/	6627	/	33804	-913393	-15755	/	/	33804	-913393	-921381
	2027	43452	42632	820	/	6717	/	/	6717	/	36725	-876668	-15132	/	/	36725	-876668	-890585
	2028	46470	45625	845	/	6829	/	/	6829	/	39641	-837028	-13519	/	/	39641	-837028	-858775
	2029	50153	49284	869	/	6933	/	/	6933	/	43220	-793807	-10978	/	/	43220	-793807	-825587
	2030	53838	52942	896	/	7039	/	/	7039	/	46799	-747009	-8495	/	/	46799	-747009	-791197
	2031	57525	56603	922	/	7174	/	/	7174	/	50378	-696630	-5329	/	/	50378	-696630	-755772
	2032	61211	60261	950	/	7258	/	/	7258	/	53953	-642677	-2284	/	/	53953	-642677	-719467
	2033	64899	63920	979	/	8027	/	/	8027	/	56872	-585805	394	394	79	56793	-585884	-682896
	2034	68368	67360	1008	/	8141	/	/	8141	/	60227	-525578	2893	2893	579	59648	-526236	-646141
	2035	71836	70798	1038	/	8259	/	/	8259	/	63577	-462001	5133	5133	1027	62551	-463685	-609257
	2036	75308	74239	1069	/	8378	/	/	8378	/	66930	-395979	7649	7649	1530	65401	-398284	-572353
	2037	78778	77677	1101	/	8500	/	/	8500	/	70278	-324792	10745	10745	2149	68129	-330155	-535566
	2038	82250	81116	1134	/	8625	/	/	8625	/	73626	-251167	13750	13750	2750	70875	-259280	-498943
	2039	85721	84553	1168	/	8751	/	/	8751	/	76970	-174197	16805	16805	3361	73609	-185671	-462546
	2040	89195	87991	1204	/	13762	/	/	8881	4881	75433	-98764	20114	20114	4023	71410	-114261	-428756
	2041	92669	91430	1240	/	16888	/	/	9013	7875	75781	-22984	23783	23783	4757	71025	-43236	-396596
	2042	96133	94856	1277	/	17330	/	/	9147	8183	78803	55820	27729	27729	5546	73257	30021	-364854
	2043	98819	97504	1315	/	18301	/	/	9941	8360	80518	136338	30463	30463	6093	74425	104446	-333994
	2044	101508	100153	1355	/	18678	/	/	10081	8597	82830	219168	38312	38312	7662	75168	179614	-304168
	2045	104198	102803	1395	/	19058	/	/	10224	8834	85141	304309	36003	36003	7201	77940	257554	-274574
	2046	106887	105450	1437	/	19440	/	/	10370	9070	87447	391756	39027	39027	7805	79642	337195	-245636
	2047	109579	108099	1480	/	19825	/	/	10518	9307	89754	481510	442301	442301	8460	81294	418489	-217370
	2048	112272	110747	1525	/	20213	/	/	10670	9543	92059	573568	45419	45419	9084	82975	501464	-189762
	2049	114967	113396	1570	/	20605	/	/	10825	9780	94362	667930	48361	48361	9672	84690	586154	-162796
	2050	117658	116041	1617	/	20998	/	/	10982	10016	96660	764590	50628	50628	10126	86534	672688	-136430
	2051	120356	118690	1666	/	21396	/	/	11143	10253	98960	863551	52311	52311	10462	88498	761186	-110627
	2052	123052	121336	1716	/	21976	/	/	11307	10489	101256	964806	53459	53459	10692	90564	851750	-85358
figure		2370700	2336079	34642	/	1405894	1031066	/	259641	115188	1995872	-5855533	434173	113056	113056	1882816	-6644652	-16988771

3.5. *Comparative analysis and recommendations*

3.5.1. Comparative analysis

To facilitate a comprehensive comparison between the system dynamics simulation method and the discounted cash flow method, and to assess the realism and rationality of the system dynamics model, we utilize the calculation results from the cash flow table in Table 3.4. By selecting representative key indices of the net present value based on the cash flow, we can conduct a detailed comparison. The results for the project's after-tax net cash flow and net present value using both methods are presented in Table 3.5.

Table 3.5. Comparison of after-tax net cash flows and net present values.

vintages	Net cash flow after tax (¥ million)		Cumulative after-tax net present value (¥ million)	
	system dynamics	cash flow statement	system dynamics	cash flow statement
2020-2022	-1031066	-1031066	-1031066	-1031066
2023	24810	25031	-1006035	-1006035
2024	27694	27958	-979681	-979281
2025	30575	30880	-952303	-951003
2026	33460	33804	-923580	-921381
2027	36325	36725	-893585	-890585
2028	39204	39641	-862575	-858775
2029	42731	43220	-830076	-825587
2030	46253	46799	-796287	-791197
2031	49772	50378	-761402	-755772
2032	53286	53953	-725527	-719467
2033	56020	56793	-689295	-682896
2034	58861	59648	-652911	-646141
2035	61711	62551	-616317	-609257
2036	64496	65401	-579687	-572353
2037	67172	68129	-543055	-535566
2038	69844	70875	-506522	-498943
2039	72503	73609	-470165	-462546
2040	70304	71410	-436376	-428756
2041	69911	71025	-404165	-396596
2042	72086	73257	-372323	-364854
2043	73251	74425	-341313	-333994
2044	73877	75168	-311242	-304168
2045	76614	77940	-281374	-274574
2046	78225	79642	-252086	-245636
2047	79793	81294	-223410	-217370
2048	81381	82975	-195380	-189762
2049	83045	84690	-167976	-162796
2050	84713	86534	-141120	-136430
2051	86566	88498	-114787	-110627
2052	88545	90564	-88928	-85358

There is a discrepancy between the after-tax net cash flow and net present value calculated by the two methods. They are shown in Figures 3.19 and 3.20. The inaccuracy range of the after-tax net cash flow is found to be between 0% and 2.23%, which is considered a reasonable margin of error. The discrepancies primarily stem from the Vensim PLE software's handling of data, which may introduce rounding inaccuracies and storage limitations, especially for values with seven or more digits. The software uses scientific notation for such values, which can lead to inaccuracies in the calculation results. These inaccuracies tend to amplify with the number of iterations, contributing to the observed differences in the calculations. The iteration inaccuracy in the calculation of cumulative NPV is more pronounced, with a range of 0% to 4.18%, which is considered reasonable. Additionally, the internal rate of return (IRR) calculated by the cash flow statement and simulated by the system dynamics model is 3.85% and 3.82%, respectively. The payback period is 33.5 years according to the cash flow statement and 33.7 years according to the system dynamics model. All the inaccuracies fall within the requirement of less than 10% inaccuracy in the feasibility study stage of the project, as specified in the "Yunnan Provincial Construction Project Cost Consulting Service Standards" [21]. This indicates that the results from the system dynamics model simulation are highly credible and adaptable for the investment evaluation system of highway projects.

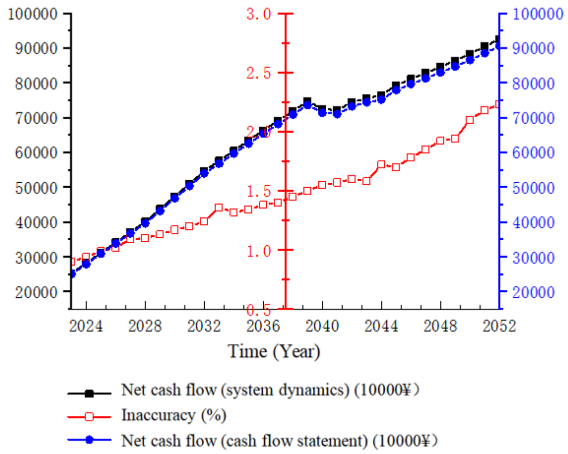

Figure 3.19. After-tax net cash flow inaccuracy analysis.

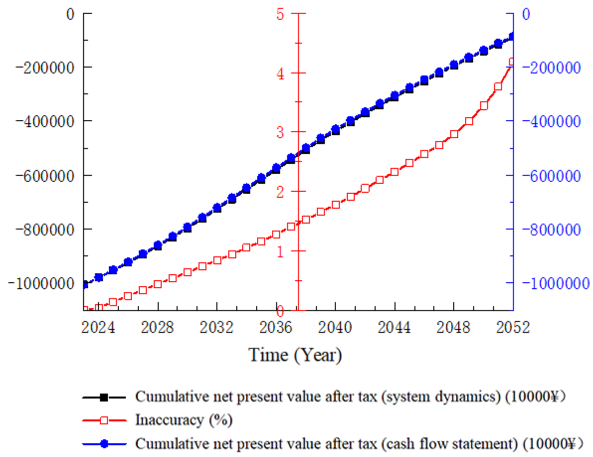

Figure 3.20. Cumulative after-tax NPV inaccuracy analysis.

4. Conclusions

Addressing the limitations of the traditional discounted cash flow method in the investment evaluation of highway construction projects, this paper proposes a highway project investment evaluation method based on system dynamics. The conclusions drawn from this approach are as follows:

(1) We construct an investment evaluation model for highway projects based on system dynamics.

We establish the investment evaluation index system for China's current construction projects, considering feasibility, favorability, and achievability. Following the principles of index system construction, the model uses the basic theory of system dynamics, functional equations, and accounting basics to describe the qualitative and quantitative relationships between relevant elements. This approach aims to create an investment evaluation model that better reflects the reality of highway construction projects. It presents multiple financial statements in a holistic manner, emphasizing the systematic nature of the evaluation object.

(2) Refinement of the highway investment evaluation subsystem.

The highway investment evaluation includes six subsystems: Income, cash flow, investment evaluation, profit, cost, investment and financing, and liabilities. The revenue subsystem improves the generality and vagueness of the toll revenue forecast in the traditional evaluation method, analyzes the different generating mechanisms of the passenger toll revenue and freight toll revenue, and presents them intuitively through the system dynamics model; the cash flow subsystem is more simplified and clearer and the model is presented in the form of a chart to highlight the correlation between the elements compared to the cash flow statement in the traditional evaluation method; the investment evaluation subsystem integrates and lists the relevant evaluation indicators, influencing factors and mutual functional relationships, and highlights the relevant relationships among elements compared to the traditional discounted cash flow evaluation method. The investment evaluation sub-system integrates and lists the relevant evaluation indicators, influencing factors, and inter-functional relationships, which is more intuitive than the traditional discounted cash flow evaluation method and more efficient in integrating the results of the indicators.

(3) The system dynamics model can more directly reflect the dynamic situation of evaluation indicators and projects and has strong applicability. Compared with the traditional discounted cash flow method, the system dynamics model can overcome its limitations and provide a more comprehensive and dynamic financial evaluation idea. By comparing and analyzing with the discounted cash flow method, the inaccuracy range of after-tax net cash flow calculated by the cash flow statement and the system dynamics simulation is 0 to 2.23%, and the inaccuracy range of cumulative net present value is 0 to 4.18%. The internal rates of return are 3.85% and 3.82%, and the payback periods are 33.5 years and 33.7 years, respectively, and the inaccuracies are within reasonable ranges.

Author contributions

Yonghua Liu: Conceptualization, Methodology, Supervision, Writing–review & editing; Deng Hao: Validation, Visualization, Writing–original draft; Hanqi Gao: Data curation, Formal analysis, Writing–original draft; Wei Ni: Investigation, Resources, Writing–review & editing. All authors have read and approved the final version of the manuscript for publication.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflict of interest

All authors declare no conflict of interest in this paper.

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