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Study on the Relationship between Highway Maintenance and Concession Period of PPP Project

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Abstract. In order to solve the problem of shortage of funds for highway construction and maintenance, Public-Private-Partnership (PPP) has been widely used and the concession period is one of the core issues in the negotiation of the highway PPP project. The system dynamic (SD) method is adopted to model relationship between highway maintenance and concession period of PPP project. The aim of this study is to study the long-term dynamic relationship between different highway maintenance strategies and project concession period, therefore to help the government to determine a reasonable concession period. Case study is presented to demenstrate the validation of the proposed SD model.

Introduction

Since the construction of the first highway in 1984, China's highway industry has made rapid development. With the continuous expansion of the highway network and the passage of time, the demand for the maintenance of the highway is also increasing day by day. On the other hand, it still need to invest a lot of money into the construction for a long time in the future. Because of the limited funds for highway maintenance and construction, the highway with large area in China can only get the most basic maintenance.

PPP is a public-private partnership project financing pattern in public infrastructure. In this pattern, private enterprises and capital get cooperation with government, participating in the construction of public infrastructure, thus effectively ease the government pressure in providing infrastructure and services.

The current studies on the concession period of highway PPP project include: Concession period research based on the bargaining game theory between investors and the government [1], research on the impact of risk and uncertainty on concession period[2], the influence of construction and market risks on the concession period with key path method and Monte Carlo simulation[3]. However, rare studies on the relationship between highway maintenance and concession period have been taken. Therefore, this paper proposes a system dynamic model of concession period of highway PPP project, including the quantitative relationships between relevant variables, based on the characteristics of highway maintenance management in China.

System Dynamics Methodology

System dynamics (SD) developed by Jay Forrester is able to handle the system issues of high order, nonlinear and multiple feedbacks[4]. The SD method has been successfully applied in different fields, including economics, health science, physics, mathematics as well as civil engineering and management[5][6].

Stock-Flow Diagram for Interactions around Pavement Condition. The subsystem shown in Fig. 1 models the dynamic interactions among the variables around highway deterioration process and maintenance operations. Pavement performance is the key indicator of the highway conditions and is generally represented by Pavement Condition Index (PCI)[7]. The pavement performance reflecting integrity of pavement structure can be classified as five discrete states including excellent, good, fair, poor and very poor.

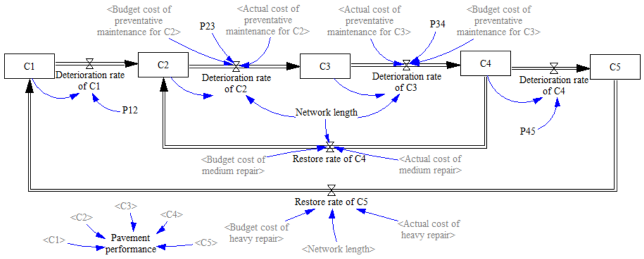

Figure 1. Stock-flow diagram for interactions around highway

The Markov deterioration process model is applied to predict the pavement performance[8]. The pavement condition can be represented as a set of probabilities for five states, i.e., [C1, C2, C3, C4, C5], and the sum of the probabilities is equal to 1.0, Using the medium values of the PCI ranges for the five states, i.e., [92.5, 77.5, 62.5, 47.5, 20.0], then the PCI for the current pavement performance can be calculated.

When the pavement deteriorates, the performance state becomes worse and leads to higher costs for the highway operator. Based on engineering experience, the pavement performance states can only be one of two cases, i.e., remaining unchanged or deteriorating to the next state when no maintenance measures are adopted. In addition, the pavement performance cannot transit from low level states to high level states. Therefore, the state transition matrix can be simplified as Eq. 1.

$$P = \begin{bmatrix} P_{11} & P_{12} & 0 & 0 & 0 \\ 0 & P_{22} & P_{23} & 0 & 0 \\ 0 & 0 & P_{33} & P_{34} & 0 \\ 0 & 0 & 0 & P_{44} & P_{45} \\ 0 & 0 & 0 & 0 & P_{55} \end{bmatrix} \tag{1}$$

Stock-Flow Diagram for Interactions around Highway Operator. The subsystem shown in Fig. 2 models the dynamic interactions among the variables around the highway operator. Based on the pavement conditions, the highway operator needs to plan appropriate maintenance measures such as daily maintenance, preventative maintenance for C2, preventative maintenance for C3 medium repair and heavy repair. The above activities are repeated in the whole life cycle of the highway until the road is not economic tor maintenance[9]. The operator should determine thresholds to start corresponding maintenance measures.The yearly cost of each maintenance measure will be summed to obtain the total maintenance costs of all maintenance measures over the long-terms period under consideration.

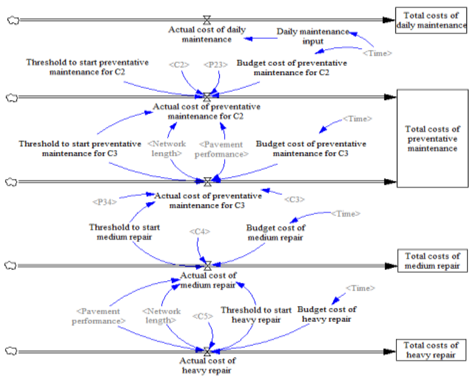

Figure 2. Stock-flow diagram for interactions around highway operator

Stock-Flow Diagram for Interactions around Concession Period. Fig. 3 models the dynamic interactions among the variables around concession period. The operator gets investment return mainly through the collection of highway toll, and the toll is affected by traffic volume and toll rates.The operator's expenses include annual debt, operation cost, maintenance cost and tax. The amount of debt depends on the amount of the operator's loan, the repayment of the way and the repayment period. Operation cost is mainly affected by the scale of the project. Maintenance cost depends on the maintenance measures taken by the operator each year. Tax is proportional to toll.

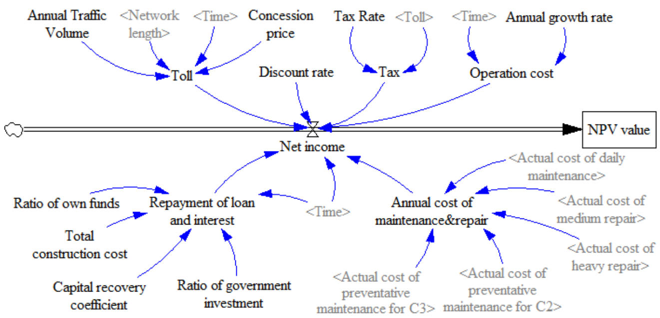

Figure 3. Stock-flow diagram for interactions around concession period

Case Study

Validation tests have been performed with regards to the structure and behavior of the proposed SD model according to the SD model validation procedure.

Case Date. A highway in midwest of China has been taken as an example to verify the validity of the model in this study. The highway, with a total length of 100 km, is constructed and operated in PPP financing pattern. The initial condition of the highway pavement is [0.8145, 0.1809, 0.0046, 0.0, 0.0] and the state transition probability matrix of the highway before taking maintenance measures are obtained as Eq. 2[10].

$$P=\begin{bmatrix} 0.8145 & 0.1855 & 0 & 0 & 0 \\ 0 & 0.6451 & 0.3549 & 0 & 0 \\ 0 & 0 & 0.5598 & 0.4402 & 0 \\ 0 & 0 & 0 & 0.5602 & 0.4398 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

The construction period of the highway is 3 years. The total construction cost is 500 billion yuan which consists of 25% operators own funds, 5% government subsidies and 70% bank loans. According to the provisions of the contract, the loan rate is 6% and all loans are paied off in equal annual debt repayment in a period of 25 years. According to the relevant policies, the tax rate is 9%. The initial operation cost is 40 million yuan with a growth rate of 3%. The budget cost for each maintenance measure is considered as shown in Table 1 based on engineering experience with a growth rate of 3% in consideration of the influence of inflation and interest rate. All vehicles are converted into a standard model, the traffic volume is expected to increase from7.5 million per year to 13 million per year in a period of 10 years and thereafter to maintain a relatively stable state. Approved by the relevant departments, the toll rate is 0.47 yuan/km. Maintenance threshold identified by the operator is (95, 85, 75, 65, 55).

Table 1 Budget cost for each maintenance measure

Maintenance measures	Daily maintenance	Preventive maintenance for C2	Preventive maintenance for C3	Medium repair	Heavy repair
Cost (Yuan/km)	70000	150000	200000	900000	3300000

Simulation Experiments and Analysis. The simulation period is 30 years and the construction period is not included. Fig. 4 describes the net present value is increased year by year in the simulation period and the value becomes positive in the 28th year. It implies that the government can set up the concession period of the highway project for 28 years. Through the linear interpolation method, government can get more accurate concession period.

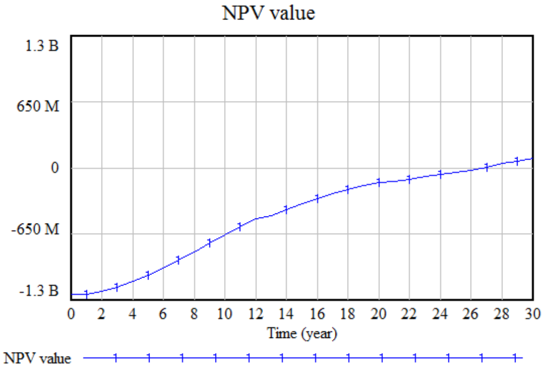

Figure 4. Change of net present value

Table 2 describes the value of different thresholds from 26th year to 30th year.

Table 2 NPV of different thresholds [Million Yuan]

Year	(100,90,80,70,60)	(95,85,75,65,55)	(90,80,70,60,50)
26	-23.75	-42.28	-28.92
27	15.43	-41.75	94.94
28	50.94	30.40	44.02
29	82.89	61.55	63.39
30	111.67	81.51	92.20

Fig. 5 describes the pavement performances over 30 years for different thresholds determined by the highway operator to initiate corresponding maintenance measures. It is shown that before the first heavy repair, the pavement performance decreased over time, while after the heavy repair, pavement performance is significantly improved, and the performance of the pavement is periodic fluctuation. What's more, the lower the threshold, the bigger the fluctuation of pavement performance. Combined with Table 2, we can conclude that to improve maintenance thresholds can effectively improve the performance of the pavement, and not significantly extend the highway project concession period.

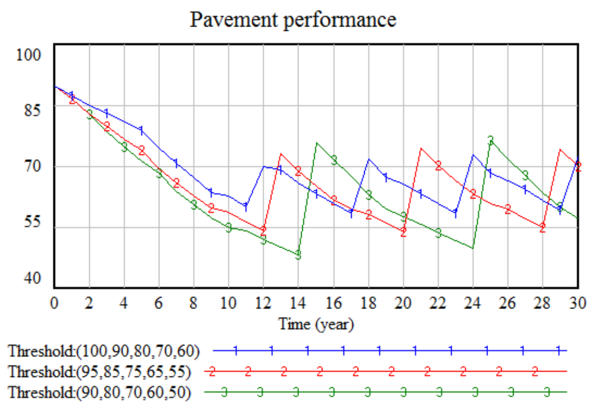

Figure 5. Pavement performance over time of different thresholds

Summary

This study has shown that to improve maintenance thresholds can effectively improve the performance of the pavement, and not significantly extend the highway project concession period. The study can provide a good simulation evaluation means for government to determine a reasonable concession period and to develop relevant regulatory measures for the operator. Further studies can consider the impact of pavement performance changes on traffic and toll rates, and establish a more comprehensive model of concession period.

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