

Toll Rates and Related Factors on China's Highways

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Toll rates and traffic volumes (or demand) are the two major factors affecting revenue as well as investment strategies on toll roads. Although China has been experiencing dramatic growth in its highway systems during the past 10 years, there has been a lack of understanding in maintaining and operating its toll roads. Since most of the freeways in China are toll roads, it is necessary to establish a methodology for the toll road system based on the characteristics of China's transportation systems and social economy. A methodology to determine the toll rates for China's toll road systems is introduced. Factors affecting the toll rate are analyzed, including gross domestic product, total number of vehicles, growth rates of passenger and freight transport, and roadway conditions. The theory of elasticity is applied in a case study to investigate the effect of toll rate on traffic volumes. A critical-volume model is established on the basis of the analyses of various factors such as construction costs, operating costs, expected time of return, and internal rate of return.

With the continuous growth of China's economy, construction on highways and other transportation infrastructure has been increasing dramatically in recent years. The highway is becoming another major transportation mode in addition to railways. Of particular interest has been management strategies for highway construction projects. As a result of reform in highway construction and investment policies, a variety of investment and management strategies have been developed. Investment and construction have been shifted from previously centralized governmental control to more diversified investment resources. Currently, most of the high-standard roads, either newly constructed or rehabilitated, are toll roads. The revenue from the tolls becomes a major resource for loan payoffs, investment return, and daily management and operations. Currently, most toll roads are operated and maintained by local companies. One of the major problems facing toll road authorities in China is the lack of a rational methodology to determine the optimal toll rates. Toll rates are basically determined by toll road authorities on the basis of past experience and methods used in other similar locations. The government lacks control from a system management point of view. In addition, there is usually no active participation by roadway users in the decision-making process.

Both the roadway authorities and the public believe that there is an urgent need to develop a system to determine reasonable toll rates based on certain circumstances. Although some developed countries, such as the United States, Italy, and France, have many years of management and operating experience on toll roads, China is still at a primitive stage in toll road management and operations. It is important to develop related theories that would reflect the special

situations in the toll road system in China. Since the 1960s, a significant effort has been made to derive a quantitative relationship between traffic demand and its related factors. However, many such models were based on work from other developed countries. Development of a model that would reflect the specific situations in China has not been successful. One of the difficulties is that personal income and land use in China, as in other developing countries, are experiencing dramatic changes every year. The lack of high-quality statistical data makes it difficult to develop and calibrate such models. In addition, constantly changing transportation policies, such as pricing, are very difficult to include in the model.

An attempt is made here to address the relationship between traffic volume and toll rate on the basis of specific situations in China. Both qualitative and quantitative evaluations are made on the basis of recent developments in China.

METHOD OF DETERMINING TOLL RATE

Basic Methodology, Principle, and Process

The basic principle of determining the toll rate is to consider the financial situation of both the toll authorities and the roadway users. The toll rate should satisfy the following conditions:

- The revenue from the toll should be sufficient to pay off loans within the required time period and to cover capital investments and operating and maintenance costs for transportation facilities, such as bridges and pavements.
- The toll rate should be within the affordable range of travelers. As a general rule, the toll should be less than one-third of the traveler's total benefit from using the toll road (1, 2).

Both of the foregoing conditions have to be met. If the toll rate is too high, the toll road becomes less attractive to the users, and a shortage of demand will result. In contrast, if the toll rate is too low, the investment cannot be adequately recovered, which would affect further investment and development on toll road projects. A procedure that can be used to determine a toll rate is illustrated in Figure 1.

Case Study on SA Expressway

A case study is presented using the foregoing principles. The project is the SA Expressway project, a tolled expressway between Shijiazhuang, in Hebei Province, and Anyang, in Hubei Province. The project used loans from the World Bank for construction and was completed in 1998 (3).

The first task was to conduct a financial analysis. The two major factors, toll rate and traffic demand, were analyzed. Traffic demand

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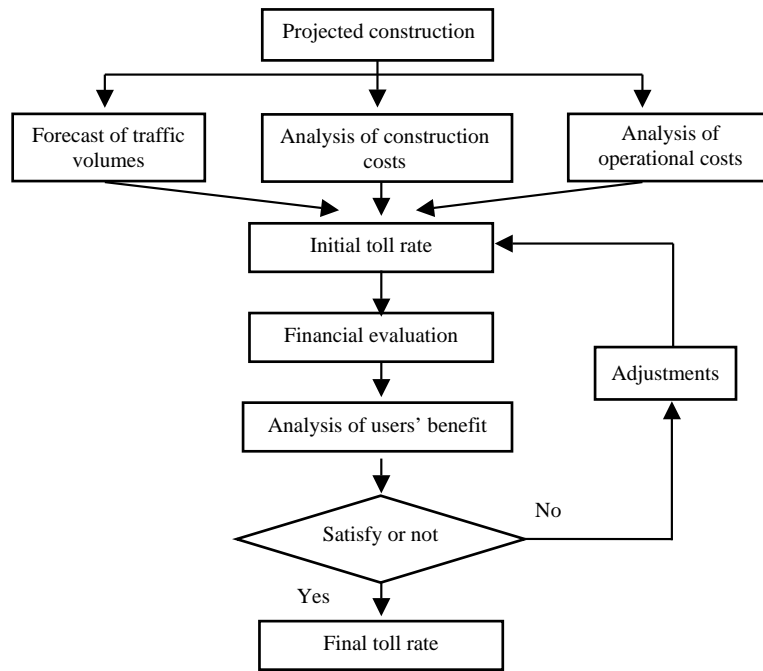


FIGURE 1 Procedure for toll rate determination.

forecasting was conducted on the basis of existing traffic volumes and economic situations in the surrounding areas. Considering both the existing vehicle composition and potential future development, vehicles were classified into four groups or types, A, B, C, and D, based on the size of the vehicle. Three toll rate alternatives were evaluated as shown in Table 1. On the basis of the principles of financial benefit analysis for highway projects, four major indexes were calculated: financial net present value (FNPV), financial internal rate of return (FIRR), financial benefit-cost ratio (FBCR), and the period of return, P_r . Table 2 shows the results for toll rate Alternative 3, in which a higher range of forecast traffic demand was used and compounded interest rates of 5% and 6% were assumed.

In recognition of the fact that the toll rate would directly affect the user's decision whether to use the toll expressway or alternative routes, the user's economic benefits must be taken into consideration. The user's benefits are reflected by the following aspects: reduction in transportation costs, such as savings on fuel and travel time, and reduction in traffic accidents. From the forecast traffic volumes and the proposed toll rate, it was estimated that toll road users could gain a financial benefit totaling about 3.7 billion yuan (1.0

China yuan Renminbi = \$0.12 U.S.). The projected financial income through the tolls was about 1.7 billion yuan. From the general principle that the toll should be between one-third and one-half of the user's benefit (in this case, the ratio is less than one-half), the proposed toll rate was feasible. The operation of the toll expressway to date has proved successful and close to the projected results.

RELATIONSHIP BETWEEN TOLL RATE AND TRAFFIC VOLUMES

Price Elasticity of Transport Projects

The main purpose of collecting tolls on some highways is to cover the operating costs and reimburse the capital investors. It is obvious that toll road users must perceive an economic benefit by selecting the toll road over other roads. The benefit of using the toll road should outweigh the toll that the users would have to pay. Therefore, toll pricing must be carefully designed so that both the toll authority

TABLE 1 Proposed Toll Rate Alternatives

Toll Rate Alternatives	Toll Rate Based on Vehicle Types, Yuan/veh-km			
	A	B	C	D
1	0.25	0.40	0.55	0.75
2	0.30	0.45	0.55	0.75
3	0.35	0.50	0.65	0.85

TABLE 2 Major Indexes for Alternative 3

Index Type	Interest Rate: 5%	Interest Rate: 6%
FNPV(m.yuan)	193202.1	10417.3
FIRR(%)	7.30	7.30
FBCR	1.32	1.17
P _i (year)	20.9	23.0

and the road users achieve financial benefit. The relationship between toll pricing and traffic volumes is illustrated in Figure 2 (1).

In Figure 2, two toll rates as well as their related traffic volumes are shown. As can be seen, when the toll rate is reduced from C_1 to C_2 , the number of users would increase from T_1 to T_2 . This result would also suggest that the number of users would be reduced from T_2 to T_1 if the price were increased from C_2 to C_1 . The areas AT_1OC_1 and BT_2OC_2 would represent the scales of toll income with a toll rate of C_1 and C_2 , respectively. The difference between them would be $AEC_2C_1 - BT_2T_1E$, which can be used to determine a preferred alternative toll rate. A major factor called price elasticity plays an important role in determining the quantities of the areas in terms of financial value.

The elasticity between toll rate and traffic volumes is affected by many factors, of which social economic development and transportation systems are the major ones. During the past 10 years, the transportation systems in China have experienced dramatic change, with improved infrastructure and an expanded roadway network. Travelers now have more choice in selecting their routes. Financial benefit has become a major influence in their decision making. Statistics in recent years have clearly shown such a trend. For example, after a significant increase in toll rates on all major roads between 1998 and 1999, traffic volumes were noticeably lower. At some locations, the drop was more than 30%. Price elasticity is also affected by competition among other transportation modes such as air and railways. In the following section, an application of the factor-weighting method for analysis of price elasticity is introduced.

Factor-Weighting Method

For a better understanding of this method, the following terms are defined:

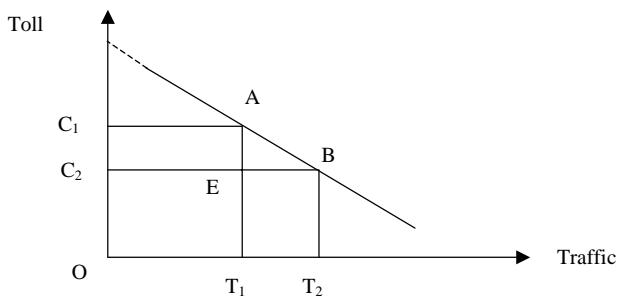


FIGURE 2 Relationship between toll rate and traffic volumes.

- **Weight.** Among the factors that affect the toll rate, some may illustrate stronger influences than others. Weight is a measure of the magnitude of such an influence.

- **Performance criteria.** One or more performance criteria can be selected for each analyzing factor to provide a quantitative representation of the factor. These performance criteria can be determined by a panel of experts from planning and engineering departments.

- **Utility curves.** Once a set of factors with their associated performance criteria and assigned weights has been obtained, the next step is to develop a means of converting them into a unified quantitative measure. Thus, a technique based on the utility curve concept can be used, that is, to graphically display the relationship between the toll rate policy and the response of the individual or the community to that policy. Different utility curves would reflect different evaluation results.

However, the utility curve concept has never been fully developed and applied in practice. Therefore, a score between -3 and +3 was allocated, with the sign representing deterioration or improvement, respectively. Each performance criterion possesses a linear transformation relationship with the factors, which gives a consistent and fixed score for any given condition. The score of each criterion can also be obtained from a panel of experts. Tables 3 through 5 illustrate the proposed procedure and format for conducting such an analysis.

The weighting factors in the foregoing tables need to be obtained from a group of experts in the fields of economy and transportation. A final evaluation can then be reached and a judgment can be made on the degree of influence of the toll rate on traffic volumes.

TABLE 3 Identified Influencing Factors and Weights

No.	Influencing Factors	Weight
1	Economy of related regions	20
2	Parallel highway	5
3	Other mode of transport	15
4	Traffic composition	10
5	Price and cost of transport company	50

NOTE: Weight is based on a 100 scale

TABLE 4 Performance Criteria

No.	Criteria	Weight
1.1	GDP Growth Rate	40
1.2	Quantity of Vehicles	20
1.3	Growth Rate of Number of Vehicles	10
1.4	Growth Rate of Passenger and Freight Traffic	30
2.1	Number of Parallel Highways	10
2.2	Conditions of Parallel Highways	50
2.3	Toll Rate of Parallel Highways	40
3.1	Benefit of Other Transport Modes	30
3.2	Fare of Other Transport Modes	70
4.1	Proportion of Private Vehicles	50
4.2	Proportion of Freight Traffic	50
5.1	Proportion of Toll to Total Cost	100

NOTE: Weight is based on a 100 scale for each criterion

CRITICAL TRAFFIC VOLUME MODEL

Traffic volume on toll roads is affected by many factors. In addition to the price elasticity evaluation discussed in the previous sections, some kind of financial analysis should be taken into consideration, which is used as a threshold control for the entire process. The concept of critical traffic volume is presented in this section for potential application. The critical volume is the minimum traffic volume at a certain toll rate.

In this study, a cost-benefit method is adopted to establish the critical-volume model. By analyzing the cash flow, a model in the form of $M_L = f(e)$ can be established, in which M_L is the critical volume and e is the toll rate. The required factors and indexes for such a model are given in Table 6.

The following assumptions can be made to conduct the analysis:

- When the cash flow is calculated, the same average annual operating cost is used for each year.
- A constant toll rate is assumed for the entire analysis period.
- The required operating and income taxes are all included.
- Normal toll road operation for 360 days each year is assumed.

Further assuming that the total construction investment occurs in the first year of the analysis period, the critical volume model can be expressed as follows:

TABLE 5 Scores and Interpretation

Increase in Traffic Volume	Score
Most Favorable	+3
Highly Favorable	+2
Moderately Favorable	+1
No Change	0
Moderately Unfavorable	-1
Highly Unfavorable	-2
Least Favorable	-3

$$M_L = \frac{27.8}{e(1-y)} (C_j i \times A + C_y) \tag{1}$$

where M_L is the critical volume and A is the adjustment factor, which is related to the tax rate, the expected internal return rate, and the expected period of return:

$$A = \frac{1}{1-s} + \frac{1}{2(1-s)[(1+i)^T - 1]} \tag{2}$$

Now if it is assumed that the traffic in the first year is M_0 and the yearly growth rate is m , the model becomes

$$\frac{M_{0L}}{i - m_L} \left[1 - \left(\frac{1 + m_L}{1 + i} \right)^T \right] = \frac{27.8}{e(1-y)} (C_j i \times A + C_y) \tag{3}$$

where M_{0L} is the critical traffic volume in the first year and m_L is the critical yearly growth rate of the traffic volume.

CONCLUSIONS AND RECOMMENDATIONS

With the rapid development of the toll road system in China, both toll authorities and toll road users feel an urgent need to establish a methodology to determine toll rates. The methodology should consider the special situations and characteristics in China. Addressed here are the current issues regarding China's toll road systems. A case study is presented using the price elasticity theory. The relationship between traffic volume and toll rate is analyzed, and a methodology is proposed to conduct a comprehensive evaluation of toll rate alternatives based on situations in China. A critical-volume model is also presented for potential application to China's toll roads. From the study, the following conclusions and recommendations are made:

- The methodology presented in this paper proved to be successful in the SA Expressway case, and similar approaches should be adopted for other toll road locations in China.

TABLE 6 Factors and Indexes Used in Model

Factors		Symbols	Unit	Remark
Cost	Average Construction Cost	C_j	m.yuan/km	
	Average Operating Cost	C_y	m.yuan/km · year	
Benefit	Toll Rate	E	yuan/km · v	
	Traffic Volume (AADT)	M	v/day	in PCU
	First Year Traffic (AADT)	M_0	v/day	in PCU
	Accretion Rate of Traffic	m	%	
Tax	Operating Tax	y	%	
	Income Tax	s	%	
Index	Expected Internal Rate of Return	i	%	
	Expected Period of Return	T	year	

NOTE: PCU = passenger-car units

- Any policy making on toll rates should be based on comprehensive evaluation of financial benefits from both the toll road authority's and the users' point of view.
- A comprehensive database on toll road systems in China needs to be further established. It is important from now on to keep track of all the data related to toll road operations, such as toll rate, location, traffic volume, and financial benefit.
- Future study should introduce time values and alternative routes into the model.

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