Economic Benefit Analysis of the Construction and Keeping Open Program Under the Condition of Unidirectional Closure of Highway Reconstruction and Expansion Project

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Abstract. Highway traffic accidents often cause traffic disruptions, leading to economic losses. The current methods of quantifying and reporting road traffic accident losses in China are unclear, lacking analyses of economic losses in reconstruction and expansion projects. Given the variety of traffic organization design schemes involved in reconstruction and expansion projects, a model was proposed to calculate the economic losses from traffic accidents under two modes: "construction while keeping traffic open" and "one-way closure." The calculation key points of economic losses from accidents were clarified. The key points of traffic organization schemes under one-way closure conditions were established. The analysis covered economic losses from accidents, construction period savings, reduction of project costs, and operational toll revenue benefits. The economic benefits of different traffic organization modes were compared to provide references for selecting traffic organization schemes in other projects.

Keywords: Road traffic accidents; Economic losses; Evaluation index system; Analytical models

1 Introduction

With the advancement of urbanization, China's highway network has gradually improved, but the significant increase in vehicle traffic has continuously added pressure on highway services. In response to this issue, in addition to proper maintenance work, active development of highway reconstruction and expansion projects is necessary [1]. Based on early construction, most highways were four-lane, and with low local technical standards, traffic volume gradually saturated. The existing roads can no longer meet the demands of regional economic development and the increasing traffic volume. Reconstructing and expanding existing highways can achieve land and resource

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savings, reduce project costs, and shorten the construction period without changing the existing road network distribution [2-3]. During reconstruction projects, traffic accidents often pose increased risks due to the concurrent construction and traffic flow. Yang Zhenqi [4], Rong Huan [5], and Wu Juan [6] proposed methods for evaluating and calculating the economic losses of road traffic accidents based on a comprehensive consideration of direct and indirect economic losses, as well as social economic losses. He Qiong [7], Cong Haozhe [8], Liu Wei [9], and Liu Enmeng [10] studied various methods of measuring traffic accident economic losses and the economic losses caused by personal injuries, considering factors such as time, key steps, comparison of different calculation methods, and calculation principles. Lin Yu [11], Gou Rui [12], and Tao Gang [13] constructed fuzzy comprehensive evaluation models and proposed quantitative evaluation methods for traffic accident grades and economic loss prediction methods using time series analysis, multiple linear regression analysis, and grey prediction models. Currently, research on highway reconstruction and expansion projects, and the evaluation of the socioeconomic losses of road traffic accidents, is relatively mature. Research mainly focuses on improving road capacity and service level, and saving resources and costs in reconstruction projects. In the evaluation of socioeconomic losses of road traffic accidents, research covers the evaluation of direct and indirect economic losses, considering multiple indicators such as personal injuries, property damage, traffic congestion, and environmental pollution. However, existing research on the evaluation of traffic economic loss indicator systems mainly focuses on personnel and accident vehicles, with models still lacking in certain aspects. Additionally, fuzzy evaluation models and various data analysis methods have been applied to traffic accident grade evaluation and economic loss prediction, improving the objectivity and accuracy of evaluations.

Building on this research, a model for calculating economic losses from traffic accidents in reconstruction and expansion projects was proposed to address the lack of analysis in this area. The model evaluates two modes: "construction while keeping traffic open" and "one-way closure." The analysis includes economic losses from accidents, savings in construction time, reduction in project costs, and operational toll revenue benefits. The economic benefits of different traffic organization modes were compared, providing references for selecting traffic organization schemes in other projects.

2 Methodology

During the reconstruction and expansion of highways, severe interference between traffic operations and construction activities significantly increases the probability of traffic accidents or congestion. This risk is particularly heightened when large trucks are involved in accidents due to their size and weight, leading to greater impact areas, increased handling difficulty, longer resolution times, and larger economic losses and social impacts. Drawing on relevant research results of economic losses from road traffic accidents in China, and based on economic and statistical theories, an analysis of economic losses from traffic accidents during highway reconstruction and expansion projects was conducted. This analysis considers aspects such as traffic delay economic losses, traffic facility economic losses, and obstruction service fee losses, constructing a corresponding evaluation measurement model. Therefore, the method for calculating per-kilometer traffic economic losses in highway reconstruction and expansion projects comprises the sum of traffic delay economic losses, traffic safety facility economic losses, and obstruction service fee losses.

2.1 Traffic Delay Economic Loss L_1

Traffic delay economic loss refers to the economic losses from negative impacts on social material production, travel, and the environment, indirectly related to traffic accidents. This loss specifically appears as additional transportation time and costs due to road congestion. Traffic accidents or congestion in construction sections of highway reconstruction and expansion projects mainly cause an increase in passenger travel time. This increase can be indirectly measured by the national income potentially generated during this period.

Thus, the method for calculating traffic delay economic losses per kilometer in highway reconstruction and expansion projects is provided in Equation 1.

$$L_1=N\times Q_k\times T/8/250 \tag{1}$$

$$L_1 = N \times Q_k \times T/8/250 \tag{2}$$

Style:
L_1: Traffic delay economic loss (ten thousand yuan per kilometer);
N: Per capita national income (yuan per person);
Q_k: Delayed passenger volume (persons);
T: Average delay time per kilometer (hours per kilometer).

2.2 Economic Loss of Traffic Safety Facilities L_2

During the reconstruction and expansion of highways with ongoing traffic, movable steel guardrails, concrete barriers, cones, and water-filled barriers are used to separate the traffic areas from the construction areas. When a traffic accident occurs, these temporary traffic safety facilities are often damaged, resulting in economic losses.

The method for calculating the traffic safety facility loss costs per kilometer in highway reconstruction and expansion projects is provided in Equation 2.

$$L_2= P_{jsh}\times J_w \tag{3}$$

$$L_2 = P_{jsh} \times J_w \tag{4}$$

Where:
L_2 - Traffic safety facility loss costs (ten thousand yuan per kilometer);
P_{jsh} - Average traffic safety facility loss cost per accident (ten thousand yuan per incident);
J_w - Project accident rate (incidents per kilometer).

2.3 Obstruction Service Fee Loss L_3

Obstruction service fee loss includes the costs of clearing service for accident vehicles, towing fees, and the social labor value loss of rescue personnel. The loss cost of obstruction services is mainly related to the extent of vehicle damage and the number of vehicles that need to be cleared.

The formula for calculating the obstruction service fees per kilometer in highway reconstruction and expansion projects is provided in Equation 3.

$$L_3 = P_{qz} \times J_w \tag{5}$$

$$L_3 = P_{qz} \times J_w \tag{6}$$

Where:

L_3 - Traffic accident obstruction service fees (ten thousand yuan per kilometer);

P_{qz} - Average obstruction service fee per traffic accident (ten thousand yuan per incident);

J_w- Project accident rate (incidents per kilometer).

3 Engineering Application

The G5011 Wuhu-Hefei Expressway is an important part of the national expressway network and a vital corridor for Anhui Province to access the eastern coastal regions such as Zhejiang. It spans a total length of 100 kilometers, featuring a fully enclosed, fully interchanged, and controlled-access four-lane expressway with a design speed of 100 km/h.

3.1 Comparison of Economic Benefits Between Two Construction Modes

3.1.1 Comparison of Delay Economic Benefits

① **Construction mode while opening to traffic.** According to the latest statistics from the National Bureau of Statistics, the per capita national income in China in 2021 was 80,976 yuan.

Data provided by the Wuhu-Hefei Expressway operation unit indicates that the average daily traffic flow during the closure of the hard shoulder for construction in the reconstruction and expansion project was 48,800 vehicles. Based on statistical data from the Wuhu-Hefei reconstruction and expansion project and accident rates from other highway reconstruction and expansion projects in Anhui Province, the annual rate of general or more severe traffic accidents on roads under construction while keeping traffic open is 0.18 incidents per kilometer, and the rate of minor scraping accidents without casualties is 47 incidents per kilometer per year. According to relevant traffic accident statistics, the average handling time for general or more severe traffic accidents is 6.5 hours, and for minor scraping accidents, it is 0.5 hours. The accident handling time is used as the average delay time in the calculation model for indirect economic losses in passenger transport.

Therefore, the calculated traffic delay loss under the construction while keeping traffic open mode is 86,700 yuan per kilometer. Based on the total route length of 1.573 kilometers for this project, the annual traffic delay economic loss for the project is 3.6063 million yuan.

② **One-way closure construction mode.** There are no traffic vehicles or operational traffic accidents under the one-way closure construction mode in highway reconstruction and expansion projects, and thus no social economic losses are involved.

3.1.2 Comparison of Traffic Safety Facility Economic Losses

① **Construction while keeping.** Traffic Open According to statistical data from the Wuhu-Hefei reconstruction and expansion project and other highway reconstruction projects in Anhui Province, the annual rate of general or more severe traffic accidents on roads under construction while keeping traffic open is 0.18 incidents per kilometer, and the rate of minor scraping accidents without casualties is 47 incidents per kilometer per year. Considering the damage to temporary traffic safety facilities in the construction area caused by major traffic accidents and minor accidents, the preliminary determination is that the economic loss for road facilities due to general or more severe traffic accidents is 56,000 yuan per incident, and for minor scraping accidents, it is 3,400 yuan per incident.

Therefore, according to the traffic accident loss cost calculation model, the traffic accident loss cost under the construction while keeping traffic open mode is 169,800 yuan per kilometer, with the total project traffic accident loss cost amounting to 7.135 million yuan.

②**One-way Closure Construction Mode.** There are no traffic vehicles or operational traffic accidents under the one-way closure construction mode in highway reconstruction and expansion projects, and thus no economic loss costs for road facilities.

3.1.3 Comparison of Obstruction Service Fee Losses

①**Construction while Keeping Traffic Open.** Based on the previously collected relevant data, general or more severe traffic accidents usually require obstruction services, while minor scraping accidents do not. Therefore, in this cost calculation, only general or more severe traffic accidents are considered. Under the construction while keeping traffic open mode, the annual rate of general or more severe traffic accidents on roads is 0.18 incidents per kilometer. Market research preliminarily determined that the obstruction service fee for general or more severe traffic accidents is 96,000 yuan per incident.

Thus, the calculated obstruction service fee loss under the construction while keeping traffic open mode is 17,280 yuan per kilometer, with the total project traffic obstruction service fee amounting to 725,760 yuan.

②**One-way Closure Construction Mode.** There are no traffic vehicles or operational traffic accidents under the one-way closure construction mode in reconstruction and expansion project sections, and thus no obstruction service fees are involved.

3.2 Analysis of Construction Period Savings

During reconstruction and expansion while keeping traffic open, traffic lanes are compressed, lacking yielding conditions. To prevent widespread congestion, only one unit is constructed simultaneously on both sides, requiring multiple traffic organization changes throughout the route. This significantly increases the construction period. For example, relevant standards such as "Road Traffic Signs and Markings Part 4: Work Zones" (GB 5768.4-2009) and "Highway Maintenance Safety Operation Regulations" (JTG H30-2015) state that the general work area is set to 4-5 km. In a 10 km section, at least 2 traffic organization changes are necessary for half-width closure construction, leading to an extended construction period. The half-width full closure construction mode effectively reduces the number of traffic diversions.

The approved construction period for the Wuhu-Hefei reconstruction and expansion project is 28 months, 2 months less than the first phase, with a significant increase in workload. Due to delays in red-line land approval in the early stages, construction progress was extremely slow, with less than 8% of the subgrade earthworks completed by the end of March 2021. After adopting the half-width closure traffic organization mode, new bridges and old bridge decks were implemented simultaneously, existing highways replaced construction detours, increasing transportation machinery efficiency. The ample construction workspace allowed large equipment, such as bridge rotary drilling rigs and full-width pavement machines, to be fully utilized.

According to actual project progress calculations, the project can save at least 4 months in the overall construction period under the one-way closure construction mode.

3.3 Analysis of Reduced Construction Costs

After adopting the one-way closure traffic organization mode, the originally designed traffic diversion projects were canceled, reducing construction costs and saving on construction expenses, as detailed below:

①**Cancellation of originally designed traffic diversion roads and bridges.** With the one-way closure traffic organization mode, diversion projects such as the Huainan Railway diversion bridge were canceled, saving approximately 23 million yuan.

② **Cancellation of micro-surfacing for traffic diversion.** In the original third-phase traffic organization plan, a micro-surfacing layer was to be added for traffic diversion after completing the lower pavement layer in the first phase. With the one-way closure traffic organization mode, the closed side pavement can be fully constructed to the upper layer before traffic diversion. Thus, canceling the micro-surfacing layer saves a total cost of 3.48 million yuan.

In summary, adopting the one-way closure traffic organization mode saves a total of 26.48 million yuan in construction costs.

3.4 Analysis of Toll Revenue Benefits

Highway toll revenue serves as the primary income for highway operations and is crucial for economic benefits during the operation phase. During the reconstruction and expansion period, adopting the one-way closure construction mode results in some vehicles diverting to other routes. This diversion reduces highway toll revenue to a certain extent.

Traffic volume and toll rates are the two major factors determining vehicle toll revenue. The toll revenue prediction model based on traffic volume and toll rates is one of the most commonly used models. The calculation formula is shown in Equation 4.

$$R_t = \sum_i \sum_j (Q_{ijt} \times \tau_{ijt} \times L_i) \times N \times K \tag{7}$$

$$R_t = \sum_i \sum_j \left(Q_{ijt} \times \tau_{ijt} \times L_i\right) \times N \times K \tag{8}$$

Where:

R_t - Total vehicle toll revenue for the target year (starting from the base year);

Q_{ijt} - Annual average daily traffic volume of vehicle type jj on section ii in the target year;

τ_{ijt}- Toll rate of vehicle type jj on section ii in the target year (yuan/vehicle-km);

L_i - Highway mileage of section ii (km);

N - Number of days in the year;

K - Additional coefficient, generally around 0.95.

Theoretical analysis indicates a direct relationship between toll revenue loss and traffic diversion volume, diverted vehicle types, and corresponding toll rates. With a fixed vehicle composition, a larger diversion volume leads to greater toll revenue loss. Specific vehicle toll rates, generally fixed short-term, relate linearly to toll revenue loss. Diverted vehicle types should include large trucks or larger due to their significant impact on regional traffic operations. Excessive heavy vehicles reduce highway service levels, compromising its ability for fast passage. Additionally, trucks have high load capacity, slow startup, slow movement, poor braking, and high risk, making them prone to causing full-line congestion in traffic accidents.

The "Adjustment Plan for Vehicle Toll Charging Methods on Toll Roads in Anhui Province" has uniformly adjusted truck tolls from a weight-based to an axle-based charging method. Table 1 shows the current toll rates for vehicles on highways in Anhui Province.

Table 1. Toll Rates for Vehicles on Highways in Anhui Province

Vehicle Classification	JT/T489-2019 Classification Standard	Toll rate (yuan/kilometer)
Category 1	2 axles, length less than 6000mm and maximum permissible gross mass less than 4500kg.	0.45

Category 2	2 axles, length not less than 6000mm or maximum permissible gross mass not less than 4500kg.	0.90
Category 3	3 axes	1.35
Category 4	4-axis	1.70
Category 5	5-axis	1.85
Category 6	6-axis	2.20
For trucks with more than six axles, a factor of 1.1 is applied for each additional axle on top of the rate for trucks in category 6. Determine the rate; the rate for 10-axle and above trucks is based on the 10-axle truck rate.		

①**Construction while keeping traffic open.** Based on the actual traffic volume observed in the Wuhu-Hefei Expressway reconstruction and expansion construction sections, the passenger-to-goods vehicle ratio was found to be 7:3. The diversion volumes for each section during the construction phase were determined by comparing traffic forecasts and the carrying capacity of the reconstruction sections. The loss in toll revenue for diverted large trucks was then calculated based on the vehicle type ratio and corresponding toll rates, as shown in Table 2.

Table 2. Toll Revenue Losses in Construction while Keeping Traffic Open Mode

Sections	Kilometers	Diversion ratio	Large vehicle diversion (pcu/d)	Loss costs ($ million/d)
G3	51.612	16.02%	2539	23.26
G5011	54.026	26.68%	3471	33.28
G40	89.351	10.68%	853	13.52
aggregate	/	/	6863	70.06

② **One-way closure construction mode.** If the one-way closure construction mode is adopted, the toll revenue loss for all diverted vehicle types on the construction sections is calculated as shown in Table 3.

Table 3. Toll Revenue Losses in One-way Closure Construction Mode

Sections	Kilometers	Diversion ratio	Traffic volume (pcu/d)	Loss costs ($ million/d)
G3	51.612	100%	57476	229.15
G5011	54.026	100%	50045	208.86
G40	89.351	100%	29820	157.87
aggregate	/	/	137341	595.88

3.5 Comprehensive Economic Benefit Comparison Analysis

A comprehensive comparison analysis of the benefits of reducing accidents, saving construction periods, lowering construction costs, and toll revenue benefits between the different traffic organization modes was conducted, as shown in Table 4.

Table 4. Comprehensive Economic Benefit Comparison of Different Traffic Organization Modes in Highway Reconstruction and Expansion Projects

Form	Construction while open to traffic	One-way closure for construction	Benefits Comparison
1 Accident reduction benefit ($ million)	1146.71	/	1146.71
Economic losses from passage delays ($ million)	360.63		
Economic loss of road facilities ($ million)	713.50	/	
Loss of clearing service costs ($ million)	72.58	/	
2 Duration saving benefits	/	Saved 4 months of construction time	15% savings in construction time
3 Reduction in construction cost ($ million)	/	Lower 2678	2648 .00
4 Operational fee benefits ($ million)	70.06	595.88	-525.82
(grand) total			3268.89

The analysis in the table indicates that comparing the economic benefits of the construction while keeping traffic open mode and the one-way closure construction mode in reconstruction projects shows significant economic benefits of the one-way closure construction mode. Although closing traffic reduces operational toll revenue by over 5 million yuan, it effectively reduces accident loss costs by 11.4671 million yuan, lowers construction costs by 26.48 million yuan, and shortens the construction period by approximately 15%. Overall, the one-way closure construction mode has significant economic benefits. This approach can be considered for future highway reconstruction and expansion projects, especially for projects with tight schedules.

4 Conclusion

In this study, an accident economic loss model was established for the highway reconstruction and expansion scenario where traffic continues to flow alongside construction activities. The model considered three aspects: traffic delay, traffic safety facilities, and clearance service costs. The economic losses were quantified based on calculation formulas. A comparative analysis of the comprehensive economic benefits of two modes—traffic flow with ongoing construction and one-way closure—was conducted using actual engineering cases. In the referenced project, the one-way closure method effectively reduced accident loss costs by 11.467 million yuan, lowered project costs by 26.48 million yuan, and saved approximately 15% of the construction period. The results indicated that the one-way closure mode allows for flexible traffic organization, minimizes the impact of construction on traffic flow, and demonstrates significant economic benefits overall. This can provide a useful reference for similar reconstruction and expansion projects.

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