Quantitative analysis and calculation of traffic social cost during the construction of open-cut subway station

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Abstract. With the rapid development of rail transit, traffic problems caused by open-cut metro construction have become increasingly prominent. In order to quantify the negative impact of subway station construction, taking a metro stations under construction in Chengdu as example, collected relevant data such as traffic flow, congestion time, speed during congestion and noise decibel value at metro construction intersection by field test. Through quantitative calculation, the negative effects of open-cut construction are monetized from four aspects: extra fuel cost, time delay cost, environmental pollution cost and fatigue cost. It is found that the social cost is as high as 20 million yuan per year. Based on the calculation results and the actual traffic situation in Chengdu, the corresponding measures to reduce social costs are put forward.

1. Introduction

With the rapid development of rail transit, the problems brought about by the construction of rail transit are also becoming more and more obvious. Usually, Constructors often uses open cut method for station construction, encroaching on road resources, causing the reduction of circulation capacity at local road sections and intersections, resulting in road congestion, extending travel time, environmental pollution, and additional a series of problems such as carbon emissions and fatigue of drivers and passengers. This article takes the Chengdu Metro Station as an example to analysis the above-mentioned negative effects brought about by subway construction by Open-cut method in monetary terms.

This paper takes Chengdu Metro's current construction station as the research object. Collecting traffic data through the field. Quantitatively measure the additional fuel cost, delay cost, environmental pollution cost and the fatigue cost of the driver and passenger caused by the open-cut subway construction.

2. Methodology

In view of the small impact of subway station construction on non-motor vehicles, this research mainly measures the negative impact of subway station construction on motor vehicles, and classifies motor vehicles into private cars, taxis, buses, minivans, trucks and coach. Reference to the classic calculation model of the Texas Transportation Institute, besides the extra fuel cost and delay cost, we add the air pollution cost, noise pollution cost and fatigue cost into the total traffic social cost. Theoretical analyzed and actual calculated the traffic social costs of Xingsheng Station (Line 6).
2.1. Additional fuel cost
Based on Liu Lijun's application to the Texas Transportation Institute's measurement model [1], the expression of the extra fuel cost of the car during congestion ($\Sigma C_F$) is:

$$\Sigma C_F = \Sigma T \times V \times \eta \times P$$  \hspace{1cm} (1)

- $\Sigma T$ — all vehicle delay time each year, unit: hour
- $V$ — average speed in congestion, unit: km / hour
- $\eta$ — average fuel economy efficiency, unit: liter / km
- $P$ — the price of fuel, unit: yuan / liter

The total vehicle delay time ($\Sigma T$) is the sum of the time delays of all vehicles passing the intersection in one year:

$$\Sigma T = \frac{t \times N \times 365}{3600}$$  \hspace{1cm} (2)

- $\Sigma T$ — All vehicle delay time each year, unit: hour
- $t$ — average delay time per car, unit: second
- $N$ — Daily average traffic flow, unit: vehicle/day

2.2. Delay time cost
The expression [3] of the delay time cost ($\Sigma C_T$) is:

$$\Sigma C_T = \Sigma T \times C_0 \times \lambda$$  \hspace{1cm} (3)

- $\Sigma T$ — Total vehicle delay time, unit: second
- $C_0$ — The cost per unit time, unit: yuan / (person · minutes)
- $\lambda$ — Passenger capacity, the average number of passengers per vehicle, unit: person / vehicle

The total vehicle delay time ($\Sigma T$) is equal to the waiting time (one signal period) of all stranded vehicles in the intersection at the end of a green light. In areas where the economy is more developed and the social production efficiency is higher, more social wealth can be created per unit time and the unit time value is higher. Because the survey point is located in Chengdu, this paper selects the GDP per capita unit time in Chengdu to describe the unit time value ($C_0$)[3].

$$C_0 = \frac{\text{GDP in the region each year}}{\text{Resident population} \times \text{Annual working days} \times \text{Daily working hours}}$$  \hspace{1cm} (4)

According to the statistics report of the Sichuan Provincial Bureau of Statistics, Chengdu's GDP in 2018 was 154.427 billion yuan, and the resident population was 160.447 million. Therefore, the annual per capita GDP is about 95,600 yuan. According to the legal working hours, it is assumed that the annual working day is 250 days and 8 hours of working time per day. From this:

$$C_0 = \frac{9.56 \times 10^4}{250 \times 8 \times 60} = 0.797 \text{ (yuan/minute)}$$  \hspace{1cm} (5)

2.3. Pollution cost
The main index of air pollution is particle concentration, studies have shown that the proportion of air pollution costs, which accounts in GDP, is mainly concentrated in the interval of 1%-6%[4-10]. The share of PM in mobile sources in Chengdu in 2017 is 27%. Taking non-road mobile source emissions (in 2017, the national road source emissions PM were 488,000 tons, and the non-road source emissions PM were 460,000 tons.) into account, Chengdu road mobile source PM shares about 13.5%. Therefore, the ratio of air pollution social costs to GDP caused by road mobile sources is 0.135%-0.81%. This is also close to the research results of road-related air pollution in Beijing [11].

Combining with the above research, the lower limit of air pollution cost of Chengdu mobile source should be about 0.135%. Combined with Chengdu's GDP and diesel consumption, we get the air pollution cost per liter, it is more than 2.15 yuan. Therefore, the calculation method of the cost of particulate matter pollution ($\Sigma C_a$) is:

$$\Sigma C_a = V \times Pa$$  \hspace{1cm} (6)

- $V$ — Additional diesel consumption, unit: liters
The cost of particulate matter pollution caused by single-liter diesel oil, and take 2.15 yuan/liter.

For the cost of noise pollution, this study takes the WTP (willingness to pay) method. It obtains people's willingness to pay for environmental quality improvement or the willingness to endure environmental losses through a willingness survey, that is, a questionnaire or inquiry, and uses it to measure the amount of money people are willing to pay and the recognition of the value of life to avoid or reduce the degree of injury and economic loss. The EU countries use the method to calculate the noise cost. For every 1 dB increase in the noise level, the Increment in willingness to pay is 0.11% of the per capita disposable income. Therefore, the calculation method of noise pollution cost in this paper is:

\[ \sum C_s = \Delta S \times PG \times NH \]

\(\Delta S\) — Noise difference before and after construction, unit: dB
\(PG\) — The compensation value required for each additional 1dB, unit: yuan/dB
\(NH\) — Number of people to be compensated, unit: person

In addition, additional oil consumption results in additional carbon emissions, which can be calculated by multiplying carbon trading prices by additional emissions:

\[ \sum C_C = V_{EF} \times Q_F \times P_C \]

\(V_{EF}\) — Additional consumption volume of steam and diesel, unit: l
\(Q_F\) — Carbon emission factors of gasoline and diesel, unit: kg/L
\(P_C\) — Domestic carbon rights trading price, unit: yuan / t

2.4. Fatigue cost

For the calculation of fatigue cost, this study refers to the method of willingness to pay for noise pollution costs. Through the questionnaire survey, the unit fatigue cost value is 3.60 yuan/(person·day). The sampling statistics of monthly average number of vehicles and the corresponding proportion, passing through the station, have been made. Finally, the fatigue cost of the passengers can be calculated by the following formula:

\[ \sum C_P = N_d \times N \times \lambda \times \sum_{n=1}^{k} (P_n \times D_n) \times 12 \]

\(N\) — Average daily traffic flow, unit: vehicle/day
\(\lambda\) — passengers per car, unit: person / vehicle
\(P_n\) — The proportion of the number of people passing through the congested intersections at different frequencies
\(D_n\) — Number of days passing the congested intersection in a month, unit: day
\(N_d\) — Unit fatigue cost, unit: yuan / (person · day)

3. Results

3.1. Additional fuel cost

Field statistics indicate that the number of taxis is relatively small compared to the number of cars, and only a small amount of fuel is natural gas or electricity, so taxis are classified as cars. Therefore, the additional fuel cost calculation consists of five categories: private cars, buses, minivans, trucks, and coaches. Among them, the private car fuel is 92# gasoline, the unit price is 7.01 yuan/liter, and the minivans, trucks and coaches use 0# diesel oil, unit price 6.70 yuan / liter. The buses are electric driven and powered from the vehicle’s battery, not gasoline. Related information shows that the electric bus’s 100 kilometers of energy consumption is equivalent to 84.64 yuan, which is 0.85 yuan / km. According to the "Car Fuel Consumption Mark" and field survey data, the basic information of various vehicles at the time of congestion is as follows (Fig 1).

As the Xingsheng Station in the E-W direction (in the direction of JinFurong Avenue), there is almost no delay in the vehicle. So, there is no additional fuel cost. Statistics show that the average delay time of the vehicles in the N-S direction of the Xingsheng Station is 108.33 seconds. The extra fuel cost shows in the figure 2.
Figure 1. Related data of traffic flow

Figure 2. The extra fuel cost

3.2. Delay time cost
According to statistics, the signal period of the Xingsheng Station in the N-S direction (in the direction of Xihua Avenue) is about 220s, and the average number of vehicles stranded is 60. In order to get the number of the passengers per car, this paper first adopts the sample survey method according to the vehicle type to obtain the average number of passengers of each vehicle on the survey section and obtains the traffic flow structure according to the traffic volume of each type of intersection. Then take this as the weight to find the average number of passengers per car, it is 1.96 passengers per car.

The delay time cost of the primary signal cycle of the intersection is:

\[ C_T^{J-S} = 60 \times \frac{220}{60} \times 0.797 \times 1.96 = 343.67 \text{ (yuan)} \]  

In the same way, there is almost no vehicle delay of Xingsheng Station in the E-W direction (in the direction of Jin Furong Avenue), so \( C_T^{E-W} = 0 \). Total delay time cost:

\[ \sum C_T = (0 + 343.67) \times 250 \times 8 \times \frac{3600}{220} = 11247.5 \text{ thousand yuan} \]

3.3. Pollution cost
In this paper, professional audio analyzers and other equipment are used to collect noise data within the influence range of noise. The information is as follow (Table 1).

| Category | gasoline consumption (liter) | diesel oil consumption (liter) | Noise difference before and after construction (dB) | Number of exposed people (person) |
|----------|-----------------------------|-------------------------------|---------------------------------|----------------------------------|
| Quantity | 365837.0                    | 91065.2                       | 7                               | 10520                            |

The per capita disposable income of Chengdu in 2018 is 36,142 yuan, and the carbon emission factor of gasoline is known (\( Q_g \)) is 2.26kg/L, diesel carbon emission factor (\( Q_d \)) is 2.74kg/L. According to China Carbon Emissions Trading Network data, the latest carbon rights trading price (\( P_c \)) is 86.9 yuan/ton (price in Beijing in October 2019). According to the calculation model, the pollution costs are calculated as follow (Table 2).

| Category          | Particulate pollution | Noise pollution | Carbon emission | Total   |
|-------------------|-----------------------|-----------------|-----------------|---------|
| Quantity          | 182                   | 2927            | 94              | 3203    |

3.4. Fatigue cost
The fatigue cost of the two stations is gotten by the unit fatigue cost value known as 3.60 yuan / (person·day) as follow (Table 3):
### Table 3. Fatigue cost

| Category | Average daily traffic (vehicle / day) | Passenger coefficient (person / car) | Fatigue cost (thousand yuan / year) |
|----------|--------------------------------------|--------------------------------------|-------------------------------------|
| Quantity | 40249                                | 1.97                                 | 9106                                |

#### 3.5. Total cost

In summary, the calculated social cost of the subway station is as follows (Table 4):

### Table 4. Summary of traffic social cost (thousand yuan / year)

| Category                  | Additional fuel cost | Delay time cost | Pollution cost | Fatigue cost | Social cost of transportation |
|---------------------------|----------------------|-----------------|----------------|--------------|------------------------------|
| Quantity                  | 3262                 | 11247           | 3203           | 9106         | 26818                        |

### 4. Conclusion

Through the analysis and calculation of the negative impact on the road traffic of the open-cut subway station, it is found that the annual social cost of transportation is as high as more than 20 million yuan. In the construction period of the subway station for several years, the social cost of transportation is undoubtedly huge. Therefore, the reduction and control of social costs should be noticed. The early construction method optimization and the noise-reduction measures during the construction process are all effective ways to reduce the cost of social transportation.

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