Study on Social Benefit Measurement Model of Urban Rail Transit

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Abstract. More and more urban rail transit projects will be constructed in order to alleviate the traffic problem along with the speeding up of urbanization. As a public product, rail transit project serves the public, and its benefits should be evaluated from social benefits. How to reasonably calculate the social benefit of urban rail transit has become the necessary basis to consider whether to build rail transit. Therefore, after taking into account the factors that influence social benefits, this paper constructs the calculation model of social benefits of rail transit, which provides the model basis for the calculation of social benefits in the future.

1. Introduction
The speeding up of urbanization makes the city traffic demand and supply contradictions increasingly prominent, urban rail traffic because of its large capacity, high speed, and low energy consumption, making the development of rail transit is the important means to solve the problem of urban transportation. By the beginning of 2017, 31 cities in China had opened subway, among which the top three cities in terms of operating mileage were Shanghai 617km, Beijing 574km and Guangzhou 287km. At present, cities that do not have rail transit are constantly introducing rail transit planning and cities with existing rail transit have been constantly supplemented and adjusted on the basis of the original planning. Therefore, the development scale of rail transit will increase exponentially in the future.

The early stage investment of urban rail transit project is large and the investment payback period is long, the reason why local governments promote the construction of urban rail transit projects is to perform the basic functions of governments in the market economy to provide public goods and services, whether to construct rail transit projects should consider the social benefits of rail transit. How to calculate the social benefits of urban rail transit has become a primary problem, after taking into account the factors that influence social benefits, this paper constructs the calculation model of social benefits of rail transit, which provides the model basis for the calculation of social benefits in the future.

2. Indicators of Influencing Factors for Social Benefit Measurement of Urban Rail Transit.
Reducing the investment in infrastructure, Tong Wang (2010) proposed the benefit of reducing the investment in road traffic construction due to the operation of urban rail.

Reducing urban air pollutant emissions, Tianhong Gang (2003), Ming Lu (2012) put forward due to the operation of urban rail transit with the green energy that other transportation ways do not have and operation of urban rail transit can benefit from reducing emissions of pollutants.
Driving along the real estate appreciation, Ming Lu (2012), Xue Zhang (2011), Wei Li (2007) proposed that due to the operation of urban rail transit, the accessibility and convenience of traffic along the routes have been improved, which changes the original location condition of the land and causes the benefit of the increase of real estate value.

Enhancing the traffic accessibility, Ming Lu (2012) put forward the urban rail transit lines can also operate under the condition of abnormal climate, that is the benefits of urban rail transit.

Comfort and reduce fatigue improving, Fugui Chen (2010), Gang Chen (2009), Haidan Wang (2004) put forward compared with the ordinary buses, the urban rail transit vehicles due to the internal space is capacious and comfortable, which can reduce a train journey fatigue to improve labor productivity and the benefits of passengers.

Employment opportunities increasing, Fugui Chen (2010) and Hui Mu (2007) proposed the benefits of increasing employment opportunities brought by the operation of urban rail transit network.

Land resource saving, Tianhong Gang(2003), Xue Zhang, (2011) put forward as the urban rail transit line mainly uses the underground or elevated line reduces the use of the land on the ground of benefits.

Energy saving. Lu Ming (2012), Zhang Xue (2011) proposed that because of the strong transportation capacity of urban rail transit lines, the energy consumption of urban rail transit unit passenger flow is lower than that of other urban traffic modes.

Reducing the economic cost of the bus. Li Zhi (2006) proposed that due to the operation of rail transit, it reduced the benefits of other public transportation such as buses to complete the input of the same traffic passenger transport.

Reducing the traffic accidents. Li Zhi (2006) proposed that the huge transport efficiency of urban rail traffic brought the diversion effect on the ground passenger traffic, reduced the congestion level of the ground road traffic and reduced the efficiency of the frequency of traffic accidents on the ground traffic vehicles.

3. Research on Social Benefit Measurement Model of Urban Rail Transit

3.1 Improve Travel Efficiency

The maximization model of consumer welfare is the most objective and comprehensive for the benefit calculation of improving travel efficiency. The benefit calculation model of improving travel efficiency is as follows:

\[ B_{1(n)} = U \times T \times V_n \times \lambda + U \times T \times V_{nr} \times (1 - \lambda) \] (1)

In equation (1), \( B_{1(n)} \) be the benefits of the year \( n \) because of improving travel efficiency, \( U \) represents the sum of transfer passenger flow and natural growth passenger flow in the \( n \)th year of the operation, \( T \) be the passenger travel saving time, \( \lambda \) is the coefficient of passenger flow, \( V_{n} \) be the unit time value of employment personnel, \( V_{nr} \) be the unit time value of employment personnel, \( T \) be the passenger travel saving time, \( \lambda \) is the coefficient of passenger flow, \( V_{n} = G_{1(n)}/TW_{(0)}; G_{1(n)} = G_{(n)}/N_{(0)}; TW_{(0)} \) represents the actual working time of the \( n \)th year of the laborer, \( N_{(n)} \) be the number of urban employment in the city where the urban rail transit project is located in year \( n \).

\( L_{(n)} \) represents the average ride distance of passengers per unit of urban rail transit in year \( n \), \( v_{1} \) and \( v_{2} \) are the average speed of urban buses.

\[ T = \frac{L_{(n)}}{v_{1} + v_{2}} \]

3.2 Improve Comfort and Reduce Fatigue Benefits

\[ B_{2(n)} = U \times \frac{1}{2} \times V_{(n)} \times t \times \beta \times c_1 \times c_2 + \frac{1}{2} \times V_{(n)} \times t \times \beta \times c_3 \] (2)

\( B_{2(n)} \) represents improve comfort and reduce fatigue benefits. \( \eta \) is the return coefficient of working passenger flow, \( t \) is the working hours a day of workers, \( \beta \) is to improve the labor productivity coefficient of urban rail transit compared with the bus system. \( c_4 \) is the operation congestion time.
coefficient, \( c_2 \) is the ride coefficient in the operation congestion time, \( c_3 \) is the non-crowding time coefficient during the operating.

### 3.3 Reduce Traffic Accident Loss Benefits

\[
B_3(n) = U \times L_i(n) \times \alpha \tag{3}
\]

\( B_3(n) \) represents the reducing traffic accident loss benefits, \( \alpha \) is the loss of traffic per passenger turnover.

### 3.4 Benefits of Attracting and Increasing Passenger Flow

The calculation model of the benefits generated by the operation of urban rail transit project to induce increased passenger flow is as follows:

\[
B_4(n) = f_p \times Y_i(n) \times p \tag{4}
\]

\( B_4(n) \) represents the benefits of attracting and increasing passenger flow in the nth year, \( Y_i(n) \) be the inducing increased passenger flow in the nth year, \( p \) is the fare, \( f_p \) be the conversion coefficient of shadow fare.

### 3.5 Benefits of Air Pollutant Emission Reducing

\[
B_5(n) = B_{51}(n) + B_{52}(n) \tag{5}
\]

\[
B_{51}(n) = (W_{1CO_2} - W_{2CO_2}) \times U \times k \times L_2 \times P_{CO_2}
\]

\[
B_{52}(n) = \sum_{i=1}^{m} (W_{1i} - W_{2i}) \times U \times (1-k) \times L_2 \times P_i
\]

\( B_5(n) \) represents the benefits of air pollutant emission reducing, \( W_{1CO_2} \) represents \( CO_2 \) emissions per unit of urban bus traffic, \( W_{2CO_2} \) represents \( CO_2 \) emissions per unit of urban rail transit, \( P_{CO_2} \) be the unit loss of \( CO_2 \), \( k \) is the public transport sharing rate of city buses, \( m \) is the type of hazardous substances emitted from the tail gas of ordinary vehicles, \( W_{1i} \) is the number of harmful substances of type i discharged per vehicle unit, \( W_{2i} \) is the number of harmful substances of kind i discharged per urban rail transit unit, \( P_i \) be the loss caused by a pollutant of type i or cost of treatment of a pollutant of type i.

### 3.6 Energy Saving Benefits

\[
B_6(n) = \frac{(U \times L_i(n) \times 0.631 \times 55\% + 55\%) \times P_q}{35544} - \frac{(U \times L_i(n) \times 2.27 \times (1-30\%) \times 30\%)}{31441.1} \times P_y \tag{6}
\]

\( B_6(n) \) represents urban rail transit in the nth year to save energy efficiency, \( P_q \) is the price of natural gas for the nth year of operation of urban rail transit, \( P_y \) is the price of natural gas for the nth year of urban rail transit operation, 0.631 be the rail transport unit energy consumption is lower than CNG bus 0.631 KJ, 2.27 be the rail transport unit energy consumption is lower than a regular car 2.27 KJ, 55% be the gas engine thermal efficiency and thermal efficiency, 30% be the gasoline engine, 31441.1 according to the general principles of the comprehensive energy consumption calculation of gas calorific value of 43070 KJ/kg, according to the density of gasoline conversion is 31441.1 KJ/L, 35544 according to the general principles of the comprehensive energy consumption calculation for gas field gas calorific value of 35544 KJ/m^3.

### 3.7 Benefits of Land Resources Saving

\[
B_7(n) = (NT \times S_1 + L_g \times d) \times P_t \tag{7}
\]
\( B_{f(n)} \) represents the benefits of land resources saving in the nth year, \( S_i \) is an area of each bus covering, \( d \) is the standard width of urban rail transit, \( P_e \) is the shadow price of land.

### 3.8 Employment-driven Benefits

\[
B_{8(n)} = \Delta N_j \times C_{1(n)} \times f_B \tag{8}
\]

\( B_{8(n)} \) represents the nth year of urban rail transit operation, the promotion of employment efficiency of the region, \( \Delta N_j \) be the additional post in the nth year, \( f_B \) is the shadow price of wage.

### 3.9 Land Appreciation Benefits

\[
B_{9(n)} = \sum_{i=1}^{n_2} \pi \left[ \frac{L_i}{(CZ_i - 1) \times 2} \right]^2 \times P_f \tag{9}
\]

\( B_{9(n)} \) represents the urban rail transit land appreciation benefits in the nth year, \( L_i \) is the length of route \( i \) of rail transit, \( CZ_i \) is number of stations on route \( i \), \( P_f \) be the unit price of land appreciation.

### 4. Case Study

A city opened the first subway line at the end of 2016, and the whole process was 24.58km, with 23 stops. Combined with the data of total passenger traffic, subway passenger average ride distance, population number and per capita GDP in 2017, the social benefit of a city subway operation in 2017 is obtained by using the social benefit calculation model. The results are as follows: the following figure 1:

![Figure 1. Social benefits during the operation of a subway in 2017](image)

The results showed that the social benefit of the urban rail transit in 2017 was 14 billion 398 million yuan, of which the benefits of reducing urban air pollutant emissions, saving land resources, land appreciation and improving travel efficiency are significant and more than 80% of the social benefits are quantified. When the subway is built, the total investment of the line is 6 billion 427 million yuan, and the social benefit of the city's subway operation in 2017 has been more than 2 times more than the initial investment. The social benefit will be further expanded as time goes on.

### 5. Conclusion

After summarizing and analyzing the factors that influence the social benefit of urban rail transit, this paper constructs a social benefit measurement model during urban rail transit operation in order to realizes the monetization transformation of social benefits. Although there is a gap between the model analysis and the real situation, the model analysis has scientific reasoning and has operational and practical significance for the quantification of social benefits.
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