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Procedia - Social and Behavioral Sciences 96 (2013) 565 – 573

Procedia
 Social and Behavioral Sciences

13th COTA International Conference of Transportation Professionals (CICTP 2013)

Study of Urban Rail Transit Operation CostsBin Shang^a, Xiaoning Zhang^{b*}^aKey Laboratory of Road and Traffic Engineering of the Ministry of Education, Tongji University, Shanghai 201804, China^bSchool of Economics and Management, Tongji University, Shanghai 200092, China. Corresponding author,**Abstract**

In order to analyze variation of urban rail transit (URT) operation cost against the distance from the city center, the URT of Shenzhen was taken as an example to study in the three cases. The costs of URT operation were addressed through the real data of URT, and the skeleton planning method was used to estimate the costs of Shanghai and Hangzhou metro. The results show that the cost of URT operation is nearly 15 million Yuan/(Km·year) when the URT is just opened; the cost of URT operation is nearly 35 million Yuan/(Km·year) before the network operation and nearly 12 million Yuan/(Km·year) after the network operation. The cost of Hangzhou metro operation is about 60 million Yuan/year. The cost of Shanghai metro operation is about 5.7 billion Yuan/year. More specifically, the findings of this paper have insightful implications to planning, design, operation, and assessment of urban rail transit.

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Selection and peer-review under responsibility of Chinese Overseas Transportation Association (COTA).

Keywords: Urban transportation; Urban rail transit; Operation costs; Network operation; Skeleton planning method**1. Introduction**

With more and more cities operating URT, a large number of scholars began to study the rail transit operation costs. Allport (1981) developed costing models for LRT and for bus and metro, from comparable primary source data, and in a form which may be modified for use in different situations and to demonstrate the application of the models for a typical urban corridor in which the total social cost of the modes are compared, and the least economic cost mode identified, at different demand levels and in different situations. Todd (2007) suggests high quality, grade-separated transit does reduce urban traffic congestion, and that urban transit improvements can be cost effective investments when all economic impacts are considered. Li and Yin (2012) took Line 4 of Beijing URT as an example to analyze the internal and the external costs of systematically then divided the internal cost into preliminary planning, designing cost, constructing cost and operating cost and the external cost into the cost

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of air pollution, traffic accident and noise pollution based on the value chain theory. At last, The external cost is quantified. Ou and Zhang (1994) set up a cost forecasting model to predict the approaching transportation cost through classifying the elements of the cost in detail and analyzing their effects to the total cost. Chen (2006) showed that the subway fixed costs was more than 80% of the total cost through analyzing the characteristics of Shenzhen Metro operation costs under different headway. Yu and Li (2009) proposed major cost items affecting operational costs and major influencing factors based on the statistical analysis of the actual operational data on domestic rail transit operating costs through the analysis of rail transit operating costs constitute. Zhou (2010) discusses how to reduce the operation cost combining with the actual operational situation data including passengers and operation mileages from the aspect of the personnel management, operational arrangement, quota management and selection of equipment types. Han (2009) determine that vehicle management is the key to cost control system of rail transit operators through using the analytic Hierarchy Process (AHP) to sort the relevant factors according to the degree of importance of the rail transportation system operators. Using data from Australian cities, Tirachini, Hensher, and Jara-Díaz (2010) developed a model for an urban network with radial lines emanating from the borders to the city center to compare three alternative forms including URT and BRT assuming an operation aimed at minimizing the total cost encompassed both operator and users costs. Gunduz, Ugur, and Ozturk (2011) developed early cost estimation models for light rail transit and metro trackworks using the multivariable regression and artificial neural network approaches. These two approaches were applied to a data set of 16 projects by using 17 parameters available at the early design phase. The regression analysis estimated the cost of testing samples with an error of 2.32%. On the other hand, artificial neural network estimated the cost with 5.76% error, which was slightly higher than the regression error. As a result, two successful cost estimation models have been developed depending on the findings of this paper.

As can be seen from the above description, they are effect factors on the URT as well as the how to control the operation costs. There are few case studies on operation costs of URT. The operation costs of URT were set as a goal in this paper. We analyzed the unit operation costs of the URT at first, and then made empirical studies of the operation costs which used the skeleton planning method (SPM) and the actual URT data of cities including Shenzhen, Shanghai, Tianjin, Hangzhou to calculate the total operation costs.

2. The constitute of URT operation costs

Operating costs of URT include main business costs, business tax and surcharges, sales charges, management fees, and finance charges. Table 1 shows the contents contained in the various fees [*Annual report of Shanghai shentong metro CO., LTD*, Ding (2008)]. The study of URT operating costs in this paper including operating costs of rail transportation, sales taxes and surcharges, selling expenses and administrative expenses.

Table 1 Operating costs list

Operating costs		Contents of every items
The operating costs section considered in article	Main business costs	Wages, welfare, the fee of electricity and vehicle repairs, etc.
	Business tax and surcharges,	Business tax, urban maintenance and construction tax, education surcharge, local education surcharge
	Sales charges,	Card fees, invoice printing costs
	Management fees	Office and conference fees, agency fees, social insurance funds, the cost of taxes, rent and physical management fees, travel expenses, business entertainment costs, vehicle costs, external staff, depreciation charges, trade unions and education funding, other
Finance charges.		Interest expense, interest income, handing fee

3. The data and variables of URT operating costs

This paper takes Shenzhen as an example to analyze operating costs of URT

3.1. The data sheet of URT operating costs

Table 2 gives the operation condition of Shenzhen URT for the year 2006 to 2011. The Table 2 shows that when the Shenzhen URT only has the one line in the first phase of operations, operating income of URT increased from 179.7 million Yuan in 2006 to 8.6 billion Yuan in 2010. Meanwhile operating costs do increase sharply from 2.53 billion Yuan in 2006 to 7.28 billion Yuan in 2010 with the increasing of operating income.

Tab. 2 Shenzhen URT financial revenue and expenditure for the year 2006 to 2010 (10^4 Yuan)

Number	Items	2006	2007	2008	2009	2010	2011
1	Operating income	17969	45650	57940	77192	86021	96861
2	Main business costs	25365	55328	58755	72479	72832	75320
3	Business tax and surcharges,	637	1727	2252	3600	4453	5364
4	Sales charges,	102	60	62	78	107	69
5	Management fees	3871	3957	4182	10839	13706	14670
6	Wages	12186	13631	20914	29397	39978	59854

As can be seen from table 2 and figure 1, every costs of the Shenzhen URT increased from 2006-2011 especially the operating costs substantially increasing in 2007 and 2009. Be seen from Table 2 also showed that operating costs increased more than 300 million Yuan in 2007 than in 2006, increased more than 100 million Yuan in 2009 than in 2008, and increased more than 30 million Yuan in 2011 than in 2010. We also could see that staff wages increased substantially among the year of 2006 to 2011 from table 2 and Figure 1. It increased 10 million Yuan in 2007 than in 2006. In 2008-2010, the annual growth of wages closed to 100 million Yuan. Wages increased by 200 million Yuan in 2011 than 2010, which is up to 599 million Yuan that the increasing rate is close to 50%. Through the analysis of trends in a substantial increasing of operation costs of the Shenzhen Metro Group especially the wages, the biggest reason was that the Shenzhen Metro Group recruited and trained staff since 2008 to prepare for URT network operation in 2011. The magnitude of the total increase in operating costs of Shenzhen is not large comparing 2011 to 2010 which explained that the increasing of operating costs is mainly the increase of wages.

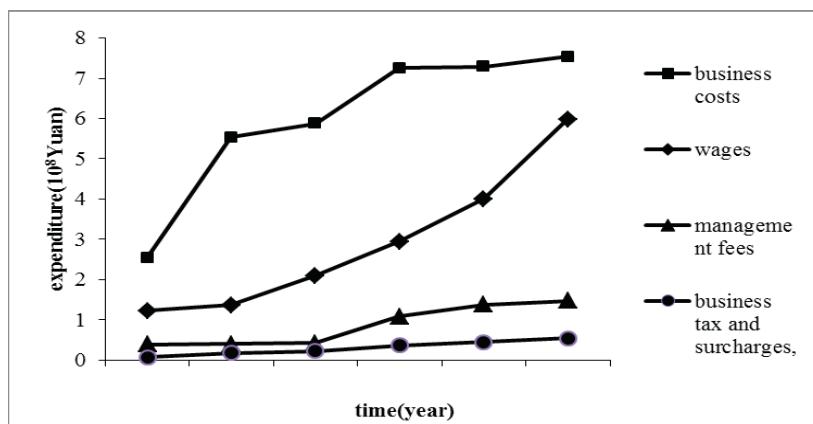


Fig. 1 The growth curves of costs

Tab 1 Shenzhen URT operating costs for the year 2006 to 2010 (10^4 Yuan)

Year	2006	2007	2008	2009	2010	2011
operating costs (10^4 Yuan)	29975	61072	65251	86996	91098	95423
length (Km)	21.866	21.866	21.866	21.866	21.866	153.733
operating costs per Km (10^4 Yuan/Km)	1370.85	2793.01	2984.13	3978.60	4166.19	1086.83

We can find that the operating costs of Shenzhen URT have tended to increase from the year 2006 from table 3 and figure 2. Total operation costs in 2006 were 299.8 million Yuan and it dramatically increased 300 million Yuan and reached 610.7 million Yuan in 2007. Increasing operation costs is more than 115 million Yuan in 2009 than in 2008 and annual increasing of operation costs is about 50 million Yuan2010 and 2011.

Shenzhen Metro Group began a large-scale recruitment of staff from the year of 2007 and the length of URT in operation has remained unchanged in 21.866Km from the above description. As can be seen from Table 3 and Figure 2, its operating costs per kilometer in 2006 were 13.7085 million Yuan. The operation costs of URT kept

continuous growth trend in the 2007-2010 which increased from 13.709 million Yuan/Km in 2006 to 41.662 million Yuan/Km in 2010. The per Km operation costs of URT is up to 27.93 million Yuan and the growth rate was more than 100%.

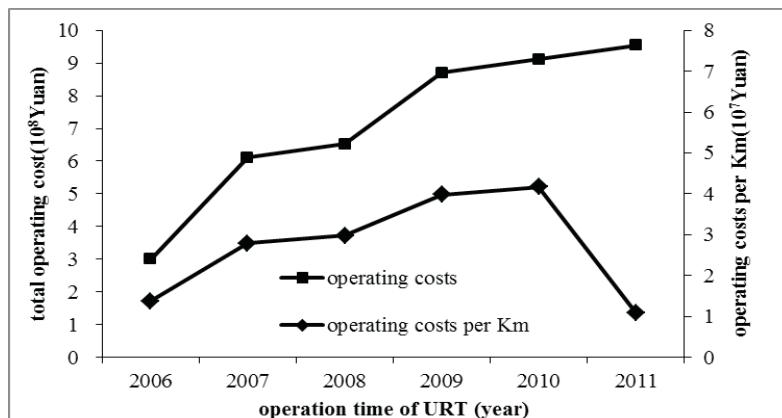


Fig. 2 The total operating costs and the cost per kilometer

As the length was up to 153.733Km in 2011, Shenzhen URT began network operation. The total operating costs increased from 911 million Yuan in 2010 to 954 million in 2011. The “per kilometer operating cost” dropped significantly from 41.6619 million Yuan in 2010 to 10.8683 million Yuan in 2011. From the above analysis, the changing process of per km operating costs of Shenzhen URT can be divided into three periods: before 2006 is the period of just opened, from 2007 to 2010 is the period of before network operation and after 2011 is network operation period. For operational rail transit city, the operating costs data of three periods of Shenzhen has reference.

As can be seen from the above analysis, there is a large gap in the cost of URT operation in different cases. This paper studied operating costs in the three cases including the period of just opened of URT, before network operation and network operation. The period of URT just opened is before the network operation that the metro company has not prepared for network operation. The period before URT network operation is that the metro company has already prepared for network operation such that Company has recruited and trained staff for work. This period will be last 4 to 5 years that costs of wages will be increasing substantially because of a large of staff and unchanged length of URT. The period of URT network operation is that the metro company has already been network operation that there are at least 3 lines in operation.

3.2. Variable Symbol Description

The variables and the corresponding symbols which are used to compute the operating costs are shown in table 4.

Tab. 4 Variables and the corresponding symbols

Symbol	Variable name	Symbol	Variable name
L	The total length of URT	COP	The operating costs of URT
JPC	Per Km operating costs of URT just opened after adjusting	Jcop	Operating costs of URT just opened

BPC	Per Km operating costs before URT network operation after adjusting	Bcop	Operating costs before URT network operation
NPC	Per Km operating costs of URT network operation after adjusting	Ncop	Operating costs of URT network operation
T	The operation time	Tcop	Total operating costs

4. The operation costs of URT

As known from the above description, the unit operating costs of Shenzhen can be divided into three periods including the period of just URT opened, the period of before network operation and the period of network operation. We analyze operating costs of just opened period of Shenzhen URT.

4.1. The operation costs of URT just opened

The “per Km operating cost” and the total operation costs of 2006 of Shenzhen Metro are listed in table 3. As can be seen from the table, the total operating costs of the Shenzhen Metro which length is only 21.866Km was 299.8 million Yuan in the year of 2006 including the line 1 and line 4. Therefore we can determine the Shenzhen subway operating costs is 13.709 million Yuan/Km in 2006.

Based on the above analysis, the operating costs of the Shenzhen Metro in the period of URT just opened are 13.709 Yuan/Km. we analyze operating costs in the period of URT just opened using data in this paper. Considered that Electricity bills, staff salaries and other expenses of the other major cities are lower than the mega-cities of Beijing, Shanghai, Guangzhou, Shenzhen, per Km operating costs should be reduced in the city except the mega-cities, but taking into account the low level of the management of major cities and a waste of resources as well as the city prices rise, so we take the adjustment factor of 1.1 to pairs per km operational costs. All cities adopt this adjusted value.

The adjusted per Km operating costs equals to the adjustment factor multiplied by the operation cost.

$$JPC = 1.1 \times COP = 1.1 \times 1370.85 = 1507.935 \approx 1.5 \times 10^7 (\text{Yuan} / \text{Km}) \quad (1)$$

Through the above analysis and calculations, we determine the adjusted per km operating cost is 15 million Yuan/Km.

We take line1 of Tianjin URT as an example, using the adjusted value 15 million Yuan/Km to calculate the operating costs.

Step 1: determine the length of URT

$$L = 26.2(\text{Km}) \quad (2)$$

Step 2: determine the annual operation costs of URT

$$Jcop = JPC \times L = 1500 \times 26.2 = 3.93 \times 10^8 (\text{Yuan}) \quad (3)$$

We also take Hangzhou URT as an example, using the adjusted value 15 million Yuan/Km to calculate the operating costs.

Step 1: determine the length of URT

$$L = 39.83(\text{Km}) \quad (4)$$

Step 2: determine the annual operation costs of URT

$$J_{cop} = JPC \times L = 1500 \times 39.83 = 5.975 \times 10^8 (\text{Yuan}) \quad (5)$$

4.2. The operation costs of URT before the network operation

From the above description the Shenzhen Metro invest large sums of money to recruit and train employees in the period of 2007-2010 to prepare for 2011 network operators. Operating costs before network operation of Shenzhen URT will be analyzed in this section.

The per Km operating costs and the total operation costs in the period of 2007 to 2010 of Shenzhen Metro are listed in table 3. In 2006-2010, the total operating costs of the Shenzhen Metro has increased from 299 million Yuan to 911 million Yuans, the annual growth is nearly 1.5 billion. Shenzhen Metro's operating costs in 2006 is 13.709 Yuan/Km. The operating costs was nearly 28 million Yuan/Km in 2007 which grew more than 14 million Yuan compared to 2006, a growth rate is over 100%. The operating costs of 2008 closed to 30 million Yuan/Km. The highest operation costs is appeared in the year of 2010 which reached 41.662 Yuan/Km, a growth rate is over 300% compared to 2006. In order to prepare for network operation such that Company has recruited and trained staff for work, the per Km operation costs of URT will be increasing substantially because of a large of staff and unchanged length of URT in the period of before URT network operation.

According to the above analysis, the average operating costs of Shenzhen Metro network operation is 3.480 million Yuan/Km in the period of 2007 to 2010. As the mega-cities, per kilometer of its operating costs are higher caused by higher electricity fee and wages of Shenzhen. From the above analysis and calculations, we determine per km operating cost is 35 million Yuan/Km without any adjusting.

We take line 1 of Tianjin URT as an example, using the value 35 million Yuan/Km to calculate the operating costs.

Step 1: determine the length of URT

$$L = 26.2(\text{Km}) \quad (6)$$

Step 2: determine the annual operation costs of URT

$$B_{cop} = BPC \times L = 3500 \times 26.2 = 9.17 \times 10^8 (\text{Yuan}) \quad (7)$$

Step 3: determine the total operation costs in the period before network operation assumming that the operation time is 4 years.

$$T_{cop} = B_{cop} \times T = 9.17 \times 4 = 3.668 \times 10^9 (\text{Yuan}) \quad (8)$$

4.3. The operation costs of the network operation

The “per kilometer operating cost” and the total operation costs of 2006 of Shenzhen Metro are listed in Table 3. As can be seen from the table, the total operating costs of Shenzhen network operation are 95.423 million Yuan. Operating costs of the Shenzhen Metro in the period of network operation are 10.868 Yuan/Km because that compared to 21.866Km of in the first half of 2011, Shenzhen URT began network operation with the length of 153.733Km in the second half of 2011. According to the above data, the operation costs in the period of network operation are listed in the Table 5.

Tab 5 Shenzhen URT operating costs of 2011 (10^4 Yuan)

Time	January to June	July to December
Operating costs (10^4 Yuan)	95423	
Total length (Km)	21.866	153.733
Operating costs per Km (10^4 Yuan/Km)	1086.83	

Now only the mega-cities URT including Beijing, Shanghai, Guangzhou, Shenzhen began network operation, the management level, commodity prices such as electricity fee, wages did not differ much in these cities, so the gap of per km operating costs is not large. Considered that Electricity bills, staff salaries and other expenses of the other major cities are lower than the mega-cities such as Beijing, Shanghai, Guangzhou, Shenzhen, per Km operating costs should be reduced except the mega-cities, but taking into account the low level of the management of major cities and a waste of resources as well as the city prices rise, so we take the adjustment factor of 1.1 to pairs per km operational costs. All cities adopt this adjusted value.

The adjusted per Km operating costs equals to the adjustment factor multiplied by the operation cost.

$$NPC = 1.1 \times COP = 1.1 \times 1086.83 = 1195.513 \approx 1.2 \times 10^7 (\text{Yuan} / \text{Km}) \quad (9)$$

Through the above analysis and calculations, we determine the adjusted per km operating costs are 12 million Yuan/Km.

The Shanghai Metro has been network operation from 2007. At the end of 2011, the total length of Shanghai URT is up to 476.246Km. We take Shanghai URT as an example, using the adjusted value 12 million Yuan/Km to calculate the operating costs.

Step 1: determine the length of URT

$$L = 476.246(\text{Km}) \quad (10)$$

Step 2: determine the annual operation costs of URT

$$Ncop = NPC \times L = 1200 \times 476.246 = 5.7 \times 10^9 (\text{Yuan}) \quad (11)$$

Conclusion

As can be seen from the above analysis, the unit operating costs can be divided into three periods including the period of just URT opened, the period of before network operation and the period of network operation. The unit operation costs of URT just opened is 15 million Yuan/Km, The unit operation costs before network operation is 35 million Yuan/Km and the unit operation costs of network operation period is 12 million Yuan/Km.

Acknowledgements

This work was supported by the National Natural Science Foundation Council of China (Grant No. 71125004).

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