# A New Method to Calculate the Cost of Urban Rail Transit Operation

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Abstract—For urban rail transit enterprises, estimation and forecast of operating costs is important reference basis to keep runinng well, and it is also an effective means to maintain the sustainable development. In this article, firstly, a framework of calculating the urban rail transit operating costs will be formed, and on this basis, the calculation method is put forward, which is called operating expenditure cost method, Based on this method, the operating costs of Shanghai rail transit line 1 are worked out, the calculation results are highly close to the actual operating costs, it is proved that the operating expenditure cost method is reliable and efficient and can be well used to predict the urban rail transit operating costs.

Key words-urban rail transit;framework;operating costs calculation; Shanghai rail transit line 1;estimation and forecast

# I. INTRODUCTION

Urban rail transit operating costs are defined to be the sum of all the costs of rail transit system during transporting passengers which including employee wages and bonus, material costs, electric power costs, depreciation costs, capital costs and other costs, and mainly composed of operating costs, administration expenses, financial expenses and non-business expenses[1].The calculation of urban rail transit operating costs is an important method to evaluate subway operation conditions, it reflects the business operation level, and it is also the important technological data of the national development of urban rail transportation planning. At present, the calculation method of urban rail transit Yuxin Zheng School of Mechanical Engineering Tongji University Shanghai, China e-mail: zhengyuxin1989@126.com

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operating costs is mainly the reference element cost method and the activities-based cost method[2], the former provides a good basis of feasibility analysis for urban rail transit design and planning, the latter, based on the causes of work, provides a reasonable method to predict the operating costs happening in the future. However, the factors involved in the operating costs are a large number, the reference element cost method is to cause a huge work, and because it is difficult to classify the content of the work, the activities-based cost method lacks accuracy to some extent.[3]. To sum up, after figuring out the merits and demerits of these two methods introduced above, a new and more rational method to calculate the urban rail transit operation costs is put forward in this paper, that is the operating expenditure cost method.

In the operating expenditure cost method, the cost is calculated by means of expenditure items, but it is different from the activities-based cost method in which the expenditure cost is simply added together. In the new method, firstly, a framework of operating costs is compiled, secondly, according to the framework, a formula which is associated with the operating state is deduced, and then the actual and upcoming predicted data are assigned to the corresponding parameters in the formula, and a cost value which is related to the content of the framework is worked out, finally, after putting the actual or predicted business expenses, administration expenses and financial expenses together, the final total operating costs can be got.

#### II. THE FRAMEWORK OF OPERATING COST OF URBAN RAIL TRANSIT

Railway operating cost calculation method mainly includes the reference element cost method and the activities-based cost method, and due to the railway business develops early, the management theories and experiences are perfect. In recent few years, several versions of railway design of comparatively operating costs quota and instruction[4] have been revised, and in the instruction, there are many quota standards for partly railway operating indicators. Due to the expense content of urban rail transit and railway transportation system to keep the normal operation are basically same only with a few different matching cost value, according to the principle of similarity, and combining the characteristics of urban rail transit, a framework which is adapted to calculate the operating cost of urban rail transit is proposed after analyzing the existing railway quota.

By Referring to the *railway design of comparatively operating costs quota and instruction*, we can divide the urban rail transit framework into two parts, the first part is related to the amount of subway running, the second part is related to the fixed equipment maintenance. Among them, the first one includes motor car and trailer car repair fees and basic depreciation costs, steward wages, electricity power costs, the latter one includes maintenance fees of trunk lines, station lines, stations, signal and communication equipments, electric traction substations and catenaries, etc.

#### III. THE RELATIVE COST OF RUNNING

#### A. Ordinary Steel Car Maintenance Costs

According to Beijing subway maintenance procedures, vehicle regular repair can be divided into train inspection, monthly repair, periodical repair, un-wheeling repair and shop repair[5], the maintenance cycle and cost are set in the following table I. In 20 years, each ordinary steel car maintenance cost is about to 208,114.5 yuan for each year.

	Quotas						
Repair items	Repair cycle	Unit cost	Maintenance cost/ thousand yuan				
train inspection	4d/100 km	8yuan/km	192.00				
monthly repair	1mon/10 thousand·km	240 yuan /per car	57.60				
periodical repair	1.5a/130~150 thousand·km	14000 yuan/ per car	140.00				
un-wheeling repair	3 a/270~300 thousand km	380000 yuan / per car	152.00				
shop repair	7~9 a/720~900 thousand∙km	500000 yuan / per car	1000.00				
cost of labor		—	2620.69				
total		_	4162.29				

TABLE I. VEHICLE REGULAR REPAIR

# B. Stainless Steel Car and Aluminium Alloy Car Maintenance Costs

According to Japanese urban rail transit vehicle maintenance costs statistics, in shop repair, car body maintenance costs occupy one third of the whole shop repair costs, and the body maintenance cost of stainless steel car is about 8.6 % of ordinary steel one, the cost of aluminum alloy car is 40.50 % of ordinary steel one. The twenty years shop repair cost of ordinary steel car is  $10^6$  yuan, so, the shop repair maintenance cost of a stainless steel car body is 28,666 yuan, stainless steel car maintenance cost is 3,857,623 yuan, Similarly, a aluminum alloy car maintenance cost is got, and the three kinds of materials vehicle maintenance costs are summarized in the table II.

TABLE II.	THREE KINDS OF MATERIALS VEHICLE
	MAINTENANCE COST

	Vehicle Material				
Costs	Ordinary Stainless steel steel		aluminum alloy		
maintenance cost/ thousand yuan	4,162.29	3,857.62	3,963.97		
per year maintenance cost/ yuan	208,114.5	192,881	198,198.5		

## C. Daily Maintenance Costs

By Referring to repair quota of Beijing subway, each vehicle train inspection fee is about 9,600 yuan per year.

# D. The Daily Work of A Trailer Car

Average daliy work of a trailer car can be stated as follows:

1) Mechanical work of resistance

$$W_{resistance} = q \times \omega_{cpt} \times l_B \times 10^{-3}.$$
 (1)

Where q denotes average total weight of a trailer car, and  $\omega_{cpt}$  indicates average unit basic force of resistance during run, and  $l_B$  represents vehicle average daily run kilometers.

The experience formula of  $\omega_{cpt}$  can be stated as follows:

$$\omega_{cnt} = 1.66 + 0.005 \ 7 \times v + 0.000 \ 155 \times v^2. \tag{2}$$

Where *v* denotes traveling speed.

According to Beijing subway data, a ordinary steel trailer car is 68 t with 250 passengers in average, and its vehicle average daily run kilometres is about 300 km, its average speed is 40 km/h, so the calculated mechanical work of resistance is 43.574 t·km, with the same method, the result of a stainless steel car and a aluminum alloy car is 40.217 t·km and 39.730 t·km respectively.

2) Vehicle hours

The subway running time is generally from 5:00 AM to 10:00 PM[6], so vehicle hours in a day is 17 hours.

#### E. Trailer Car Expenditure Calculation

According to Beijing subway, CSR Qingdao sifang Co.,Ltd. materials and *railway design of comparatively operating costs quota and instruction*, the urban rail transit vehical regular repair costs are divided into four parts. The first part is related to mechanical work of resistance accounts for 25 % of regular repair costs , the second part is related to time consumption accounts for 75% of regular repair costs , the third part is related to mechanical work of mechanical work of resistance accounts for 95 % of daily maintenance costs and the last part is relate to time consumption accounts for 5% of daily maintenance costs, for 5% of daily maintenance costs and the last part is relate to time consumption accounts for 5% of daily maintenance costs, for 5% of daily maintenance

The unit cost of a ordinary steel car is listed in the table 3.

TABLE III. ORDINARY STEEL TRALIER COSTS IN EIGHT MARSHALLING CONDITION

	Costs									
Classify the Vehical	Regular repair costs/(yuan·a <sup>-1</sup> )		Daily maintenance costs/(yuan·a <sup>-1</sup> )		Total of regular and daily cost		Daily work		Unit cost	
Maintance Costs	Percent	Costs	Percent	Costs	Whole	Whole	Mechanical work	Vehicle	Yuan	Yuan
	/%	/yuan	/%	/yuan	year	day	of resistance/(t·km)	hours	/(t·km)	/h
total cost	100	416229	100	19200	435429	1193		_		
related to mechanical work of resistance	25	104057	95	18240	122297	335	43.574		7.688	_
related to time	75	312172	5	960	313132	858	_	17		50.5

With the same method, the unit cost of a stainless steel trailer car and a aluminum alloy trailer car are calculated and listed in the following table IV.

TABLE IV. ORDINARY STEEL AND STAINLESS STEEL TRAILER AND ALUMINUM ALLOY TRAILER CAR COSTS IN EIGHT MARSHALLING CONDITION

Classify the Vehical	Cost					
Maintance Costs	Ordinary steel		Stainless steel		Aluminum alloy	
related to resistance mechanical work $e_4^{a}$ yuan/(t·km)	7.688		7.812		8.092	
related to time $e_8^a$ yuan/h		50.5		46.84	_	48.07

a. a variable of corresponding item used in follow costs calculation formula

#### F. The Work of Motor Car in A Shop Repair Cycle

Motor car maintenance costs are divided into four parts, the part is related to the power consumption, mechanical work of traction, mechanical work of resistance and vehicle hours respectively.

1) Mechanical work of traction and resistance

$$W_{traction} = W_{resistance} = Q \times L_K \times \omega_{cpd} \times 10^{-3}.$$
 (3)

Where Q denotes the load of motor car, and  $L_K$  indicates the running distance in a shop repair cycle, and  $\omega_{cpd}$  represents the average unit basic force of resistance during run.

According to experience formula,  $\omega_{cpd}$  can be stated as follows:

$$\omega_{cpd} = 2.49 + 0.005 \ 3 \times v + 0.000 \ 203 \times v^2. \tag{4}$$

Where *v* denotes traveling speed.

According to Beijing subway materials, in eight marshalling condition, a ordinary steel train is 556 t, so a motor car is about to 92.67 t with 238 passengers, the running distance in a shop repair cycle is  $8 \times 10^5$  km, and the average traveling speed is 40 km/h, so the mechanical work of traction and resistance of a ordinary steel motor car is 224,394.8 t km, with the same method, the

mechanical work of traction and resistance of a stainless steel motor car and a aluminium alloy motor car is 214,006.9 t·km and 211,214.1 t·km respectively.

# 2) The calculation of power consumption

According to Beijing subway statistics for recent years, the metro vehicle power consumption is 400 kW ·h per car in a distance of 100 km, through calculation, the power comsuption in a shop repair cycle of ordinary steel car, stainless steel car and aluminum alloy car is 3,200,000 kW ·h, 3,004,602 kW ·h and 2,935, 032 kW ·h respectively.

3) Vehicle hours

$$l_{day} = s/(n \times 365) = 273.97 \text{ (km/d)},$$
 (5)

$$t=16\times8\times10^{5}/l_{day}=46,720$$
 (h). (6)

Where s denotes the running distance in a shop repair cycle, n indicates the number of years and t represents vehicle hours

#### G. Motor Car Expenditure Calculation

According to materials, the maintenance cost is related to power consumption accounts for 15 %, related to the mechanical work of traction accounts for 40 %, related to mechanical work of resistance is 40 %, and related to the vehicle hours is 5 %. Through calculation, the unit cost of three material motor cars.are listed in the following table V

TABLE V. UNIT COST OF THREE MATERIALS MOTOR CAR IN EIGHT MARSHALLING CONDITION

	Costs Quotas					
Name of Items	Unit	Ordinar y steel	Stainless steel	Aluminum alloy		
related to power consumption $e_I^{a}$	yuan /(kW h)	0.327	0.485	0.510		
related to traction mechanical work $e_2^{a}$	yuan /(t km)	12.489	18.166	18.890		
related to resistance mechanical work $e_3^{a}$	yuan /(t km)	12.419	18.166	18.890		
related to vehicle hours $e_6^{a}$	yuan /h	11.184	10.401	10.675		

a. a variable of corresponding item used in follow costs calculation formula

#### H. Vehicle Basic Depreciation Costs

According to the statistics of Japan, the maintenance costs increase so dramatically in the 20th year, so the calculation of operating costs is limited to within 20 years, the purchase price of a ordinary steel car, a stainless steel car and a aluminum alloy car is 5.16 million yuan, 6.12 million yuan and 9.29 million yuan respectively[7], by 4% residual value ratio, the average annual depreciation cost is 248,000 yuan, 297,500 yuan and 446.500 yuan respectively.

#### I. Worker Wages

Each subway vehicle is equipped with a driver and a steward, according to the work duty of 8 hours a day, 250 work days per year, the workers wages are 56.25 yuan/h, and uses  $e_7$  to represent the value.

## J. Electricity Price

The urban rail transit belongs to public welfare undertaking, and also belongs to large industrial electric power, according to many city standards, the electricity unit price is 0.55 yuan/(kW·h)[8], and uses  $e_5$  to represent the value.

# IV. FIXED EQUIPMENT MAINTENANCE COSTS

#### A. Trunk Line Maintenance Costs

Trunk line maintenance costs include daily maintenance costs, overhaul and medium period repair costs, depreciation costs of track, roadbed, tunnel. The daily maintenance cost is  $a_1$  yuan/km, major and medium period repair cost is  $b_1$  yuan/km, the track depreciation rate is 2%, and the unit price of track is  $c_1$  yuan/km, so the cost of track is  $c_1 \times 2\%$  yuan/km.

The design life of tunnel is 100 years, the depreciation rate is 2%, and the unit price of tunnel is  $d_1$  yuan/km, so the depreciation cost is  $d_1 \times 2$  % yuan/km per year.

The earthwork volume of per kilometer of truck line is  $e_1 \text{ m}^3/\text{km}$ , and the unit price of earthwork is  $f_1 \text{ yuan/m}^3$ , the depreciation rate is 2%, so the calculated roadbed depreciation cost is  $e_1 \times f_1 \times 2$  % yuan/km.

The total cost of truck line is  $a_1+b_1+c_1\times 2 \ \%+d_1\times 2 \ \%+e_1\times f_1\times 2 \ \%$  yuan/km, and uses  $e_{zhe}$  to represent the value.

### B. Station Lines Maintenance Costs

The maintenance costs of station lines include daily maintenance costs, medium and overhaul maintenance costs.

Daily maintenance costs include arrival-departure lines, marshalling lines and other station lines costs, the three kinds costs have the proportion of 1:0.7:0.5. and the quantity account for 50 %,15 % and 35 % of the total number of the station lines, uses  $e_{d_{\lambda}} e_{bi_{\lambda}} e_{z}$  to represent the costs respectively.

The number of medium maintenance of station lines is half of the trunk lines, and uses  $e_{zx}$  to represent the value.

The unit cost of overhaul maintenance is  $a_2$  yuan/km, the depreciation rate is 3%, so the overhaul maintenance cost is  $a_2 \times 3$  % yuan/km per year, and uses  $e_{dx}$  to represent the value.

## C. Station Maintenance Costs

The station workers wages are  $a_3$  yuan/mon, and each station has  $b_3$  workers, so the station maintenance cost is  $a_3 \times b_3 \times 12$  yuan/a, uses  $e_c$  to represent the value.

D. Signal and Communication Equipments Maintenance Costs

The daily maintenance cost of Communication equipments and its circuit which including medium maintenance cost is  $a_4$  yuan/running kilometer, and overhaul cost of unit running kilometer is  $b_4$ , the overhaul period is 15 years, so the annual overhaul cost is  $b_4/15$  yuan/running kilometer, the total cost is  $a_4+b_4/15$  yuan/running kilometer.

The circuit of section track and automatic block signal daily maintenance cost is  $c_4$  yuan/running kilometer, the overhaul expense is  $d_4$  yuan/ running kilometer, so the annual cost is  $d_4/15$  yuan/running kilometer. The total cost is  $c_4 + d_4/15$  yuan/running kilometer.

Centralized control traffic signal daily maintenance cost is  $e_4$  yuan/ running kilometer, overhaul expense is  $f_4$  yuan/running kilometers, the annual overhaul expense is  $f_4/15$  yuan/ running kilometer, the total cost is  $e_4 + f_4/15$  yuan/ running kilometer

So the total maintenance cost of the station inner communication and signal equipments that is related to the amount of operation is  $a_4+b_4/15+c_4+d_4/15+e_4+f_4/15$  yuan/running kilometer, and uses  $e_x$  to represent it.

*E.* Electric Traction Substations and Catenaries Maintenance Costs

Electric traction substation maintenance cost is associated with the substation capacity and the group number, each substation daily maintenance cost is  $a_5$  yuan, each substation overhaul cost is  $b_5$  yuan on average, the overhaul period is 20 years, the annual overhaul expense is  $b_5/20$  yuan, so each electric traction substation maintenance cost is  $a_5 + b_5/20$  yuan.

Daily maintenance cost for catenaries or the third rail is  $c_5$  yuan/km, an overhaul expense is  $d_5$  yuan/km, an overhaul period is 15 years, so the annual overhaul expense is  $d_5/15$  yuan/km, the total cost of catenaries or the third rail maintenance cost is  $c_5 + d_5/15$  yuan/km per year, uses  $e_w$  to represent it.

# F. Other Fixed Equipments Maintenance Costs

N	Cost Quotas					
Name of Items	Life cycle cost /thousand yuan Life cycle/a		Annual cost /thousand yuan			
ventilation and air conditioning system	10 420.0	8	1 302.5			
escalators and elevators	7 900.0	10	790.0			
automatic fare collection	8 950.0	10	895.0			
fire alarm system	2 670.0	15	178.0			
equipment monitor	3 100.0	15	206.7			
communication	7 530.0	15	502.			
signal	11 740.0	15	782.7			
shielded gate	6 520.0	20	326.0			
car depot and parking space	32 100.0	18	1 733.3			

TABLE VI. OTHER FIXED EQUIPMENTS MAINTENANCE COSTS

# V. THE OPERATING EXPENDITURE COST METHOD OF URBAN RAIL TRANSIT

Urban rail transit operation costs mainly includes the operating costs which are related to the amount of running, uses  $E_x$  to represent the value, and the fixed equipments maintenance costs, uses  $E_g$  to represent the value, in additional, the other fixed equipments maintenance costs  $E_{qg}$ . the business expenses  $E_{yy}$ , the administrative expenses  $E_{gi}$ , the financial expenses  $E_{cw}$ , must be add up into the final operating costs E, namely,  $E=E_x+E_g+E_{qg}+E_{yy}+E_{gi}+E_{cw}$ .

A. The Operating Cost is Related to the Amount of Running

$$E_{y} = 365 N_{L} \left[ N \times (e_{1} + e_{5}) + A_{Q}e_{2} + A_{Z}(e_{3} + e_{4}) + (e_{6} + e_{7} + e_{8})\frac{T}{\beta_{L}} \right] (yuan/a).(7)$$

Where  $N_L$  denotes the running times of a subway vehicle in a day,  $e_1$  denotes a motor car maintenance cost is related to energy consumption,  $e_2$  denotes a motor car maintenance cost is related to the mechanical work of traction,  $e_3$ . denotes a motor car maintenance cost is related to the mechanical work of resistance,  $e_4$  denotes a trailer car maintenance cost is related to the mechanical work of resistance,  $e_5$  denotes the unit price of electric power,  $e_6$  denotes a motor car maintenance cost is related to time consumption,  $e_7$  denotes worker wages, e8 denotes a trailer car maintenance cost is related to time consumption,  $\beta_L$  denotes speed coefficient,  $N_{\gamma} A_{Q\gamma} A_{Z\gamma} T$ denotes the energy consumption of a cycle journey, the mechanical work of traction in the journey, the mechanical work of resistance in the journey and the running time of the journey respectively.

In additional, the operating cost is related to the amount of running includes the vehicle basic depreciation cost  $e_{cz}$  and other workers wages  $e_{cz}$ , so the total cost is related to the amount of running is  $E_x=E_y+e_{cz}+e_{cz}$ .

# B. The Fixed Equipments Maintenance Costs

$$E_{g} = \begin{bmatrix} L_{zhe} (e_{zhe} + e_{w}) + L_{x}e_{x} + N_{b}e_{b} + L_{d}e_{d} + \dots \\ \dots + L_{bi}e_{bi} + L_{z}e_{z} + L_{zx}(e_{zx} + e_{dx}) + N_{c}e_{c} \end{bmatrix}$$
(yuan/a).(8)

Where  $L_{zhe}$  denotes the length of track lines,  $L_x$  denotes the length of running kilometers,  $L_d$  denotes the length of arrival-departure lines,  $L_{bi}$  denotes the length of marshalling lines,  $L_z$  denotes the length of other station lines,  $e_{zhe}$  denotes the maintenance cost of truck lines,  $e_w$ denotes the maintenance cost of the catenaries or the third track,  $e_x$  denotes the maintenance cost of signal and communication equipments,  $e_b$  denotes the maintenance cost of electric traction substations,  $e_d$  denotes the maintenance cost of arrival-departure lines,  $e_{bi}$  denotes the maintenance cost of marshalling lines,  $e_z$  denotes the maintenance cost of other station lines,  $e_{zx}$  denotes the medium maintenance cost of station lines,  $e_{dx}$  denotes the overhaul maintenance cost of station lines,  $e_c$  denotes the upkeep cost of station,  $N_b$  denotes the number of electric traction substations,  $N_c$  denotes the number of stations.

#### VI. CALCULATION EXAMPLE

Shanghai rail transit line 1 is start from Xinzhuang station to the terminal station Fujin, this line by way of Baoshan, Zhabei, Jing'an, Huangpu, Xuhui and Minhang districts, the length is 36.89 kilometers, with 28 stations, two car depots, and a tunnel coverage from Caobao station to the Shanghai railway station, the dynamic drag ratio is 3:1, namely, six motor cars and two trailer cars, take type A vehicles in eight marshalling condition [9].

With the urban rail transit traction calculation software, the bi-directional operation energy consumption of eight marshalling subway train is calculated, and the result is 252.86 kW·h, the running time is 1.375 h, according to the formula[10], the traction work, is 183.172 5 kW·h, it is equal to 659.421 kN·km, and the resistance work is also 659.421 kN·km. Put the actual values into the formula (7), (8) get the follow calculation result.

When full loaded, the operating cost related to the amount of running is:

$$E_{y} = 365 N_{L} \left[ N \times (e_{1} + e_{5}) + A_{Q}e_{2} + A_{Z}(e_{3} + e_{4}) + (e_{6} + e_{7} + e_{8})\frac{T}{\beta_{L}} \right]$$
  
= 308,683,650 (yuan/a)

Because of the vehicle number of Shanghai rail transit line 1 is twenty, so the basic vehicle depreciation cost is  $500 \times 8 \times 20 = 80,000$  (thousand yuan/a), and worker wages are 2.25 million/a. So the total operating cost related to the amount of running is 390.93365 million/a.

The fixed equipments maintenance cost is:

$$E_{g} = \begin{bmatrix} L_{zhe}(e_{zhe} + e_{w}) + L_{x}e_{x} + N_{b}e_{b} + L_{d}e_{d} + \dots \\ \dots + L_{bl}e_{bl} + L_{z}e_{z} + L_{zx}(e_{zx} + e_{dx}) + N_{c}e_{c} \end{bmatrix}$$
  
= 140,095,400 (yuan/a)

-

Other fixed equipment depreciation cost is 6716.2 (thousand yuan/a).

Due to the business expenses, administrative expenses and financial expenses are dramatically change in actual condition[5], so the related reasonable data are required from 2002 to 2012 financial statement of the Shanghai Shentong Metro Co.,Ltd., get the average spending of the three expenses in decade, the average sum of the cost is 38,341,142.35 yuan/a.

So in eight marshalling condition, the total operating cost of Shanghai rail transit line 1 is:

*E*=390,933,650+140,095,400+6,716,200+38,341,142 =576,086,392 (yuan/a).

#### VII. CONCLUSION

In 2007~2009, huge captical had been put into purchase new cars because of the marshalling refrom of Shanghai rail transit line 1, in 2010, the World Expo had been held in Shanghai, the service expenses were huge, and in 2011, Shanghai Hongqiao Railway Station had been built, the passengers of line 1 had been shunted, so this line was not in normal operating condition until 2012, through the Shanghai Shentong metro co., Ltd. finanical statement in 2012, the operating cost is 570.95 million yuan, it is very close to the calculation result 576.086 million yuan, so it proves this new method is rational and accurate. The calucaltion of operating costs with this new method has a very practical value, such as making cost prediction at the beginning of construction to provide a reference for investment and lines design, providing the basis of government subsidies, and calculating the future operating costs to provide support for a better development of enterprises .

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