Route Planning's Impact Analysis on Energy Consumption and Emission of Bus in Beijing

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ABSTRACT: Bus is regarded as one of key patterns that can solve the problem of urban public transportation by various countries in the world, because it has advantages of higher passenger capacity and lower unit passenger capacity consumption. We proceed with impact of energy consumption emission on bus from the perspective of running speed, based on Beijing transportation, constructs calculation model for energy consumption emission of urban bus on the basis of SCF correcting algorithm, translates bus route planning and public transport priority scheme into route speed distribution, brings it into calculation, formulates development planning of energy conservation and emission reduction for urban passenger transportation and provides data basis for transportation management planning of transport enterprises.

KEYWORD: Bus; Energy consumption; Emissions; SCF correction factor

1 BACKGROUND

Urban public transport planning has an important influence on urban ecology. Undesirable urban traffic line has multiple influences on urban energy consumption and emission. From historical experience of Europe and other western countries, single volumes of electric buses are larger, and its transport efficiency is higher. Thus, compared with other means of transportation, it has huge advantages in energy consumption and emission of unit passenger capacity [1].

From the perspective of total energy consumption in Beijing road transportation industry, with the rapid development in the period of "the 11th Five-Year Plan" and 2011's economy, traffic total demand in whole society of Beijing presents rapid growth trend, while urban passenger transport energy consumption also increases correspondingly: standard coal increases from 2005's 1.1786 million tons to 2011's 1.545 million tons. The increase proportion is up to 31.09% [2]. Until the 2011, Bus act as the biggest occupation in urban public passenger transport energy consumption. Its total energy consumption is 665200 tons of coal, occupying 37.92%.

Carbon emission increases increases from 2005's 2.2973 million tons to 2011's 2.8194 million tons. The growth proportion is up to 22.73%. Buses act as the biggest occupation in urban public passenger transport energy consumption. The total carbon dioxide emission is up to 1.3495 million tons, occupying 47.86%.

Therefore, when urban passenger transportation management department formulates corresponding policy, it should deliberate control energy consumption and emission accessional range carefully, while considering how to satisfy increased passenger transport demand effectively.

2 RESEARCH THOUGHT

2.1 *Influences of Route Planning on Fuel Efficiency and Emission of Bus*

The operation route of Bus will distribute in urban rapid passage section and slow passage section in line with planning situation. When operating bus in daily life, fuel efficiency and emission factor is not constant. The one that has larger influence should belong to running speed of bus.

When buses run inslow passage section, buses actually stay in frequent starting and braking. In this working condition, fuel efficiency of buses is lower a lot than normal running condition. Its fuel consumption will increase in geometric multiples, and emission will increase with it.

2.2 *Quantitative Idea of Policy and Route Planning*

In order to ensure route entire speed, while promoting passenger capacity, when urban passenger

transportation management department plans route scheme of Bus, two categories usually include as follows:

- Rapid bus route;
- Main body of common bus route designs in urban rapid section;

The essence of the above two policy schemes is to improve the proportion of rapid passage section in daily lines in operation of Bus, for the sake of improving urban passenger traffic capacity.

3 RESEARCH METHOD AND ESSENTIAL DATA

3.1 Elaboration on Correctional Theoretical Method of Fuel Efficiency

We use the way of multiplication constant to correct fuel efficiency and emission of bus, and expresses influences of speed on fuel efficiency and emission in the function of speed, when Bus run in daily life. The function value serve as multiplication constant to multiply with fuel efficiency and emission coefficient of standard working condition, so as to reach the correction on fuel efficiency and emission factor [3]. Calculation method of SCF correction factor is derived by Dr. Song Guohua in Beijing Jiaotong University through FCD floating car experiment [4]. The usability and correctional precision of this correction factor are kept in tolerance interval. Meantime, matching data of its correction factor stem from actual transportation network of Beijing. This conforms to the requirement of this calculation.

SCF calculation formula of correction factor is as follow:

$$\eta = SCF(v) = \alpha \cdot v^{\beta} \tag{1}$$

In the formula, v is average speed of Bus in corresponding section. α and β serve as external model parameters, which are derived from FCD floating car data, as shown in Table1.

Table 1 Fuel Efficiency Emission Correction Factor Based on Speed

Objects	Correction factor on fast road	Correction factor on non-fast road
α	11.211	12.87
β	-0.694	-0.74

3.2 Vehicle Model Division on Urban Ground Public Transportation

With the overall consideration historical vehicle model structural data and future policy tendency of Beijing Bus, we will divide Bus involved in energy consumption and emission calculation model into 8 fuel types: diesel vehicle Bus, gasoline car Bus, LNG Bus, CNG Bus, diesel-electric hybrid car Bus, gasoline-electric hybrid car Bus, trolleybus buses and full electric vehicle buses.

3.3 Fuel Efficiency and Emission Parameters of Bus

3.3.1 Basic Fuel Efficiency of Bus

Generally speaking, standard fuel efficiency should regard the fuel efficiency under standard working condition of Bus as the criterion. This paper adopts 2010 statistical data of public transportation group as the standard fuel efficiency.

In order to be convenient for connecting with other energy models, the energy consumption calculation result of this model ultimately will be translated in standard coal.

3.3.2 Computing Method of Fuel Emission Coefficient:

In this computing method, it mainly considers three kinds of emissions: carbon dioxide, nitric oxide and PM2.5. When computing the model, discharge of three emissions can be obtained by using fuel consumption to multiply with emission factor of corresponding Bus.

3.4 Running Data of Bus

3.4.1 Disposal of Annual Average Range of Bus

Through traffic statistical materials, we can obtain annual average operation range of various Buses and disassemble these data.

Generally speaking, we regard main line section, accommodation road section and public transport priority section in bus routes as fast passage sections uniformly. Other sections are considered as non-fast passage sections. Daily operation routes of Bus usually include fast passage section and non-fast passage section [5]. We can use the following formula and gain the specific value.

$$\gamma_i = \frac{L_q}{L_i} \tag{2}$$

Here, L_i is corresponding fuel Bus. L_q is operation range of fast passage section.

3.4.2 Speed Calculation Method of Bus

Operation route of Bus on the proportion of different ranks has stronger relevancy with average speed and congestion degree of urban roads [6]. Congestion degree of urban roads and road average speed are calculated and obtain average running speed v_q of fast passage section and average running speed v_s of

non-fast passage section required by SCF comprehensive correction factor calculation method. By calculating 2010's average running speed, required v_s can be obtained. The data are shown as Table 2:

Table 2 Average Speed of Fast Road and Non-Fast Road of Beijing Bus in 2010

Speed type	Unit	Value
Fast road v_q	km/h	13.05
Non-fast road v_s	km/h	8.41

4 CALCULATION AND SCENE DESIGN

4.1 *The calculation formula for the total energy consumption of public electric vehicle is：*

$$\text{EN}=\sum_{i=1}^{8} N_i \cdot (EFI_i \cdot L_i \cdot \gamma \cdot \alpha_q \cdot v^{\beta_q} + EFI_i \cdot L_i \cdot \tag{3}$$
$$(1-\gamma) \cdot \alpha_s \cdot v^{\beta_s}) \cdot \rho_i \cdot \mu_i$$

In the formula, N_i is the data of possessing capacity for each type of vehicle model that burning fuel, and EFI_i is the combustion efficiency of each type.

The calculation formula of the total emission of public electric vehicle is as follow:

$$\text{EM}_{CO_2}=\sum_{i=1}^{8} N_i \cdot EMI_{CO_2 i} \cdot (EFI_i \cdot L_i \cdot \gamma \cdot \alpha_q \cdot v^{\beta_q}$$
$$+ EFI_i \cdot L_i \cdot (1-\gamma) \cdot \alpha_s \cdot v^{\beta_s}) \cdot \rho_i \tag{4}$$

$$\text{EM}_{NO}=\sum_{i=1}^{8} N_i \cdot EMI_{NO i} \cdot (EFI_i \cdot L_i \cdot \gamma \cdot \alpha_q \cdot v^{\beta_q}$$
$$+ EFI_i \cdot L_i \cdot (1-\gamma) \cdot \alpha_s \cdot v^{\beta_s}) \cdot \rho_i \tag{5}$$

$$\text{EM}_{PM2.5}=\sum_{i=1}^{8} N_i \cdot EMI_{PM2.5 i} \cdot (EFI_i \cdot L_i \cdot \gamma \cdot \alpha_q \cdot v^{\beta_q}$$
$$+ EFI_i \cdot L_i \cdot (1-\gamma) \cdot \alpha_s \cdot v^{\beta_s}) \cdot \rho_i \tag{6}$$

In the formulas, $EMI_{CO_2 i}, EMI_{NO i}, EMI_{PM2.5 i}$ are the emission factors for each type.

4.2 *Scene design and calculation results*

4.2.1 *The basic situation*

The basic situation is the scheme without any adjustment, which means it will be continually carried out according to the current route planning.
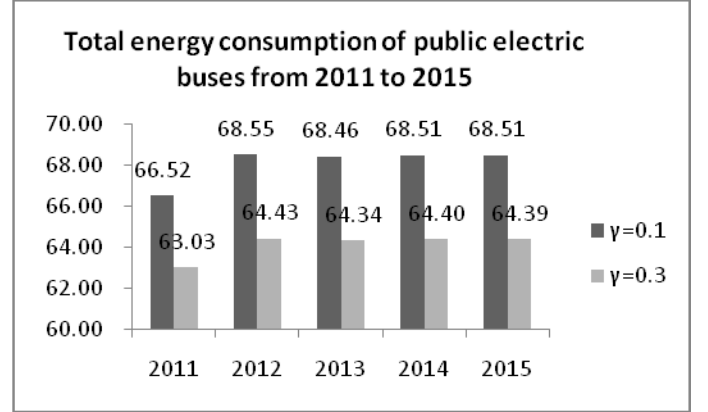
4.2.2 *Encouraging politic situation*

Encouraging policy situation means that the passenger management department will give priority to the consideration of the distribution of routes and the effect to the energy consumption and emission of t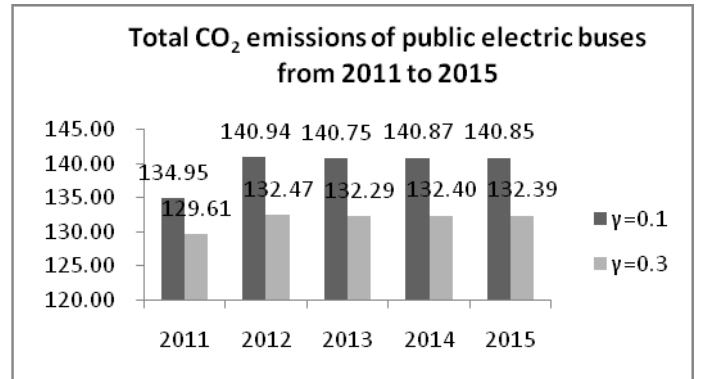he whole transportation. In the routes of the city's public transportation, there will be priority to the planning of the Bus Rapid Transit and the high-speed road of the regular bus lines.

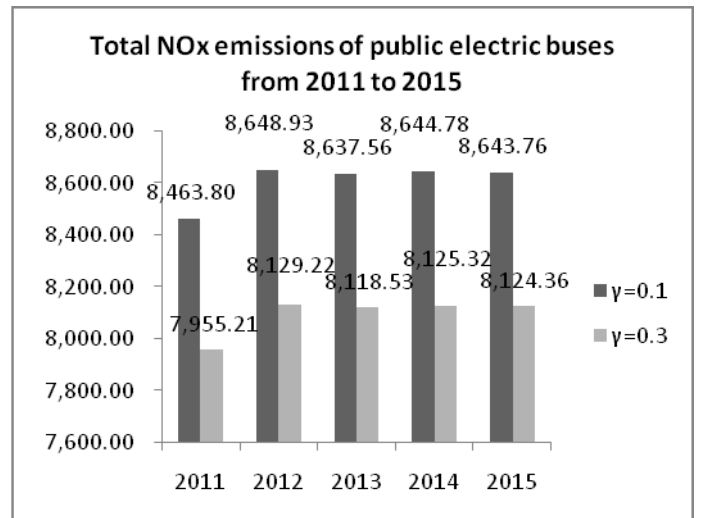#### 4.2.3 *Calculation of the consumption and emission*

According to the checking of the existing lines of the bus service, we can get the $\gamma_i = 0.1$ under the basic situation nowadays. Under the encouraging politic situation, we assume that $\gamma_i = 0.3$, and then we can get the data by calculation and the following graph:
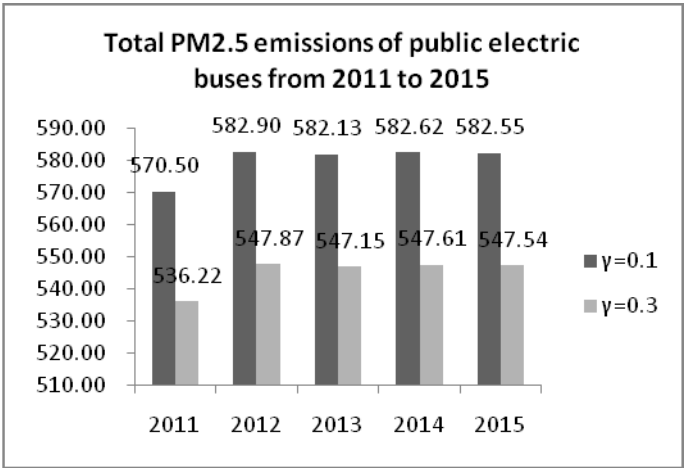

Graph 1.The comparison of the total energy consumption of public electric buses from 2011 to 2015 (ten thousand ton)

Graph 2 .The comparisons of the total CO_2 emissions of public electric buses from 2011 to 2015(ton)

Graph 3 The comparison of the total NOx emissions of public electric buses from 2011 to 2015(ton)

Graph 4 The comparison of the total $PM_{2.5}$ emissions of public electric buses from 2011 to 2015

From the graphs above, we can simulate the encouraging policy situation when $\gamma_i =$ according to the historical data from 2011 to 2014, finding that there was a drop for the total energy consumption and the total quantity of the three emissions compared with the historical baseline data. In the meantime, to be more instructive, we added the data of 2015. Assuming the new policy planning has been accomplished in 2014, the added data is the natural growth of the number of buses in 2015 and other invariants. At this time, we can get the total energy consumption under the basic situation is 685.1 thousand tons of coal, and consumption under the encouraging politic situation is 633.9 thousand tons of coal, with a decline of 41.2 thousand tons of coal, which means the energy saving is remarkable; In addition, the total CO_2 emission in 2015 under the basic situation is 1408.5 thousand tons, and the emission under the encouraging politic situation is 1323.9 thousand tons, with a decline of 84.6 thousand tons; the total NO_x emission in 2015 under the basic situation is 8643.76 tons, and the emission under the encouraging politic situation is 8124.36 tons, with a decline of 519.4 tons; the total $PM_{2.5}$ emission in 2015 under the basic situation is 582.55tons, and the emission under the encouraging politic situation is 547.54 tons, with a decline of 35 tons, leading to a remarkable reduction of emissions

5 DISCUSSION AND ADVICE

Then, we can get the following conclusions by comparison between the basic situation and the encouraging politic situation:

(1) As the increase of the need or public transportation along with the gradual growth of per capita GDP in Beijing, there will be a slight increase in the energy consumption under the same planning. Since the public transportation devices cannot adjust downwards, the simulating calculation in the planning stage is the key of energy saving and emission reduction.

(2) From the simuluating resultsthere is a remarkable emission reduction under the politic situation. In the simulating situation, the proportion of public electric buses is only increased to 0.3, leading to an evident reduction. Take the whole future planning of public transportation into consideration, this simulating result is rather conservative, which can increase further, leading to a huge extent of reduction in the energy consumption and emission.

Based on the conclusions above, we can give the following suggestions:

(1) Additional bus priority routes and rapid bus service frequency

(2) Accelerating the replacement of the traditional fuel-burning buses

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