Evaluating Environmental Impacts of Major Road Network Improvement in Beijing Based on a Combined Traffic Demand and Vehicle Emission Model

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Abstract

Vehicle emission forecast method is developed in this paper. Firstly, it generalizes achievements in traffic planning and methods for vehicle exhaust emission forecast in this field. Secondly, the relationship between the vehicle average speed and its exhaust emissions is established based on the present methods. Finally, data collected from the urban expressway and the arterials in the road network of Beijing is used to calculate the emission factors and to prove the feasibility of this method. So, environmental impacts of major road network in Beijing can be evaluated. it can be shown that using the method combined traffic demand and vehicle emission model to estimate emission factors, the average emission level of three main emissions at some major traffic corridors can be calculated, and this result can be used as a very important factor to evaluate traffic planning project.

Key Words: emission factors, traffic planning, vehicle emission

1. Introduction

According to the statistics about the pollution in big cities of China, more than 70% CO, 40% NOx and 80% HC come from vehicle emission. Vehicle emission has become one of main factors that do harm to the life of residents. Urban environment is much worsened by the exhaust of CO, NOx, HC and particulate substance. These pollutants do much harm to the health. Environment problem will become an important and decisive problem in proceeding of developing economy and improving living standard

in China. Therefore, in order to improve the air condition and the living standard, to insure the sustainable development of country's economy of China and to carry out the society, which has a high level life, the vehicle emission level must be controlled and reduced efficiently.

Control strategy of the air quantity must be established at accurate forecast about the vehicle emission level. At present, study on the vehicle emission forecast is still at the stage of beginning in China. And there is no method that based on traffic planning that is ideal enough to be widely used. Many researches are based on the consideration of individual vehicle conditions. These methods always regard an urban or a certain district as a unit and the average level of the vehicle emission in the study; district is calculated by the analysis of some charts. However, these methods only considered the average vehicle emission level in wide district. But emission level of some certain road or link can't be calculated accurately. Therefore, in the proceeding of improving urban environment, it is difficult to ascertain which road or link is badly polluted than other. Therefore, a set of accurate and perfect vehicle emission forecast system must be established.

2. A Combined Traffic Demand and Vehicle Emission Model

There are two important parameters, distribution parameters of vehicle group and vehicle driving parameters, are used to incorporate traffic planning model and vehicle emission model. Vehicle group can be a certain vehicle, and also can be a combination of some different vehicle types. To classify vehicle types proper can make traffic planning model and vehicle emission forecast model incorporated efficiently. For the microcosmic vehicle emission model, main parameters about vehicle driving is speed, acceleration, position, and secondly is the parameters such as the air-conditioner and gap of the distance between reader vehicle and following vehicle.

By the incorporation of the output and input, a uniform standard between traffic planning model and vehicle emission model can be established (Figure 1). In this way, two models can be appraised each

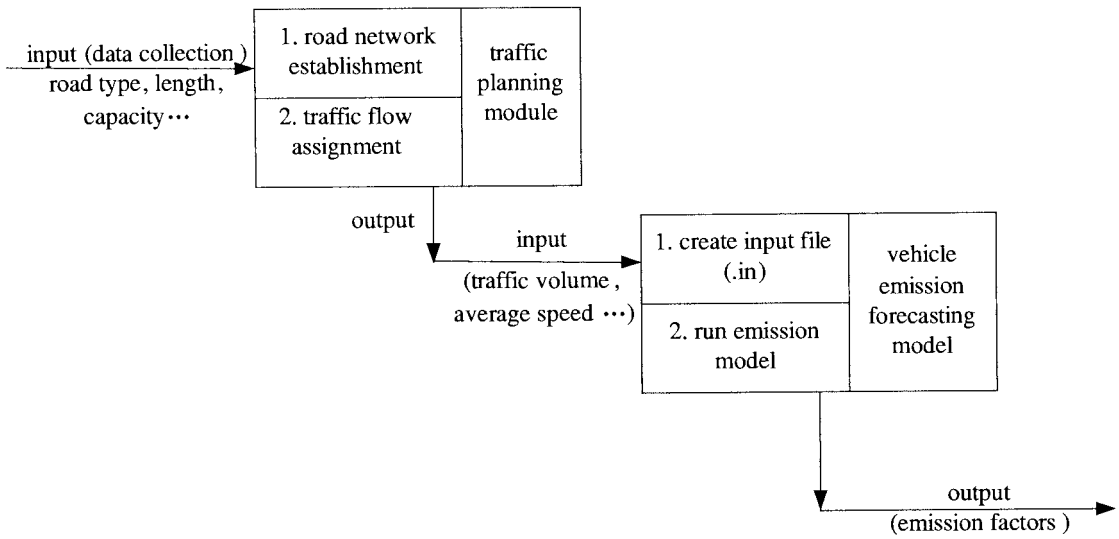

Figure 1. Theory of vehicle emission forecast method based on traffic planning.

other. For example, vehicle emission model can be used to appraise the validity of certain measures which were used in traffic management and control, and traffic planning model is also can be used to analyze vehicle emission level (Mensink et al., 2001).

2.1. Sub-model of traffic demand

2.1.1. Data collection

For a certain road link in urban road network, forecast for vehicle emission level must be established at accurate traffic flow. Therefore, data collection determines the veracity and the effect of forecast.

Based on a latest standard of vehicle type classification, which is made by The Ministry of Public Security of P.R. China, vehicle types are classified as follows:

a. Large bus, middle bus, small car and micro car.
b. Heavy truck, middle truck, light truck and micro-truck.
c. Heavy semi-trailer, middle semi-trailer and light semi-trailer.
d. Large special vehicle, middle special vehicle, small special vehicle, micro special vehicle, heavy special vehicle.
e. Tree wheel motorbike, motorbike and scooter.
f. Trolley bus with rail and trolleybus.
g. Heavy trailer, middle trailer and light trailer.

Because vehicle type is an important factor that influences vehicle emission level, in the data collection process, trips data must be collected in accordance with the classification of vehicle types.

2.1.2. Establishment of road network

In this paper, expressways and arterial roads in a road network are taken into account.

2.1.3. Distribution of traffic flow and traffic planning module

Making use of the distribution model to assign traffic flow which is made by traffic demand, traffic volumes are assigned on each road in the network and the average speed can be calculated, and the result is classified by vehicle types.

2.2. Sub-model of vehicle emission

2.2.1. Choice of vehicle emission model

Emission evaluation models can be classified into macroscopic model, middle scale model and microcosmic model. Macroscopic model is used to evaluate the emission level in wide area, for example the emission level in whole country area, province area or a certain urban area. Middle scale model is used to evaluate emission level in narrow field area, and it lays emphasis in evaluation to the condition of traffic improvement. Though this kind of analysis is also included in microcosmic analysis, middle scale relation and analysis are also established in evaluating the effect of traffic planning and relevant budget analysis. Microcosmic model is used to evaluate emission level in a certain road or an intersection. For the aim of this research, the middle scale emission evaluation model is adopted to evaluate vehicle emission level.

2.2.2. Input and output of vehicle emission model

Conditions must be satisfied by a selected vehicle emission model are as follows:

The input data that shows traffic service level in certain roads or links should be calculated by the proceeding of traffic planning, and the vehicle emission factors should be calculated by using vehicle emission model to analysis the input data. Emission model selected in the paper needs an input file to run and calculate the emission factors, and there is an important parameter and vehicle speed in the input file. Average speed of traffic flow also exists in the output of traffic demand model.

2.3. Calculation of vehicle emission level incorporating the influence of average speed

Traffic volume is distributed in each link using traffic planning module. It is classified by vehicle type and the vehicle average speed (km/h) in each link can also be calculated. The average speed can be used as an input parameter that is used in the vehicle emission estimate module, and by using proper emission model, emission factors (EF, g/km) of three main pollutants for each vehicle type in every link are calculated (Fu, et al., 1997). For example, in the MOBILE6.0, the average speed is an input parameter, which is written in the input file. And after running the MOBILE6.0 using the input file, the output file is created by the program with emission factors (EF, g/mile). Then, the average emission level (E) of each link can be calculated by using the formula as follows:

$$E_a^k = E_{a,i}^k (i = AB) + E_{a,i}^k (i = BA) \qquad (1)$$

$$E_{a,i}^k = \sum_{m=1}^{n} N_{a,i}^m \bullet EF_{a,i}^{m,k} \bullet L_{a,i} \qquad (2)$$

where,

E_a^k : Denotes the average emission level of pollutant *k* in link *a* in unit time, and *k* denotes HC, CO or NOx.

$E_{a,i}^k$: Denotes the average emission level of pollutant k in direction i of link a in unit time.

$N_{a,i}^m$: Denotes the traffic volume of the vehicle type *m* in direction *i* of link *a*.

$EF_{a,i}^{m,k}$: Denotes the emission factor of pollutant *k* for the vehicle type *m* in direction *i* of link *a*.

$L_{a,i}$: Denotes the length of link *a* in direction *i*.

i : Denotes the directions ‘AB’or ‘BA’.

3. Calibrations, Validation and Evaluation of the Combined Model

In this paper, urban expressway and arterial road in the Third Ring Road of Beijing are used for this study, and the feasibility of the forecast method for vehicle emission is also carried out and validated. TransCAD4.5 (Caliper Corporation 2003) and MOBILE6.0 model that is issued by USEPA (2002) are used in the process of carrying out the forecast method.

3.1. Carrying out a traffic planning module

3.1.1. Establishment of the road network

A road network is established in the TransCAD4.5 environment (Caliper Corporation). The district in the Third Ring Road of Beijing area is considered, including urban expressway and arterial road. It is

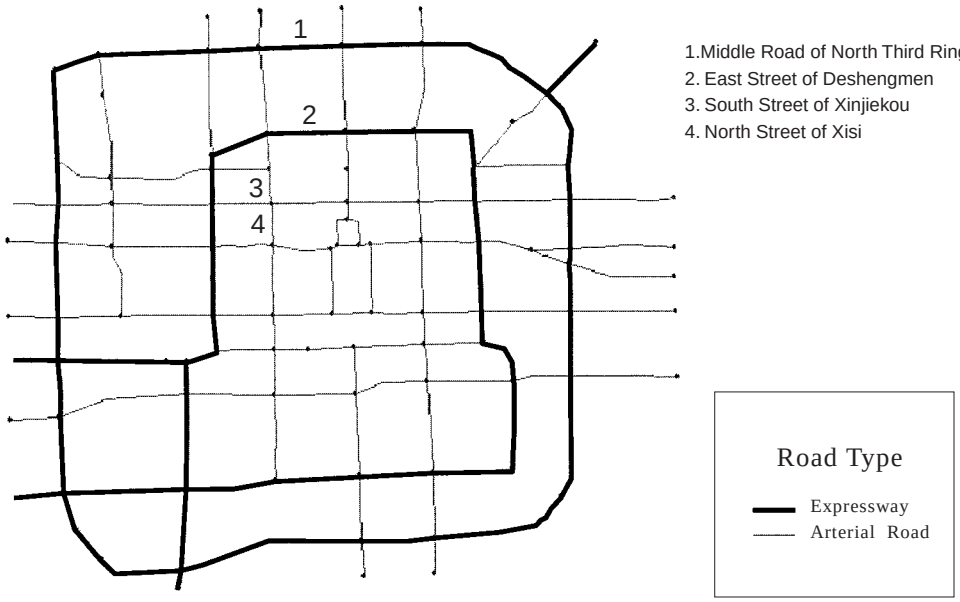

Figure 2. Road network.

shown as Figure 2.

The road network includes 99 nodes and 147 links. The establishment of the trip generation and attraction zones is based on vehicle OD traffic volume investigation which data is collected by vehicle types. The OD matrix is daily OD matrix. The data of Beijing Person-Trip Survey in 2000 is adopted as traffic volume.

3.1.2. Classification of vehicle types

Vehicle of different types is different at weight, engine type, cleansing technology of exhaust and so on. Therefore, different pollutant is exhausted by vary vehicle. In order to calculate the gross pollutant of different vehicle type accurately, emission factors of every vehicle type must be measured according to the different exhaust characteristics.

According to the new classification standard is issued by The Ministry of Public Security of China, vehicles in the Third Ring Road of Beijing area can be classified as follows:

a. Large bus, middle bus, small car and micro car.
b. Heavy Truck, middle truck, light truck and micro truck.
c. In consideration of the development of vehicle emission model, the classification method for the vehicle types above is improved again as Table 1.

Table 1. Vehicle type classification.

Vehicle types	Large bus	Small car	Large truck	Middle truck	Bus	Taxi	Motorbike
VS vehicle type in MOBILE	HDGV	LDGV	HDDV	LDDT	HDGV	LDGV	MC

According to the MOBILE classification standard, the medium-sized passenger car is accounted into the HDGV (namely large bus), and the medium-sized truck is accounted into the HDDV (namely large truck).

3.1.3. Assignment of traffic flow

As the statement above, the data of Beijing urban traffic synthesizes investigation in 2000 is used in this study. The OD traffic volume data is the result of passenger car traffic volume plus truck OD traffic volume, namely the data is the relevant traffic volume of each vehicle type.

The results of traffic volume assignment mainly include road capacity, traffic volume in direction of AB and BA, traffic time and the average speed in direction of AB and BA.

3.2. Calculation of vehicle emission factors

Proper vehicle emission model must be used in the calculation of vehicle emission factors. In this study, MOBILE6.0 model issued by USEPA is used (USEPA, 2002).

The result of traffic assignment with TransCAD4.5 is used as the parameters to calculate the emission factors (other parameters are adopted from the default of MOBILE6.0). Sequentially, emission factors in each link by classification of vehicle types can be calculated.

Table 2 and Table 3 denote traffic volume and vehicle emission factors in Middle Road of North Third Ring, East Street of Deshengmen (urban expressway), South Street of Xinjiekou and North Street of Xisi (arterial road) respectively. The emission level in other corridors can be calculated in the same way.

MOBILE6.0 model issued by USEPA is used in this study, and vehicle emission factors are shown in the output file. The result is showed as Table 3.

Traffic with different directions is considered in this paper. Because in each corridor, the daily traffic volume is different in different directions. And different traffic volume may lead different emission volume.

Table 2. Length of each road and traffic volume.

Road No. in Figure 2	Road name	Road length (km)	Traffic volume in the direction of AB	Traffic volume in the direction of BA	Average speed in the direction of AB	Average speed in the direction of BA
1	Middle Road of North Third Ring	4.26	7565	7886	52.3	51.2
2	East Street of Deshengmen	4.10	2299	2758	59.9	59.8
3	South Street of Xinjiekou	1.76	1936	2615	56.1	48.6
4	North Street of Xisi	2.05	4238	4264	36.1	35.9

Table 3. Emission factors (g/km) in each link classified by vehicle types.

Road name	Direction	Pollution category	LDGV	HDGV	HDDV	LDDT	MC
Middle Road of North Third Ring	AB	VOC	1.365	2.121	0.589	0.973	2.390
	AB	CO	13.240	16.520	2.822	1.579	13.720
	AB	NOx	1.010	4.414	12.325	1.369	1.080
	BA	VOC	1.375	2.149	0.599	0.983	13.970
	BA	CO	13.210	16.820	2.877	1.593	13.970
	BA	NOx	1.012	4.389	12.338	1.370	1.080
East Street of Deshengmen	AB	VOC	1.308	1.966	0.527	0.917	2.280
	AB	CO	13.480	14.830	2.506	1.497	12.270
	AB	NOx	1.001	4.562	12.275	1.362	1.120
	BA	VOC	1.309	1.968	0.529	0.918	2.280
	BA	CO	13.470	14.860	2.511	1.498	12.290
	BA	NOx	1.001	4.558	12.270	1.361	1.120
South Street of Xinjiekou	AB	VOC	1.301	1.981	0.534	0.922	2.290
	AB	CO	12.730	14.980	2.535	1.505	12.420
	AB	NOx	0.985	4.545	10.493	1.360	1.110
	BA	VOC	1.368	2.157	0.602	0.986	2.410
	BA	CO	12.510	16.920	2.894	1.597	14.05
	BA	NOx	1.014	4.382	10.575	1.371	1.080
North Street of Xisi	AB	VOC	1.529	2.637	0.770	1.140	2.680
	AB	CO	12.860	23.140	3.955	1.871	18.09
	AB	NOx	1.107	4.115	11.416	1.483	0.990
	BA	VOC	1.535	2.654	0.775	1.145	2.690
	BA	CO	12.880	23.360	3.992	1.881	18.220
	BA	NOx	1.110	4.108	11.450	1.487	0.990

3.3. The average emission level

Based on the traffic volume of each vehicle type in each link of Beijing in peak hour, the data is got from Beijing urban traffic investigation in 2000, and the traffic volume in each concerned link can be calculated by classification of vehicle types. By using formula (1), average emission level (kg/day) of the three kinds of main pollutants in the four links in 24 hours can be calculated by gathering relevant data. The result is shown in Table 4.

A methodology to evaluate the environment impacts with vehicle emissions is shown in this paper, and it is attempted to combine a travel demand model and a vehicle emission model to get the emission level of each corridor in the road network. Accordingly, there are more problems should be solved in the future research, such as vehicle type re-classification, and data accuracy etc.

Table 4. Average emission level (kg/day) of three main pollutants in a day.

Pollution / Category Road name	VOC (HC)	CO	NOx
Middle Road of North Third Ring	64.92	546.57	68.86
East Street of Deshengmen	17.66	172.28	21.00
South Street of Xinjiekou	6.87	63.30	6.14
North Street of Xisi	17.64	148.14	15.69

4. Discussion

Methods for traffic planning and vehicle emission forecast are summarized in this paper, and an emission model is established to show the relationship between average speed and vehicle emission level. Two software, TransCAD4.5 and MOBILE6.0 issued by USEPA are used to calculate the vehicle emission factors (HC, CO and NOx) in certain links in this study, and then the average emission level (kg/day) of the three kinds of main pollutants in the four concerned links in 24 hours can be calculated.

The main research of this study is the integration of the two modules, traffic planning module and vehicle emission forecast module. Now integrating traffic planning model with vehicle emission model is still an important question, which needs to be further discussed (Wang et al., 2002). A new way to evaluate traffic measurement effectively is achieved, and a new method to forecast vehicle emission level is provided (Wang and Ding, 2002).

Vehicle emission factors is not only determined by vehicle types and its average speed but also determined by other vehicle parameters and environment parameters. For example, firebox size of engine, vehicle carrying capacity and self weight, outside temperature, humidity and air pressure; maintenance planning, frequency of vehicle use, running cycle of vehicle, condition of road, fuel quality and so on (Fu et al., 1997). Therefore, further study is still needed on integrating traffic planning module with vehicle emission forecast module. Moreover, the default data offered by USEPA is used to run the MOBILE model except average speed calculated from the proceeding of traffic planning. And this data is difficult to be applicable to the Chinese circumstance. Therefore, according to Chinese actual circumstance, vehicle emission forecast model needs to be established and it will be used in the proceeding of making decisions to improve the traffic circumstance. And it will also provide reasonable basis to establish control strategies for urban vehicle pollution.

It should be developed for future studied, such as re-classifying the vehicle types in Chinese cities, finding the relationship between urban traffic planning and vehicle emission level based on real time speed, finding a way for traffic assignment and the result of the traffic volume assigned in each corridors are classified by vehicle types. So that the vehicle emission level in each corridors can be calculated accurately.

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