Study on the Appropriate Level of Motor Vehicles in Shenyang

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Abstract. Based on the urban box theory model, a maximum limit model for vehicle exhaust emissions was established to determine the maximum limit of NOX emissions in Shenyang. Based on the model for calculating the appropriate level of vehicle ownership in Shenyang City, the vehicle ownership was calculated under different standards, promoting the grey prediction of motor vehicle ownership in Shenyang city. Studying the appropriate level of motor vehicle ownership in Shenyang city can help reduce urban traffic pollution to a greater extent and ensure people's happy life.

1. Introduction
With the continuous development of urban economy, the process of urbanization is accelerating. The development of economy and urbanization has improved people's standard of living to a certain extent, but brought about the consequent situation of increasing traffic pressure and deteriorating traffic environment. The previous pollutants in the city were mainly soot, but now motor vehicle exhaust pollution has accounted for a growing proportion. Motor vehicle exhaust emissions mainly include carbon monoxide (CO), nitrogen hydride (NOx), as well as inhalable particulate matter (PM2.5, PM10) and other harmful substances. In recent years, the number of motor vehicles in Shenyang city has shown a trend of continuous and rapid growth, leading to more serious traffic air pollution, urban traffic congestion and other problems. If these problems cannot be better solved, the normal life of urban residents will be affected to a large extent.

2. Measurement of atmospheric environment capacity in Shenyang city

2.1. The commonly calculating methods of atmospheric environmental capacity
Atmospheric environmental capacity refers to the maximum amount of pollutant discharge that the environmental unit can withstand under the premise that human health in the environmental unit is not harmed and the natural ecological environment is not damaged.

Box model is the most widely used at present in atmospheric environmental capacity measurement. "City box" model is based on the box model, whose basic assumption is that when the concentration of pollutants in the atmospheric environment is simulated, the entire study city or study area is regarded as a box, and the box size is fixed. The height of the box itself is the height of the mixed layer in the model, in which the concentration of pollutants is equal at each place. [2]
The calculation formula of this model can be expressed as:

\[ C = \frac{\bar{u}C_0 + \Delta X\bar{u}}{u + (V_d + V_w + H/T)\Delta X/ H} \]

The formula (1)

In the formula:

- \( C \) — Target concentrations of air pollutants, the unit is mg/m³
- \( C_0 \) — Background concentration of atmospheric pollutants in the wind direction boundary airflow flowing into the box, the unit is mg/m³
- \( \bar{u} \) — The average wind speed inside the box, the unit is m/s
- \( X \) — Length of downwind direction in the box, the unit is m
- \( H \) — The height of the box, the unit is m
- \( V_d, V_w \) — Respectively represent the dry deposition velocity and the wet deposition velocity of air pollutants, the unit is m/s
- \( T \) — Half-life of air pollutants

In practical application, the chemical conversion rate \( K_c \) is used to replace the \( T \) term in formula 1. The chemical conversion rate of pollutants can be measured by experiments. Compared with the half-life of pollutants, the process is easier to obtain and the results are more accurate. The calculation formula of the improved atmospheric environmental capacity model can be expressed as:

\[ Q(T) = q \cdot S \cdot t = \left[ C(V_d + V_w + K_c) + \bar{u}(C - C_0)H/\Delta X \right]S \cdot t \]

The formula (2)

In the formula:

- \( S \) — Study area of built-up area, the unit is km²
- \( t \) — Study time
- \( K_c \) — Chemical conversion of air pollutants, the unit is S⁻¹
- \( C \) — Target concentration of air pollutants, the unit is mg/m³

The remaining parameters are the same as those in formula (1).

In the actual calculation, the research time is generally set as one year, that is, \( t=1 \), then formula (2) can be expressed as:

\[ Q = \left[ 3.1536 \times 10^4 CS(V_d + V_w + K_c) \right] + 27.948\bar{u}H\sqrt{S(C-C_0)} \]

The formula (3)

There are generally two types of air pollutants. One is the gaseous pollutant, such as carbon dioxide and carbon monoxide, and the other is the solid pollutant, such as inhalable particles. [3] When calculating the capacity of gaseous pollutants, the influence of secondary dust should also be considered. Therefore, concentration should be taken into account in both urban greening and bare ground dust raising. At this time, the calculation model formula of solid atmospheric environmental pollutants can be expressed as:

\[ Q = \left[ 3.1536 \times 10^4 CS \left( 1 - \beta + \alpha\beta \right) \right] + 27.948\bar{u}H\sqrt{S \left[ C \left( 1 - \beta + \alpha\beta \right) - C_0 \right]} \]

The formula (4)

In the formula:
$\alpha$—Urban greening rate  
$\beta$—bare ground dust raising rate  
Other parameters are the same as those in formula (2).

2.2. Vehicle exhaust emission maximum value calculation model

The atmospheric environmental capacity of motor vehicles is the maximum limit of motor vehicle exhaust emissions, and the decisive factor for the limit is the motor vehicle exhaust emission sharing rate $\lambda$. The larger the $\lambda$ value is, it indicates, the more serious the vehicle exhaust emission is to the air environment. [4] According to China's environmental air quality evaluation report, the largest contribution rate of motor vehicle pollutants is nitrogen hydride. Therefore, when calculating the maximum vehicle exhaust emission, we can take the nitrogen hydride as the pollutant to calculate the maximum limit value, and the calculation model formula can be expressed as:

$$Q = \lambda Q = \lambda \left[3.2 \times 10^3 \times CS(V_d + V_w + K_c) + 27.948 \mu H \sqrt{S(C - C_0)} \right]$$

The formula (5)

2.3. Model basic parameter Settings

2.3.1. Dry settlement velocity $V_d$ and wet settlement velocity $V_w$

The dry deposition rate of nitrogen hydride can be obtained by adding the sum of the dry deposition rate of nitrogen hydride and carbon dioxide, obtaining the dry deposition rate of nitrogen hydride $V_d$ as $7.01 \times 10^{-4}$ m/s. The wet deposition rate of nitrogen oxides can be obtained according to relevant literature. The wet deposition rate $V_w$ is $10^{-4}$ m/s.

2.3.2. Chemical conversion rate $K_c$

The chemical conversion rate of nitrogen oxides can be obtained according to relevant literature. The chemical conversion rate of nitrogen oxides $K_c$ is $10^{-8}$ s $^{-1}$.

2.3.3. Environment background value $C$

The background value of carbon monoxide and nitrogen oxides in the atmospheric environment is very low, almost close to 0. Therefore, in the calculation, we set the background value of the atmospheric environment of nitrogen oxides at 0 ug/m3.

2.3.4. Urban greening rate and dust raising rate of bare land

In the statistical yearbook of Chinese cities, the average annual growth rate of urban greening coverage rate of Shenyang city can be calculated. We assume that the growth rate will remain unchanged from 2017 to 2022, and calculate the urban greening rate of Shenyang city from 2017 to 2022. The results are shown in table 1.

| Year | Urban greening rate (%) |
|------|-------------------------|
| 2017 | 43.1                    |
| 2018 | 43.28                   |
| 2019 | 43.47                   |
| 2020 | 43.65                   |
| 2021 | 43.84                   |
| 2022 | 44.03                   |

The dust raising rate of bare land is affected by the increasing number of motor vehicles. In northern China, the dust raising rate of bare land is 20-30 in summer and 40-50 in winter. When calculating, the average value is 40 and it is assumed that the dust raising rate of bare land will not change from 2017 to 2022.
2.3.5. Average wind speed and mixing layer height
According to relevant literature, the height of the atmospheric environment mixing layer in Shenyang city is selected as 800m. Wind speed is one of the important conditions that can affect the diffusion of pollutants in the atmospheric environment. According to the relevant literature of Shenyang meteorological bureau over the years, the average wind speed of Shenyang city is 2.28m/s.

2.3.6. Vehicle emission sharing rate λ
According to the environmental statistics of Shenyang city, the sharing rate of nitrogen oxides in industrial pollution sources, domestic pollution sources and motor vehicle pollution sources can be obtained, among which the sharing rate of nitrogen oxides in motor vehicle pollution sources is 35.42%.

2.4. Measurement of Shenyang’s atmospheric environment capacity
Setting the basic parameters of the model in 1.3: dry settlement velocity Vd and wet settlement velocity Vw, chemical conversion rate Kc, environmental background value C0, study area of urban built-up area S, average wind speed V and mixed layer height H, motor vehicle exhaust emission pollutant sharing ratio λ, which is substituted into equation (5) in turn. The maximum limit value of nox emission in the vehicle exhaust emissions that can be accommodated in the atmospheric environment of Shenyang city is obtained through calculation under certain environmental limitation value. Specific results are shown in table 2.

Table 2: The maximum limit of nox emission from vehicle exhaust in Shenyang

| year | Maximum nox value (t) |
|------|----------------------|
| 2017 | 22094.67             |
| 2018 | 22657.49             |
| 2019 | 23234.82             |
| 2020 | 23826.93             |
| 2021 | 24419.04             |
| 2022 | 25011.15             |

3. Estimation of the optimal level of vehicle ownership in Shenyang

3.1. Calculation model
The moderate level of Shenyang motor vehicles can be obtained according to the maximum limit value of exhaust pollutants of Shenyang motor vehicles. Factors affecting the appropriate level of motor vehicle ownership include not only atmospheric environmental capacity and pollutant emission factors, but also urban traffic planning and motor vehicle driving mileage. Taking all factors affecting vehicle ownership into consideration, the model for calculating the appropriate level of vehicle ownership is as follows.

\[
EC = \frac{Q_i}{\sum_{j=1}^{e_j} \epsilon_j \epsilon_i}
\]

The formula (6)

In the formula:
- EC—Appropriate level of motor vehicle ownership
- Q_i—Maximum limit of vehicle exhaust emission
- \(\epsilon_i\)—The proportion of type I models
- j_i—Annual average form mileage of type I vehicle
- \(\epsilon_i\)—Average emission factor of type I vehicle
3.2. Model parameter setting

3.2.1. Proportion of different models
The motor vehicles involved in this paper include five categories of gasoline bus, diesel bus, gasoline truck, diesel train and motorcycle. It is assumed that the motor vehicle ownership and proportion of each model will not change during the period of 2017-2022, as shown in table 3.

Table 3: The ownership and proportion of various types of motor vehicles

| Motor vehicle type          | Possession (vehicle) | Proportion (%) |
|-----------------------------|----------------------|----------------|
| Gasoline passenger car minibus | 55120                | 2.26           |
| Small gasoline passenger car | 1520040              | 71.7           |
| Diesel buses                |                      |                |
| Medium-duty diesel bus      | 53212                | 2.51           |
| Large diesel bus            | 27348                | 1.29           |
| Gasoline truck              |                      |                |
| Micro gasoline van          | 424                  | 0.02           |
| Diesel truck                |                      |                |
| Light diesel truck          | 223236               | 10.53          |
| Medium diesel truck         | 21200                | 1              |
| Heavy diesel truck          | 61480                | 2.9            |
| The motorcycle              |                      |                |
| Ordinary motorcycle         | 163240               | 7.7            |
| mopeds                      | 1908                 | 0.09           |

3.2.2. Different emission standards and emission factors of different pollutants
The emission factor of motor vehicle pollutants is the total amount of pollutants discharged by each motor vehicle within the driving unit mileage, which reflects the emission level of motor vehicle pollutants and is the specific basis for the formulation of motor vehicle exhaust control measures. Standards for the discharge of different types of pollutants are prescribed by the state explicit and mandatory provisions on the concentration or specific quantity of man-made environmental pollutants discharged into the environment, the main purpose of which is to control the emission of pollutants from the source and promote the environmental quality to meet the standards. In this paper, emission factors of different types of motor vehicles in euro III, euro IV and euro V pollutant emission standards are adopted to calculate the emission factors of different pollutants under different emission standards in Shenyang, which is shown in table 4.

Table 4: NOx emission factors of different types of motor vehicles under different emission standards

| standard classification | Mini bus | Small gasoline passenger car | Medium-duty diesel bus | Large diesel bus | Micro gasoline van | Light diesel truck | Medium diesel truck | Heavy diesel truck | Ordinary motorcycle | mopeds |
|-------------------------|----------|------------------------------|------------------------|------------------|-------------------|-------------------|--------------------|-------------------|---------------------|--------|
| Euro III                | 0.2      | 0.2                          | 5.7                    | 11.2             | 0.2               | 1.4               | 8.4                | 14.3              | 0.1                 | 0.2    |
| Euro IV                 | 0.1      | 0.1                          | 3.3                    | 6.4              | 0.1               | 1.1               | 4.9                | 8.6               | 0.1                 | 0.2    |
| Euro V                  | 0.1      | 0.1                          | 1.9                    | 3.6              | 0.1               | 0.8               | 2.8                | 4.9               | 0.1                 | 0.2    |

3.3. To estimate the appropriate level of vehicle ownership in Shenyang
Assuming that the vehicle exhaust emission standard of Shenyang is implemented in accordance with euro III, euro IV and euro V standards, the values of different parameters in 2.2 are put into formula (6) to calculate the appropriate level of vehicle ownership in Shenyang. The specific results are shown in table 5.

Table 5: Appropriate level of vehicle ownership in Shenyang under different emission standards (Ten thousand vehicles)

| year | Euro III | Euro IV | Euro V |
|------|----------|---------|--------|
| 2017 | 68       | 112     | 177    |
According to the chart above, the appropriate level of vehicle ownership varies under different emission standards. For example, if the vehicle ownership in Shenyang had met the requirements of euro III standard in 2017, the moderate level of motor vehicle ownership would have been 680,000. However, according to the statistical data in the above content, it can be concluded that the motor vehicle ownership in Shenyang in 2017 was 2.12 million, which is far beyond the moderate level. Under euro IV standard, the vehicle ownership should be 1.12 million in Shenyang in 2017, which is far lower than the actual vehicle ownership. If the appropriate level of motor vehicle ownership in Shenyang meets the requirements of the European V standard, the motor vehicle ownership should be 1.77 million, and the actual motor vehicle ownership is far beyond the appropriate level.

4. Prediction of future vehicle ownership in Shenyang

4.1. Model for predicting future vehicle ownership in Shenyang

The grey system analysis was first proposed in 1982 by Deng Julong, a professor in the department of control science and engineering of Huazhong university of science and technology. It is a mathematical method used to solve a system with incomplete information. Grey system analysis is made to study many grey problems existing in the real world. In this paper, GM (1,1) model is established based on the historical data of motor vehicle ownership in Shenyang to make a gray prediction of future motor vehicle ownership in Shenyang.

Assuming that the sequence X (0) formed by the original time data has n observed values, the sequence can be expressed as: $X^{(0)} = \{X^{(0)}(1), X^{(0)}(2), ..., X^{(0)}(n)\}$.

The GM (1,1) model can be established by summing the above sequence once, and the first-order differential equation of the model can be expressed as: $\frac{dX^{(1)}}{dt} + aX^{(1)} = u$  

The formula (7)

In the formula:

A is Development of grey number
U is Endogenous control of ash number

Formula (7) is solved, and the prediction model of the original sequence is expressed as: $X^{(1)}(t + 1) = \left[ x^{(0)}(1) - \frac{u}{a} \right] e^{-at} + \frac{u}{a}$

The formula (8)

$X(0)(t) = X(1)(t) - X(1)(t - 1); t = 1, 2, ..., n$

The formula (9)

The result of X (t) (k) can be calculated through formula (8), and then it can be reduced according to formula (9). The predicted value of vehicle ownership in Shenyang can be further calculated through reduction and reduction.

4.2. The calculation results of future vehicle ownership in Shenyang

Through the calculation of formula (8) and formula (9), the predicted results of vehicle ownership in Shenyang from 2017 to 2022 can be obtained, as shown in table 6.

Table 6: Predicted results of motor vehicle ownership in Shenyang from 2017 to 2022

| year | Vehicle ownership (Ten thousand vehicles) |
|------|------------------------------------------|
| 2017 | 1961423                                  |
| 2018 | 2129112                                  |
| 2019 | 2311892                                  |

| year | 2018 | 70  | 115 | 182 |
|------|------|-----|-----|-----|
| 2019 | 72   | 118 | 186 |
| 2020 | 73   | 121 | 191 |
| 2021 | 75   | 124 | 195 |
| 2022 | 76   | 127 | 200 |
As can be seen from the chart above, the predicted results of future motor vehicle ownership in Shenyang during 2017-2022 do not meet the requirements of euro III, euro IV and euro V standards. If Shenyang does not take measures to control the growth of the number of motor vehicles in the next few years, it will also lead to more serious problems such as traffic congestion, environmental pollution, cause further atmospheric pollution, and affect the health of urban environmental construction and urban life.

5. Conclusion and countermeasures
Based on the "city box" model, the maximum limit value model of vehicle exhaust emissions in Shenyang has been built. Through the model’s calculation, it is concluded that the maximum limit value of vehicle exhaust emissions of motor vehicles in Shenyang will remain between 22,000 tons and 25,000 tons in six years after 2017. Then an appropriate level measurement model of vehicle ownership in Shenyang has been further built. The appropriate level of vehicle ownership is calculated under different standards. In 2017, the appropriate level of vehicle ownership in Shenyang should be 680,000, 1.12 million and 1.77 million. However, in 2017, the actual number of motor vehicles in Shenyang reached 2.12 million, far exceeding the appropriate level. Finally, the grey prediction method is adopted to predict the motor vehicle ownership in Shenyang from 2017 to 2022. GM (1,1) model is established to calculate the predicted results. Through comparison, it is not difficult to find that the predicted results of future motor vehicle ownership have far exceeded the appropriate level.

Based on the above calculation results and the specific situation of Shenyang, starting with the control of motor vehicle ownership and emission of motor vehicle pollutants, Shenyang should focus on optimizing the urban traffic development planning, accelerating the establishment of intelligent and efficient urban traffic management system, and constantly strengthening the supervision of environmental protection of motor vehicles.

5.1. Optimizing urban transportation development planning
Shenyang Municipal Government should give full play to its macro-control function, properly raise the price of motor vehicles, and reduce the purchase number of motor vehicles to a certain extent. In addition, automobile manufacturers should be encouraged to change production and the number of motor vehicles should be kept within a moderate level as far as possible. Urban public transport should be vigorously developed. The difficulty of motor vehicle driving license examination and test items should be increased and the number of issuance should be controlled.

The optimization of urban traffic development planning needs to adjust the number of different types of motor vehicles in the city to achieve the goal of reducing traffic air pollution. In view of the current traffic situation in Shenyang, firstly, the number of diesel trucks and buses should be greatly reduced; secondly, the number of private cars should be appropriately reduced; finally, the urban public transportation should be fully developed. First, the market access standards and emission standards for diesel vehicles should be improved. Sales of diesel buses and trucks that do not meet emission standards are prohibited. Second, trading standards for used cars should be strictly controlled, and diesel vehicles with high consumption, emission and pollution should be strictly controlled for trading in the market. Thirdly, learning from other cities for automobile photo auction, pollutant emission standards should be formulated according to Shenyang's atmospheric environmental capacity. According to the actual situation at present, the target of reduction should be calculated and determined, and economic means should be employed to control the increase of private cars within a moderate range.

5.2. Establish an intelligent and efficient urban traffic management system
First of all, intelligent traffic lights should be built as soon as possible. Intelligent traffic management on the road section prone to congestion can improve the vehicle traffic volume per unit time, which can
not only reduce the congestion, but also reduce the fuel consumption of vehicles, and ultimately reduce the emission of pollutants from vehicles. Secondly, it is necessary to speed up the improvement of supervision methods. Traffic management departments should make full use of advanced technology to sort out and analyse the number of new cars and obsolete cars, vehicle testing, and automobile exhaust emission qualification status in Shenyang every day so as to formulate feasible control measures according to the analysis results.

5.3. Increase environmental protection supervision of motor vehicles

First of all, it is necessary to carry out long-term and effective supervision and management of the motor vehicle environmental protection inspection institutions, which can promote the motor vehicle exhaust emission to meet the standards. Secondly, the number of environmentally friendly green label road should be increased and green label road construction projects should be implemented in Shenyang city, the number of label changing vehicles and old motor vehicles prohibited driving range should be increased, and the road electronic monitoring facilities should be improved. Finally, the establishment of inspection and maintenance system should be accelerated. It is suggested that the performance of motor vehicles should be checked regularly to keep the emission of pollutants within an appropriate level. With Shenyang's transportation department as the main body and the environmental protection department as the coordination, enterprises with motor vehicle maintenance qualifications in the city are inspected and assessed, and qualified enterprises are identified for publicity, so as to achieve regular inspections.

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