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SYSTEM COMPONENTS AND OPERATION OF THE BEIJING URBAN TRANSPORTATION SYSTEM

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ABSTRACT

An urban transportation system is a complex subsystem of an urban system, forming the arteries and link for all facets of life in a modern city. It has become increasingly important to plan and manage an urban transportation system scientifically and rationally. This is not only influenced by the structure of a city, the level of economic development, the population distribution, and the industrial distribution, but is also influenced by other subsystems of the city. Understanding the components and operation of the Beijing Urban Transportation System provides a theoretical basis for managers in the process of policy-making. Therefore, based on previous research, this paper first presents an analysis of the internal and external subsystems of urban transportation systems in general, and then builds a model of an urban transportation system in the form of a system dynamics model. The resulting system used data from Beijing to simulate the Beijing Urban Transportation System. Finally, based on the analysis of the development of the Beijing Urban Transportation System, the study explored the system components and operation of the system and presents proposals that offer a theoretical basis for the integrated development of Beijing's urban transportation requirements.

Keywords: Urban transportation system; Component Mechanism; System Dynamics; Transport system simulation

1. INTRODUCTION

The problems of urban transportation in China are different from those in developed countries, because in China the development of motorized transport really only started after World War II. During the last six decades, infrastructure construction in China has evolved smoothly. In particular, rapid urbanization in China means that there will be as many as 600 million people living in cities by the end of 2030(Task Force on Sustainable Transportation Development in China, Sustainable Urban Transportation, 2006). At the same time economic growth accompanied by this rapid urbanization results in more families with the ability to afford private cars. More comprehensive transport services will be needed to meet the growing transport demand. However, urban transportation causes a negative impact on the ecological environment, social development and demand for energy, which must be taken into account. Indulging in the development of mobility, but lacking the necessary traffic education and environmental considerations, not only leads to a decrease in the efficiency of urban transportation because of congestion, but also causes an irreparable negative impact on society as a whole.

By the end of 2009, the operation mileage of the Beijing metro reached 228 km, which is double the 114 km in 2004, while the carrying capacity of public transport also increased significantly (Wang, 2006). According to the plan of the Beijing Municipal Development and Reform Commission, in 2010, Line 7 and Line 14 will be opened, and the operating mileage of the metro will surpass 300 km. By 2015, the total operating mileage will reach 561 km, which is 2.5 times the present level. These additions to public transport will greatly enhance Beijing's economic development. Furthermore, with Beijing's urbanization, population growth and the accelerating need for mobility, the increasing demand for urban transportation becomes obvious. Currently the congestion in Beijing is the principal problem that urgently needs to be solved. Therefore, finding the crux of the Beijing urban transportation system is worthy of study. However, an urban transportation system is not only a complex and dynamic system in itself, but is also affected by the external environment. That is, the normal linear mathematical model cannot fully explain the complex relationships in the system.

In this paper, through extensive analysis of the literature and related research, the Beijing urban transportation system is broken down into reasonably identifiable parts, and, using a system dynamics model, it is simulated. This provides a more scientific and rational approach to the integrated development of the Beijing Urban Transportation System. It is organized in this paper as follows. Section 2 provides the literature review and Section 3 presents the outline of a system dynamics (SD) model. Section 4 describes the SD model and its amendment. The running results and model validation are also provided in this section. Finally in Section 5, the rationality of the model is tested to improve the scientific basis for this paper and to provide some policy guidance for the development of transportation in Beijing according to the conclusions of the SD model.

2. LITERATURE REVIEW

With the continuous development of Beijing's urbanization and motorization, traffic jams have become a common problem in cities. At the same time, the private ownership of cars has increased rapidly, and the pressure on urban transportation has further increased making traffic jams more serious, which has led to congestion, decrease in vehicle speed, environmental pollution and a series of severe traffic problems. To tackle these problems managers and scholars have done a great deal of work, such as employing a policy of public transport priority, building sustainable transportation systems and green transportation systems (Xi, 2008; Lu, 2009 and Tian, 2006). These measures have solved some urban transportation problems, but not all of them. A comprehensive understanding of the Beijing urban transportation system is a necessary prerequisite to better supervise and improve the system to make it serve the community better.

Many scholars have proposed to evaluate the urban transport system, and its corresponding evaluation system, using methods such as data envelopment and set pair analysis to research it scientifically and rationally(Wang and Qiu,2006; Yan et al, 2009) . However, simple evaluation still cannot find the crux of the system, because, as a subsystem of the city's larger system, the city traffic system is not only influenced by the interaction between the various subsystems within the city, but is also affected by various factors in the external environment that play an important role in the development of the city. Therefore, some scholars are using the idea of a system to analyze and research the urban transport system. They divide the factors that affect urban transport systems into internal and external factors.

For internal factors, the study is focused on the coordination of public and private transport. The gradual comprehensive application of the “transit first (transport priority)” policy, appears to have improved traffic congestion, but has not yet met the expectations of management and traffic users. For the transport system itself, some scholars have proposed an increase in the technology content of the traffic system to create an "intelligent transportation system"(Zhu, 2005). Meyer (1997) proposed that the urban transportation should carry out Traffic Demand Management (TDM), by influencing residents’ modes of travel and changing the demand for different modes of transportation to reduce traffic congestion. Zeng (2009) considered that people, vehicles, and transport facilities are the basic elements of an urban transportation system and are independent and mutually influenced. The "people" in transport systems, can be divided into transport users and traffic managers. Traffic managers better serve the community and transport users through the management of the urban transport system; and transport users impact on traffic demand by independently selecting their mode of travel.

In the larger systems of an entire city, there are many external factors affecting urban transport systems. The research in this field is at a very early stage. In the location theory of the classical economics school, the relationship between transportation system and land utilization is comprehensively covered by the Region Spatial Structure Theory of the Chicago School transport system (Mao and Yan, 2004). They all point out that the relationship between urban transportation systems and land utilization is an important area of study (Mao and Yan, 2004). Later, Chinese scholars also carried out research on transportation systems and land utilization (Liu and Juan, 2007; Guo and Jia, 2004). Zhang (2005) noted that in studying the development of urban transport systems, city size is an important factor. Zeng (2009) also noted that the city's traffic is not an isolated system, but has constraint relationships with various external environmental factors such as policy, social economic development level, city size and morphology, land utilization and layout, as well as an integrated level of management.

With regard to system dynamics, the study of a system’s dynamic complexity was established by Professor Jay W. Forrester of The Massachusetts Institute of Technology (MIT) in the second half of the 20th century. This approach combines the traditional science of feedback, in which all system dynamics models are related to the three variables of stock, rate and auxiliary and to the two streams of physical material and information. These two streams cause the interaction between the variables. Sterman (2000) summarized the research process of system dynamics with the following steps: Posing the question →Dynamic hypothesis→ Simulation → Test → Policy formulation, and then returning to the original problem; the model forms a feedback loop through a finite number of iterations.

As for research status, system dynamics has begun to be applied in different fields, such as research on global environmental sustainability, regional sustainable development (Meadows et al., 1992), environmental management (Mashayekhi, 1990), water resources program (Ford, 1996), and ecological models (Wu et al, 1993), agricultural sustainable development (Saysel, Barlas, & Yenigun, 2002), as well as transport and land utilization (Heimgartner, 2001). The first of these to use system dynamics theory in the transport sector was Professor Forrester's paper, Urban Dynamics, which considered traffic system as a subsystem of a large social system, set up casual cycle relationships between the factors of the systems, and simulated them with data and software (Forrester, 1969).
In summary, in this paper the subsystem function of the transport manager is called the "traffic organization subsystem" while the function of the transport user is called the "transport mode choice sub-system". Both of the subsystems affect transport systems by choosing or managing transport facilities, so the "transport facilities subsystem" is the basis of the entire transport system. The external factors that affect urban transport systems are divided into five areas: economic development, technical level, policy, natural and ecology. From the research viewpoint, the initial analysis is made systematically and specifically through the literature and practical investigation on the urban transportation system in Beijing. After the dynamic assumptions of the model are presented, for the purpose of the study the feedback structure is analyzed and a variety of variables are defined for the simulation, testing and adjustment of the model. Finally, proposals for transport policy in Beijing are made on the basis of the simulation results.

3. SYSTEM DYNAMICS MODEL OF URBAN TRANSPORTATION SYSTEM

Based on the analyses of previous literature, the causal and feedback relationships of an urban transportation system will be explored using the system dynamics model.

3.1 Cause loop diagram

The urban transportation system studied in this paper is a complex, large system which is influenced by economic development, society, ecological environment, natural resources and transport investment.
Figure1 shows the cause and effect relationships between transport facilities, transport organizations, level of technology, economics, population, as well as ecological environment and transport operation. The cause and effect relationship between two variables is shown by the arrows. The '+' and '-'signs represent the direction of causality. The '+'sign indicates that the variable has a positive effect on the result While the '-'sign indicates that the variable has a negative effect on the result. For example, the increase in population can increase the birth rate, while the increase in the death rate can cause a decrease in population.

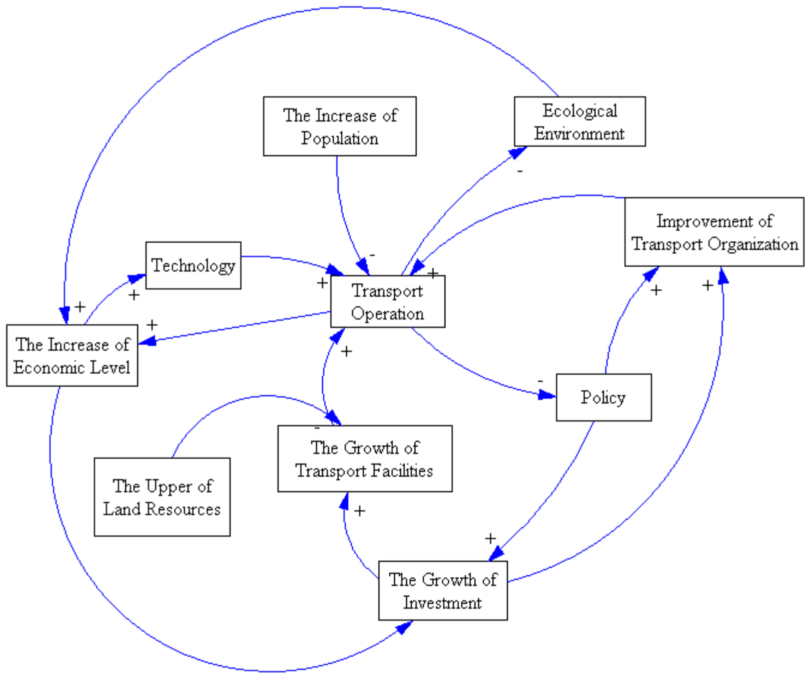

Fig.1 Cause-and-Effect Diagram for a Transportation System in terms of External Systems

The main causal loops in this model are depicted below:

① Transport operation $\xrightarrow{+}$ the increase of economic level $\xrightarrow{+}$ the growth of investment $\xrightarrow{+}$ the growth of transport facilities $\xrightarrow{+}$ transport operation, which is a reinforcing feedback loop.

The development of technology can overcome the limitations of traditional resources, and promote effective coordination of transport modes. For example, implementing the metro overcomes many of the limitations of road-based public transport, and makes full use of underground space. New fuel can replace conventional oil resources. Thus, technology has a positive influence on transport operation. Effective transport operation also promotes the development of social economy, and raises the level of the economic infrastructure. This in turn creates more funds to invest in new transport technology.

Effective transport operation will promote the growth of economic development. The transport facility is an important investment commitment. If the level of the social economy rises, investment will obviously increase in the transport field, which will increase the allocation to transport equipment and further promote the development of transport operation.

②Transport operation $\xrightarrow{-}$ Ecological Environment $\xrightarrow{+}$ An increase in the level of the economy $\xrightarrow{+}$ Technology $\xrightarrow{+}$ Transport operation, which balances the feedback loop.

In reality, an increasingly intensive transport infrastructure is not conducive to the local ecological environment, and the causal relationship is negative. However, the ecological environment is conducive to an increase in the level of the economy, and the development of the economy will bring more investment to transport technology.

③ Transport operation $\xrightarrow{-}$ Policy $\xrightarrow{+}$ Improvement of Transport Organization $\xrightarrow{+}$ Transport operation, which balances the feedback loop.

Transport operation is closely related to national policies. If there are major problems in transportation, national policies will be applied to meet the population's travel demands. Thus, transport operation has a negative impact on transport policy. Policy is often realized by the transport organization, so transport policy has a positive impact on the transport organization. Meanwhile, transport policy will be reflected by growth in investment, and will positively impact on the development of transport operation.

3.2 Feedback Structure of the system and the definition of the sub-models

The model in this paper for estimating urban transport demand regards the relationship between motor vehicles, environment, and resources as a critical factor, because there are no sound transportation systems in most cities in China. We note that the metro is not only a mass transit system, but it does not occupy land resources and creates little pollution, which will play a decisive role in future urban transport. Consequently, the metro is incorporated in the model. The flow graph is shown in Fig.2.

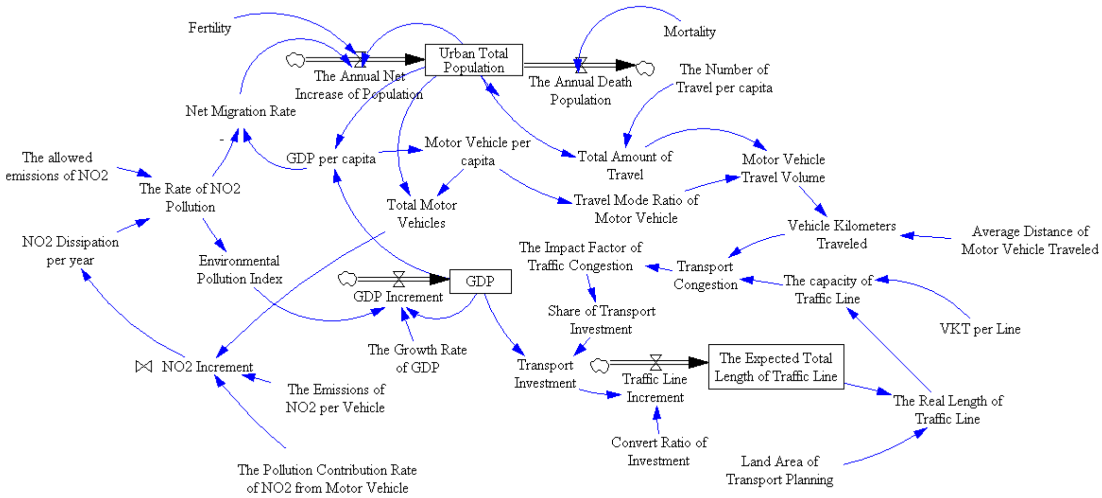

Fig.2 Flow Graph of an Urban Transportation System

(1) Population sub-model

Total urban population is an important factor in traffic demand, especially in Beijing and Shanghai. The rapid increase in migration population results in the pressure of congestion, and, while it has a close correlation with the level of economic development, it is also influenced by the city's environment. The total urban population is a status variable of the sub-model. The annual net increase in population and the annual death rate are regarded as rate variables. Fertility, mortality and migration rates are auxiliary variables, for which, the net migration rate is influenced by the GDP per capita and the air environment. In particular, urban population depends on fertility and mortality. The main equations follow:

$$\text{Urban total population} = \text{Initialvalue} + (\text{Annual net increase of population} - \text{Annual death Rates}) \tag{1}$$

$$\text{The annual net increase of population} = \text{Urban total population} \times (\text{Fertility} + \text{Net migration rate}) \tag{2}$$

$$\text{The annual death rate=Urban total population} \times \text{Mortality} \tag{3}$$

$$\text{Net migration rate} = f\left(\text{GDP, NO}_2\text{ pollution ratio}\right) \tag{4}$$

The relationship between the net migration rate, GDP and the rate of NO2 pollution was obtained through simulation and comparison with Beijing's data, while other data can be obtained from statistical yearbooks[1].

(2) Economic development sub-model

The level of economic development is a key element of a city's competitiveness, which directly affects the population immigration and emigration and is the main driver of urban agglomeration effects. Meanwhile, economic development will promote and increase the level of motor vehicle ownership. On the other hand, economic development is related to transport investment. To maintain good traffic conditions, government should allocate a certain percentage of funds annually for the construction and improvement of the transportation infrastructure. In the sub-model, the aggregate GDP is regarded as the level variable, and the GDP increase as the rate variable, while the increased rate of GDP, transport investment, and environmental factors are auxiliary variables for which, the environmental factor reflects the impact of the quality of the environment on GDP. The main equations follow:

$$\text{GDP} = \text{InitialValue} + \text{GDP increment} \tag{5}$$

$$\text{GDP increment=GDP} \times \text{The rate of GDP growth} \times (1 - \text{Environment factor} \times 0.02) \tag{6}$$

$$\text{Transport investment} = \text{GDP} \times \text{The rate of transport investment} \tag{7}$$

Since the difference between green GDP and real GDP is 0.02, the function of the GDP increase can be determined.

(3) The number of motor vehicles sub-model

The system for the number of motor vehicles is a core subsystem of urban transport, which has feedback relationships with other subsystems. The growth in the number of motor vehicles results from economic development and the growth of travel demand. The rapid increase in motor vehicles results in traffic congestion and exhaust emissions which affects economic development and the environment system. The auxiliary variables in the sub-model include the total number of motor vehicles, motor vehicles per capita and policy intervention. The main equations follow:

$$\text{Total motor vehicles} = \text{Urban population} \times \text{Motor vehicles per capita} \tag{8}$$

$$\text{GDP per capita} = \text{GDP/urban population} \tag{9}$$

$$\text{Motor vehicles per capita} = \gamma \times EXP(\beta \times EXP(\partial \times \text{GDP per capita})) \tag{10}$$

The sub-model refers to the model of *Income's effect on car and vehicle ownership, worldwide: 1960 – 2015*, in which parameters γ , β , ∂ can be obtained by regression from Beijing's data.

(4) Air environment sub-model

The air environment system is an important subsystem of urban transport and influences the city population and economic development. The exhaust emissions of the motor vehicle mainly include NO2, CO, CH and particulates. From previous research, more than half of the nitrogen oxides come from motor vehicle fuel in the large cities of China. Taking the availability of data into account, the level of NO2 in the atmosphere is regarded as a level variable, while NO2 increase and dissipation are regarded as rate variables. In addition, the

[1] *Beijing Statistical Yearbook* from 2003 to 2008

rate of NO2 dissipation, the capacity of NO2, the rate of NO2 pollution, the emissions of NO2 per vehicle per year, the pollution contribution rate of NO2 from motor vehicle and environment factors are regarded as auxiliary variables. The main equations follow:

$$\text{The stock of } NO_2 = \text{InitialValue} + NO_2 \text{ increment - Dissipation per year} \quad (11)$$

$$NO_2 \text{ increment} = \text{The emissions of } NO_2 \text{ per vehicle each year} \times \text{The total motor vehicle/Pollution contribution rate of } NO_2 \text{from motor vehicle} \quad (12)$$

$$\text{Dissipation per year} = \text{the stock of } NO_2 \times \text{the rate of } NO_2\text{dissipation} \quad (13)$$

$$\text{The rate of } NO_2 \text{ pollution} = \text{The stock of } NO_2 / \text{The capacity of } NO_2 \quad (14)$$

(5) Transport demand sub-model

Transport demand is a type of derived demand, related to the city population and the level of economic development. There are some secondary variables in this sub-model including the total amount of travel, the number of travel trips per capita, the ratio of motor vehicle travel to total travel, motor vehicle travel volume, average distance of motor vehicle travel and kilometers vehicles traveled. Nowadays, the total amount of travel, the number of travel trips per capita, and the ratio of motor vehicle travel to total travel can be obtained by investigation, and reflect the trend in transport total demand, while other data can be obtained from statistical yearbooks. The main equations follow:

$$\text{Total amount of travel trips} = \text{City population} \times \text{The number of travel per capita} \quad (15)$$

$$\text{Motor vehicle travel volume} = \text{Total amount of travel trips} \times \text{The ratio of motor vehicle travel to total travel} \quad (16)$$

$$\text{Total length of vehicle travel} = \text{Motor vehicle travel volume} \times \text{Average distance of motor vehicle traveled} \quad (17)$$

According to the survey of Beijing public transportation in 2003, the number of travel trips per capita is 2.64, which is close to the result of the laboratory investigation in February of 2010[2].

(6) Transport Supply Sub-Model

Transport supply reflects the level of urban road facilities, which when compared with transport demand signifies the level of transport congestion. If demand and supply are in a state of dynamic balance, urban transport retains balance. Overall, transport supply depends on the limits of the urban road transport infrastructure and the investment of the city's economy in road construction and improvement. The main equations follow:

$$\text{Transport Investment} = \text{GDP} \times \text{Share of Transport Investment} \quad (18)$$

$$\text{The total length of traffic line} = \text{Original value} + \text{Traffic line increment} \quad (19)$$

$$\text{Traffic line increment} = \text{Transport investment/Convert ratio of investment} \quad (20)$$

$$\text{The capacity of traffic line} = \text{The stock of traffic line} \times \text{The capacity of each line} \quad (21)$$

(7) Congestion sub-model

The congestion subsystem belongs to a bound subsystem, which reflects the conflict between transportation supply and demand. In addition, the impact factor of traffic

[2] From *The Third Comprehensive Survey of the City Traffic of Beijing*

congestion is an index that reflects the impact of transport investment on transport congestion. For example, if transport investment is increased by local government, serious congestion in the short term will be resolved.

4. THE SIMULATION OF BEIJING URBAN TRANSPORTATION SYSTEM

4.1 Model Assumptions

Assumptions are as follows:
(1) When estimating the changes in the motor vehicles number in the future, no account is taken of the effect that subways, bicycles and other means of transport make on the number of private cars.
(2) No account is taken of technical progress on the improvement in the utility of vehicles. At present, nearly 50 % of NO2 emissions come from vehicles. If new cars are designed or new fuels are found, the amount of NO2 emissions may be quickly reduced. At present, petrol and diesel are assumed to be the main fuels consumed for the next 30 years.

4.2 Model Modification

In Beijing, with the rapid construction of subways in recent years, the commitment rate to public transportation has increased correspondingly. In the system dynamics model, the role that public transportation has played in Beijing must be considered. Meanwhile, the share ratio for the different travel modes is essential information in the development of transportation. Based on the content above, the modified model is presented in Figure 3.

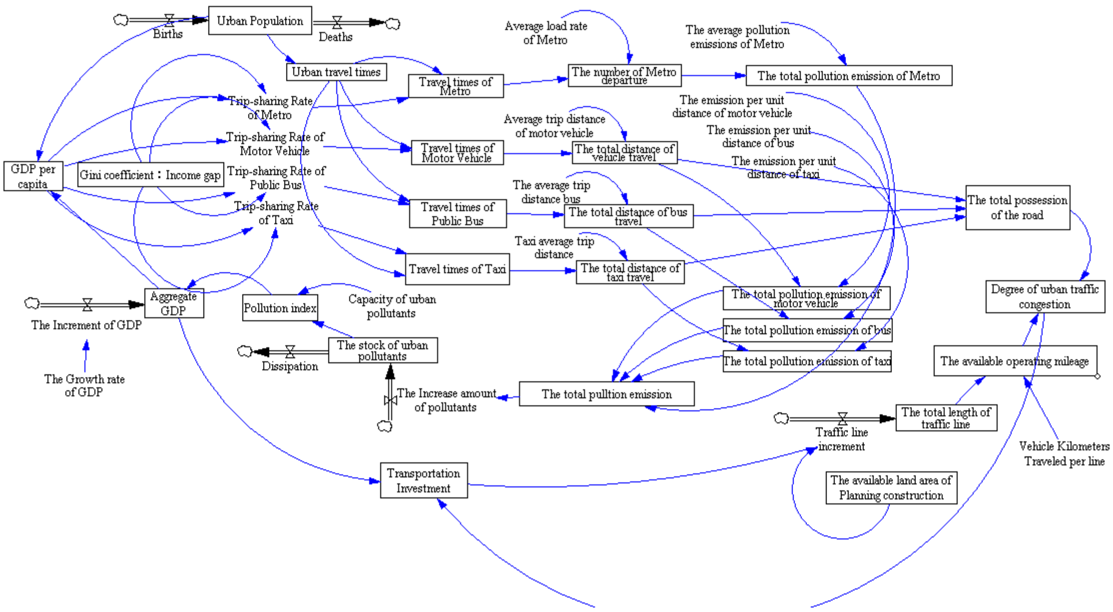

Fig.3 Modified flow chart of transportation system

One difficulty in this study is the share ratio of the different travel modes, which depends on the preferences in travel mode choice. This choice is affected by many factors at once. So the obvious functional relationship is not easy to determine and will be the subject of future work.

4.3 The Result of Model Simulation

The data and equations were incorporated into the model, using the software Vensim, and the time interval was set. The trend of variables in the model could be established for the subsequent intervals of time. In this study, we analyzed the development of these variables including the number of motor vehicles, the total population, GDP and environmental factors, to explore the internal causes and interactions of the trends.

4.3.1 The increase in the Number of Motor Vehicles in Beijing

(1) The average number of motor vehicles

With the increase in GDP per capita and the pursuit of higher quality of life, the number of motor vehicles per capita is expected to increase from the current 0.175 to around 0.3, in the next 15 years and continue rising. It is estimated that every family in Beijing will have at least one motor vehicle in 15 years' time.

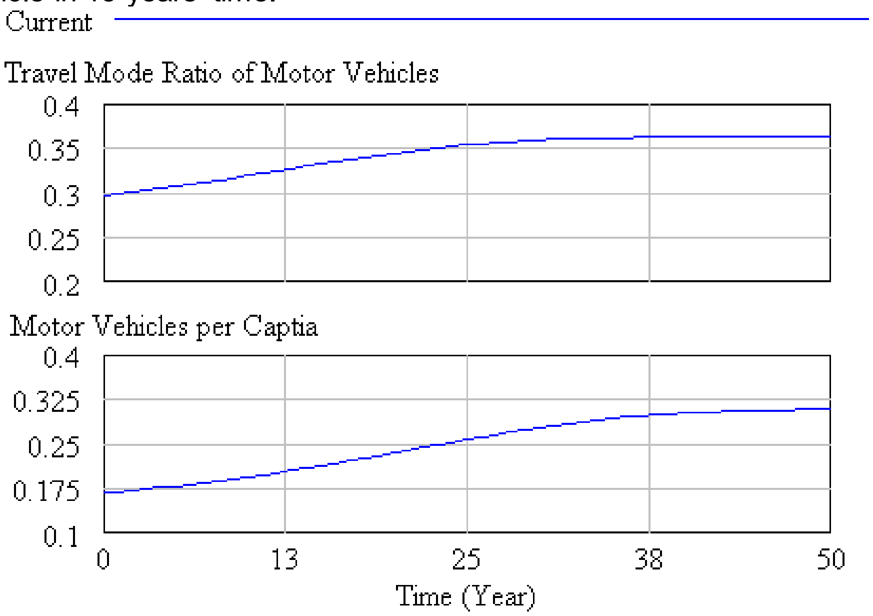

Fig.4 The Trends of the Proportion of Vehicles and Vehicles per capita

In Figure 4, when the proportion of the average vehicles per capita increases to around 0.3, the motor vehicle travels ratios and per capita figures reach a plateau. The reasons for this are as follows:

(1) With the increase in the population in Beijing, the total number of motor vehicles also increases, which leads to an increase in traffic demand and significant NO2 emissions. When the environmental factor of NO2 emissions becomes large, the migration of population into Beijing will decrease, because many people will no longer choose Beijing as a place of residence. It is anticipated that this situation will occur in the next 20 years, as the slowdown

in the increase of population relieves the pressure from the increase in the total number of motor vehicles and associated congestion.

(2) The relationship between the travel mode ratio of motor vehicles and the motor vehicles per capita is given by $Y = -0.352X^2 + 2.062X + 0.045$ (where X represents the motor vehicles per capita and Y represents travel mode ratio of motor vehicles). The maximum for Y is found when X ranges from 0.308 to 0.362. When X exceeds 0.308, Y will decrease, and when X reaches 0.362, the value of Y will tend towards a stable level.

(2) Total number of motor vehicles

With the rapid development of the economy and the increase in income levels, more people are purchasing private cars, which have led to a rapid increase in the ownership of cars in Beijing. By Dec.31, 2008, the number of motor vehicles reached 3.5 million in Beijing, of which the number of private cars was 2.483 million.

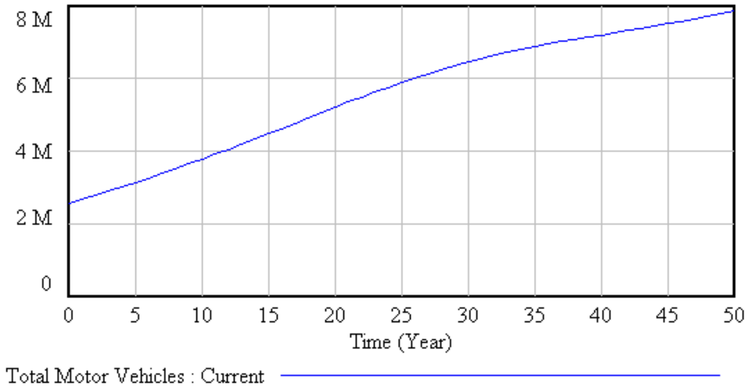

Fig. 5 the Trend of Total Motor Vehicles

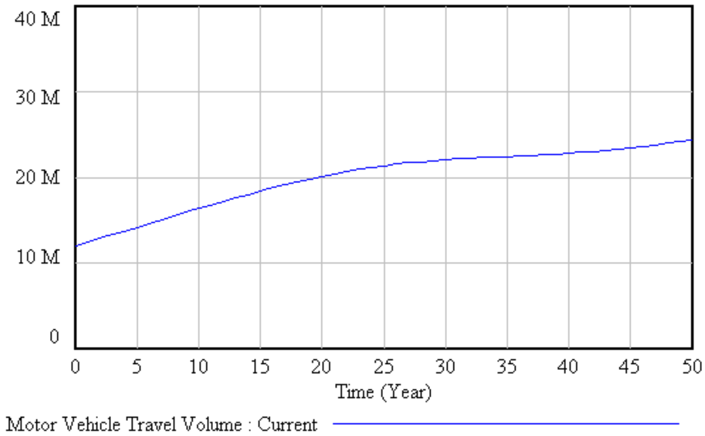

Fig. 6 the Trend of Motor Vehicle Travel Volumes

According to the results of simulation, the total number of motor vehicles will continue to increase to a stable level over the next 40 years. From Eq. 8, the total number of motor vehicles equals the total number of the population times the number of motor vehicles per capita. That is, the number of motor vehicles per capita will become stable after a period of annual increase.

4.3.2 The growth in the total population in Beijing

Under the situation of the present speed of growth of numbers of motor vehicles and the level of economic development, the trend of the total population can be predicted when birth rate, mortality and migration rates remain at the same level. However, taking into account great social change in the future, this model may no longer be suitable. In this study, we have only explored the relationship between the total population, environment and economy.

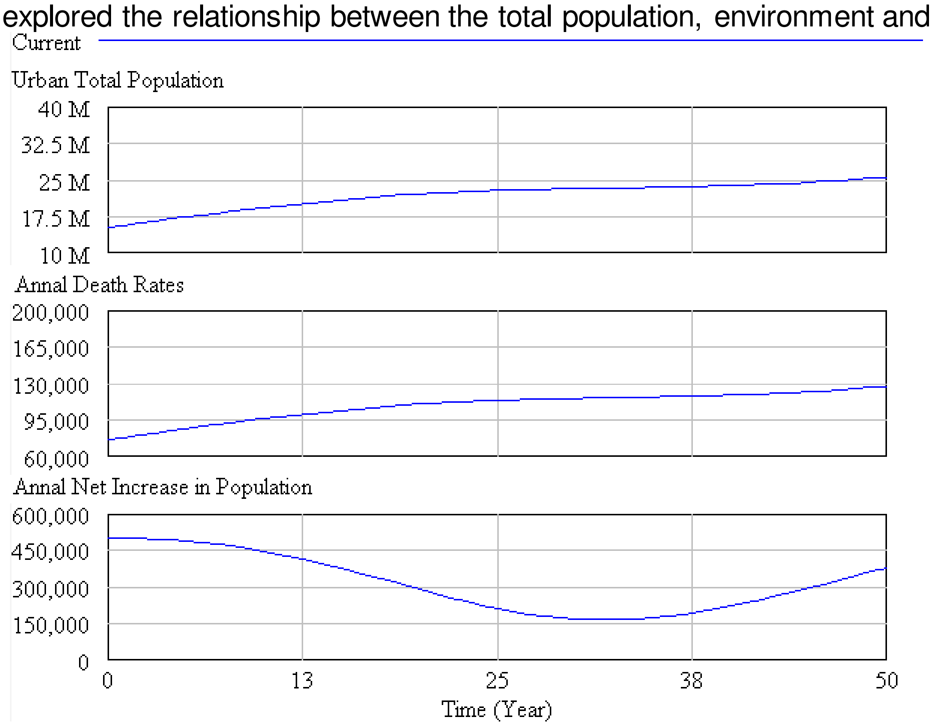

Fig.7 the Trend of Urban Total Population, Annual Death Rates and Annual Net Increase in Population

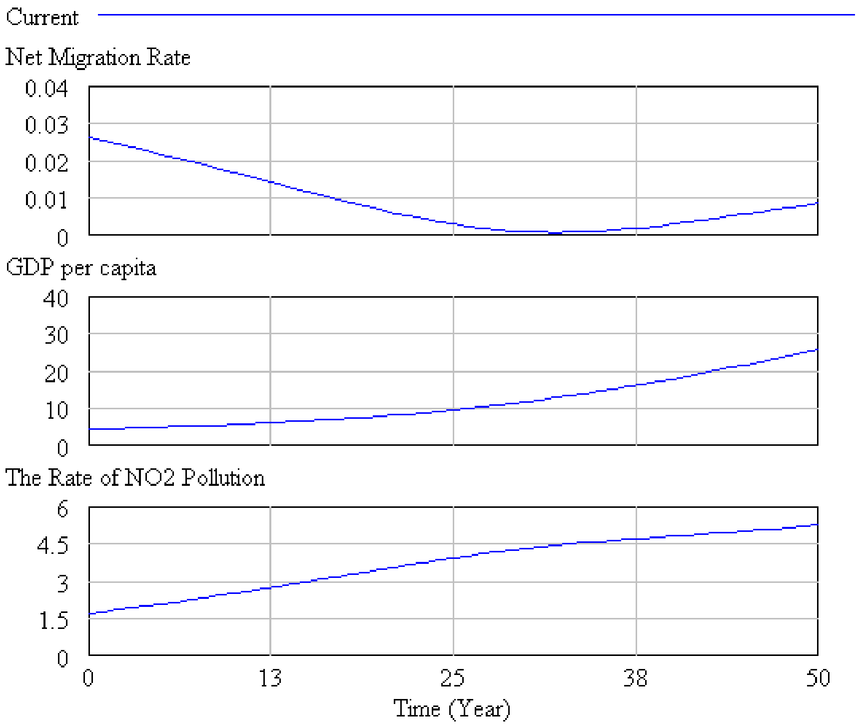

Fig.8 the Trends of Net Migration Rate, GDP per Capita and NO2 Pollution Rate

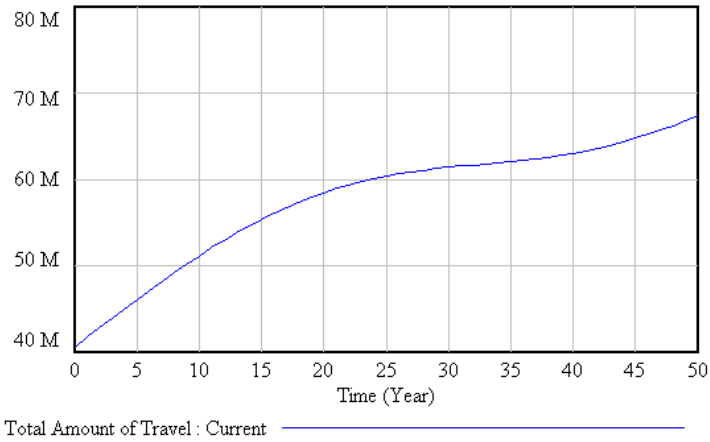

Fig.9 the Trend of Total Amount of Travel

According to the simulation, the Beijing population will increase steadily, while the net Chinese population will slowly decrease and then climb back step by step over the next 50 years. In the long run, after 50 years, the population of Beijing will increase from 16.95 million in 2008 to 25 million, which is 1.5 times the present level. After analyzing the change in the population trend, we arrived at the conclusion that the net migration rate will decrease from 0.023 to 0 in the next 10 years. As air pollution becomes more serious, it will lead to a tendency for the population of Beijing to decrease. Based on the initial mode of transport, the contamination of NO2 will seriously impact on net migration, and result in the decrease of net migration, until this reaches zero over the next 30 years. That is, with net migration decreasing, the growth rate of the Beijing population will go down, and if the birth rate and death rate remain unchanged, Beijing's population will increase steadily.

4.3.3 The growth of the GDP in Beijing

In the study, the increase in GDP depends on the given growth rate of 12 % annually and the environmental factors. If the influence of environment factors is small, the GDP will grow rapidly with a rate of increase of 12 % per annum. If the influence of environment cannot be ignored, the growth of the GDP will be affected, and the environment will have a negative effect on the economy. In this part of the model, 12% is the nominal growth rate, and, taking the inflation index and the development of economy into account, the real growth rate is set at 5%.

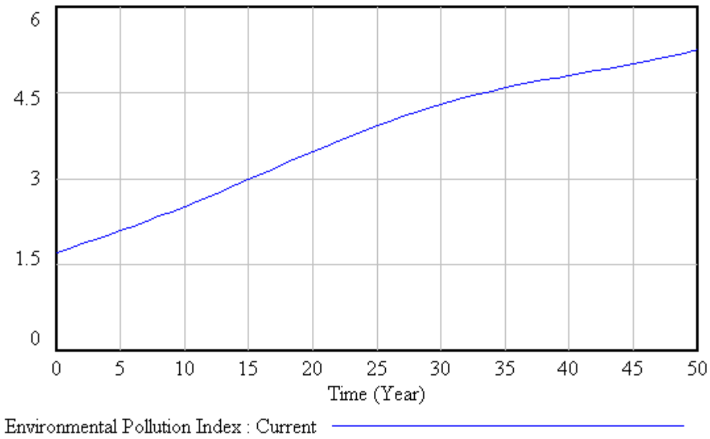

Fig. 10 the Trend of Environmental Pollution Index

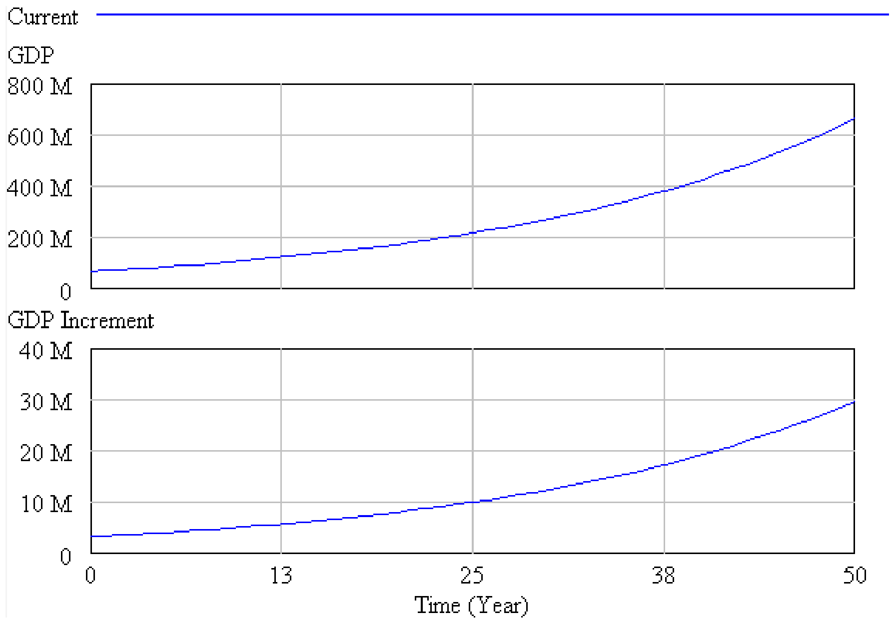

Fig. 11 the Trends of GDP and GDP Increment

The aggregated GDP equals the initial value plus the growth of GDP, so the trend of GDP growth directly determines the trend of GDP. According to Eq. 6, the relationship between the aggregated GDP and environmental factors can be analyzed.

(1) If the timeline is stretched to 200 years, the growth of GDP will show a similar incremental normal distribution curve. If we do not take environment factors into account, the curve of the growth of GDP will be a line whose slope is 5%, the real growth rate. However, the influence of environment factors should not be ignored. The curve from the simulation in Fig. 11 shows that the increase of GDP is impacted by the environment. The curve of the GDP increase is the trend of internal depression, which results in the slow growth of the aggregated GDP in the first 50 years.

(2) Environment factors (the ratio of the level of NO2 to the capacity of NO2) will increase significantly in the next 50 years from the current 1.9 to about 5, which will have a negative effect on the growth of GDP. When the year interval is in the range from 10 to 30 years, the slope of the environment factor is sizeable, and the growth of the GDP increases smoothly.

(3) When the year interval is in the range from 30 to 50 years, the slope of the environment factor is small, so the slope of the GDP increase rises, and the growth of GDP also speeds up.

4.3.4 The growth of environment factors in Beijing

As a modern vehicle, private cars bring convenience to people's lives. However, their exhaust emissions cause serious pollution to the atmosphere. There are many harmful gases in the exhaust emissions including CO, HC, NO, NO2 and so on. Their impact on the environment mainly includes the greenhouse effect, damage to the ozone layer, acid rain and black rain. The harm to human health comes mainly from various diseases, such as respiratory damage, and even cancer.
Possibly new technology and new fuels will change the level of NO2 from motor vehicles, but in this part of the simulation, it is assumed that half NO2 emissions come from the total vehicle emissions in the next 100 years.

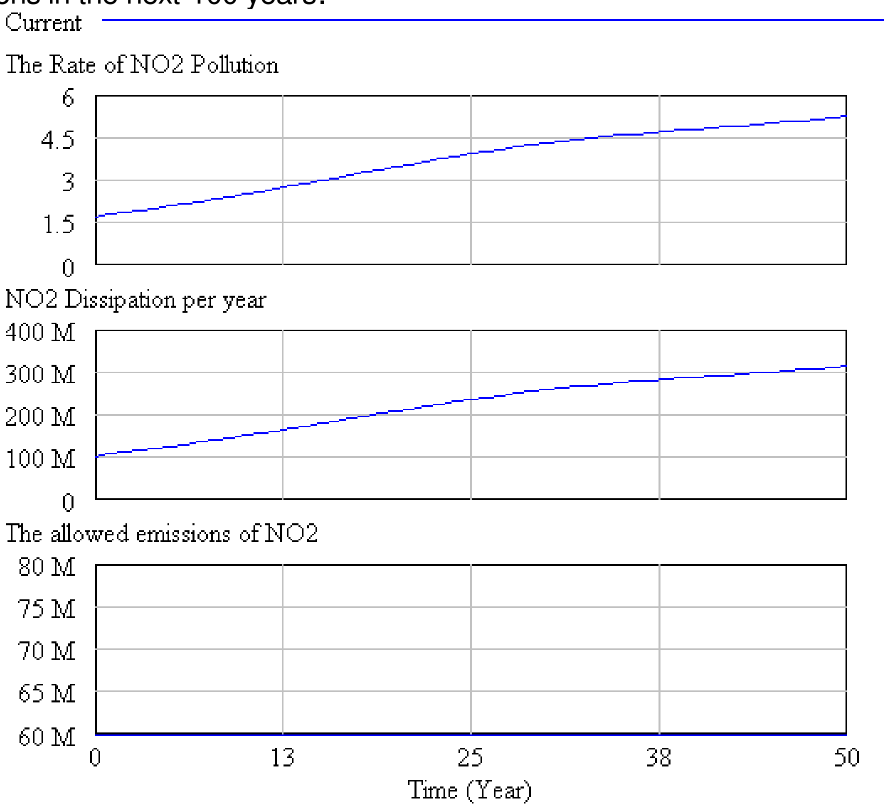

Fig.12 The Trends of the Levels of NO2 in air

In Fig. 12, according to the permitted exhaust emissions of NO2, the level of NO2, which is the difference between the NO2 increase and dissipation per year, will rapidly increase in the next 10 years, and when the year interval ranges from 10 years to 30 years, the level will still rapidly increase with no volatility. In addition, the trend of NO2 increase is similar to the trend of total motor vehicles.
According to Eq. 14, the rate of NO2 pollution is the environment factor.
The main reasons for the large amount of exhaust emissions from motor vehicles in Beijing are as follows:

(1) The demand for appropriate domestic vehicle design is lower than in developed countries; for example, the exhaust emission of CO and CH is 10 times that of America.
(2) Congestion reduces traffic speeds and increases energy consumption and polluting exhaust emissions.
(3) Because the standard of vehicles' emission is low, supervision in the form of emission testing lacks any positive effect, and the need to abandon old vehicles is ineffective.

4.4 Validity Testing of the Simulation Model

The SD model does not require very precise results, which relates primarily to the trends of the whole system and the impact of policy change on the model. So the process of validity testing is mainly to verify whether the simulation results are similar to real values, but not necessarily entirely accurate (Wang, 1993).
Based on the parameters obtained by regression, the relationships of factors are brought into the SD model. When inputting the data, the values in 2003 were regarded as the initial variables, and the relationships of the various variables were obtained by regression with the data from 2001 to 2008. Then the simulation diagram of the urban transportation system in Beijing was built and the motor vehicle was regarded as the main input variable. Some parameters were obtained from statistical yearbooks. Some data on Beijing cannot be obtained from statistical yearbooks, such as the level of NO2, the number of travel trips per capita, and the pollution contribution rate of NO2 from motor vehicles, all of which were obtained from published literature or reports. The functions were determined by least squares regression. The comparison between the simulation results and real values follows:

Table 1 Error between the Regression Result and Real Migration Rate

Year	Mobility per year	Fitting results	Errors (%)
2003	0.02	0.02	0.54
2004	0.02	0.02	2.57
2005	0.03	0.03	(7.14)
2006	0.03	0.03	4.63
2007	0.03	0.03	(1.52)
2008	0.03	0.04	3.10

The results show, except for the error in 2005, other differences were all within 5 % of the real values. So the model for this part is validated.

Table 2 Error between Regression Result and Real Vehicle Numbers

Year	Motor vehicles per capita	Fitting results	Errors (%)
2003	0.146	0.141	(3.239)
2004	0.154	0.157	1.986
2005	0.168	0.167	(0.417)
2006	0.182	0.179	(1.580)
2007	0.192	0.196	2.246
2008	0.207	0.205	(0.674)

If the range of error is within 5%, the result is deemed to be good.
There are some results in the simulation that have deviations from the historical data. However, most of them are within the error range of 5 % and they all have similar trends. So the model is validated.

5. CONCLUSIONS

An urban transportation system is a subsystem of a big complex social system, which includes many elements such as: people, vehicles, roads and social environment. Based on the theory of system dynamics, an SD model of an urban transportation system was built on the data of Beijing from 2003 to 2008. In the model, the population, economic, environment and transport were correlated using simulated equations. The trend in Beijing's growth was explored, which was basically similar to reality. The model simulated the components and operation of the Beijing urban transportation system, which offered a basis for understanding these systems. However, owing to the limitations of the data and the complexity of the system, to explore the system more clearly, a more detailed analysis of the impact factors is needed. We note that, with the development of society and the expansion of a city, there will be new subsystems to influence the urban transportation system. Finally, it is an important research field, and, through changing the model's parameters or structure, we can explore different policies and their different impacts on urban transportation.

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