Self-organization Evolution Model and Application of Travel Mode System Based on Sensitivity Analysis

Qiuping Wang\textsuperscript{1,a*}, Jingyi Ma\textsuperscript{2,b}, Ke Tao\textsuperscript{3,c}

\textsuperscript{1}Xi’an University of Architecture and Technology\textsuperscript{*} School of Civil Engineering Xi’an, China
\textsuperscript{2}Xi’an University of Architecture and Technology School of Civil Engineering Xi’an, China
\textsuperscript{3}Xi’an University of Architecture and Technology School of Civil Engineering Xi’an, China
\textsuperscript{a*} Corresponding author: wqp1168@sina.com
\textsuperscript{b}mjy19960908@xauat.edu.cn, \textsuperscript{c}dubh_linn@163.com

Abstract—The imbalance between traffic supply and demand is the root cause of urban transport problems. Travel mode is the most direct carrier of travel activities. It is feasible to improve traffic problems by optimizing the system it constitutes. Taking the evolution process of the travel mode system as the research object, we modified the model based on the characteristics of different travel modes and built the self-organization evolution model of the travel mode system based on the logistics equation. Using the sensitivity analysis we concluded that the most significant factor influencing the final state of the system evolution is the cooperation relationship among ground buses, private cars, and rail transit. We further analyzed this relationship among three travel modes based on stability theory and obtained the development characteristics of the cooperation-competition effect and the corresponding countermeasures, which provides an idea for the optimization of the system structure.

1. Introduction

The cause of urban traffic problem is the gradual imbalance of traffic supply and demand relation. With travel mode being the most direct carrier of the travel activities, failing to reach its maximum efficiency is not only one of the reasons for the urban traffic problems but also the main factor that blocks the solution of the problem. It's specifically embodied in the unreasonable development of travel modes and the lack of a well-formed system structure between them.

The optimization of the travel mode system has a direct effect on reducing the supply-demand contradiction. Most of the existing researches on the travel mode system optimization are focusing on the optimization of travel mode structure. For example, Lu [1] initially proposed a model of urban traffic structure optimization based on energy consumption; Hua [2] took the multi-mode traffic system as the research object and proposed to optimize the travel mode structure under both fixed and variable demand aiming to minimize the total consumption of the traffic system; Wang et al. [3] established the multi-objective structure optimization model targeting the lowest generalized cost, the smallest ecological impact, and the largest traffic utility. Besides, there are also studies on the factors that influence the structure of travel modes. Pei et al. [4] managed to filter the key factors affecting the...
evolution of traffic structure using grey correlation degree analysis improved by entropy method. Santos et al. [5] studied the key factors affecting different travel modes. The existing simulated results of travel mode structure optimization already reached the expected development scale based on the optimal goal, but there is no effective method of implementing the transformation of the existing structure to the optimal direction and the objectivity and operability of evaluating the existing factors that affect the structure evolution are still lacking at this stage.

Based on this, this paper introduces the self-organization theory that describes the process of system change to the analysis of the inhabitant travel mode, establishes the self-organization evolution model of the travel mode based on clarifying corresponding mechanism. Then we obtain the cooperation-competition among ground public transport, private car and subway as the control parameters that have a significant effect on the final state of the system evolution based on the sensitivity analysis. Finally, this paper uses stability theory to analyze the evolution process of the three traffic modes under different concurrent forms, and obtains the development characteristics of cooperation-competition effect and corresponding countermeasures. In order to guide and control the traveler’s choice of travel mode, improve the overall efficiency of the travel mode system, promote the formation of efficient cooperation among all subsystems, realize the orderly development of the system, and provide a feasible direction for the optimization of the travel mode structure.

2. Self-organization evolution model of travel mode system

In view of system theory, self-organization refers to the process that a system, driven by internal mechanism, develops from simple to complex, from rough to detailed, and constantly improves its complexity and fineness [6]. According to the analysis of the travel mode system based on the dissipative structure theory, the system has the self-organizing features of openness, out of equilibrium, nonlinear mechanism and fluctuation. Meanwhile, the interaction of the internal elements of the travel mode system and the impact of the external environment on the system promotes the system from disorder to order, then to a higher level of order. The internal evolution power and external environment evolution power respectively reflect the cooperation between travel modes and the dependence and sensitivity of the system to the environment. Therefore, the evolution and development of the urban passenger travel mode system have significant self-organization characteristics. In the following, the paper establishes the dynamic equation of travel mode system evolution based on the logistics equation to describe the macro characteristics of the system changing with time, and further analyzes the evolution process to obtain the corresponding optimization strategy.

2.1. System self-organization evolution model

To build a model to describe the evolution process of the system, the model state variables need to be defined. The system state variables are the macro observed quantities to describe the dynamic evolution process of the system. In the study of the characteristics of the travel mode, the passenger volume that travel mode shares is the quantity that discusses this kind of macroscopic change mainly. The share of passenger transport in a certain period can not only reflect the status and role of the travel mode in the transportation system, but also reflect its development status and utilization [6]. Meanwhile, the investment and development scale of the mode can directly or indirectly be revealed the current passenger transport volume. Taking the passenger volume undertaken by various travel modes as state variables, the urban passenger travel mode system can be described as follows:

\[ S = \left[ X_i, C_j, f(t), t \right] \]  (1)

Where \( X_i \) is the passenger volume of the i mode of travel; \( C_j \) is the system model parameter set; \( f(t) \) is the random fluctuation of the system; \( t \) is the time variable.

At this stage, it is an acceptable way to describe the self-organized system with the dynamic equation of state variables [7]. The travel mode system is an open system composed of many subjects. And its evolution process is similar to the population growth. Therefore, the logistics model which describing the continuous growth and evolution of a population of a resource-limited environment is
introduced to describe the evolution process of the travel mode system. This equation was first proposed by Raymond bill in 1920, and its standard form is:

\[
\frac{dx(t)}{dt} = rx(t) \left[1 - \frac{x(t)}{x_{\text{max}}} \right]
\]  

(2)

Where \(x(t)\) is the system state variable; \(r\) is the inherent growth rate of state variables; \(x_{\text{max}}\) is the development threshold of state variables in a certain regional socio-economic environment.

2.2. Model improvement

Comparing with the evolution process of the biological population, the travel mode system that uses the passenger volume as the state variable has a similar self-organization evolution pattern. But to be described using the logistics model it needs to be modified in combination with the system features. On the one hand, during the development of the social environment, the travel mode does not always show a positive growth; on the other hand, the coopetition between the travel modes will affect the growth of the travel mode passenger volume as well, so the model is modified:

1) When the travel mode is in negative growth (growth rate \(r < 0\)), the development scale of the travel mode will continue to reduce. To avoid the idle of the corresponding infrastructure, this paper sets the corresponding scale lower limit value of the attenuation of the travel mode. Based on the principle of the retardation growth model, the following results are obtained:

\[
\frac{dx_i(t)}{dt} = rx_i(t) \left[1 - \frac{x_i(t)}{x_{\text{max}}^i} \right] - \sum_{j=1}^{n} \sigma_{ji} \frac{x_j(t)}{k_j}
\]  

(3)

2) Considering the influence of coopetition between travel modes during their development, the following nonlinear dynamic equations are obtained by introducing coopetition factor [8-9].

\[
\frac{dx_i(t)}{dt} = r_i x_i(t) \left[1 - \frac{x_i(t)}{k_i} + \sum_{j=1,j\neq i}^{n} \sigma_{ji} \frac{x_j(t)}{k_j} \right]
\]

\[
\frac{dx_j(t)}{dt} = r_j x_j(t) \left[1 - \frac{x_j(t)}{k_j} - \sum_{i=1,i\neq j}^{n} \sigma_{ji} \frac{x_i(t)}{k_i} \right]
\]  

(4)

Where \(r_i\) is the inherent growth rate of travel mode (the growth rate of travel mode passenger volume in an ideal state when the external environment remains constant). This variable is related to the level of economic development, the degree of capital investment and the resources of road infrastructure.

\(k_i\) is the upper limit value of travel mode when it develops independently under the constraints of external resources and environment; it is reflected in the constraints of traffic infrastructure capacity, motorized traffic energy consumption, environmental capacity, construction investment funds, etc.

\(\sigma_{ji}\) is the coopetition coefficient; When the cooperative utility \(i\) is greater than the competitive utility \(j\), it is shown as way \(i\) is promoting the development of way \(j\), i.e. \(\sigma_{ji} \geq 0\). On the contrary, \(\sigma_{ji} \leq 0\). \(\sigma_{ji}\) can be understood as \(x_j\) per unit provides \(\sigma_{ji}\) times as many resources as \(x_i\) per unit. It is shown the coopetition among different ways which reflects the mutual connection and interaction between subsystems. The direct factor of the change of coopetition relationship is the operation strategy of travel mode operators. And the regulatory policy tendency of traffic controllers has a decisive influence on the pattern of travel mode coopetition.

3. Sensitivity analysis algorithm

Sensitivity analysis generally includes local sensitivity analysis for a single parameter and global sensitivity analysis for multiple parameters. Compared with the local sensitivity analysis, the global sensitivity has obvious advantages: (1) multiple parameters can be analyzed at a time, and the effect is better; (2) the interaction between parameters is also included in the sensitivity analysis; (3) the error caused by abnormal sensitivity of a single parameter sensitivity analysis is avoided. Therefore, this paper uses the multivariate regression method based on Latin hypercube sampling to analyze the global
sensitivity and uses MATLAB to program the sensitivity calculation of self-organization evolution differential equations. This paper studies the relationship between the model evolution state and the control variables, and defines how to adjust the control variables to affect the evolution final state, to realize the reasonable allocation of resources, so that the travel mode can meet the requirements of the sustainable development of the system in the process of self-organization evolution.

3.1. Latin hypercube sampling
Latin hypercube sampling is a stratified sampling method of complex multi-dimensional parameter space. The samples obtained by this method are uniform and can converge quickly. The core of Latin hypercube sampling is to stratify the cumulative probability of the parameter space, assuming that the value range of the cumulative probability distribution is [0,1]. stratifying is to divide the cumulative probability density curve into several equal sections on the interval [0,1], and then extract samples from the divided sections according to certain rules [10].The algorithm steps are as follows:

(1) set the value range of m control parameters as \((x_{i}^{\min}, x_{i}^{\max})\): first, divide the value range of each parameter into ri intervals according to the probability density, with the probability of each interval is equal and does not overlap each other;

(2) random sampling is taken as the sample value of each parameter in the probability equal division interval \((x_{i}^{k}, x_{i}^{k+1})\);

(3) randomly arrange the \(r_i\) samples from each parameter, then the m samples of the parameters constitute the vector space of the dimension.

3.2. Spearman rank correlation coefficient
As the self-organization of the travel mode system is nonlinear, if the parameter set obtained from random sampling is being substituted into the self-organization model for simulation, the distribution of simulation results is still unclear. In this case, the correlation analysis between input parameters and response values by nonparametric statistics is closer to reality [11]. Spearman rank correlation coefficient is a nonparametric statistical analysis method, that can be used to measure the correlation between variables. The calculation process is as follows:

Suppose that the input parameter of the self-organization evolution model is \(X = [x_1, x_2, \cdots, x_n]\), its rank is \(R_x\); the output result value is \(Y = [y_1, y_2, \cdots, y_n]\), its rank is \(D_y\); the observation values of X and Y are sorted according to the value size respectively, the rank is the position of each value in the sequence, when \((x_1, x_2, \cdots, x_n)\) and \((y_1, y_2, \cdots, y_n)\) have no repetition, the corresponding X and Y rank is \(R = 1, 2, \cdots, n; D = 1, 2, \cdots, n\); when there is repetition in the observation value, the rank is taken as the average. Then the Spearman rank correlation coefficient of the variable X and Y is:

\[
\rho = \frac{n \sum_{i=1}^{n} R_i D_i - \sum_{i=1}^{n} R_i \sum_{i=1}^{n} D_i}{\sqrt{n \sum_{i=1}^{n} R_i^2 - (\sum_{i=1}^{n} R_i)^2} \sqrt{n \sum_{i=1}^{n} D_i^2 - (\sum_{i=1}^{n} D_i)^2}}
\]

The size of the Spearman rank correlation coefficient indicates the closeness of the relation, and its symbol indicates the monotonicity of the relation between X and Y. When X increases with Y strictly and monotonically, the Spearman rank correlation coefficient is 1. On the contrary, when X decreases with Y strictly and monotonically, the Spearman rank correlation coefficient is - 1 [12].

4. Stability analysis
The coopetition among travel modes is the internal motivation for the coordinated development of the system. It’s also an important influencing factor for achieving a higher orderly development of the system. By means of stability theory, this paper hackles the coopetition relationship among the travel mode subsystems obtained from sensitivity analysis and discusses how to achieve an orderly transformation of the system and realize the optimal allocation of resources.
Two or more travel modes exist in the same passenger transport environment, which will inevitably involve interdependence or competition. In order to study the outcome of competition or interdependence between two or more travel modes as well as the development trend of passenger traffic volume of each travel mode. It is difficult to directly solve equation (4), so the stability analysis of its balance point is considered.

For the common competition between two subsystems, the second-order nonlinear differential equation is established to describe it

\[
\begin{align*}
\frac{dx_1(t)}{dt} &= f(x_1, x_2) \\
\frac{dx_2(t)}{dt} &= g(x_1, x_2)
\end{align*}
\]  

(6)

Generally, the right end of the equation does not contain t, which is called autonomous equation, so that let the algebraic equation

\[
\begin{align*}
f(x_1, x_2) &= 0 \\
g(x_1, x_2) &= 0
\end{align*}
\]  

(7)

To solve the equation, the real root of the equation \(x_1 = x_1^0, x_2 = x_2^0\) is the equilibrium point of the above equation -- \(P_0 = (x_1^0, x_2^0)\).

There are two methods to judge whether the equilibrium point \(P_0\) is stable: the direct method and the definition method. In this paper, the direct method is used to judge it. The steps are as follows:

(1) First, at the point \(P_0\), Taylor expansion is done, and only the first term is taken. Then the approximate linear equation of the above formula is obtained:

\[
\begin{align*}
\frac{dx_1(t)}{dt} &= f_1 \left( x_1^0, x_2^0 \right) \left( x_1 - x_1^0 \right) + f_2 \left( x_1^0, x_2^0 \right) \left( x_2 - x_2^0 \right) \\
\frac{dx_2(t)}{dt} &= g_1 \left( x_1^0, x_2^0 \right) \left( x_1 - x_1^0 \right) + g_2 \left( x_1^0, x_2^0 \right) \left( x_2 - x_2^0 \right)
\end{align*}
\]  

(8)

Note that the coefficient matrix is:

\[
A = \begin{bmatrix} f_1 & f_2 \\ g_1 & g_2 \end{bmatrix}_{\left( x_1^0, x_2^0 \right)}
\]  

(9)

(2) Assuming the determinant of \(A\) \(\det A \neq 0\), the stability of \(P_0\) can be determined by the root of the characteristic equation of equation 7. Therefore, the characteristic equation is obtained first:

\[
\det(A - \lambda I) = 0
\]  

(10)

The formula above can be rewritten as:

\[
\begin{align*}
\lambda^2 + m\lambda = & + n = 0 \\
m = & - (f_1 + g_1) \\
n = & \det A
\end{align*}
\]  

(11)

In the equation above, \(m, n\) are the coefficients of characteristic equation. Solve the equation group and get its characteristic roots as follows \(\lambda_1, \lambda_2:\)

\[
\lambda_1, \lambda_2 = \frac{1}{2} \left( -m \pm \sqrt{m^2 - 4n} \right)
\]  

(12)

(3) The general solution of the equation can be obtained from the root of the characteristic equation in the form of:

\[
\begin{align*}
c_1 e^{\lambda_1 t} + c_2 e^{\lambda_2 t} \left( \lambda_1 \neq \lambda_2 \right) \\
c_1 e^{\lambda_1 t} + c_2 e^{\lambda_2 t} \left( \lambda_1 = \lambda_2 \right)
\end{align*}
\]  

(13)

According to the definition of stability, if the equilibrium point of the equation \(P_0\) is a stable node, \(\lambda_1, \lambda_2\) must be negative numbers or negative real parts, otherwise, \(P_0\) is an unstable point.
5. Example analysis

5.1. Model establishment and test
Taking Beijing as the case, referring to the annual report of Beijing traffic development from 2005 to 2015, and combining with the historical annual data (see Tab.1), the self-organization evolution model of the travel mode system in the ideal state (when there is no coopetition between modes) is fitted. And the inherent growth rate and development upper limit value of bus, car, bike, taxi and subway can be obtained respectively. In order to measure the fitness between the evolution model and the actual data, calculates the fitting accuracy. The fitting results are shown in Tab.2:

| Year | Public Transportation | Bicycle | Car | Taxi | Track |
|------|-----------------------|---------|-----|------|-------|
| 2005 | 411.146               | 516.918 | 508.388 | 129.656 | 97.242 |
| 2006 | 487.512               | 553.446 | 631.368 | 161.838 | 115.884 |
| 2007 | 625.9                 | 523.48  | 741.976 | 175.252 | 159.32  |
| 2008 | 759.456               | 535.311 | 886.032 | 195.138 | 210.96  |
| 2009 | 793.594               | 497.026 | 933.64  | 194.966 | 274.6   |
| 2010 | 818.928               | 476.256 | 993.168 | 194.568 | 333.96  |
| 2011 | 810.186               | 433.823 | 948.09  | 198.237 | 396.474 |
| 2012 | 824.976               | 421.587 | 988.758 | 200.178 | 509.544 |
| 2013 | 764.286               | 364.089 | 983.943 | 195.585 | 619.854 |
| 2014 | 899.756               | 396.396 | 990.99  | 195.052 | 610.324 |
| 2015 | 755                   | 374.48  | 963.38  | 108.72  | 755     |

| Year | Public Transportation | Bicycle | Car | Taxi | Track |
|------|-----------------------|---------|-----|------|-------|
| 2005 | 40.985                | -28.62  | 38.486 | -4  | 23.738 |
| 2006 | 487.339               | 528.08  | 1023.208 | 183.252 | 1608.56 |
| 2007 | 625.9                 | 0.8571  | 0.9397 | 0.453  | 0.9867 |
| 2008 | 759.456               | 0.8571  | 0.9397 | 0.453  | 0.9867 |
| 2009 | 793.594               | 0.8571  | 0.9397 | 0.453  | 0.9867 |
| 2010 | 818.928               | 0.8571  | 0.9397 | 0.453  | 0.9867 |
| 2011 | 810.186               | 0.8571  | 0.9397 | 0.453  | 0.9867 |
| 2012 | 824.976               | 0.8571  | 0.9397 | 0.453  | 0.9867 |
| 2013 | 764.286               | 0.8571  | 0.9397 | 0.453  | 0.9867 |
| 2014 | 899.756               | 0.8571  | 0.9397 | 0.453  | 0.9867 |
| 2015 | 755                   | 0.8571  | 0.9397 | 0.453  | 0.9867 |

It can be seen from Tab. 2 that the data fitting results are ideal except for taxis. The goodness of the fit of taxis is only 0.453. From the historical data, due to the strict control of the number of taxi fleets by the operation Department, the passenger traffic volume will not increase significantly.
Take the control parameters into the self-organization evolution model of the travel mode system, take the Beijing 2005 passenger traffic volume of each travel mode as the initial value, and set the evolution period as 25 years. Use MATLAB to simulate and analyze the established differential equation group model. Then analyze the self-organization evolution situation of the travel mode system. The results are shown in Fig. 1:

According to the analysis of the evolution trend of various travel modes in the Figure, the following characteristics can be found in the system evolution at this stage:

(1) Bus and car have entered the mature area of evolution, and the growth rate has gradually slowed down. It is expected to reach the upper limit determined by the current external environment around 2020, then maintain a stable situation. Meanwhile, according to the simulation results, in the future, the share of car passenger transport will continue to be larger than that of bus, thus the road traffic issue remains unresolved.

(2) At the beginning of the 21st century, the subway build began vigorously, and the share of passenger transport has always been in the stage of rapid growth. According to the changing trend, it can be inferred that the development of subway is still in the stage of development, with great potential. In the future, the share of passenger transport will gradually surpass that of cars, and take up the leading position in the way of travel.

(3) The passenger share of bike and taxis will continue to decline in the coming years, and remain at the lower limit of development scale.

5.2. Global sensitivity analysis of model parameters
The paper analyzes the global sensitivity of the self-organization evolution model using the multivariate regression method based on Latin hypercube sampling. It selects 2000 samples in total to ensure the representativeness of the extracted samples to the parameter space. To compare the sensitivity of each parameter more intuitively, based on the absolute value of the sensitive data of each parameter, the radar chart showing the sensitivity value change of five travel mode state variables regarding the control parameters of the evolution model is drawn. The sensitivity of the evolution end state of different travel modes to 32 parameters can be easily obtained from Fig.2. (The corresponding relationship between number and parameter is shown in the Tab.3).

| Parameter number | Parameter meaning | Parameter symbol | Parameter number | Parameter meaning | Parameter symbol |
|------------------|------------------|-----------------|------------------|------------------|-----------------|
| 1                | The growth rate  | $r_{bus}$       | 17               |                  |                 |
| 2                |                  | $r_{biker}$     | 18               | Bicycle-related concurrence factors | $\sigma_{12}$ |
| 3                |                  | $r_{car}$       | 19               |                  | $\sigma_{32}$ |
| 4                |                  | $\sigma_{12}$   | 20               |                  | $\sigma_{32}$ |
| 5                |                  | $\sigma_{32}$   | 21               |                  |                 |
| 6                |                  | $\sigma_{32}$   | 22               |                  |                 |
| 7                |                  | $\sigma_{32}$   | 23               |                  |                 |
| 8                |                  | $\sigma_{32}$   | 24               |                  |                 |
| 9                |                  | $\sigma_{32}$   | 25               |                  |                 |
| 10               |                  | $\sigma_{32}$   | 26               |                  |                 |
| 11               |                  | $\sigma_{32}$   | 27               |                  |                 |
| 12               |                  | $\sigma_{32}$   | 28               |                  |                 |
| 13               |                  | $\sigma_{32}$   | 29               |                  |                 |
| 14               |                  | $\sigma_{32}$   | 30               |                  |                 |
| 15               |                  | $\sigma_{32}$   | 31               |                  |                 |
| 16               |                  | $\sigma_{32}$   | 32               |                  |                 |

Figure 1. Evolution results of travel mode self-organization
From Figure 2 (a), it can be concluded that the final evolution state of bus is significantly affected by the coopetition of cars and subway. It’s also slightly affected by the development scale of bus and the coopoetition of bike, and relatively less affected by other control parameters. Similarly, the final evolution state of the cars and subway is strongly affected by the coopetition of bus, cars and subway. The evolution of bike and taxi is influenced by the coopetition of bus, cars and subway. It can be concluded that the self-organization evolution model is most sensitive to the change of the coopetition between the bus, cars and subway. The control parameters are the manifestation of the comprehensive...
effect of the external environmental conditions. Therefore, based on the global sensitivity analysis of the parameters, the evolution of the travel mode system can be regulated by reasonably formulating the coopetition strategy of the travel mode system. So that the overall development of the whole system can meet sustainable requirements.

5.3. Analysis of concurrence evolution based on stability

In the whole travel mode system, the development of bus, cars and subway has a significant impact on the evolution of the whole system. At the same time, motorized traffic is the root cause of urban traffic problems and the main entry point to alleviate the problems. Based on the above considerations, it is more realistic to optimize the coopetition relationship between the above three travel modes. This paper uses MATLAB to establish the coopetition model of urban public transport mode, simulate the coopetition relationship under the following three variable conditions: both sides adopted a competitive posture (-1<σij<0), competition by one party and cooperation by the other (-1<σij<0; 0<σji<1), and both sides adopt cooperation strategies (0<σij<1).

The conclusion is as follows:

(a) competing with each other       (b) one competing with the other collaborating       (c) collaboration

Figure 3. Simulation Analysis of the evolution model of bus and car

In a state where bus and cars compete, as shown in Fig.3(a), the development scale is limited for both sides under the condition of mutual competition between bus and cars, which should be avoided in the actual development process. In the cooperation state, as shown in Fig.3(c), the development potential of both bus and cars has been enlarged. But the development of cars is better than that of bust. In this state, many problems of urban passenger transport (such as congestion, pollution, occupation of space resources, etc.) still cannot be alleviated. Fig.3(b) shows that when bus is coordinated and cars are in competition, the development of the market is in a positive situation, which has practical significance for the implementation of public transport priority strategy and the sustainable development of transport.

(a) competing with each other       (b) one competing with the other collaborating       (c) collaboration

Figure 4. Simulation Analysis of the evolution model of subway and bus

Combined with the actual analysis, subway and bus have similar characteristics in terms of ticket price, line network station distribution, etc. While subway has higher speed, large traffic volume, more
exclusive right of way, and higher service level compared with bus. It has obvious advantages in the competition. Considering that, the development scale of bus needs to be increased while, maximizing the overall passenger transport of public transport is an important means to achieve public transport priority. Therefore, the efficiency of the travel mode system can be better improved when the two sides are in a collaborative state as shown in the state of Fig.4(c). In addition, the simulation diagram, shows that, the sum of the passenger traffic shared by the two is greater when the synergetic effect of bus on subway is higher.

(a) competing with each other   (b) one competing with the other collaborating      (c) collaboration

Figure 5. Simulation analysis of evolution model of car and subway

In Fig.5(a), due to the situation of mutual competition, the development speed and scale of cars and subway are limited, which results in the reduction of passenger flow of subway. Thus it is not advisable. In Figure. 5 (b), cars are in a collaborative state with subway, while subway takes competitive strategy to cars. After the evolution stabilizes, the development scale of the car is limited to about 8 million passengers, while the subway has grown by about 18 million passengers. The development of subway has obvious advantages in this competitive situation and is more accord with the goal of orderly development of the travel mode system.

6. CONCLUSIONS
This paper takes the self-organization evolution process of the travel mode system as the research object. It takes Beijing as an example, and builds the self-organization evolution model of the travel mode system based on the logistics equation. Furthermore, the sensitivity analysis algorithm is used to quantify the relationship between the model state variables and the control parameters. Finally, based on the stability theory, the cooperation among the three modes of bus, cars and subway are analyzed. The main conclusions are as follows:

1. The simulation results of the model show that at present, the main contradiction of the travel mode system is still concentrated in the low proportion of public transport share, and the travel of cars is still on the high side. Under this trend, the problems of the traffic such as traffic congestion, parking difficulties and other problems with the further increase of car ownership are still difficult to improve.

2. Based on the sensitivity analysis, we can get the influence degree of model parameter changes on the final evolution state of travel mode. The self-organization evolution model is most sensitive to the change of cooperation between bus, cars and subway. Through reasonable improvement of external conditions, we can regulate the evolution of travel mode system.

3. The typical strategy of system coordinated development is obtained through the stability analysis. The development of bus and cars should adopt the development mode in which the cars synergize with bus while bus competes with car. For the development of bus and subway, the coordination of the two is more effective for the sustainable development of travel mode system. And it should adopt the coordinated strategy that public transportation is synergizing with subway. In terms of the development of subway and car, it helps to maximize the overall efficiency of the travel mode system and realizes the sustainable development of the travel mode system when cars are in a collaborative state with subway, and on the contrary, subway adopts a competitive strategy towards cars.
REFERENCES

[1] Lu, H.P.; Wang, J.W., Zhang, P. Urban transport structure optimization based on energy consumption [J]. Journal of Tsinghua University (NATURAL SCIENCE EDITION) 2004 (3),383-386

[2] Hua, X.D. Transportation modal split optimization of multimodal traffic system based on supply-demand equilibrium [D]2016 Nanjing: Southeast University

[3] Wang, Q.P., Tao, K. Research on optimized model of urban passenger transport structure for sustainable development [J]. Journal of East China Jiaotong University 2018 35 (3): 76-82

[4] Pei, Y.L., Ba, J.Y. Selection of the key influencing factors of urban traffic structure evolution [J]. Journal of Transport Science and Engineering 2017 29 (1): 66-71

[5] Santos, G., Maoh, H., Potoglou, D. et. Factors influencing modal split of commuting journeys in medium-size European cities[J]. Journal of Transport Geograph, 2013 30, 127-137

[6] Si, D.P. The structural evolution research of the city’s public transportation based on self-organization theory [D]. Beijing: Beijing Jiaotong University, 2012.

[7] Tan, C.G. Research on dynamic equilibrium situation theory [M]. Chengdu: University of Electronic Science and Technology Press 2004, 17-46.

[8] Lin, Z., Yang, H. Optimization model analysis of urban traffic structure [J]. China Civil Engineering Journal 2005 (5), 100-104

[9] Fan, W.T. Research of coopetition mechanism among urban traffic modes [D]. Changsha: Changsha University of science & technology, 2009.

[10] Miao P.B. Electric vehicle load model based on improved kernel density estimation and Latin hypercube sampling [D]. Chongqing: Chongqing University, 2016

[11] Gao, J., Huang, Z.X. Parameter sensitivity analysis of viscoelastic damage constitutive model of PBX explosive [J]. Engineering mechanics 2015 32 (2),201-206

[12] Chen, G.D. Risk sensitivity analysis of investment projects based on Monte Carlo simulation [J]. Finance and Accounting Monthly 2012 (18),59-61