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A Study of Urban City Traffic Congestion Governance Effectiveness Based on System Dynamics Simulation*

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ABSTRACT: *Traffic congestion has been a hurdle preventing urban cities from being developed healthily and rapidly. This paper establishes a causal loop diagram and the stock-flow chart for the urban traffic congestion system of Chongqing city based on the system dynamics method. It also develops a traffic demand system and the main structural equations for the urban city. In addition, with taking the population, the per capita GDP, the resident travel times, the annual freight traffic volume, the rail transportation share rate into account, the population, economy and traffic system data are simulated and compared to the actual data which is showing a good match. The Vensim software is successfully applied to simulate the effectiveness of different traffic congestion governance policies and the influence of various parameters in the traffic system. Simulation results show that the license plate limit policy is proved to be incapable of fundamentally solving the traffic congestion although the driving restriction on selected road system policy is able to ease the traffic congestion to a certain extent. In addition, more new observations includes: the railroad share rate increases proportionally with the railroad length; investment of rail transportation and increasing of the road mileage is positive to alleviate the congestion in a short time. Based on the simulation results and analysis, this paper proposes the following strategies to tackle the traffic congestion problem in Chongqing city: accelerating the rail transportation construction, setting high priority to the development of public transportation, collecting reasonable traffic congestion fee, implementing driving restriction on selected road system policy, developing intelligent traffic management technology, promoting and improving online vehicle reservation platform.*

KEYWORDS*: urban city traffic, traffic congestion, system dynamics, traffic congestion governance*

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I. INTRODUCTION

Urban city traffic congestion has been becoming a global "urban city disease" for decades. Domestic and foreign scholars have conducted researches on the urban city traffic congestion problem, strategies, and solutions. Cao et al.(2009), Cheng et al.(2014), He(2012) believe that the main reasons are from two aspects: on one hand, the contradiction between the development of traffic supply and demand imbalance; on the other hand, contradiction between the growth of traffic demand and limited available urban city land. Wang et al.(2013) think the main reasons are from the contradiction between urban city economic development and transit participants,brought up that the causes of traffic congestion are: urban city development and traffic development contradictions, unscientific urban traffic planning, obsolete urban traffic management, unlawful traffic congestion governance, unclear boundaries between responsibility and right of transportation officers.

Different strategies are proposed by researchers, think that solving traffic congestion problem including reasonable urban planning, improving walking and bicycle lanes, redevelopment and management of urban city land, improving transit transfer system, encouraging and advocating 'green' travel， more methods and solutions that are used to analyze and evaluate traffic congestion from literature include comprehensive fuzzy evaluation method, data envelopment analysis (DEA)(Jiang et al., 2011) ,Gaussian mixture distribution method(Wang and Zhu ,2011) and cumulative logistic regression analysis(Liu et al.,2008) support vector machine classification algorithm (Zheng and Lu, 2014) . Hubert et al. (2012)use three-phase traffic theory to make the decision for early traffic congestion warning. Li et al.(2012)propose a "tree control" strategy to solve the traffic congestion decision problem based on the improved medium traffic simulation model. In addition, Stave et al.(2012) establish the system dynamics model in which the sub-modules such as population, transportation system

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facilities, land use, and air pollution are integrated, simulate the effects of various traffic policies and structure development trend of different types of traffic structures based on the system dynamics model, and further discuss the reasonable target and policy system of the traffic structure.

After a comprehensive review of the literature, an essential cause of traffic congestion include the dramatical increase of traffic demand and the lack of traffic supply which results in traffic supply and demand imbalance and the instability of traffic conditions. proposed solutions mainly focus on traffic supply and demand, such as increasing the supply of transportation facilities appropriately, guiding traffic demand, improving road capacity, developing public transport system, strictly enforcement of traffic laws and regulations. Taking the actual situation of China's urban traffic congestion and its features into account, such as China's economic development, scientific and technology strength, traffic participants' behavior and habits and other issues, hence it should make corresponding solutions for the traffic problems specifically to promote sustainable development of the urban city traffic in China.

II. METHODOLOGY (SYSTEM DYNAMICS MODEL FOR URBAN CITY TRAFFIC CONGESTION)

2.1 feasibility study of applying system dynamics to analyze traffic congestion

System Dynamics (SD) theory is founded by Jay W.Forrester in the Massachusetts Institute of Technology which is a synthesis of system science and computer simulation. It is a model based on real causal relationship and the method emphasizes modeling from different perspectives of system, integration, connection, development and dynamics. While urban city traffic system is complicated, dynamic and lay behind the real time, it is very applicable and feasible to solve the problem of urban city traffic using the system dynamics method. In the meanwhile, the characteristics of the traffic system also fit the modeling requirements of the system dynamics(Wang Qifan 1998).

①One of the salient features of urban city traffic is systematic. The use of system dynamics to study urban city traffic problems with help from tools including system structure, causal loop, flow chart model, a feedback mechanism can effectively conduct a qualitative and quantitative analysis of traffic congestion formation mechanism. Finally, we use Vensim software to build and study the effectiveness of traffic congestion governance policies.

②The use of the traditional methods for solving urban city traffic problems will be challenging. These challenges include constantly developing cities, changing urban traffic, different effects of short-term and long-term traffic congestion control, incoherent dynamic traffic data, limited data access, traffic data collection difficulties, incomplete and unrepresentative data, etc. Hence the use of system dynamics can be a good way to avoid these problems.

③Urban city transport system is highly integrated and complicated. The complexity includes phenomenon such as 'one cause and multiple effects' and 'one effect and multiple causes'. In addition, economy, population, environment, energy and other problem lead to non-linearity of the system. The dynamics model should be applied to solve this problem with taking the whole system into account.

④ When the system dynamics method is implemented to optimize the traffic system, the optimized traffic system can be achieved using parameter optimization (by changing sensitive parameters of the system to find the optimal system behavior), structural optimization (by changing the horizontal or speed variables in the model to find the optimal system behavior) and boundary optimization (by changing the boundary condition to find the optimal system behavior). And the optimized traffic system obtained from system dynamics optimization method has a better fitting to the actual system and the proposed strategies are more convincing.

2.2 System dynamics causal loop diagram of urban city traffic congestion

The final urban city traffic congestion system causal feedback diagram is obtained as shown in figure 1 with taking the urban city traffic, economy, population and the relationship between the elements of the

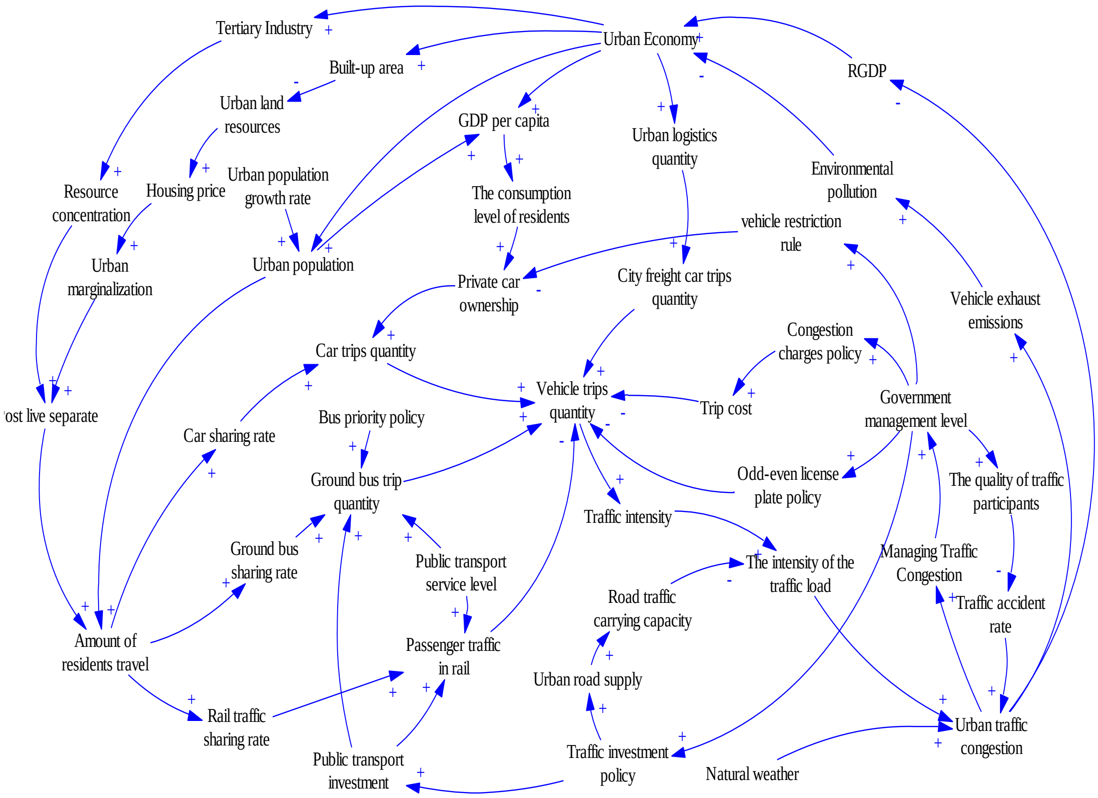

Figure 1 Urban city traffic congestion system causal loop diagram

system into account. Urban city traffic congestion system causal loop diagram has the following causalities: The feedback loop indicates that under the traffic congestion pressure, several measurements can be implemented to ease the traffic congestion which include: government strengthens the management of the traffic participants, actively promotes the traffic safety education, strictly carries out the traffic laws and regulations, and improves the traffic knowledge of the traffic participants in order to reduce the traffic accidents and ease the traffic congestion. The analysis of several feedback loops will be illustrated in the following sections which include: license plate limit policy, driving restriction on selected road system policy, the collection of traffic congestion fee, traffic investment increase and public transport investment increase strategy.

1）Urban city traffic congestion degree → + governance pressure → + government management level → + license plate limit policy → - private vehicle ownership number → + car travel volume → + motor vehicle travel volume → + traffic intensity → + traffic load intensity → + urban city traffic congestion degree

The above feedback loop indicates that the number of private vehicle ownership can be reduced by the license plate lottery system and further reduce traffic congestion.

2）Urban city traffic congestion degree→ + governance pressure → + government management → + driving restriction on selected road system policy → - motor vehicle travel volume → + traffic intensity → + traffic load intensity → +urban city traffic congestion degree

The above feedback loop shows that the driving restriction on selected road system policy (including truck limit policy), car and truck travel volume both can reduce the total amount of ground traffic travel volume and further reduce traffic congestion.

3）Urban city traffic congestion degree → + governance pressure → + government management → + traffic congestion fee policy →+travel cost →- motor vehicle travel volume → + traffic intensity → + traffic load intensity → + urban city traffic congestion degree

The above feedback loop proves that enforcement of traffic congestion fee collection, vehicle travel cost increase, and partial vehicle travel volume reduction can reduce traffic congestion.

4）Urban city traffic congestion degree → + governance pressure → + government management → + traffic investment policy →+traffic road supply →+ transportation load capacity → + traffic load intensity → + urban city traffic congestion degree

5）Urban city traffic congestion degree → + governance pressure → + government management → + traffic investment policy → +public transportation investment→ + passenger total amount (ground public transportation travel volume) →-vehicle travel volume →+traffic intensity→ + traffic load intensity → + urban city traffic congestion degree

The above two feedback loops explain that increasing transportation investment can enhance transportation capacity and relieve traffic pressure from the following two aspects respectively. On one hand, improving transportation fundamental facilities supply (including transportation main road extension, urban parking lots increase), on the other hand, increasing public transportation investment to attract more resident traveling with public transportation,

2.3 System dynamics stock-flow chart of the urban city traffic congestion

The causal relationship between all variables are qualitatively explained by the causal loop diagram. In addition, the system dynamics stock-flow chart needs to be determined in order to validate the simulation results. The variables such as urban city GDP, urban city permanent resident population, urban city road mileage, urban city railroad length, urban city logistics volume and NO2 stock are selected as the horizontal variables to form the system flow chart. The final system stock-flow chart is shown in figure 2.

III. ESTIMATION AND VALIDATION OF THE PARAMETERS IN THE URBAN CITY TRAFFIC CONGESTION SYSTEM DYNAMICS MODEL

3.1 System stock-flow chart and structural equations

The population, economy and traffic data used in this model are from Chongqing city urban area. Several assumptions have been made as follow in order to simplify the model.

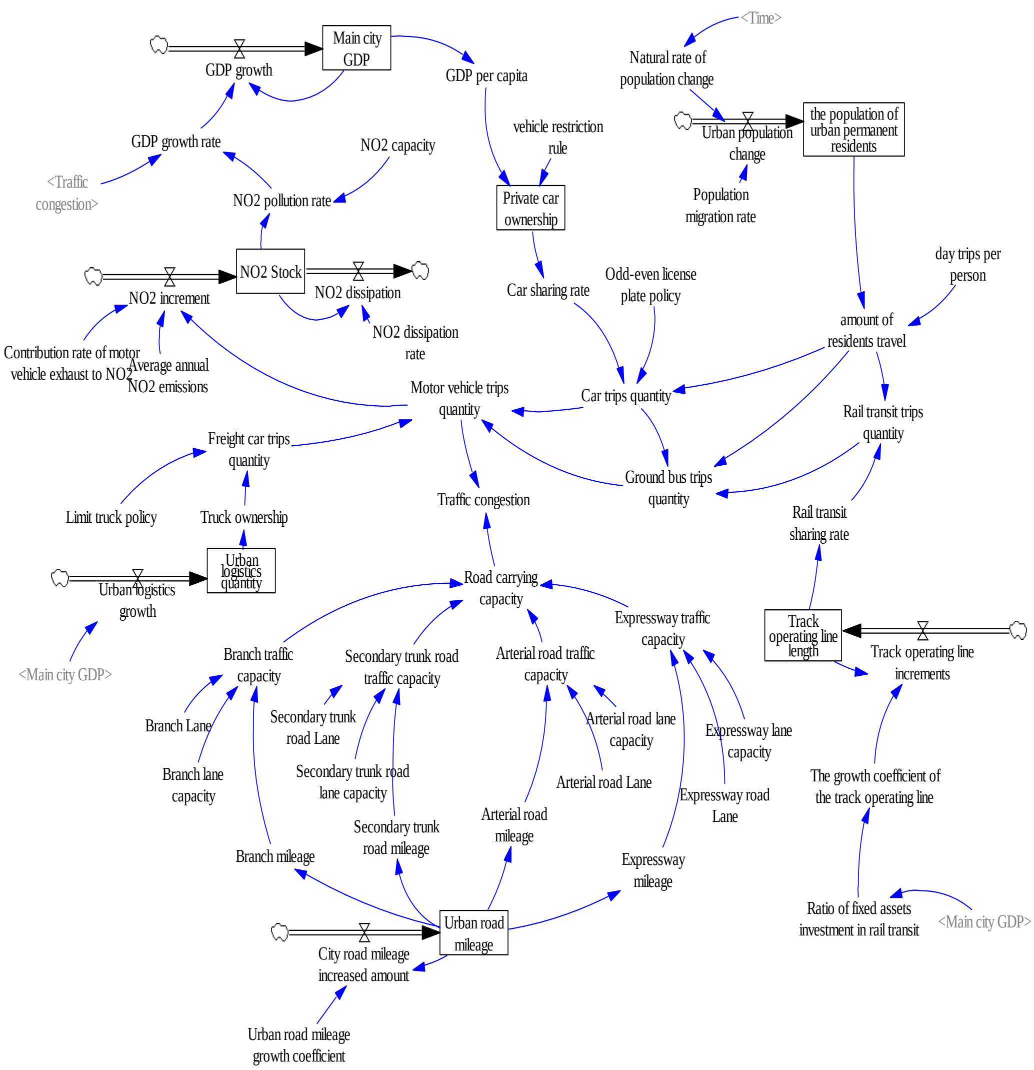

Figure 2 urban city traffic congestion system stock-flow chart

Assumption 1: data is from Chongqing city main urban area
Assumption 2: population only accounts for permanent resident in the main urban city
Assumption 3: immigration rate is the average of all years and not influenced by any other factors
Assumption 4: car mentioned in this paper includes private car and taxi
Assumption 5: motor vehicle only includes ground public bus, truck, and cars
Assumption 6: resident travel modes only consider ground transportation, rail transportation, cars, and walking
Assumption 7: environment pollution is measured by NO2
Assumption 8: license plate limit policy assumes that there will be a reduction of 10% car travel volume with limiting of one more number (Because the license mantissa 0 to 9, the license mantissa evenly distributed)
Assumption 9: different types of travel volume is distributed based on resident travel total times, unit is 10,000 times/day

（1） Traffic demand system

The traffic demand in this simulation mainly includes resident daily trip times and urban city logistics transfer in which resident daily trip modes mainly include car and ground public transportation travel total volume. Table 1 and 2 shows the average resident daily trip times in the urban city.

Table 1 Urban city resident daily trip times each year

Resource: Chongqing Transport Planning Institute yearly survey of resident trip in Chongqing city urban area

Year	2007	2008	2009	2010	2011	2012	2013	2014
resident daily trip total times (10，000 trips/day)	1210	1258	1271	1339	1378	1424	1466	1513
Resident daily trip times(trips/day)	2.18	2.21	2.2	2.25	2.28	2.31	2.32	2.35

Table 2 Urban city yearly resident trip share rate

<table>
<tr><td colspan="2">Year
Resident trip share ratio</td><td colspan="2">2007</td><td colspan="2">2008</td><td colspan="2">2009</td><td colspan="2">2010</td><td colspan="2">2014</td></tr>
<tr><td colspan="2">Walking ratio</td><td colspan="2">50.3%</td><td colspan="2">49.9%</td><td colspan="2">49.7%</td><td colspan="2">47.5%</td><td colspan="2">46.3%</td></tr>
<tr><td rowspan="3">Motor vehicle ratio</td><td>Rail transportation share ratio</td><td rowspan="3">49.7%</td><td>1.6%</td><td rowspan="3">50.1%</td><td>1.8%</td><td rowspan="3">50.3%</td><td>1.6%</td><td rowspan="3">52.5%</td><td>1.1%</td><td rowspan="3">53.3%</td><td>10.8%</td></tr>
<tr><td>Ground public transportation share ratio</td><td>69%</td><td>66.4%</td><td>64%</td><td>62.5%</td><td>49.9%</td></tr>
<tr><td>Car share ratio</td><td>29.4%</td><td>31.8%</td><td>34.4%</td><td>36.4%</td><td>39.3%</td></tr>
</table>

Resource: Chongqing Transport Planning Institute yearly survey of resident trip in Chongqing city urban area

As seen from table 2, resident choosing rail transportation ratio is increasing, the ratio of ground public transportation is decreasing while traveling by driving car is more and more popular.

The total logistics statistic is measured using yearly freight traffic volume of Chongqing city, while the truck ownership in the urban city is applied to measure the urban city truck number changing trend. Results are shown in table 3.

Table 3 Chongqing city logistics and freight traffic volume

Year	2007	2008	2009	2010	2011	2012	2013	2014
Urban city truck ownership number(unit: 10,000)	6.3	5.3	5.7	6.4	6.0	6.5	7.2	7.3
Yearly volume of freight traffic (unit: 10,000 tons)	49973	63651	68491	81385	96782	86398	97404	97284

Resource: Chongqing statistical yearbook 2007-2014.

The main structural equation of the traffic demand system is expressed as follow:

1）Resident total trip number = urban city permanent resident population*daily trip times per resident (unit: 10,000 trips/day).

2）Car travel volume = IF THEN ELSE(driving restriction on selected road system policy = 1, resident total trip times*car share rate*0.9, resident total trip times*car share rate)　　unit: 10,000 trips/day.

Note: driving restriction on selected road system policy equals to 1 which means limiting one number and the corresponding car trip times reduces 10 percent.

3）Ground public transportation travel volume= resident trip total number – light rail transportation travel volume – car travel times – resident travel total times*0.49 (unit: 10,000 trips/day).

Resident travel modes include rail transportation, car, ground public transportation, walking, in which walking takes up to 49percentage (average value)of all travel modes (According to the data in table 2).

Private car ownership number = IF THEN ELSE(license plate limit policy = 0, 3*10-8*urban city per capita GDP2+13.46,), (3*10-8*urban city per capita GDP2+13.46)*0.6). (According to the data in table 4).

Note: urban city private car ownership number is proportional to per capita GDP. Resident consumption increases with per capita GDP improvement. Hence car buying affordability also improves. It’s found that there is a quadratic relationship between per capita GDP and private car ownership number from SPSS software. The expression is as follow:

Private car ownership number = $3*10^{-8}$*urban city per capita GDP^2+13.46 (According to the data in table 4).

Table 4 Chongqing city yearly rail transportation situation

Resource: Chongqing statistical yearbook 2007-2014.

Year	2007	2008	2009	2010	2011	2012	2013	2014
Daily total number of passenger (10,000 trips)	9.5	10.9	18.6	12.3	34	69.1	109.8	141.7
Rail transportation operation length(Km)	19.2	19.2	19.2	19.2	74.8	131.0	170.0	202.3
Rail transportation investment(￥10,000)	—	—	652656	1169406	1671356	995152	816416	—
Private cars (unit: 10,000)	15.7	19.3	25.1	32.5	40.7	49.7	59.8	76.5
The city's per capita GDP (yuan)	16629	20490	22920	27596	34500	38914	42795	47688

Rail transportation structural equation is expressed as follow:

1） Rail transportation travel total volume = resident travel tirp times*rail transportation share rate(unit: 10,000 trips/day)

2） Rail transportation share rate =
([(0,0)-(1000,10)],(19.2,0.016),(19.2,0.018),(19.2,0.016),(202.3,0.108),(478,0.22),(820,0.3))

3） Railroad operation length = INTEG(railroad operation increase, 19.2)

4） Railroad operation increase = railroad operation length*railroad operation increase coefficient

5） Rail transportation fixed asset investment ratio = ([(2000,0)-(20000,1)],
(2986.23,0.0123),(3596.71,0.0168),(4207.63,0.0219),(5116.49,0.0106),(5681.17,0.0073))

In summary, Chongqing city urban are traffic congestion system dynamics model related parameters and initial values are presented in table 5 with combination of parameters’ true value.

Table 5 Chongqing city traffic system model parameters and initial values （2005）

Parameter or initial value	Value	Unit	Note
Main urban city permanent resident initial value	645.51	10,000	Initial value
Urban city logistics volume	42808	10,000tons	
GDP main urban city GDP	1514.73	100million	
Rail transportation length	19.2	Km	
Urban city road mileage	1934.83	Km	
Express lane capability	1800	Pcu/h	refer to Chongqing city urban area road planning index, average
Express lane number	6	lane number	
Main road capability	1700	Pcu/h	
Main road lane number	5	lane number	
Secondary road capability	1640	Pcu/h	
Secondary road lane number	3	lane number	
Branch road capability	1570	Pcu/h	
Branch road lane number	2	lane number	
Immigration rate	0.0215	N/A	yearly average
Per capita daily trip times	2.16	trips/day	
Urban city road mileage increase coefficient	0.087	N/A	
Rail transportation fixed asset investment ratio	—	%	table function

Urban city logistics volume increase rate	—	10,000ton	
Limit truck policy	1	N/A	limit truck policy
License plate limit policy	0	N/A	no license plate number limit policy
Population changing rate	—	N/A	Natural birth rate – natural death rate

Resource: Chongqing statistical yearbook 2005.

2）Urban city development system
Urban city resident is measured in the city development system and expressed in table functions. The main structural equation of the city development system is as follow:
1）Urban city permanent resident population = INTEG(urban city population changes, urban city permanent resident population initial value) unit: 10,000
2）urban city population changes = urban city permanent resident population*(population change rate + immigration rate) unit: 10000
birth rate table function =
{[(2006,0.01149),(2007,0.01388),(2008,0.01333),(2009,0.0125),(2010,0.0191),(2011,0.01244),(2012,0.01102),(2013,0.01069),(2013,0.01069)}
3）urban city economic system
City GDP is the main research objective in the city economic system and the main structural equation is as follow:
1） Urban city GDP = INTEG(GDP increase, urban city GDP initial value) unit: 100 million
2） GDP increase = urban city GDP * GDP increase unit: 100 million

3.2 Model validation

The population, economy and transportation system data are simulated based on the equations and initial data as shown in table 6

Table 6 Chongqing city traffic congestion simulation and actual value comparison

	Simulation	Actual value	Relative error(%)
Urban city permanent resident	818.784	818.98	-0.02%
Main urban city GPD	6487.94	6289.05	3.1%
Yearly freight traffic volume	105503	97404	8.3%
Railroad operation length	170.084	170.00	0.49%
Urban city road mileage	3771.2	3730	-1.1%
Resident trip total times	1555.69	1513	2.8%
Main urban city per capita GDP	79239	76791	3.2%

Resource: Chongqing statistical yearbook 2014.

As seen from table 6, the relative error between the simulation results and actual values is less than 10% in which most of them are under 5%. The model shows a good match with actual value.

IV. SIMULATION AND ANALYSIS OF THE EFFECTIVENESS OF TRAFFIC CONGESTION GOVERNANCE

The simulation functionality plays a critical role in applying system dynamics to solve various problems. Solutions to a problem can be evaluated using simulation software Vensim in which critical parameters can be varied to analyze their influence. This paper conduct simulation to evaluate the effectiveness of different limit policies including plate number lottery policy, driving restriction on selected road system policy, rail transportation investment increase and influence of different parameters including urban city private car ownership number, car travel times and rail transportation operation mileage. The simulation results and analysis are analyzed and summarized as follow:

（1） Effectiveness of license plate limit policy

License plate limit policy including limit single or double number or limit of no. Figure 3 shows that the policy can help to reduce traffic congestion in a short time when the household car number is one. While wealthy family or people relying on a car for commuting purchases a second car to avoid the policy, the effectiveness of this policy is diminishing and even bringing in worst side effects finally. Results show that the license plate limit policy may reduce traffic congestion temporarily, but not permanently especially when the motor vehicle ownership increases.

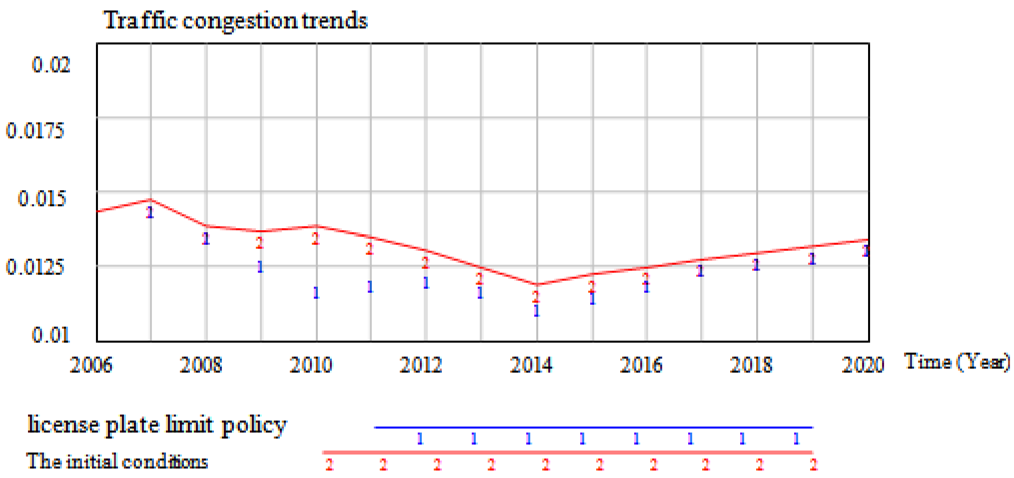

Figure 3 Traffic congestion trends with enforcement of license plate limit policy

（2） Effectiveness of driving restriction on selected road system

Simulation results are generated and plotted in figure 4 based on the assumption 7. Private car travel decreases while public transportation travel increases with enforcement the policy which also helps to reduce urban city motor vehicle total travel volume so as to ease traffic congestion. However, side effects occur in the urban city of which it has a slow public transportation development progress, immature public transit system, and online reservation platform. (Chongqing city has not enforced this policy yet instead of collecting ￥2300 toll for local vehicles and high ‘city entrance’ fee for non-local vehicles)

Policy application: 1) collecting traffic congestion fee necessarily. According to a survey from America, it’s found that the traffic flow was obviously reduced by 20% and the traffic congestion was eased with enforcement of this policy. 2) differentiating parking management policies, such as increasing parking fee in business areas, encouraging resident to travel with avoiding traffic peak; collecting parking fee based on car capacity and load; optimizing logistic distribution center and appropriately selecting freight hubs. 3) developing travel information website and urban city intelligent transit system by taking advantage of internet technology to ease traffic congestion

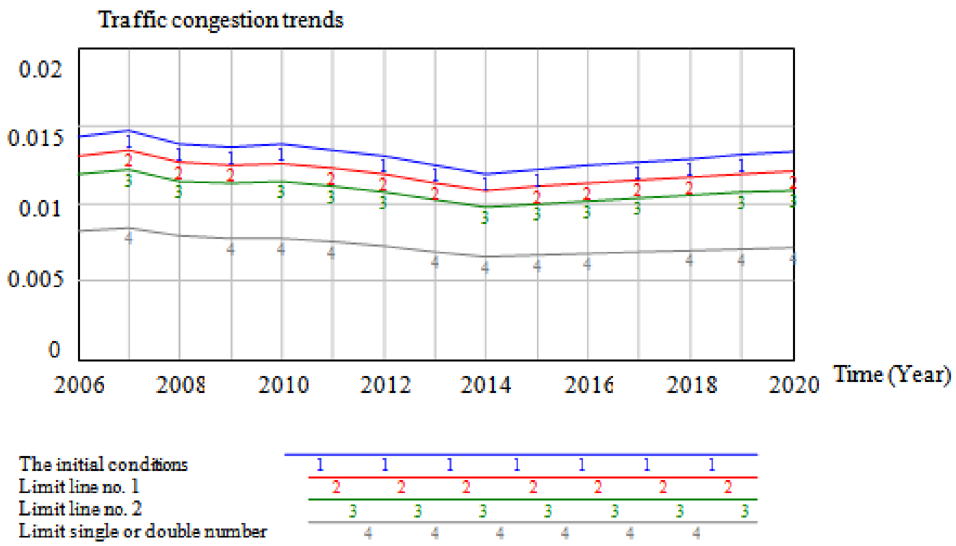

Figure 4 Traffic congestion trends with enforcement of driving restriction on selected road system policy

（3） Comparison of license plate limit policy and driving restriction on selected road system policy

As shown in figure 5, driving restriction on selected road system policy is working better than the license plate limit policy while it can achieve the best performance with enforcement of both policies at the same time. However, the effectiveness is reduced and diminished with more motor vehicles which prove that both policies are only able to ease traffic congestion temporarily when the total number of motor vehicles is fixed.

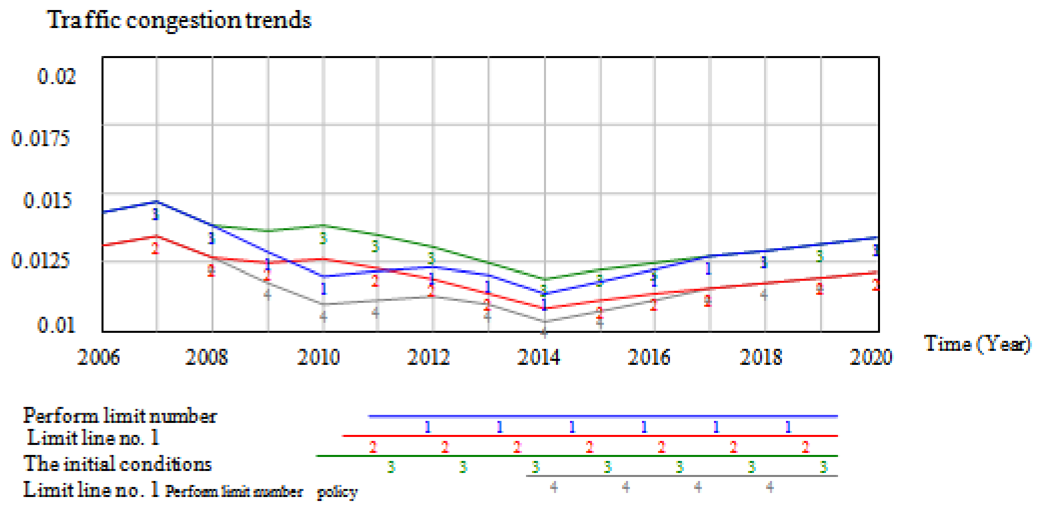

Figure 5 Effective of two policies comparison and combination of two

（4）Railroad share rate and railroad length relationship

Rail transportation share rate directly impact car and ground transportation share rate and indirectly reduce the motor vehicles travel volume and ease traffic congestion. Figure 6 indicates the trend of rail transportation share rate with the implementation of the rail transportation investment policy and reducing railroad operation length. The results show that the rail transportation share rate is changing proportionally with the railroad length.

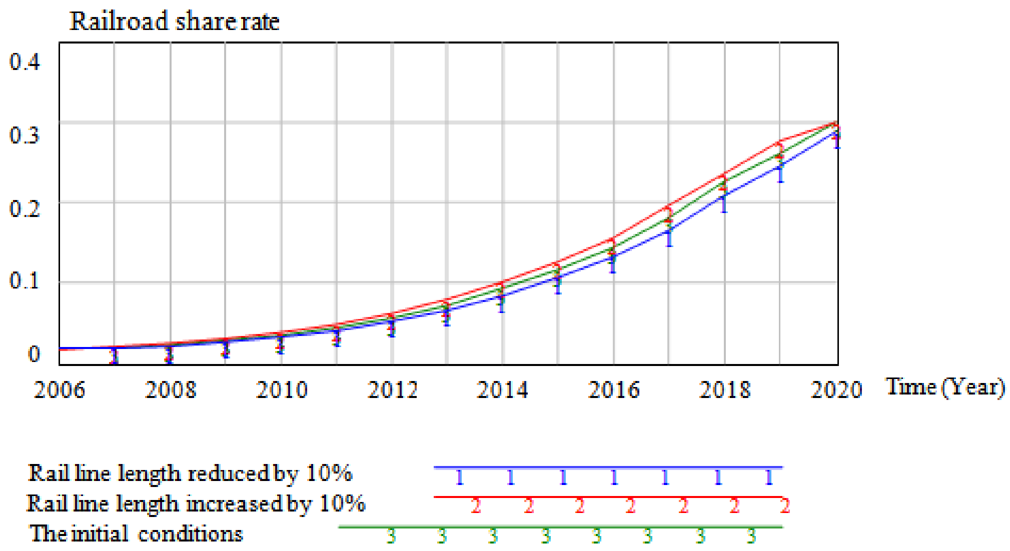

Figure 6 Railroad share rate vs railroad line changes

Suggested policy: encouraging resident travel with public transit system such as rail transportation, optimizing rail station distribution and reduce travel distance.

（5）Effectiveness of increasing rail transportation mileage

As seen the trend shown in figure 7, the railroad mileage increase can ease traffic congestion to a certain extent since the increase of railroad share rate leads to the decrease of the car and ground public transportation. In contrary, it may result in worse traffic congestion since the total length of operated railroad is small and its influence on the traffic congestion is insignificant. Such as a 10% increase of a total 19.2km railroad wouldn't be able to make a huge difference.

Based on the comparison of simulation results in figure 6 and 7, rail transportation rate can be increased with a 5% increase of railroad length. Rail transportation has its unique advantages such as large volume, no environment pollution, on time, fast, energy efficient, low accident rate and low operation cost. Development of rail transportation is sustainable to the environment and city development; hence it should be strategized in a very high priority.

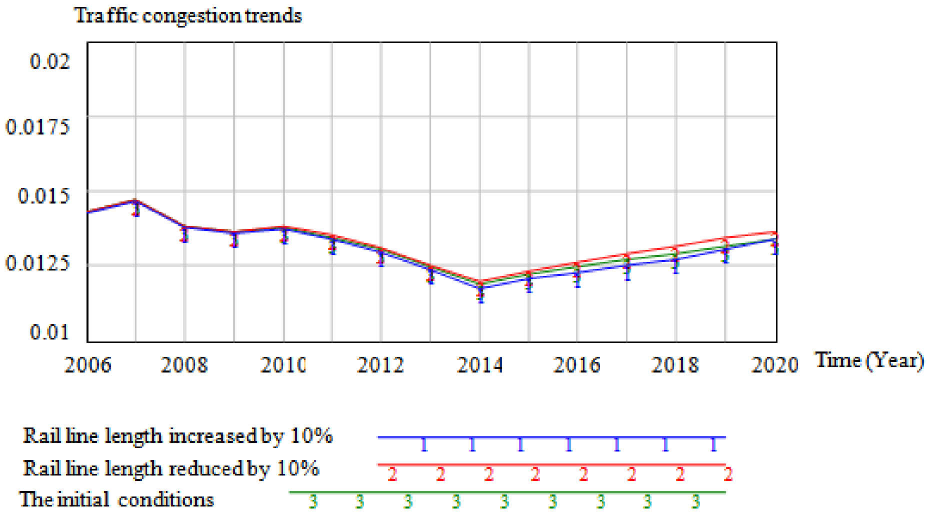

Figure 7 Urban city traffic congestion changes with railroad length

（6）Effectiveness of urban city road mileage changes

Figure 8 is the influence of increasing urban city road length on urban city road capacity and traffic congestion improvement. As seen from the results, a half reduction of urban city road length will significantly worsen the traffic congestion, while a 50% increase of road length wouldn't have sufficient easement to the current traffic congestion situation. Since a significant increase of road length will hugely ease the traffic congestion in a short period of time, however, it will attract more motor vehicles and worsen the traffic in a long term. Hence it is urgent to emphasize on clearing traffic at all busiest roads with taking measurements such as acceleration of the improvement and new construction of each interchange and intersections, restarting the Chongqing city inner ring highway interchange project and making policies fitting the unique situation of Chongqing city.

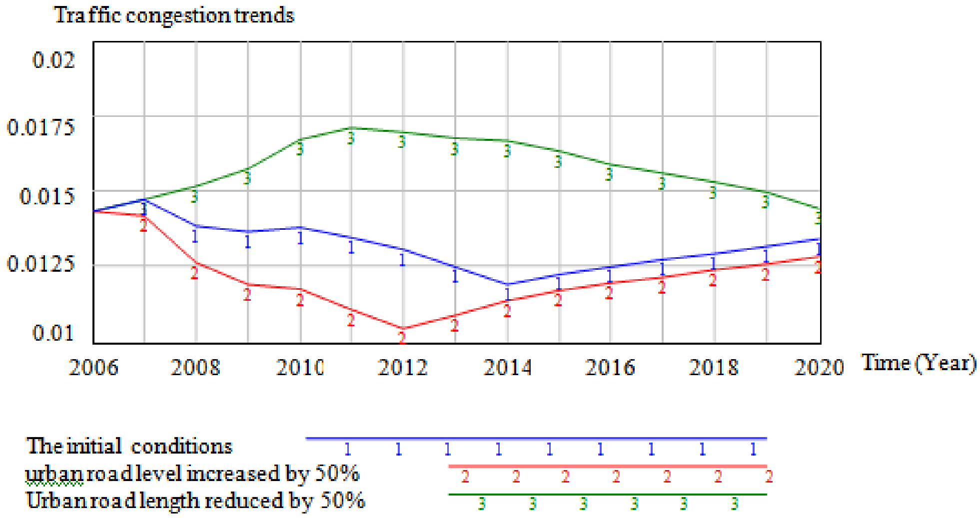

Figure 8 Urban city traffic congestion changes with road length

V. CONCLUSION

In conclusion, based on the system dynamics methodology and simulation results:
(1)License plate limit policy including limit single or double number can help to reduce traffic congestion in a short time when the household car number is one. Results show that the license plate limit policy may reduce traffic congestion temporarily, but not permanently especially when the motor vehicle ownership increases.
(2) Driving restriction on selected road system helps to reduce urban city motor vehicle total travel volume so as to ease traffic congestion, limit line policy still has its negative effects. Policy Suggestions: collecting traffic congestion fee necessarily; differentiating parking management policies; developing travel information website and urban city intelligent transit system by taking advantage of internet technology to ease traffic congestion
(3) Prioritize public transportation development , rail transportation share rate directly impact car and ground transportation share rate and indirectly reduce the motor vehicles travel volume, encouraging resident travel with public transit system such as rail transportation, optimizing rail station distribution and reduce travel distance.
(4)It is urgent to emphasize on clearing traffic at all busiest roads with taking measurements such as acceleration of the improvement and new construction of each interchange and intersections, restarting the city inner ring highway interchange project and making policies fitting the unique situation of city.

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