The System Dynamics Research on the Private Cars' Amount in Beijing

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Abstract. The thesis analyzes the development problem of private cars' amount in Beijing from the perspective of system dynamics. With the flow chart illustrating the relationships of relevant elements, the SD model is established by VENSIM to simulate the growth trend of private autos' amount in the future on the background of "Public Transportation First" policy based on the original data in Beijing. Then the article discusses the forecasting impacts of "Single-and-double license plate number limit" on the number of city vehicles and private cars under the assumption that this policy implemented for long after the 2008 Olympic Games. Finally, some recommendations are put forward for proper control over this problem.

Keywords: Private cars' amount in Beijing, System dynamics, Social economic modeling, Policy simulation and control.

1 Introduction

The 2008 Beijing International Automotive Exhibition, which was the largest one of such kind hitherto in China, had dropped its curtain. Cars purchase had become a fashion since recent years, and the sales volume made the final success of Beijing auto expo. Over the past decade, cars' sales quantity increased by almost 10 times in China. Beijing, as China's political and cultural center, its people's living standards kept ahead compared with others and the amount of individual cars in city was rapidly expanding. On the one hand, along with the entrance into WTO, the automobile industry opened more widely, the prices of cars went in line with equal level of the international market gradually, and the price wars were not uncommon launched in full swing. On the other hand, the potential production capacity in autos manufacture made excess quota and formed a seller's market. In Beijing, with the higher salary and cars' price shrinkage, it's no longer a dream for average residents to possess a small or medium-sized car. However, if everyone owns a personal auto, whether this nice dream would end in a nightmare? The large population in Beijing had resulted in city crowd and housing tension, for the traffic works as the city venation, too many private cars will aggravate the traffic congestion and deteriorate the environment even worse undoubtedly. The theme of Auto China 2008 was impressing as saying "Dream, Harmony, New Vision". Then how to unify this motif with the development of city harmoniously? The research on trend forecast of private cars and finding reasonable ways for good control is significant.

System Dynamics (SD) was created by Forrester, one famous professor of MIT, in the 1960s. This approach emphasizes system internal structure and feedback mechanisms,

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being good at solving complex system problems featured as long-period, high-order, non-linear and multi-variables (see [1]). This method has been used in various fields universally since it was founded and the problem of urban development belongs to the social complex systems area which suits for SD to make further study. The recent researches were more about city's resources and ecological environment, involving urban water resources, land resources and reserves, waste management etc. On the city traffic aspects, Liu Qing in [2] structured a dynamic model to analyze the effect and structure of urban road transport system, Zhang Lin-feng in [3] established SD models about city centers forming and evolvement to make a conclusion that the traffic situation can promote or inhibit city centers development. In [4], Le Ming-bo proposed the implementation of traffic jam fee illustrated by the cause relation chart in urban traffic. Most of these studies focused on macroeconomic structural analysis and model establishment, rarely made simulation runs or forecast with historical data, not to mention expound and adjust on the background of policy. Whereas by using the scientific SD simulation method, this paper analyzed main causes that impact private vehicles' amount in Beijing and its feedback loops, established system dynamic model. Then with the statistical data combined qualitative and quantitative analysis, it made simulation run under the policy that encourage the public transportation career to predict the future trend of private cars in city. Lastly the article renewed the model aiming at the hot issue that whether the "odd-even license traffic restriction" strategy should be applied permanently after the Beijing Olympic Games, compared the simulate results and gave some policy recommendations.

2 System Analysis and Modeling

2.1 System Boundary

The system's behavior is generated by the interactions of system inner elements. SD assumed that the external environment changes which are not controlled by internal factors wouldn't affect the system's behavior essentially. So the conception factors and variables in the internal border of the system which have intrinsic relationships with the dynamic research issue should be brought into the model, while those external variables should be excluded (see [5]). The system of urban dwellers' private cars is complex and socio-economic. It not only includes sections such as circulation, exchange and consumption of motor vehicles, but also contains urban population, economic, environment, control policy, public transportation and other sub-parts. According to the modeling purpose of this paper, the system is defined in a scope involving private cars' amount, price, use expending, per capita disposable income, the number of resident population, the total number of Beijing household, passengers transportation amount by public traffic, the total amount of motor vehicles, the number of buses and taxis, the number of parking spaces, roads areas and other level variables.

2.2 Cause Relationship and Dynamic Model

Causalities determine the system behaviors and functions. Analyzing the factors that affect private cars demand, it can be summed up as follows: urban road construction, traffic management level, parking lot building, public transport, cars' price, use expending, purchase tax, people's income, and control policy.

Some condition changes such as speeding up the road construction in city, increasing the residents' income, declining private cars' price and renovating peoples' consumption conception would help to encourage the purchase of private cars. While others, such as increasing the use expending (included fuel cost, road toll, parking fee, insurance fee etc.), strengthening the policy control power, developing the public transportation will curb private cars' consumption in Beijing. In addition, the increasing amount of private cars raises the per capita ownership, which could stir the comparison psychology of consumption and take a role in promoting the purchase of private cars. Then the volume expansion of the city total motor vehicles decreases per vehicle road area leading in more road traffic pressure and potential environment threats, which should force the government to focus its control intensity. Besides, the supply and demand ratio of parking lot is deflating along with the vehicles growth. The increasing fee of parking would result in use expending rising and effect consumption psychology. Such factors may choke back consumption of the private cars as well.

Based on the analysis above and taken the causalities of elements into account, a SD flow chart of private cars' amount in Beijing is designed in which correlative level variables, rate variables and information flows are combined organically to point out the action mechanism of this system. (Figure 1)

The SD model is built as follow:

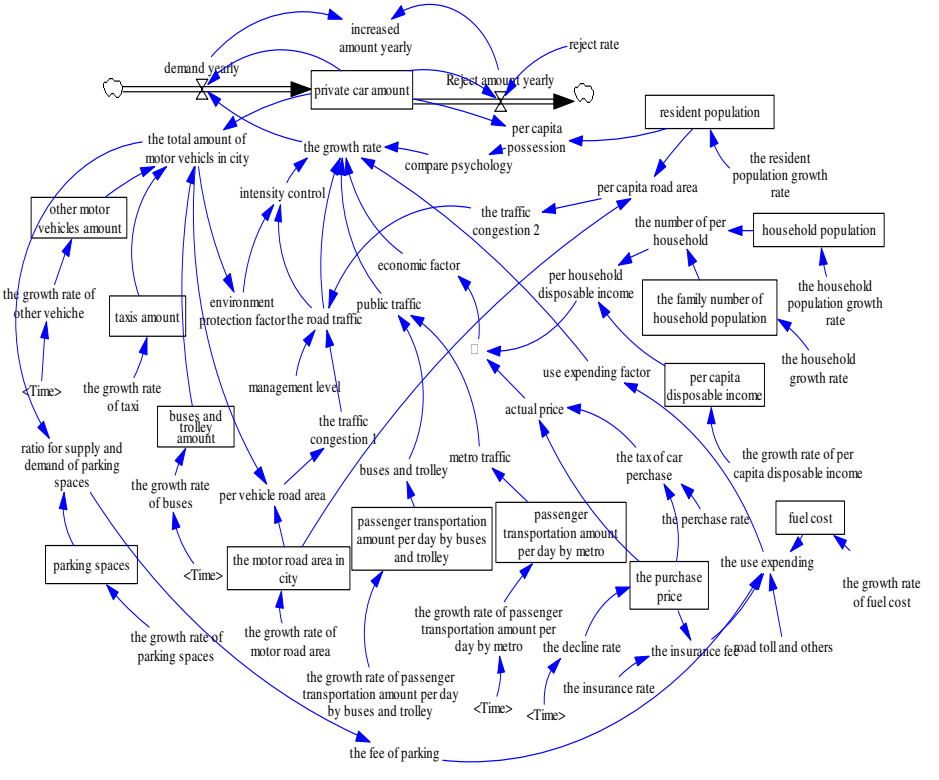


Fig. 1. The SD model for the amount of private cars in Beijing (VENSIM platform)

According to the research finding of Qian Ping-fan, it is the Ⅱ value (the ratio that price of cars is divided by annual income of household) that decides the actual progress of private cars' household in China when choose the best parameter among some reference standards (per capita GDP, R value, Ⅱ value) to judge whether and when private cars enter into families in a region. In his thesis (see [6]), 2001 was the starting year indicating the entry of private cars into resident families in Beijing. Therefore in this paper, it adopts the standard of Ⅱ value to weigh the consumption effect made by residents' income level and adjusts the cars' price to actual price. The statistical data of 2001 are filled as initial values in the follow-up simulation as well.

2.3 Model Equations and Parameters

The System Dynamics model contains level equations, rate equations, auxiliary equations, parameters equations and initial value equations. Make out these model equations, initial parameters and lookup functions and check them as a whole. The parameter values are calculated by statistic samples from 2001 to 2006, and the data of 2007 remained as a test sample.

Referring to "Beijing Statistics Yearbook, 2001", the statistical data collected from Beijing traffic management office and other relevant information gathered, the initial values are set as below.

Table 1. The model initial value

Variable name	Initial value	unit
Private car amount	624000	liang
Taxis amount	65155	liang
Buses and trolley amount	14803	liang
Other motor vehicles amount	995042	liang
The purchase price	200000	yuan
Resident population	1.3851e+003	Ten thousand person
Household population	1.1223e+003	Ten thousand person
The family number of household population	4.053e+002	Ten thousand family
Parking spaces	30	Ten thousand wei
The motor road area in city	5.2087e+003	Ten thousand square meter
passenger transportation amount per day by metro	1.28411e+002	Ten thousand person per day
passenger transportation amount per day by buses and trolley	1.1037e+003	Ten thousand person per day
Fuel cost	4000	yuan
per capita disposable income	11577.8	yuan

Parameters setting:

1. Computer the logarithm of resident population in Beijing from 2001 to 2006. The trend chart is shown as follow by SPSS (Figure 2).

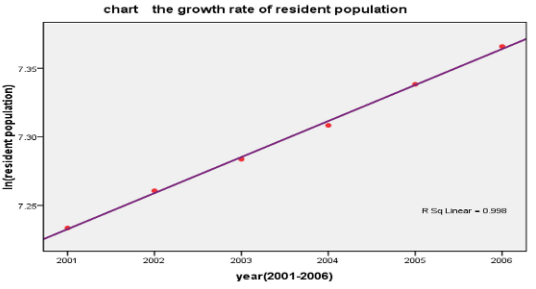


Fig. 2. The growth trend of resident population in Beijing

It's unnecessary here to forecast the resident population growth precisely. As seen from the scatter diagram, the increase of resident population properly fits the linear growth rule by and large. To simplify the model, the resident population growth rate is reckoned as a constant. Fitting the line to get the equation:

$$Y=0.026N-45.295 \tag{1}$$

$R^2=0.998$ Y—the logarithm of resident population N—year

So the average resident population growth rate is 2.6%. Similarly, based on the historical data collected, figure and fit each level variable into logarithm growth equation and make out the average growth rate. Finally some basic growth parameters of the model are gained: the growth rate of per capita disposable income is 11.7%, the growth rate of household population is 1.31%, the growth rate of the number of urban households is 2.62%, the growth rate of road area is 3.1%, the growth rate of parking spaces is 23% and the growth rate of taxis' amount is 3.78%. Besides, because the linear fitting equation figures the growth rate of buses' amount without a high accuracy, the same as the growth rate of other vehicles' amount counted, these two parameters are given in the form of lookup functions.

According to "Beijing traffic planning--11.5", it's said that till 2010, the public passenger transportation system of city center would assume 40% of total passenger transportation volume, among these, 13~15 million passenger transportation taken by buses and trolley other than 5~6 Million taken by metro. Thus taking the average growth rate computed by historical data into account, the growth rate of passenger transportation amount per day by buses and trolley is set as 0.8%. And in view of the hold of 2008 Olympic Games, along with Metro Transportation Development Policy in Beijing, the construction speed of metro career would be even faster than before, so set the growth rate of passenger transportation amount per day by metro as 6% till 2010 and 15% after then.

2. The initial car purchase price is set as 200,000 Yuan. Since the automotive market is opening more widely, suppose that the price decrease gradually and remain

around 100,000 Yuan till 2015. In addition, the insurance rate of Private car is 4% and the reject rate is 6.67% according to National Automotive Rejection Policy. The parameter of road toll and other costs is set as 6,000 Yuan approximately.

3. The growth rate of private cars' demand is determined by factors combined such as control power, road traffic, public traffic, economic factor, use expending factor and compare psychology. These factors act in the form of lookup functions with a range of 0~1. The formula of lookup function is presented as below.

$$Y = withloopup\,(X, ([(x_{\min}, y_{\min}) - (x_{\max}, y_{\max})](x_1, y_1)(x_2, y_2)\cdots\cdots(x_n, y_n)))$$

4. Take some equations in the SD model for example:

L private car amount = INTEG (demand yearly - Reject amount yearly, 624000) (2)

L resident population = INTEG (the resident population growth rate * resident population, 1.3851e+007) (3)

A the road traffic = the traffic congestion 1^0.6* management level* the traffic congestion 2^0.4 (4)

C reject rate = 0.067 (5)

The equation of private cars' growth rate is designed by referred the similar formula in "Impact on Sedan Demands after China Joins the WTO" written by Wang Qi-fan and Jia Jian-guo (see [7]). Then trained by several model adjustment and simulation, it is defined as follow.

R the growth rate= (1- the road traffic) ^0.05*(1- intensity control)* economic factor^0.05* compare psychology^0.095* use expending factor^0.5*(1 - public traffic)*a (ratio a=1.5) (6)

The model equations are not listed one by one since the number as a whole is very large. Finally, a complex system dynamics model which includes 64 equations, 14 orders has been established. This model, taking the main factors that influence the development of private cars' amount in Beijing into account, could make a dynamic and long-term demonstration for the object variable.

2.4 Test of the Complex System Model and Simulation

Simulate the model by different running steps as 0.25/0.5/1 and make a comparison for the forecasting trends of private cars' amount in Beijing. It is shown that the system behavior is stable (Fig.3). With non-sensibility to the changes of parameters, the model properly reflects the complexity of the socio-economic system. It has a good robustness character and gains no pathological results.

The SD model simulates the medium and long term development trend of private cars' amount in Beijing based on the statistical data from 2001 to 2006. Selecting some simulating results in 2007 of variables and making comparisons with actual values (Table 2), the contrasted results show that the errors of them are very small and

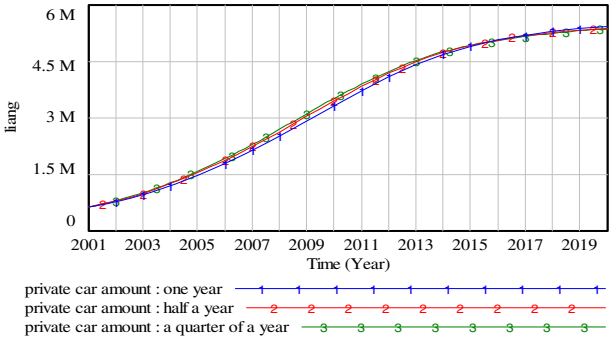


Fig. 3. Model stability analysis

Table 2. Compare the forecasting and actual with values in 2007

Item	Simulate value	real value	error
Private car amount (Ten thousand)	212.97	212.1	0.410%
The total amount of vehicles in city (ten thousand)	313.671	312.8	0.278%
Resident population(ten thousand)	1626.14	1633	-0.420%
Household population(ten thousand)	1213.45	1213.3	0.012%
The family number of household population (ten thousand)	473.335	473	0.071%
The motor road area in city (Ten thousand square meter)	6255.78	6272	-0.259%
per capita disposable income(yuan)	22487.7	21989	2.268%
Buses and trolley amount	19394.9	19395	-0.001%
Taxis amount	666.46	66646	0.000%
passenger transportation amount per day by buses and trolley(Ten thousand person per day)	1157.75	1157.93	-0.016%

the system behavior described by model is consistent with the actual action. The model is constructed effectively.

3 Model Analysis and Policy Adjustment

3.1 Trends Forecast

As shown in the simulating chart (figure 4), the development of private cars' amount in Beijing has an "S-type" growing trend and till 2020, the number will reach about 5 million. This quantity consists with the conclusion cited by "Master Plan of Beijing City (2004-2020)". According to the curve, now the development of Beijing private cars' amount still stays in its fast growth phase and the demand of private cars is expanding largely. The demand potential will peak at 2010, and after then will be decreasing slowly. The amount of private cars will stay stable gradually after 2016.

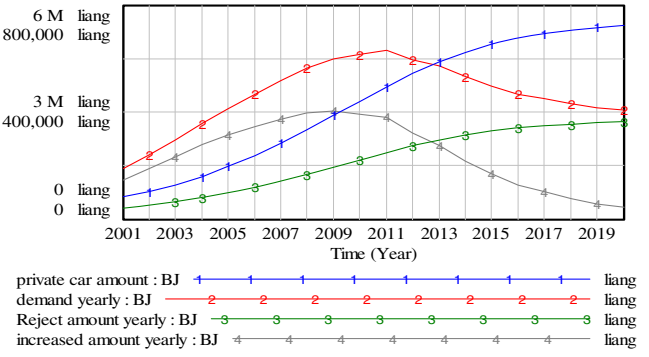


Fig. 4. The development trends of private cars in Beijing

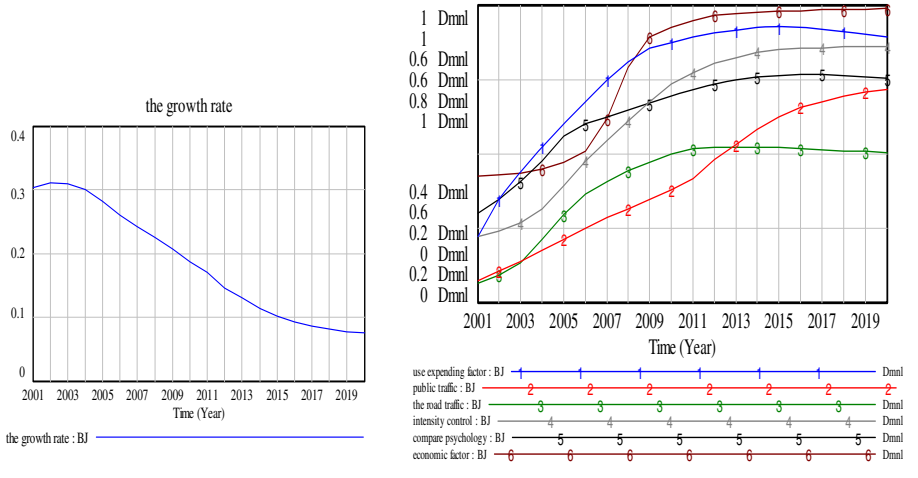


Fig. 5. The growth rate and growth factors of private cars in Beijing

Seen from the charts of growth rate and factors (figure 5) to make some analysis, it can be concluded that the growth rate had experienced modest growth in the years 2001-2002 and then reduced gradually, the forepart of that is also in line with the actual statistical data from 2001 to 2007. As forecasting result shows, the growth rate of private cars in the future will keep stable after 2016. By analyzing the growth factors, at the beginning, some elements, such as the rising of economic level, compare psychology strengthened and the reducing of use expenditure resulted by the decline of cars' price (use expending factor augments and works), promote the consumption of private cars in Beijing. However, with the amount of private cars increasing, the growth rate of urban roads can not keep the pace of motor vehicles' growth, which makes the situation of traffic congestion even worse. Meanwhile, for the increasing of the total motor vehicles' amount, taking the awareness of environment protection and traffic congestion alleviation into account, the government is forcing the control power. Besides, one factor can't be ignored is that the "Public Transportation First" policy gradually presents its advantages. Subsequently and

remarkably, all these factors take the leading role to reduce the consumption demand. The growth of private cars' amount in the future becomes stable under impacts by the whole factors' collective work.

3.2 Policy Adjustment

After the 2008 Olympic Games, whether the policy "Single-and-double license plate number limit" should be long insisted is a hot issue. As to this problem, the paper carries out a comparative study in the following part. According to "The 2008 Temporary Traffic Management Measures on Motor Vehicles during Olympic Games and Paralympics Games in Beijing", it said some vehicles that the large passenger cars, buses, trolleys, taxis and small buses, travel coaches are unrestricted by "odd-even-limitation". Then the original model is modified (Figure 7) with simulating step=0.5 for the "odd-even" policy in Beijing implemented on July 20, 2008.

The equation of "odd-even" limit ratio is set as follow:

A The ratio of "odd-even" limit= IF THEN ELSE (Time<=2007, 1, 0.5) (7)

Assumed that the policy will impact the growth rate by consumption psychology, and the effect is weakening over the time in linear form. Carry out the policy simulation as follow:

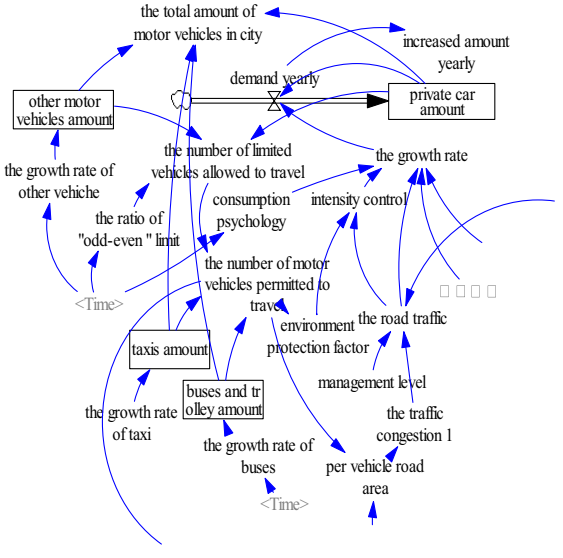


Fig. 6. Renewed part

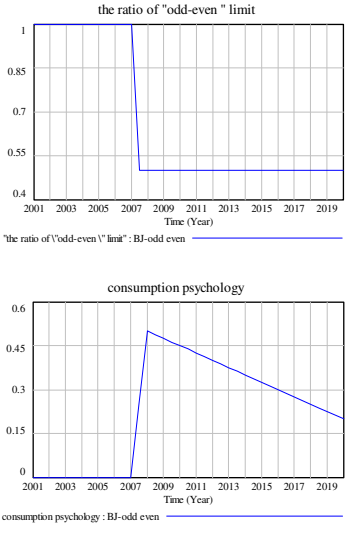


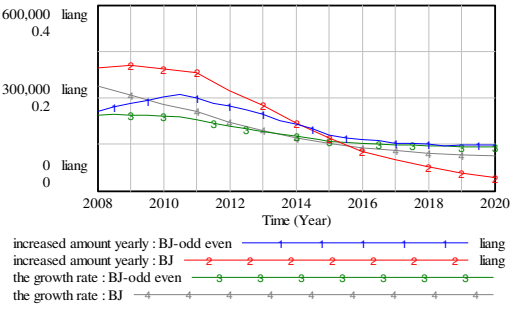
Fig. 7. The ratio of "odd-even" limit and consumption psychology

Comparing the simulating results, it shows that the growth trends of total amount of motor vehicles and private cars both shrink in recent years under carrying out the "odd-even" policy for a long time because the policy has an impact on consumer psychology, which suppresses the purchase of the private cars. But in the long term, the impact of

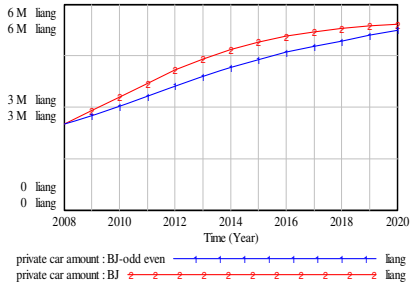
this policy acts feebly and the stable amount goes close to the original line, because the travel restriction results in less motors traveling on the road, contributing to traffic fluency, environmental pressure alleviation and government control relaxation, all of those would be in favor of the private cars purchase. That is, on this premise the impact of the policy on psychology lessens along with the time, the "odd-even Limit" policy, to some extent, can put out the enthusiasm of consumers to buy cars in early time, but in a long run, under the factors combined, the policy couldn't inhibit the growth of private cars far away. The growth rate increases faster than original level over time, making the amount even larger than that of non-implementation state.

Thus it needs to find a better solution from other way. Make an assumption that the project of Beijing Municipal Rail Transit quicken its construction speed after 2008, and adjust the parameters appropriately to improve the growth rate of passenger transportation amount per day by public traffic after 2008. The new simulating result is shown as follow.

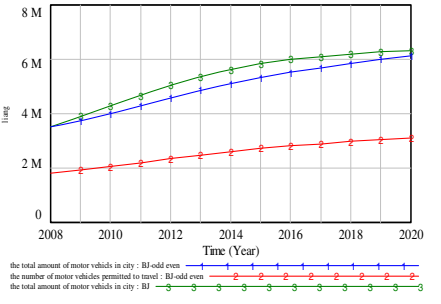
Compared the results with the original forecast, speeding up the development career of public transportation shortens the increasing period of private cars, makes the



(a)



(b)



(c)

Fig. 8. The comparison chart of simulating results (odd-even license plate limit) (a) Increased amount yearly and the growth rate (b) Private car amount (c) The total amount of motor vehicles in city and the number permitted to travel

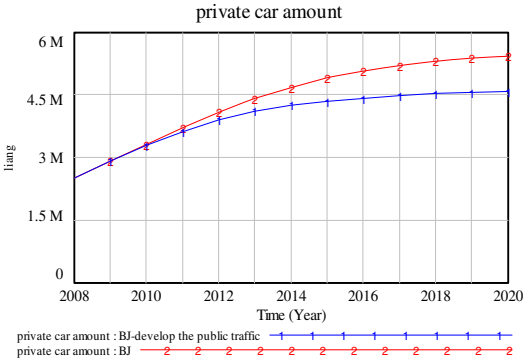


Fig. 9. The comparison chart of simulating results
(Speed up the development career of public transportation)

stable phase achieved much faster and significantly reduces the total amount of original estimated. Most importantly, this advantage of control will be more obvious over time without opposite effects and rebound. So it is an effective measure to restrain the number of private cars in Beijing.

In addition, building urban public transport system and providing high-quality public traffic services could provide a more comfortable and secure environment. That would attract more residents to utilize public transport, reduce the demand of private cars and ease traffic tension. At the same time, this measure harmoniously accords with the requirements of environmental protection, on which should be paid positive attitudes and more attention.

4 Conclusions

According to the simulating analysis, the growth of private cars amount fits an S-shaped pattern. Recently, it is still in a rapid increase period that the peak value has been untouched yet. As the highest point of the demand is coming, the amount of private cars will be expanding. It's necessary for the government to make efforts on amount control. On the study that long-term implementation of "odd–even motor license limit" policy in Beijing, this strategy is good for short term to restrict private cars' amount effectively, reduce the total amount of motor vehicles and the traffic pressure. But for long time, this policy trends to play little role and makes reverse effect that the growth rate rises higher than un-implement state. So it's better to be considered and listed in five-years program rather than long-term plan. By contrast, speeding up the development pace of public transportation can choke back the number of private car satisfactorily and won't be counterproductive along with time. Shortening the rising phase of private cars' development and shrinking the stable quantity, the development project of public transport is a long-term and optimum strategy to control the private cars' amount as well as improve the urban traffic level.

Referring to the "Master Plan of Beijing City (2004-2020)", it is expected that in 2020, urban centers passenger travel by public transport would assume 50% accounting for the total proportion, contrasted 27% in 2000. However, The public transport

development level, even if as the ratio planned, is far lower than that of many developed foreign cities, in which the index accounts 75% approximately. Thus, the program of public transport system construction, which is an effective means to control the private cars' quantity, now still, has great potential and large room for development in view of current level. It should be fully supported and encouraged to accelerate its construction speed zealously.

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