Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 4 (2014) 521 – 534

Transportation Research Procedia

www.elsevier.com/locate/procedia

Mobil. TUM 2014 "Sustainable Mobility in Metropolitan Regions", May 19-20, 2014

Assessment of the Impacts of Urban Rail Transit on Metropolitan Regions Using System Dynamics Model

Yang Yang[1,2,*] Peitong Zhang [1] Shaoquan Ni [1,2]

[1]*School of Transportation and Logistics,Southwest Jiaotong University, No.111,Section 1 of Northern 2nd Ring Road, Chengdu,610031,China*
[2]*National Railway Train Diagram Research and Training Center, Southwest Jiaotong University, No.111,Section 1 of Northern 2nd Ring Road, Chengdu,610031,China*

Abstract

Urban rail transit system (i.e., metro and light rail) has significant impacts on the mitigation of traffic congestion and sustainable developments of urban traffic system because of the system advantages in terms of speed, land occupation, and low emission. However, considering the complexity and dynamics of the urban traffic system as a whole, it is difficult to achieve effective assessments of a variety of comprehensive impacts. This paper presents the analysis of the impacts of urban rail transit system on metropolitan regions in four aspects: urban traffic, economy, society, and environment, using software Vensim to build a System Dynamics (SD) model on the basis of the system structure analysis. A series of variables are adopted in the model to represent these impacts, which contain congestion degree, GDP (Gross Domestic Product), population, land values, harmful gas emission, accident rate, etc. Construction scale of urban rail transit is selected as the control variable to simulate changes of different indexes under various levels of urban rail transit system scale. A case study of Guangzhou is carried out as a verification of this model to simulate the comprehensive impacts, including congestion degree, total number of cars, land values, and PM10, etc. under different control variables. This paper provides a feasible and effective approach to simulating complex traffic system and references for government decision-making on transportation infrastructure planning.

Selection and peer-review under responsibility of Technische Universität München
Keywords: System Dynamics model; urban rail transit; social, economic, and environmental impacts; sustainable development; Vensim

* Corresponding author. Tel.: +86-15828508427; fax: +86-028-87600706
E-mail address: tpy2615@gmail.com

Selection and peer-review under responsibility of Technische Universität München
doi:10.1016/j.trpro.2014.11.040

1. Introduction

As the step of urbanization accelerated, the size and population of metropolitan regions are expanding rapidly, and this gives increasingly more pressure on urban traffic system. A series of problems such as traffic congestion, car excess have led city bus to slow and the efficiency of urban public transport is decreasing. Furthermore, a more disturbing problem is that frequent traffic accidents are threatening people's life safety and health. Therefore, since the existing urban transport system could neither meet the growing demand of residents travel, nor meet the demand of the city's economic development, policymakers have been trying to apply other approaches to realize sustainable mobility.

Sustainable mobility is a complex concept, involving traffic system sustainability, society sustainability, economy sustainability, and environment sustainability. Sustainable urban traffic system should not only relieve above problems largely but also reduce negative effects of residents' travel such as air pollution or safety issues. Urban rail transit (i.e., metro, light rail, and tram) has many advantages: trains could carry a considerable number of passengers with high speed compared with bus; because of its spatial isolation feature, roadway will not be obstructed, through which passengers' travelling time can be guaranteed; more saved energy and less emission do favor to better environment and people's health; the accident rate of rail transport is very small, which could reduce accident mortality of city residents. There also exist some invisible effects in economic and social development. Land values along rail lines could see apparent ascent during years after the construction and operation of urban rail lines. Additionally, the department of urban rail transit offers many job opportunities for citizens, which will greatly promote society employment.

China government began to attach importance to urban rail transit in recent years, so a large number of funds are invested in this field. Before 2000, there were only three cities in China equipped with metro. During the last one decade, government invested on urban rail transit continuously with a total amount of almost 600-700 billion Yuan, which resulted to a great increase in urban rail line mileage to nearly 1500 km. Apart from this, domestic urban rail transit has gradually developed from only one type (metro) to a diversity of light rail, metro, and tram. Some cities such as Beijing and Guangzhou have owned considerable scale of urban rail infrastructure, with a network of hundreds of kilometers. However, it is more general that the urban rail transit system of many cities in China just stays in the initial stage of operation, with only one or two lines, far from forming a network.

Nevertheless, assessments of the impacts of urban rail transit are complicated because of the large system features of urban transport system. Urban transport system is a complex dynamic system, with many components and feedback mechanism inside, where exist complex non-linear interactions and feedback relationships between subsystems and each variable. Therefore, it is difficult to fully grasp characteristics of urban transport system and solve this problem properly with general research methods which use quantitative formulas.

Horn (1981) collected cost-efficiency evaluation indexes of 9 big cities with urban rail transit of developed countries and found that there were great differences between them. Hence the author concluded that there was not a set of index system which can realize impartial evaluation of urban rail transit projects in American cities since index standardization was difficult. Robert Carvero (2001) studied the commercial land price near light rail station of Santa Clara County in California with the application of hedonic price model (HPM) method. The results showed that the land prices of districts in the range of light rail stations within a radius of 400m located in central business district increased by 120%, and the prices of other areas also increased by 23%. Research in the impacts of urban rail transit on land values has made a lot of achievements.

In China, Li Sanbing and Chen Feng (2009) analyzed the social and economic benefits of urban rail transit in many aspects: reducing the passenger travelling time and cost, saving energy, reducing environmental pollution, etc. Wang Haidan (2007) made classification and quantitative analysis of the public benefit of urban rail transit according to different interest subject. Li Zhi (2006) established evaluation index system of urban rail transit, including traffic benefit, economic benefit, social benefit and environmental benefit to evaluate the comprehensive benefits of urban rail transit. With the application of analytic hierarchy process and fuzzy decision, the author made evaluation through a case study of Chengdu.

Current research on impacts of urban rail transit pays more attention on impacts on the economy and land values. Although there are calculation methods and quantitative models for each impact in various aspects, these methods and index systems showed a feature of partial evaluation. Therefore, the assessments of impacts need systematic and comprehensive perspective.

System dynamics approach is a combination of scientific theory and computer simulation, a science studying the structure and behavior of the system feedback. Since proposed by J.W. Forrester of MIT in 1950s, SD has been extensively applied in industrial enterprise management, socio-economic system and transportation system analysis. Through the establishment of a feedback loop and the set of various variables and equations, system dynamics approach achieves comprehensive analysis of system. The structure of the system is represented by causal loop diagram and stock and flow diagram. Specifically, causal loop diagram can clearly express nonlinear causality within the system by feedback loops, a series of causes and results of the closed path. Stock and flow diagram is to distinguish the characters of variables, confirm the control rule and feedback form based on causal loop diagram, through which the image of the logical relationships between system elements could be displayed more directly. The relationships between the three types of variables of the system (level variable, rate variable, auxiliary variable) are defined by formulas. This is important because all the feedback and causality relationships can be quantitatively determined by building the equations. Therefore, we can conduct simulations on the basis of the definitions and quantitative feedback system to simulate all the impacts in various aspects.

In the applications of SD model in transport research, Abbas Khaled A and Bell Michael G.H.(1994) reviewed and evaluated the strengths and weaknesses of system dynamics with respect to its suitability and appropriateness in transportation modeling. It established the ease with which system dynamics can be applied to construct useful tools for testing alternative transport-related policies. Mehmood Arif (2003) established a SD car-following model to simulate driver behavior in all types of car-following situations based on observed vehicle tracking data. Goh Yang Miang and Love Peter E.D.(2012) developed two models to demonstrate how the methodology of SD can facilitate and encourage macro level analysis of traffic safety policy and it is suggested that SD is most appropriate for formulating macro level policy as it can account for the dynamic complexity associated with the road transport system. Haghani Ali et al. (2003) presented a system dynamics model consisting of 7 sub-models: population, migration of population, household, job growth-employment-land availability, housing development, travel demand, and traffic congestion level. The results indicated that the SD method is a promising approach in dealing with complex urban land use/transportation modeling.

This paper proposes the urban rail transit SD model, applying system dynamics to the complex system of urban traffic to simulate the mechanisms and various impacts of urban rail transit on metropolitan regions. To apply this model and solve problems, there are three stages:

- Preliminary analysis of the system: determine the objective system of study and system components, make qualitative analysis of the causality of each component and draw the causal loop diagram.
- Model building stage: create a system structure model based on the results of the preliminary analysis, which is represented by the stock and flow diagram. Set different types of variables and parameters, equations between them.
- Simulation and analysis: make simulations, compare simulation results under different circumstances and control variables to evaluate different policies and make suggestions.

2. SD model of urban rail transit

2.1. Overall analysis

Since urban transportation system is very complicated, we divide the system into four subsystems to make the analysis of all aspects: economy, society, transportation, and environment. The system structure is as shown in Figure 1. (The arrows indicate the causal effect and the sign indicates a positive or negative effect.)

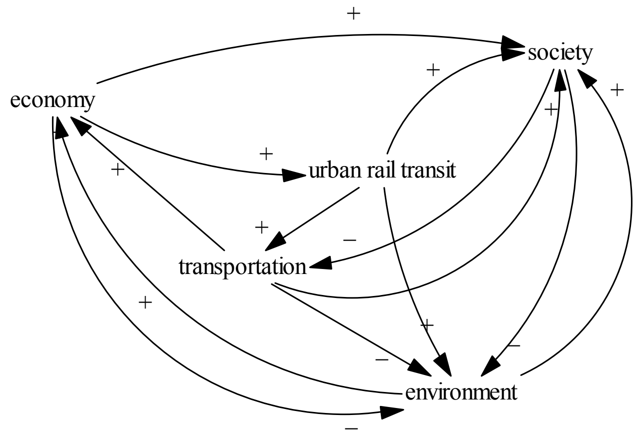

Fig. 1 System structure and feedback loops between subsystems (Own Elaboration)

In the system structure, transportation subsystem plays an important role because it has direct and distinct relationship with urban rail transit. The construction of urban rail transit will greatly improve urban traffic circumstances, through which the effects on economy, society and environment arise.

Positive feedbacks

One circuit is called a positive feedback loop when this relationship starts from a variable, resulting in increasing the variable itself after the transfer of a closed loop; otherwise we call it a negative feedback loop. The feedback chain defines the basic relationships of each main element in the system, which will help to analyze specific interactions and further establish the system structure.

The construction of urban rail transit system has apparent positive effects on urban transportation system of metropolitan regions as it will take the task of carrying passengers and improve regional accessibility to some extent. Advanced mobility could improve efficiency and reduce travelling time, thus make positive effect on economy development. Considering that the construction of urban rail project relies on strong economic foundation, the feedback of urban rail transit- transportation- economy- urban rail transit is positive(+,+,+).

Compared with other modes of transportation, urban rail transit is more environment friendly because of its high efficiency of electricity energy use and low emission. Environment is one of the favorable conditions of economy development since there is no need for government to bother to solve thorny environment issues. Thus urban rail transit- environment- economy- urban rail transit is a positive feedback (+, +, +).

It is believed that economic development is bound to bring damage to the environment. This is true especially in developing countries where heavy industrial pollution is very serious. Thus the negative effect will be transmitted to society through environment subsystem. However, the negative effect will then be offset by effect of the same property of society on transportation, and continues to influence economy itself. So the feedback of economy- environment- society- transportation- economy is positive (-, +, -, +).

Negative feedbacks

Urban rail transit has many positive effects on society in many aspects. While it is making more convenient for residents' mobility, the system plays an important role in optimizing the structure of the city and decreasing accident rate. However, society and human beings are burdens for environment since people always exploit energy while discharging pollutants. On the basis of former analysis, the feedback of urban rail transit- society- environment- economy- urban rail transit is negative (+, -, +, +).

Despite of the positive effects of urban rail transit on society, human activities are always making pressure on transport. Specifically, increasing population and transportation demand make contradiction between supply and demand, causing traffic issues such as traffic congestion more disturbing. However, the positive effects of transportation on economy continue to influence the construction of urban rail lines. So it is clear that the feedback of urban rail transit- society- transportation- economy- urban rail transit is negative (+, -, +, +).

2.2. Variables and system structure

It is assumed that the whole system is internally stable without interference from external uncontrollable factors; the average transportation demand of the residents is assumed to be constant during simulation period, shared by urban rail transit and cars.

Before building the SD model, the fundamental work is to select a series of variables to reflect components of subsystems. This is the basis of establishing quantitative relationships and making simulations. First of all, in order to indicate the current state of urban rail transit, we use Urban Rail Transit Mileage and the number of trips by URT these two variables to represent the length of rail transit of the city and annual passenger turnover respectively. Another two variables are annual increase of URTM and Construction Scale of URT, the control variable which represents the degree of policy support.

In transportation subsystem, what attracts most people's attention is traffic congestion issue. Even if the number of trips by car has direct influence on congestion degree, it is urban rail transit mileage that changes the travelling modes choice, which could be computed through the number of trips by URT and the total amount of travel. The change of residents' travel modes also affects travelling costs and travelling time due to the difference of time and costs of different modes and the change of percentages.

In terms of economy, the variables should reflect the strength and speed of economic development of the region. Normally, GDP and average GDP are considered the most representative indexes with accurate statistics which could be referred to conveniently. GDP will influence annual increase of URTM directly through invest in traffic and transportation. Similarly, according to the research on transport economics, the impacts of urban rail transit on economic development are reflected in land values along the urban rail lines.

Social impacts contain many aspects involving population, security and employment. Some basic variables such as Total Population, population growth rate, Employed Population, employment growth rate should be used. Population growth could be calculated through population growth rate, accident mortality on the basis of total population of the last year. The growth of urban rail mileage will improve employment growth rate through its impacts on urbanization rate and business along rail lines. In order to indicate the influence of rail transport on traffic safety, we use accident deaths and accident mortality to make it more intuitive and representative.

In environment subsystem, the two main considerations are environmental pollution and energy consumption. Operation consumption and gasoline consumption represent energy consumption of urban rail transit and motor vehicles respectively, and they together make up the total energy consumption. On the basis of the research on influence of car emissions on air pollution, the number of trips by car contributes greatly to PM10, and further influences GDP increase rate and population growth rate.

Base on above analysis, this paper selects the following variables:

Level variables: *Urban Rail Transit Mileage, GDP, Total Population, Employed Population*;
Rate variables: *annual increase of URTM, GDP growth, population growth, employment growth;*
Auxiliary variables: *the number of trips by URT, the number of trips by URT, attract coefficient, congestion degree, total number of cars, the total amount of travel, the number of trips by car, travelling costs, travelling time, average trip distance, average GDP, invest in traffic and transportation, land values, GDP increase rate, population growth rate, employment growth rate, accident deaths, accident mortality, car accident rate, URT accident rate, energy consumption, operation consumption, gasoline consumption, PM10.*

Level variables represent the total number of something which could be accumulated with the time in the real world. Each level variable has a rate variable, whose function is to regulate the changing rate of level variable. The other variables such as some indexes or data calculation variables are auxiliary variables.

Based on above analysis of system feedback relationships, variables and indexes, the stock and flow diagram is schemed as shown in Figure 2.

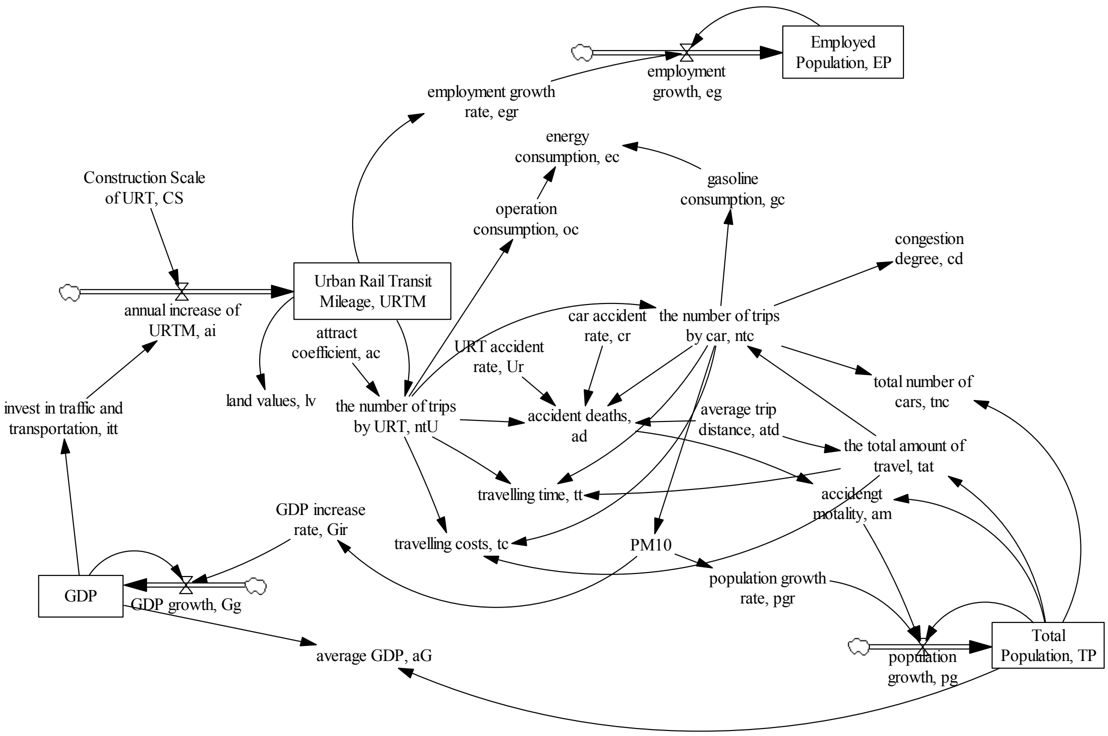

Fig. 2. Stock and flow diagram of system(Own Elaboration).

2.3. Formulas

CS (Construction Scale of URT) stands for the degree of policy support, or in other words, the proportion of the funds of traffic and transportation which are used for the construction of urban rail transit. So here we can regard it as a coefficient. Through the study of statistic data in recent years, *ntU* (the number of trips by URT) has definite proportional relationship with *URTM* (Urban Rail Transit Mileage) with a decreasing slope. This part mainly comprises the following equations:

$$\begin{cases} URTM = INTEG\ (ai) \\ ai \ = itt * CS \ * 2 \\ ntU = ac * URTM \ {}^\wedge 0.9 \end{cases} \tag{1}$$

2 represent the cost of construction of the urban rail lines, 2km/billion. $INTEG(\ )$ is a function with time attribute which represents that $URTM^{i+1} = URTM^{i} + ai$.

The main concern of transportation subsystem is the influence of urban rail transit on people's travel mode choice and the improvement of travel in terms of costs and time. *ntc* (the number of trips by car) could be calculated by *ntU* (the number of trips by URT) and *tat* (the total amount of travel), which could be derived through the relationship with *TP* (the total population). Thus *tt* (travelling time) and *tc* (travelling costs) could be computed in the conditions of known contribution rates of each mode of transportation and the average travelling time of each mode. Here we define *cd* (congestion degree) as the ratio of *ntc* (the number of trips by car) and *rl* (road length). *tnc* (total number of cars) has a functional relationship with *ntc* and *TP*, which could be obtained from regression analysis.

$$\begin{cases} tat = 365 * atd * TP / 1000 \\ ntc = tat - ntU \\ tc = ntU / tat * 2 + ntc / tat * 10 \\ tt = ntc / tat * 0.66 + ntU / tat * 0.33 \\ cd = ntc / rl \\ tnc = f\left(ntc, TP\right) \end{cases} \tag{2}$$

In (2), 1000 is a unit conversion factor. 2 and 10 represent average travelling costs of URT and car respectively. 0.66, 0.33 represent average travelling time of car and URT respectively.

In economy subsystem, the level of economic development is the city's major competitiveness and it has direct impacts on government investment in traffic infrastructure construction. As a significant aspect of the influence of urban rail transit on the city, lv *(land value)* has intensive relationship with $URTM$ *(Urban Rail Transit Mileage)*. In addition, considering the counteraction of economic development on environment, there is a definite relationship between Gir *(GDP increase rate)* and $PM10$. All the quantitative relationships could be obtained from regression analysis.

$$\begin{cases} GDP = INTEG\left(Gg\right) \\ Gir = f\left(PM10\right) \\ itt = f\left(GDP\right) \\ lv = f\left(URTM\right) \end{cases} \tag{3}$$

As the major components of the city, residents will be influenced by urban traffic circumstance while they put pressure on urban traffic system. First of all, different choice of various travel modes will affect am *(accident mortality)*, which could be calculated by TP *(total population)* and ad *(accident deaths)* of different types of transportation. Construction and operation of urban rail transit is bound to have a significant impact on employment growth since it not only improves the urban mobility but also stimulates development of business along rail lines and stations. In this model, pgr *(population growth rate)* is a comprehensive concept including birth rate, death rate, and migration rate. Since environmental pollution affects residents' health and migration desire, there is a certain relationship between *population growth rate* and *PM10*.

$$\begin{cases} ad = \left(cr * ntc + Ur * ntU\right) / atd \\ egr = f\left(URTM\right) \\ EP = INTEG\left(eg\right) \\ pgr = f\left(PM10\right) \\ pg = TP * \left(pgr - am\right) \\ TP = INTEG\left(pg\right) \end{cases} \tag{4}$$

In environment subsystem, energy consumption is mainly constituted by oc *(operation consumption)* of urban rail transit and gc *(gasoline consumption)* of motor vehicles. Both these two could be calculated by the product of unit consumption and total turnovers. In terms of environmental pollution, PM10 has a close relationship with vehicle emission, which is the main cause of air pollution. Therefore, the authors establish a functional relationship between $PM10$ and ntc *(the number of trips by car)*.

$$\begin{cases} oc = ntU * 2 * 10000 \\ gc = ntc * 8 / 3 * 10000 \\ ec = gc * 5.68 * 10 \wedge 4 + oc * 3.6 * 10 \wedge 3 \\ PM10 = f(ntc) \end{cases} \tag{5}$$

In (5), 2 is unit energy consumption 2 KW•h/km•person of urban rail transit and 10000 is unit conversion factor. 8 is unit energy consumption 8L/hundred km and 3*10000 is unit conversion factor. 5.68*10^4 and 3.6*10^3 of (22) are unit conversion factors to make the units unified into KJ.

3. Case study

In this paper, System Dynamics software Vensim PLE is applied to make simulations for the model above. Considering the urban rail transit construction status of each city of China, the authors select Guangzhou as the object of case study. Located in the southeast coast of China, Guangzhou is the third largest city of China with an area of 7,434 square kilometers and a population of 12.75 million people. More importantly, the urban rail transit of Guangzhou has formed a considerable scale and it is in a period of rapid expansion. By the end of 2013, the mileage of Guangzhou metro has reached 250.11km with an annual passenger volume of 185.61 million people. The map of Guangzhou metro in operation is as shown in Figure 3.

Fig. 3 Guangzhou metro system map.[1]

3.1. Parameter estimation and model checking

Based on the data of Guangzhou Statistical Yearbook from 1997 to 2013, parameters of functions are determined through Parameter fitting and regression analysis.

*Table 1 Values of parameters

Parameter	Value	Unit
Population growth rate	1.5	%
GDP increase rate	14	%
Average trip distance	6	km
URT accident rate	0.003	%
Car accident rate	0.081	%

In order to verify whether the model could reflect the essential characteristics of the system, we make simulations of 2010 beginning from the year of 2005 to make comparisons with statistical data of 2010. *GDP, Total Population* and *Urban Rail Transit Mileage* are selected as test variables to make comparisons and examination.

Table 2 Results of model validation

Variable	Simulation Value	statistical data	Deviation
GDP	1047.72	1074.83	-2.52%
Total Population	8253.45	8003.762	3.11%
Urban Rail Transit Mileage	204.495	213.26	-4.11%

As can be seen from the results in Table 2, the deviation of *GDP, Total Population*, and *Urban Rail Transit Mileage* are all within ±5%, which is quite reliable. Therefore, the model can be used to predict and analyze the urban rail transit construction and the impacts.

3.2. Simulations

To research the comprehensive impacts of the construction scale of urban rail transit on metropolitan regions, this study sets *Construction Scale of URT* as control variable of the model. By changing the value of construction scale, the impacts of different levels of policy support on transportation, economy, society, and environment could be simulated with clear comparisons.

Here we set the running time 20 years, time step 1 year with the initial year of 2005 to make simulations. Control variable *Construction Scale of URT* is set to 0.5, 0.8, 1, 1.5 respectively, representing the degree of support of government on the construction of urban rail transit from low to high. The graphs of simulations are as shown in Figure 4-9.

[1]website of Guangzhou metro: http://www.gzmtr.com/

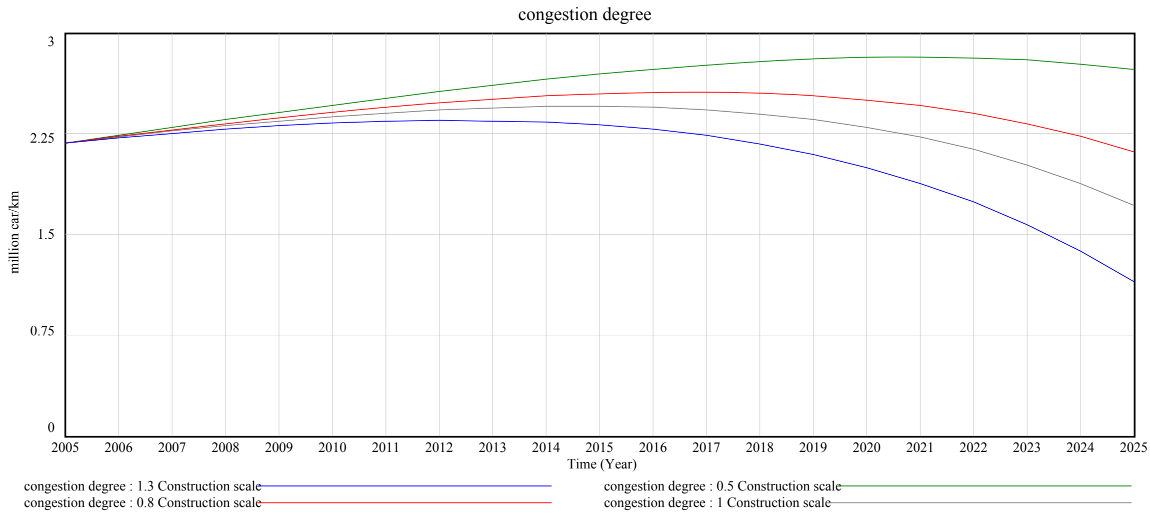

Fig. 4 Effects of Construction Scale on congestion degree (Own Elaboration).

Although the congestion degree will continue to rise in the coming several years, a decreasing trend could be seen in a long term. This is because that the impacts of urban rail transit on urban traffic system have some years of delay, which appear in a long period. Additionally, as the construction scale becomes larger, the congestion degree declines faster.

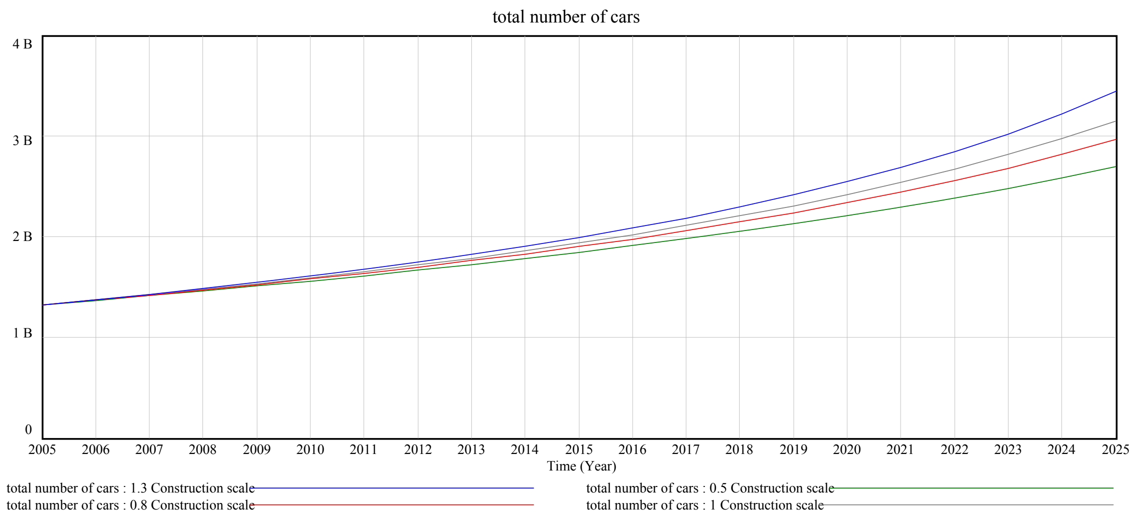

Fig. 5 Effects of Construction Scale on total number of cars (Own Elaboration).

Total number of cars will always maintain the rising trend due to population increase and economic development. Unexpectedly, the larger the construction scale, the more the number of cars, which means that urban rail transit, could not reduce total number of cars. This is due to the fact that urban rail transit will promote population increase and economic development, and further stimulate car ownerships. However, the impacts of Construction Scale on total number of cars are not very strong.

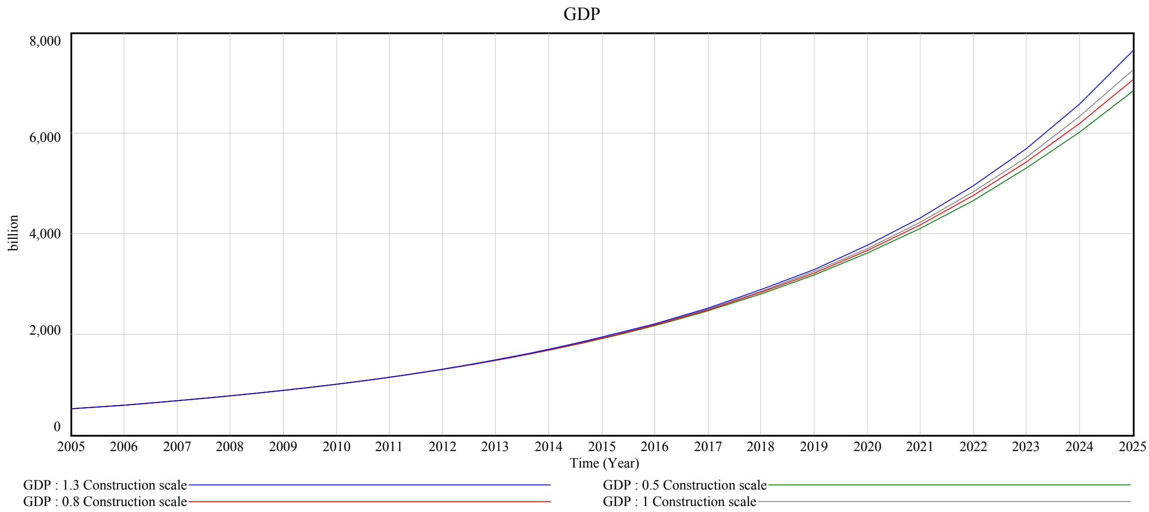

Fig.6 Effects of Construction Scale on GDP (Own Elaboration).

As can be seen from this graph, GDP will maintain rapid growth in the coming decades. Cities with stronger urban rail transit have slight advantages in GDP, but generally speaking, the impacts are quite small.

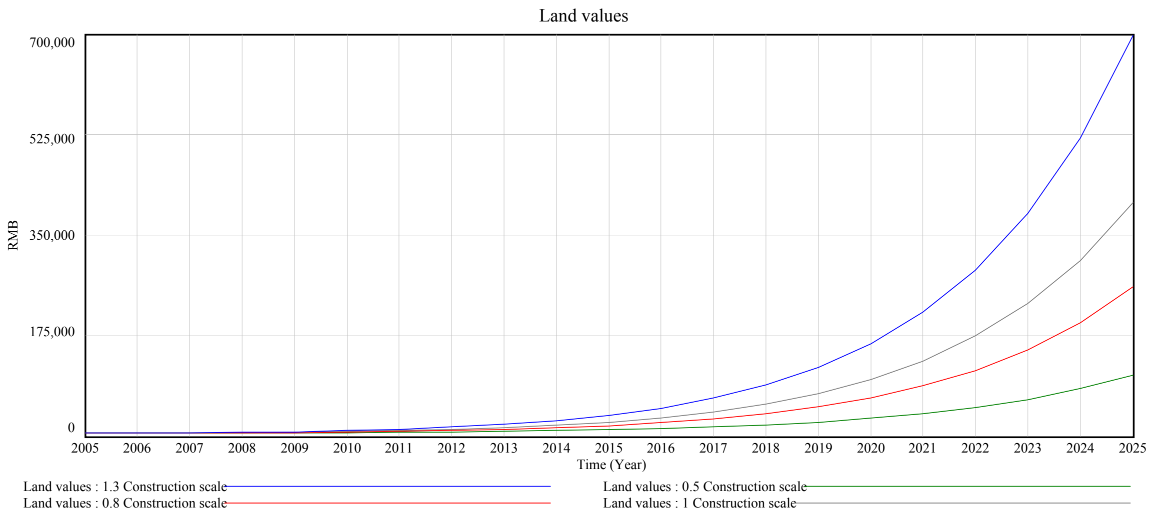

Fig.7 Effects of Construction Scale on Land value (Own Elaboration).

The impacts on land value are very distinct especially starting from the period of ten years later. Cities with larger scale of urban rail transit will achieve explosive growth in land value, and there will be very large gap in land value between cities with different policies of construction scale. The stimulations of urban rail transit on city business are quite significant.

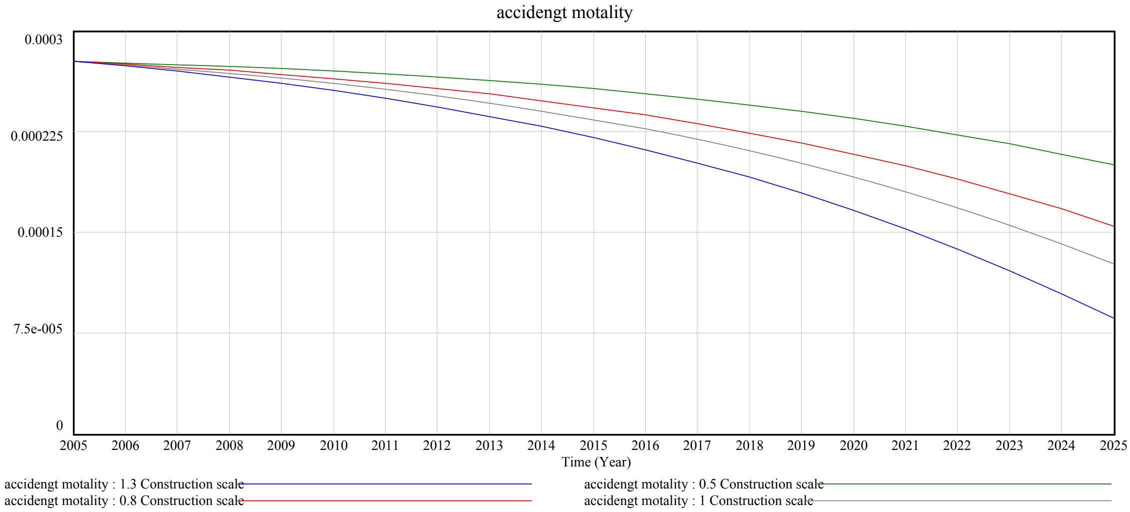

Fig.8 Effects of Construction Scale on accident mortality (Own Elaboration).

The operation of urban rail transit brings a significant decrease in accident mortality. The larger the scale, the faster it declines. Thus we can conclude that urban rail transit has great advantages in reducing the accident rate and improving traffic safety.

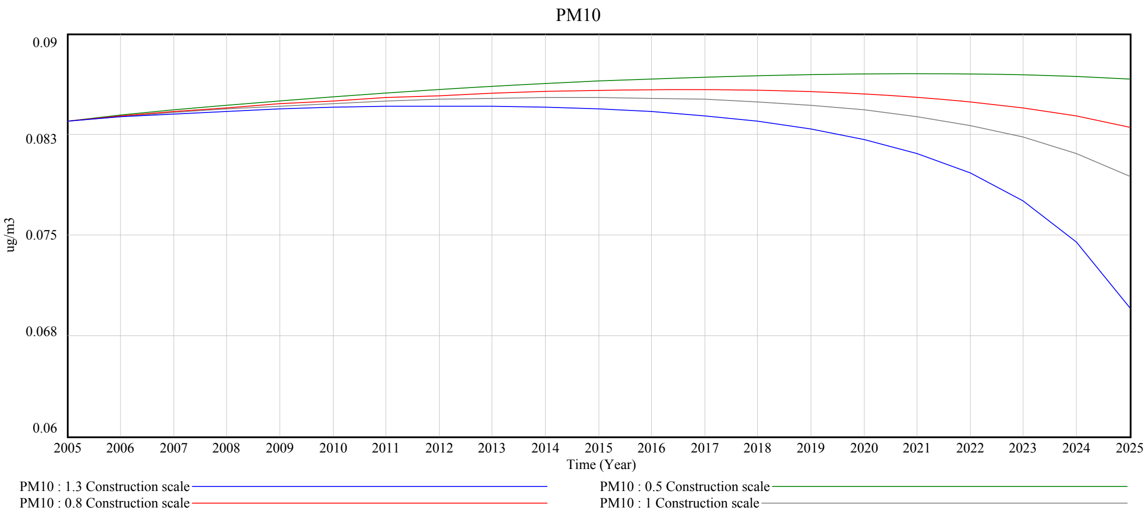

Fig.9 Effects of Construction Scale on PM10 (Own Elaboration).

As can be seen from the graph, for different construction scale of urban rail transit, the impacts on PM10 have different performances. Specifically, when construction scale is 0.5, which means that the government invests little in urban rail infrastructure construction, PM10 maintains at a relatively high value. When construction scale rises to 0.8, and 1, PM10 will begin to decrease by 2025 after some years' rise, but still with slight trends. When construction scale comes to 1.3, PM10 will decrease rapidly to a relatively low point of 0.069ug/m^3 in 2025. Therefore, the construction of urban rail transit will prevent environmental pollution and large-scale construction could effectively reduce air pollution and improve the quality of environment.

Due to space limitations, some other simulation results such as travelling time, travelling costs, energy consumption, etc. could not be shown here. But they all, without exception, show downward trends. Moreover, with construction scale increasing, the graphs show more evident trends.

3.3. Suggestions

On the basis of above simulation results, it is manifest that urban rail transit has significant impacts on the relief of traffic congestion and air pollution. Although the impacts on economic growth are not so distinct, land value will achieve great rising in the decade from 2015 to 2025. However, it should be noted that the construction of urban rail transit has no function of reducing the number of cars. Conversely, as the mileage of urban rail transit increases, the number of cars will increase continuously. Therefore, we can conclude that considering the city size of Guangzhou and the comprehensive impacts in various aspects, a relatively large scale of construction is appropriate. The government could properly increase investment in the construction of urban rail transit, so the urban rail transit system could develop to a considerable scale to serve for the city and improve the transportation condition, environment equality, and social development of the city. At the same time the disadvantages of automobile overdose and overinvestment could be avoided. Thus this will be a sustainable measure.

4. Conclusion and Future work

It is difficult to realize quantitative analysis for complex system problem due to its diversity of elements and complexity of the relationships between the elements. Urban traffic problem is such a typical problem with dynamic character. In this paper, system dynamics model is applied to assess the comprehensive impacts of urban rail transit on metropolitan regions. First of all, variables of four subsystems (transportation, economy, society, and environment) are selected to make the impacts quantitative and specific. Then, based on the theoretical analysis, more detailed relationships between system components and framework are established through formulas and functions. At last, the authors conduct a case study of Guangzhou to verify the authenticity and validity of the model, with a result of high consistency with statistic data. According to the simulation results, policy suggestions are given on construction of urban rail transit.

Compared with the existing research on urban rail transit, this paper applies system dynamics approach to realize quantitative and concrete assessments of the comprehensive impacts, which might provide strong reference for decision makers. In terms of index choosing, congestion degree, travelling time, and travelling costs are introduced to reflect the impacts on travelling behavior and urban mobility. As a preliminary exploration, this paper proposes a simulation method to research complex relationships between components of urban traffic system and the comprehensive impacts of urban rail transit on metropolitan regions. Considering the diversity and complexity of system elements, the model simplifies some variable relationships by curve fitting and regression analysis, which will probably reduce the generality of the model. On the other hand, this paper ignores some other effects of urban rail transit such as investment recovery and metro operation.

In future work, the relationships between some variables need further detailed research to make it more universal, which need to apply professional knowledge of other subjects such as sociology, economics and demography. Furthermore, some disadvantages such as cost recovery issue will also be studied to research the comprehensive impacts on both sides in a longer period.

Acknowledgements

The authors would like to thank Professor Jiang Xinguo for his support and help to this article. In the revise stage of the paper, Prof. Jiang proposed a lot of suggestions to improve the article, and we would like to pay tribute to his rigorous academic attitude and superb academic level.

References

Mehmood Arif, *et al* . (2003) Application of system dynamics in car-following models. *Journal of Transportation Engineering,*129(6),625-634.

Cervero, R, Landis, J. (1997) Twenty Years of the Bay Area Rapid Transit System: Land Use and development Impacts. *Transportation Research Part A: Policy and Practice,* 31(4), pp. 309-333.

Deloukas, A. (2008) Capitalization of Urban Rail Investments in Land Value; The Case of Athens. In: *2008 AET Conference*

Javier Gutierrez. (2001) Location, economic potential and daily accessibility: an analysis of the accessibility impact of the high-speed line; Madrid-Barcelona-French border. *Journal of Transport Geography,* 9(4), pp. 229-242

Ali Haghani, *et al.* (2001) A system dynamics approach to land use transportation system performance modeling Part I: Methodology and Part II: Application. *Journal of Advanced Transportation,* 37(1), pp. 1-41.

Abbas Khaled, A, Bell Michael, G.H. (1994) System dynamics applicability to transportation modeling. *Transportation Research Part A: Policy and Practice*, 28(5), 373-400.

Li, S, Chen, F. (2009) Analysis of social and economic benefits of ticket reform of Beijing rail transit. *Urban Mass Transit*, 12(6), 12-16

Li, Z. (2006) *The comprehensive benefit evaluation of urban rail transit.* M.Ed. dissertation, Southwest Jiaotong University

M.-Y, Pior, E. Shimizu. (2001). GIS-aided Evaluation System for Infrastructure Improvements: Focusing on Simple Hedonic and Rosen's Two-step Approaches. *Computers, Environment and Urban Systems*, 25(2), 223-246.

Wang, H. (2007) *Research on the measurement of public benefit of urban rail transit.* M.Ed. dissertation, Southwest Jiaotong University.

Wang, J, Lu H. (2008) System Dynamics Model of Urban traffic System and Its Application. *Journal of Transportation Systems Engineering and Information Technology*, 8(3), 83-89

Wang, Q. (1998) *System Dynamics.* Beijing: Tsinghua University Press.

Xu, G, Zou, J. (2006) System Dynamics: Principles, features and latest developments. *Journal of HIT*,8(4), 72-77.

Yang Miang, Goh, Peter E.D. Love(2012) Methodological application of system dynamics for evaluating traffic safety policy. *Safety Science,*. 50(7), 1594-1605.

Zheng, J, Liu, H. (2005) The Impact of URRT on House Prices in Shenzhen. *Journal of the China Railway Society*,27(5), 12-18