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

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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.

Keywords: System Dynamic model; urban rail transit; sustainable development; Vensim

1 Introduction

Assessments of 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 varable. Therefore, it is difficult to fully grasp characteristics of urban transport system and solve this problem properly with general research methods which use quantified formulas.

This paper proposes the urban rail transit SD model, appliying System Dynamics model to the complex system of urban traffic to simulate the mechanisms and various impacts on metropolitian regions of urban rail transit. 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 componens 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 varables and parameters, equations between them.
- Simulation and analysis: make simulations, compare simulation results under different circumstances and control varables to evaluate different policies and make suggestions.

2 SD model of urban rail transit

2.1 Overall analysis

Since urban transpotrtation system is very complicated, we divide the system into four subsystems to make the analysis of all sapects more clear: econoy, society, traffic, 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.)

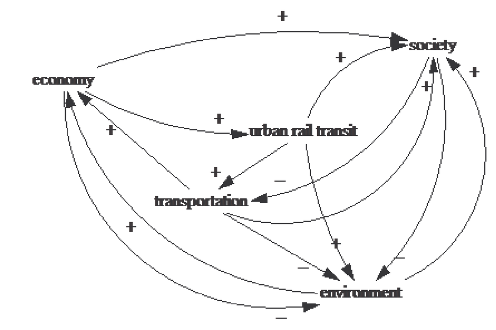

Fig.1 System structure and feedback loops between subsystems.

2.2 Variables and system structure

Before building the SD model, the fundamental work is to select a series of variables to reflet components of subsystems.

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, travlling 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 motality, car accident rate, URT accident rate, energy consumption, operation consumption, gasoline consumption, PM10.

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

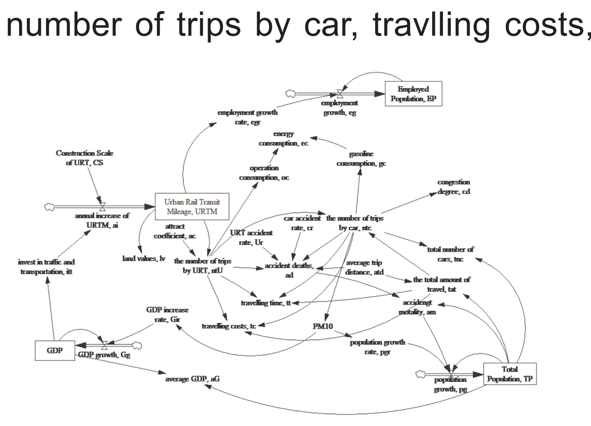

Fig. 2Stock and flow diagram of system.

3 Case study

In this paper, System Dynamics software Vensim PLE is applied to make simulations for above model. Considering the urban rail transit construction status of each city of the country, the authors select Guangzhou as the object of case study. The map of Guangzhou metro in operation is as shown in Figure 3.

Fig.3 Guangzhou Metro system map.

3.1 Parameter estimation and model checking

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

In order to verify whether the model could reflect the essential characteristics of the system well, 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.

3.2 Simulation

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.

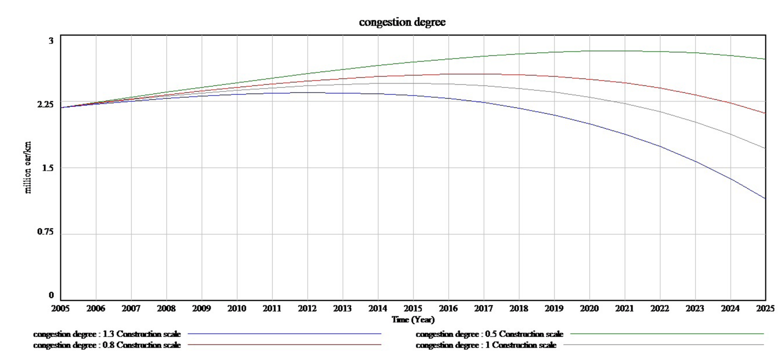

Fig. 4 Effects of Consruction Scaleon congestion degree.

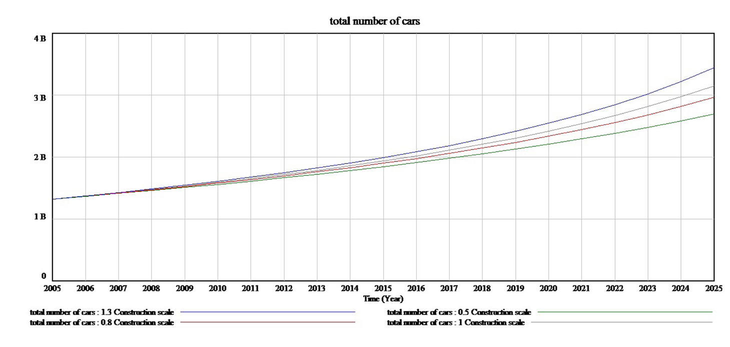

Fig. 5 Effects of Consruction Scale on total number of cars.

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.

Total number of cars will always maintain the growth trend due to population increase and economic development. The larger the construction scale, the more the number of cars. However, the impacts of Consruction Scale on total number of cars are not very strong.

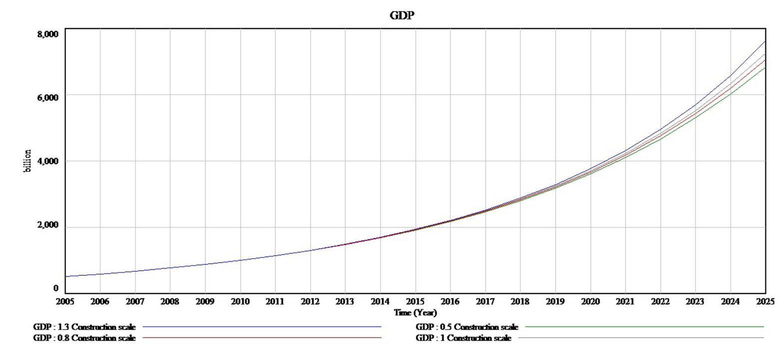

Fig.6 Effects of Consruction Scale on GDP.

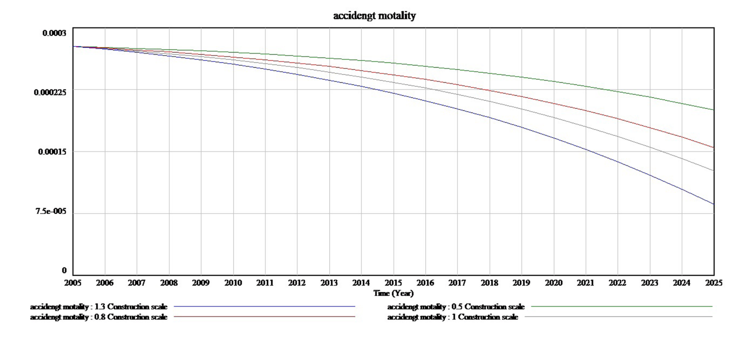

Fig.8 Effects of Consruction Scale on acccident motality.

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 samll.

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

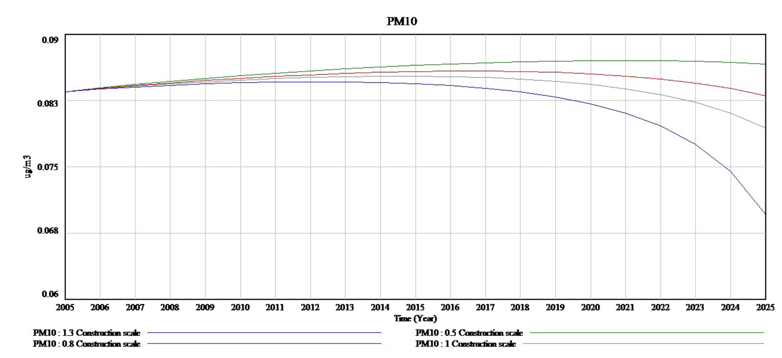

Fig.9 Effects of Consruction Scale on PM10.

3.3 Suggestions

We can conclude that considering comprehensive impacts in various aspects and the city size of Guangzhou, 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.

Conclusion and Future work

As a preliminary exploration, this paper applies system dynamics model to research complex relationships between components of urban traffic system and the comprehensive impacts of urban rail transit on meropolitian 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 should 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.

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