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ABSTRACT

Due to incompletion of comprehensive transport management system reform in China, and lack of single administrative subject in urban agglomeration, different modes of transport planning established by separate government sectors in charge are hard to be suited and connected. Moreover，comprehensive transport development in urban agglomeration is increasingly restricted by resources and environments. This paper addresses these issues by applying thoughts and methods of system dynamics into comprehensive transport planning in urban agglomeration.

We first analyze the feedback relations between transport and regional economy from three aspects, namely, investment efficiency, operation effectiveness, and placement guidance effect. Then we establish causal loop diagram of urban agglomeration transport system and define and describe major subsystems and equations. Finally we discuss the roles of this method for making comprehensive transport planning in urban agglomeration restricted by resources and environments.

System dynamics is a powerful approach in simulating and analyzing urban agglomeration transport system. Using method and softwares of SD, transport demand changes along with regional social and economic changes, or the influence of new transport infrastructure investment on regional economy can be better predicted. Dynamic simulation of urban agglomeration transport system provides a platform for policy makers from separate government sectors, thus can help them making transport planning more continuative, comprehensive, integrative and sustainable

Our findings suggest a widely application of system dynamics in transport planning and the establishment of dynamic simulation of urban agglomeration transport system.

Keywords: comprehensive transport; planning method; system dynamics; urban agglomeration transport; regional economy

1. Introduction

1.1 Status-quo of urban agglomeration transport planning in China

With the rapid development of regional economy in China, urban agglomerations, such as the Yangtze River Delta agglomeration, the Pearl River Delta agglomeration, and the Shandong Peninsula agglomeration, gradually came into being. And as in other places in the world, urban agglomerations play more and more important role in speeding up the economy, and often take significant position in regional development strategy. In China, *the Outline of the Eleventh Five-Year Plan for National Economic and Social Development (1006~2010)* emphasizes the need to actively and steadily promote urbanization to take full advantage of the leading role of groups of cities in driving development (Wen, 2006). Since an adequate transport system is often considered the prerequisite to realize urban agglomeration strategy, concerned governments put more and more emphasis on making transport planning covering the whole region. For example, the first highway and waterway regional transport planning in China—*the Outline of Modern Highway and Waterway Transport Planning in the Yangtze River Delta Region*-- was put forward in March, 2005, which broke regional and industrial limitations to form an overall transportation plan, including both highway and waterway, and covering different cities in the region. And in 2008, *the outline of integrated road transport planning in the Yangtze River Delta Region* was passed by cooperative efforts of transport administrators from Shanghai municipal, Zhejiang province and Jiangsu province. Such kind of transport plannings were also made in other urban agglomerations.

Generally speaking, there are two major aspects that may cause problems in urban agglomeration transport planning in China:

1. Different modes of transport planning are established by cooperation among separate transport government sectors in charge and concerned municipal governments. Although Chinese government has long been committed to the establishment of a comprehensive transport management system, the process is arduous and tortuous. Before 1998, there were the ministry of railway in charge of rail transport, the ministry of transport in charge of highway and waterway, and the general administration of civil aviation in charge of air transport. And as a measure of comprehensive transport management reform, the general administration of civil aviation was integrated into the ministry of transport as one of its sub-administrations in 2008. And in 2013, the ministry of railway was divided into the national railway bureau and Chinese Railway Company. The former part was integrated into the ministry of transport as one of its sub-administrations. During different stages, there were different administrative entity in charge of each mode of transport and making its planning. Although each mode of transport planning claims to be suited and connected with regional planning and other modes of transport planning, this goal is often hard to be accomplished. Some may attribute to sector interests

that often took privilege over overall transport efficiency, but mostly may attribute to the lack of proper transport planning techniques.

2. The method used in urban agglomeration transport planning in China was mostly the sequential four-step model of urban transport planning. In this method, the urban agglomeration is taken as a whole, and different cities or provinces are taken as zones divided. It usually follows trip generation, trip distribution, mode choice and route assignment procedure. However the relationships between transport and regional development are too complicated and both substitutive and competitive effects exist among different modes of transport, traditional four-step model is unable to take all these complexity into consideration. In fact, the debate on four-step model of urban transport planning has never been stopped, some point out that the sequential structure is one major criticism of this method (Pfaffenblchler, 2011). Therefore urban agglomeration transport planning using this method is also under question.

1.2 Worldwide changes of the ways of making transport planning

The ways of making transport planning are undergone worldwide changes. Handy (2007) analyzed the long-range plans of four Metro Metropolitan Planning Organizations (MPOs) in the US and presented a framework for "examining the ways in which technical aspects of the regional transportation planning process are changing in response to a broadening of goals and strategies, driven in part by an increased emphasis on public involvement". Bertrolini et al point out that urban planning practices are changing from focusing on transport as a single issue to a more holistic view of mobility in relation to a wide range of issues, who argue that new requirements on transport knowledge to support planning are needed. And in October 2009, a small conference was organized with international scholars to discuss about new models and techniques in dealing with transport problems (Brommelstroet and Bertolini, 2011).

In China, Scientific outlook on development aiming at comprehensive, coordinated and sustainable development is enthusiastically advocated nowadays, setting new requirements on the way of transport development. Due to the accumulation of industries, population, resources, etc., previous development pattern of transport in China, typicalled by exceeding energy consumption and low efficient land exploit, is unsustainable. And comprehensive transport development in urban agglomeration is increasingly restricted by resources and environments. A new development pattern, which is resource saving and environment friendly, is needed in transport industry. And this should first embody in transport planning.

1.3 System dynamics method and its application in transport planning

System dynamics (SD) is a methodology and mathematical modeling technique good at framing, understanding, and discussing systems and their dynamic behavior. The discipline of SD was founded by John Forrester and his colleagues in the late 1950s at the MIT (Pfaffenbichler, 2011). Urban agglomeration is an organic complex system, composed of various regions, natural resources and social and economic factors. Meanwhile transport is also a complex system composed of population flow, materials flow, capital flow and techniques flow. The relationship between the two complex systems is dynamical and nonlinear, and many factors are hard to be quantitatively described. It seems that SD has great potential in addressing urban agglomeration transport issues.

Pfaffenbichler discusses the advantages of SD method in general and the model MARS (Metropolitan Activity Relocation Simulator) in particular in transport planning. According to him, operational models based on SD already exist in 14 European, Asian and South American cities.

In our opinion, SD is not only a technique tool, but also a way of thinking which can help us addressing transport-related issues systematically and in a bigger system covering transport, environment, social and economics, etc.. In a word, the potential of SD application in transport is far from fully exploited. In this paper, we try to discuss the use of SD in analyzing urban agglomeration transport system and making comprehensive transport planning.

2. Feedback relations between transport and regional economy

What makes using system dynamics different from other approaches in studying complex systems is the use of feedback loops and stocks and flows. Feedback loops mainly descript the feedback relations between different variables in the system in a qualitative way.

There are abundant study about the relationship between transport and regional economy. Some scholars give evidence from history that transport system improvement have significant effect on economy growth. For example, Hunter (1965) argued that the digging of canals and the construction of railways played an important role during the industrial revolution, due to a strong reduction of transport costs. More generally, Rostow referred to the construction of railways in France, Germany, Great Britain and the USA and the economic development in these countries and concluded that an improvement of the transport system is major prerequisite for economy *take-off*. (F. W. C. J. Van de Vooren, 2004). On the other hand, transport demand is induced by social and economic activities. Many social and economic elements, such as, GDP, national income, industrial structure are major factors in determining the amount and structure of transport demand.

However, the mechanism hidden behind transport and regional economy interaction is very complicated. In this paper, we analyze it from three aspects, namely, investment efficiency, operation effectiveness, and placement guidance effect.

2.1 Transport investment efficiency on regional economy

Keynes was one of the first to consider public works including investment in infrastructure for transport as a means to trigger economic development. Keynes was especially concerned with the short period, where the influence of investment on effective demand is essential. (F.W.C.J. van de Vooren, 2004).Construction of transport infrastructure requires large amount of input of labor force, steel, asphalt, cement, wood, as well as other materials, resulting in significant short-term pulling effect on regional economy. Transport infrastructure investment can promote employment, push the development of correlative industries, thus increase passenger and freight traffic demand. From this perspective, transport investment has positive feedback effect on regional economy. On the other hand, investment on transport infrastructure occupy large amount of land, aggravating shortage of land and other resources, resulting in negative effect on regional economy, and reflecting negative feedback effect. Diagram 1 shows the feedback relationships between transport investment and regional economy. For example, one positive loop in this diagram is *transport investment--employment--residents income*--passenger *traffic--transport infrastructure--transport investment*; and one negative feedback loop is *transport investment--construction land--relevant industries--freight traffic--transport infrastructure--transport investment.*

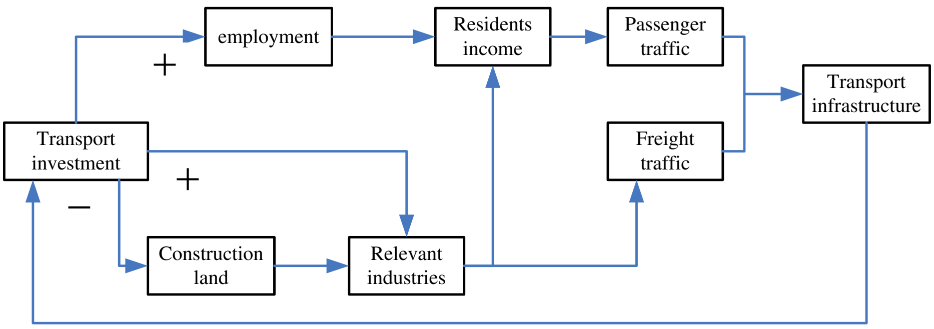

Diagram 1. Feedback loop of transport investment efficiency on regional economy

2． 2 Transport operation effectiveness on regional economy

When transport system is put into operation, its operation effectiveness will influence logistics costs and trip costs, thereby influence the transaction costs of the whole economy system, promoting or depressing economic growth. On the other hand, economic growth will influence traffic demand.

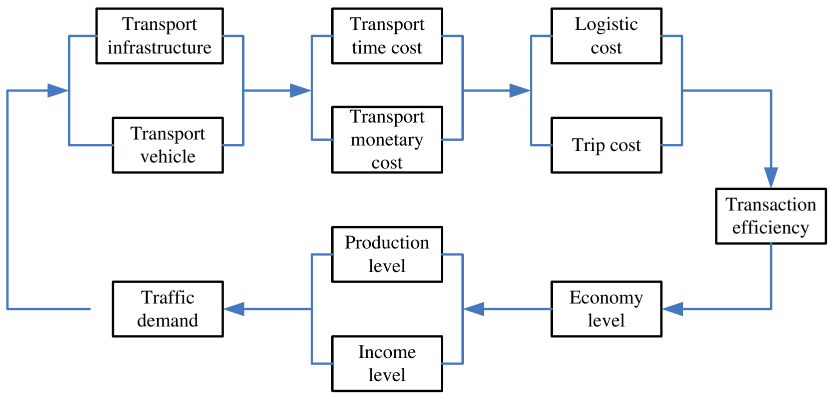

Diagram 2. Feedback loop of transport operation effectiveness on regional economy

Diagram 2 shows the feedback loop of transport operation effectiveness on regional economy. Both transport system capacity and economy development stage determine whether the feedback loop is positive or negative. According to Rong (1991), relationships between transport industry and economy development can be divided into three stages, namely, pre-transportizaiton stage, tranportizaiton stage, and post-transportization stage. And transportization stage can be further divided into preliminary transportizaion stage and advanced transportizaiton stage. In pre-transportization stage and transportization stage, incremental of economy also cause incremental of traffic demand. While in post-transportization stage, incremental of economy will cause deduction of traffic demand. In addition, before congestion points of transport infrastructure and vehicle, traffic incremental will bring economy of scale, therefore reduce unit transport cost; while after congestion points, traffic incremental will cause increase of unit transport cost, therefore increase logistic cost and trip cost, decreasing transaction efficiency, hindering economy increase. Table 1 shows the feedback relations of transport operation and regional economy. In table 1, we can see that in post-transportization stage, after congestion point, economy increase will reduce traffic demand, thus lessen traffic congestion, reduce unit transport cost, increase transaction efficiency, and further facilitate economy, reflecting positive feedback relationship.

Table 1 Feedback Relationship Between Transport System Operation Effectiveness and Regional Economy

	Pre-transportization	transportization	Post-transportization
Before congestion point	positive	positive	negative
After congestion point	negative	negative	positive

2.3 Transport system placement guidance effect on regional economy

Many scholars agree that different spatial patterns of mobility and accessibility created by different transport systems play important role in determine regional economic success. Their studies shows that after economic diversity, high quality internal and external connectivity is the most important explanation of regional economic competitiveness. The most successful regions often have class-leading transport infrastructure, which can provide securely, quickly and efficiently movement of goods, services, information and people (Docherty, 2004) .

Therefore transport system layouts will determine location choices of firms and activity scopes of human beings, thus determine various functional domain placements. On the other hand, the placement of various functional domains will determine the form of traffic demand distribution, and influence transport infrastructure layouts. While functional domain placement and transport infrastructure layout are, to a large extent, not only determined by market but also by government policies. Therefore we introduce urban agglomeration development planning and transport planning as exogenous variables. Diagram 3 shows the feedback relationships of transport system layout guidance effect on regional economy.

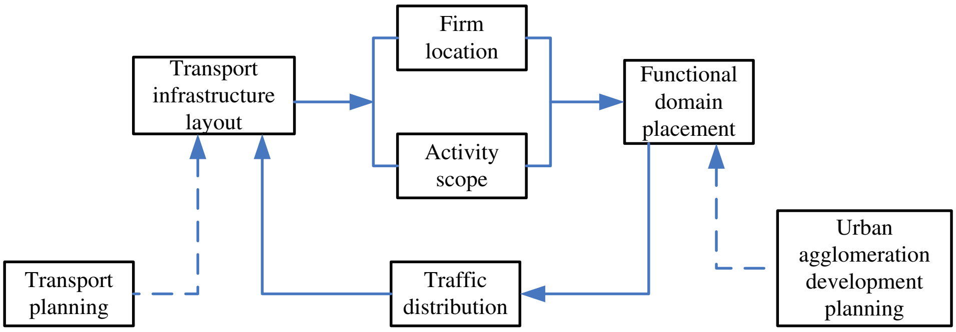

Diagram 3. Feedback loop of transport system placement guidance effect on regional economy

3. Causal loop diagram of urban agglomeration transport system

Causal loop diagram (CLD) is a qualitative description of the cause-effect relationship among variables in the system. It consists of entities reflecting both stock and flow variables, and arrows denoting their causal influences. In section 2, we analyzed the feedback relationship between transport system and regional economy. Both transport system and regional economy can be further divided into several subsystems, each subsystem can be represented by a set of variables of similar characteristics, to the sense that they usually show the same causal relations with variables from other subsystems.

Integrating transport system investment efficiency, operation effectiveness and placement guidance effect on regional economy, we can figure out the CLD of urban agglomeration transport system as diagram 4. In this CLD, we define entity not only as a single variable, but also as a subsystem consisting of a set of variables of similar characteristics. It includes four subsystems of transport system, namely, transport infrastructure subsystem, transport vehicle subsystem, passenger traffic subsystem and freight traffic subsystem; three subsystems of social and economics variables, namely, gross domestic product subsystem, passenger income subsystem and population subsystem; and two subsystems showing resources and energy restrictions, namely, land subsystem and energy subsystem. For example, in transport infrastructure subsystem, the stock data can be composed of railway mileage, highway mileage, etc. The CLD also includes two exogenous variables, namely, transport planning and regional planning. Because once such plannings are formulated, they will have great influence on future transport development and regional development in a certain period.

Arrows connecting different subsystems or variable in the CLD denote the causal-effect relations among them. We also take *transport infrastructure* as an example, the flow of *transport infrastructure* is influenced by *transport investment*, and changes of *transport infrastructure* influences *income;* and stock of *transport infrastructure* is one of the factors that determine *operation effective.*

CLD offers a qualitative and intuitively understandable tool to analyze the complex system, which might improve the transparency and insight into the underlying cause-effect relationships (Pfaffenbichler, 2011). However, to further analyze the system quantitatively and to simulate the system in computer through soft wares, a more detail description of the subsystem and variables, as well as function and equations among them are required.

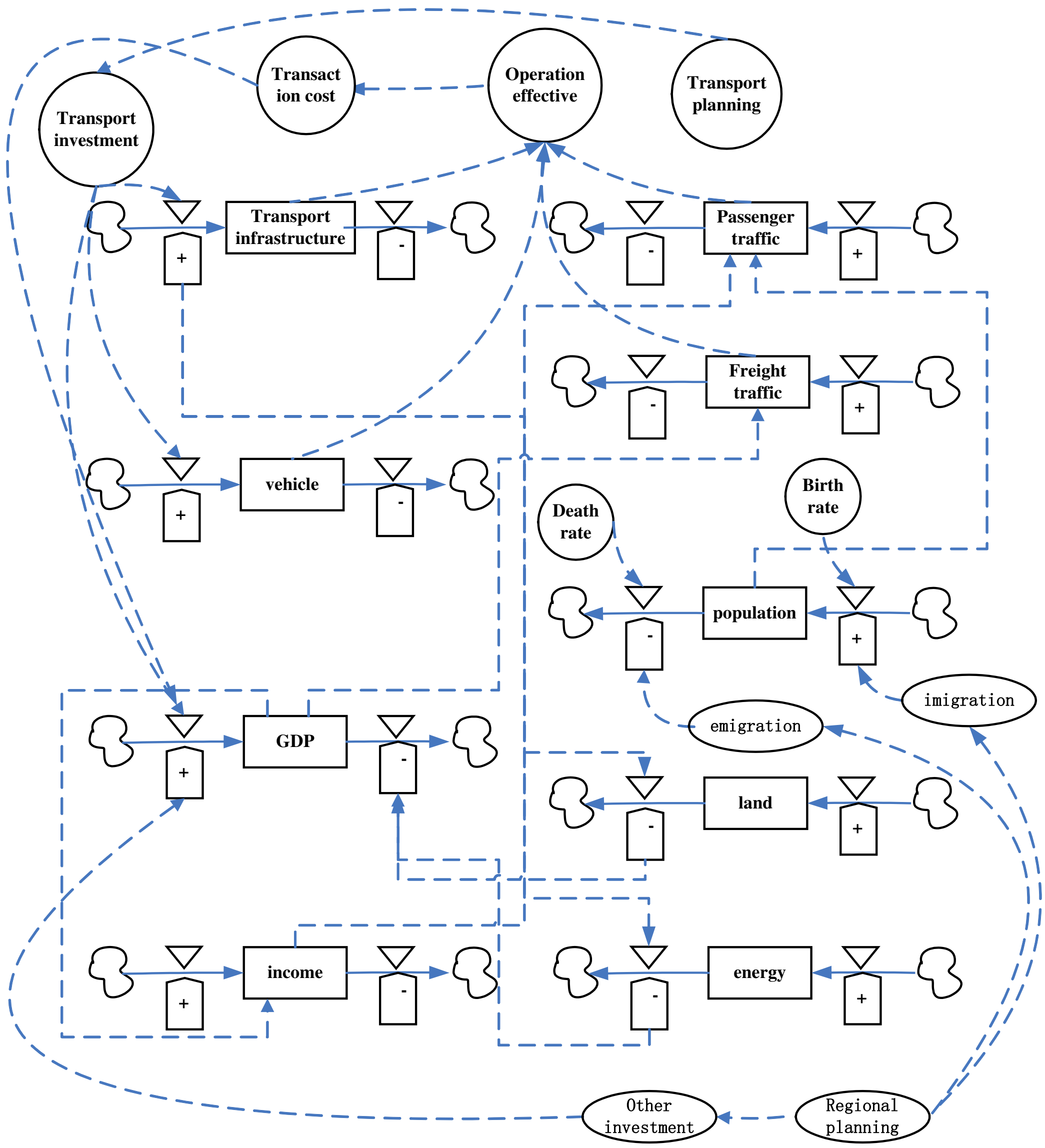

Diagram 4. Causal loop diagram of urban agglomeration transport system

4. Major equations and functions

In order to give a quantitative analysis of the system, the date base of each variables and equations and functions reflecting the quantitative relations among those variables are necessary. With the help of system dynamics softwares, given the changes of some variables, the changes of other variables can be easily deduced, and the dynamic changes of the whole urban agglomeration transport system and related social and economics systems can be monitored. However, the availability of data, and the usefulness of models often cause a lot of debates among scholars and practitioners.

In this paper, rather than give specific equations and functions, we mainly talk about the database we need to establish and the models we can choose from. We classify them into 6 categories: transport demand functions, transport facilities capacity functions, transport investment efficiency functions, transport operation effectiveness functions, transport land use function, and transport energy consumption function.

(1) Transport demand functions

Transport demand, including both passenger traffic and freight traffic, often changes with GDP, industry structure, domestic income, population, and other socio-economic factors. Transport demand functions are commonly used in traditional sequential four-step model. Within the rational planning framework, transportation forecasts have traditionally followed the sequential four-step model, namely, trip generation, trip distribution, mode choice and route assignment. Generally, in each step, there are regression model, time series model, elasticity coefficient model, and gravity model, etc. The models and parameters can be estimated using statistical methods, expert opinion, market research data or other relevant sources of information. These models can also be used in establishing the SD model, on condition that they are tailored to our specific needs.

(2) Transport facilities capacity functions

Transport facilities, such as, railway, highway, and all kinds of vehicles, have there capacities. We can give a table function according to their design capacity or maximum capacity. For example, according to "Highway Project Design Standard" established by Chinese ministry of transport, year traffic capacity of a four-lane highway is 25,000~55,000 standard motor vehicles.

(3) Transport investment efficiency functions

Transport investment efficiency functions reflect the effects that new transport infrastructure and vehicle investment will have on GDP within the urban agglomeration. According to investment multiplier theory of Keynes, we can deduce the urban agglomeration transport investment effectiveness function as formula (1).

$$\Delta GDP = \Delta I \cdot K_{\mu} \qquad \text{Formula (1)}$$

In which, ΔI represents the increase amount of investment by a new transport project;

K_u represents the investment multiplier of the region in question;

And ΔGDP represents the increase of regional GDP derived from the activity.

(4) Transport operation effectiveness functions

Transport operation effectiveness functions reflect improvement of regional economy and optimization of industrial structure caused by new transport facilities put into operation. As section 2.2 shows, new transport facilities will make passenger and freight transport more effective, and reduce transaction cost, thus have a positive effect on regional economy. Transport operation effectiveness is generally calculated as the ratio of social benefit to social cost. Social benefits include both direct benefit and induced benefit caused by the new transport project. And social costs include capital occupation cost, transport system maintenance cost and time cost, etc. (Dong, 2010). The specific function between transport operation effectiveness and urban agglomeration economy can be drawn through regression approach or time sequential approach.

(5) Transport land use functions

Transport facilities, such as, railway lines, highway, stations and airports use land in their construction. But different modes of transport have very great discrepancy as to per mile land use or per ridership land use. For example, according to “Chinese highway construction land use standard”, super high way need 7.5~8.3 hectares land per kilometer. A table function of transport land can be drawn according to different modes of transport facilities construction land use standard.

(6) Transport energy consumption function

Energy, especially petroleum, is consumed in the manufacture and use of vehicles, as well as during the construction of transport infrastructure, including road, bridges, and railways. According to Lin (2010), different modes of transport have great discrepancy in energy consumption per ton-kilometer or passenger-kilometer. As her paper shows, energy (petroleum) consumption for rail, road, airway and water way are 24.6, 776.3, 3093.1 and 120 kilogram per ton-kilometers respectively.

5. Application in urban agglomeration transport planning

Using above causal loop and specific equations and functions, as well as basic data input, urban agglomeration transport system can be dynamically simulated, assisting transport planning policy makers in many respects, including transport forecasting, exiting transport system adaptability assessment, alternative solutions selection, environment and energy assessment, etc.. A possible procedure of making urban agglomeration transport planning using this method can be shown in diagram 5.

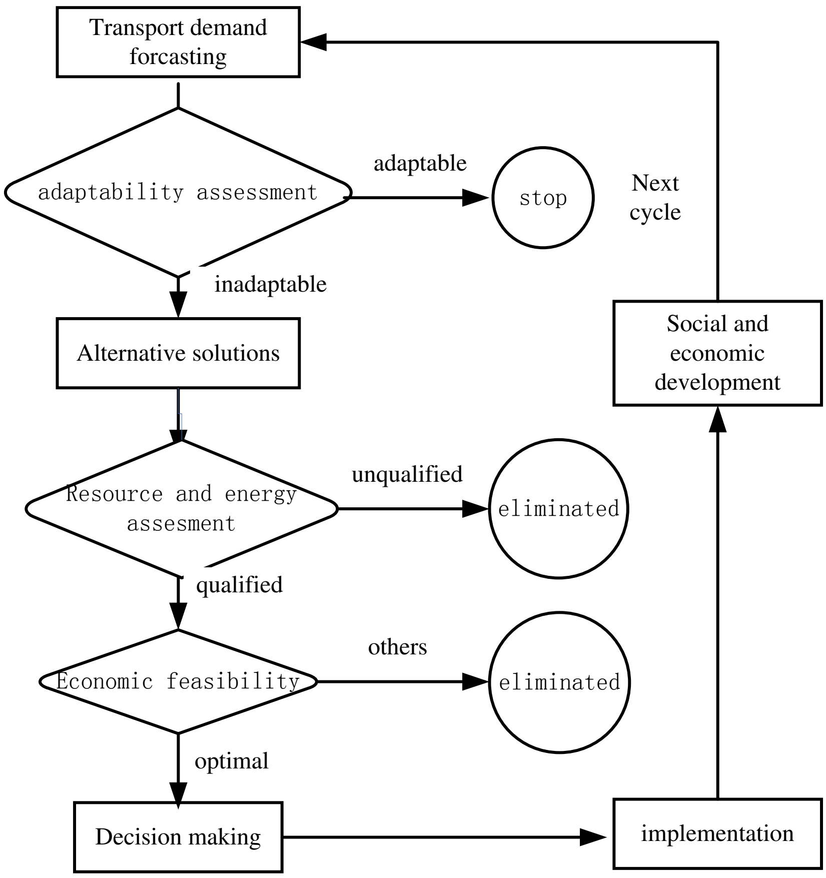

Diagram 5. Flow Chart of Urban Agglomeration Transport Planning

First step is to make transport demand forecast. Then in the second step, the adaptability assessment of present transport system is made, if adaptable then stop; if not enter the third step, which is to give alternative solutions. In the fourth step, resource and energy assessment are made on those alternative solutions, if unqualified then eliminated; if qualified then enter the next step. The fifth step is to make economic feasibility assessment, finding the optimal solution. Finally, the decision is made and put into implementation. With the development of social and economics, new patterns of transport demand are induced and enter next cycle. With the help of SD softwares, the whole decision making process is visible and possible effects on the regional economy can be easily predicted.

It will make transport planning continuously, comprehensively, harmoniously and sustainable, in the following ways:

(1) Give consideration to both long-term and short term period, making transport planning continuously

The planning period can be set according to our need. It can be either long-term transport planning, such as 20-year plan, or short-term transport planning, such as 5-year plan. Moreover, the effect of transport planning of this period can be embodied in the transport forecasting in the next period, and thus can make transport planning continuously.

(2) Give consideration to both the whole and the parts, making transport planning comprehensively

It provides a system platform for policy makers from different areas or different transport sectors, helping them making more integrated transport planning, not only transport planning direct to the whole transport system but also those local area or individual mode of transport improvement solutions.

(3) Coordinate transport and regional development, making transport planning harmoniously

Through simulation soft wares, changes of transport system are connected with that of regional social and economic system dynamically. Thus regional development planning can be embodied in transport forecasting, and make transport planning harmoniously with regional development.

(4) Emphasis on energy and environment restrain, making transport planning sustainable

New transport facilities effects on resources and environment are simulated, help policy makers making more energy saving and environment friendly choices, thus make transport planning sustainable.

6. Conclusions

System dynamics is a powerful approach in simulating and analyzing urban agglomeration transport system. This paper first analyzed the feedback relations between transport and regionally economy from three aspects, namely, investment efficiency, operation effectiveness, and placement guidance effect. Then we established causal loop diagram of the urban agglomeration transport system and define and describe the major subsystems and equations.
Using method and softwares of SD, transport demand changes along with regional social and economic changes, or the influence of new transport infrastructure investment on regional economy can be better predicted, providing a platform for policy makers from separate government sectors, helping them make transport planning more continuative, comprehensive, integrative and sustainable.
Our findings suggest a widely application of system dynamics in transport planning and the establishment of dynamic simulation of urban agglomeration transport system.

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