Urban Public Transportation Modes Coupling Study Based on Residents Travelling

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Keywords: urban public transportation coupling; public transportation contribution rate; system dynamics; residents travelling

Abstract

Using the method of system dynamics under urban transportation system theory implementation, this paper studies the impact factors of contribution rate of urban public transportation—bus, rail transit, and taxi and their corresponding coupling relationship. Four factors are defined, namely, safety factor, convenience factor, comfort factor, and cost factor, to analyze the influence on each mode of public transportation contribution rate through system dynamics flows analysis. And a public transportation mode coupling model is established to provide convenience to urban residents. Furthermore, it is indicated in this paper that the application range of the model makes it widely useful in public transport situation evaluation. The paper also provides improvement suggestion as well as inter-city comparison of public transport coupling situation.

1 Introduction

With the acceleration of urbanization process, big and medium cities around the world are facing the issue of urban traffic congestion, which has been one of major bottlenecks of urban economy and social development. At present, China's share of public travel on average is less than 10%, and only about 20% in mega-cities. Bus speed is getting lower and lower. 70% of residents are not satisfied with urban public transport service. In 2003 alone, for example, because of traffic congestion China's economic losses were up to 2,500 billion Yuan, equivalent to 2% of the GDP of that year and equivalent to 500 kilometres of subway construction.

In order to solve urban traffic congestion, major cities have introduced policies to develop public transportation, construct rail transit, implement bus priority, establish various harmony public transport coupling relationships. These policies may attract people to choose public transport instead of private one to reduce traffic congestion.

Therefore, research on urban travel demand and its influencing factors, analysis of various public transport choices, improvement of transport facilities coupling and scientific approaches to meet and guide the diverse travel needs of city dwellers, all these are urgently important issues in urban development.

2 Related definition and theoretical basis

2.1 Urban public transport items

According to the ownership of transport means, urban passenger transport modes can be classified as shown in Figure 1. In this paper, we focus on three kinds of public transport: buses, rail transportation, and taxi.

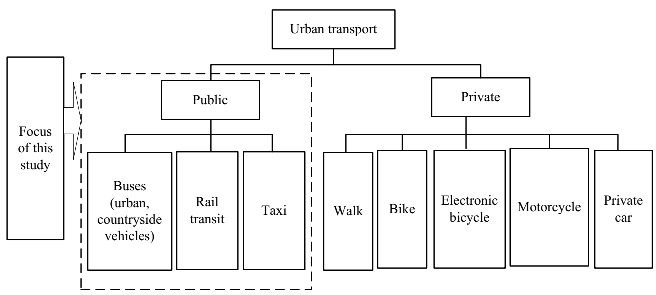

Figure 1: Classification of urban passenger transport modes.

(1) Public transport vehicles. Buses are the main force for the medium, short-distance transport. Compared with rail transit, public vehicles' passenger capacity is small, but larger than that of several other travel means. Operators have greater flexibility in lines and sites. The disadvantages of this choice lies in discomfort and low rate of quasi-point, especially during the peak hour.

(2) Rail traffic is the city's important corridor, mainly covering long-distance traffic, with large capability, swiftness, punctuality, comfort and so on. But rail transit calls for high cost of its construction and operation, and it has low network density and fixed lines which are not

susceptible to change. Though rail transit is a convenient way for a large-scale, high-efficiency delivery in the cities, it does not provide a direct access to destinations.

(3) Taxi, compared with other public traffic means owns fast speed, comfort, good service, and flexibility. Drivers are able to choose routes and transfer location based on specific need of travellers. But it demands high cost, and causes low travel capability and road utilization. The development of taxi reflects the diversity in choices of passenger transport demand, which is a complement to conventional forms of public transport. Supervisors should take reasonable measures to control and guide its development.

2.2 Concept of coupling based on urban public transport system

Coupling, a fundamental concept in physics, is the phenomenon when two or more systems or movements are united together through a variety of interactions, during which they are impacting each other, or is dynamic association with interdependence, mutual coordination and promotion within interactions among different subsystems.

The coupling mode of transportation is the interaction between certain vehicles or persons and different choices from beginning to ending. To two transportation modes, if the coupling mechanism is synergistic, the system will produce resonance increasing effect, expressed in a virtuous circle of rising trajectory. On the contrary, it causes a large number of energy dissipation and the formation of entropy barrier, resulting in a collision of two systems running track and falling into the trap of mutual weakening growth effects.

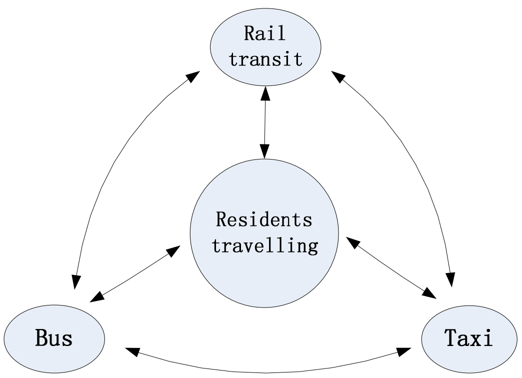

Figure 2: Public transport interaction centred by residents.

2.3 Theories of system dynamics

The research of System Dynamics mainly focuses on the feedback process of complicated problems. It provides scientific proofs to the development and balance of economics system, through analysis of changing trend of the systematic behaviours. System Dynamics points out information feedback mechanism that exists in every system, categorizes the research objects into several sub-systems, and sets up causal relationship net among different sub-systems. It explores the relationship between systems instead of the traditional factors. The traditional dynamics approach is to set up computer model of flow charts and functions, then experiment with the model to test its efficiency, and help with strategy and decision making.

3 Research on systematic dynamics

3.1 Definition of influencing factors

Impact factors for the residents of urban public transport mode choice have great influence and basic impact factors among various cities are essentially the same. This paper selects the sequence table from “The Report of Urban Transport Travel Information Service Platform Based on a Variety of Modes of Transport Coupling”, which is based on the questionnaires of Beijing residents, to apply to general analysis in more cities.

The importance degree specifically regarding factors that decide passengers’ choice are rated five levels: least important, less important, ordinary, quite important and extremely important. Respondents are asked to score 1-5, which represents the five levels above respectively. Therefore, the factor with average higher score is stressed by most citizens and is selected as the important.

In this paper, factors affecting travellers’ choice of transport modes are divided into four kinds of factors.

(1) Safety factor mainly involves personal safety and property safety. In general, the safety factor is the biggest concern for residents on travel.

(2) Convenience factors include the length of time waiting for a train, punctuality, walking distance to transfer, convenience, transfer time, distance and so on. Therefore, convenience factor is an important consideration.

(3) Comfort factor includes whether travelling in peak hours, congestion, maintaining self-image, and the various public transport modes as well as the feelings of convenience. Comfort factor is residents’ personal travel experience, and a major factor.

(4) Cost factor mainly refers to residents of the opportunity cost of travel mode choice. It mainly includes economic cost, that is, fares; time cost, that is, relative to other modes of transport time required for comparison. Cost factor is an important means to promote the development of urban public transport.

Due to the closed-loop characteristics, every factor is made up of a number of sub-factors. Meanwhile, the share ratio has close relationship with these four factors.

Table 1: Factor importance sequence for residents to choose public traffic modes.

	Factors	Average score		Factors	Average score
1	Length of time waiting for a train	4.36	8	Walking Distance to transfer	3.85
2	Property safety	4.10	9	Crowded	3.74
3	Punctuality	3.99	10	Station facility	3.68
4	Whether peak hour	3.99	11	Weather	3.61
5	Transfers	3.97	12	To keep self-image	3.60
6	Distance	3.91	13	Travel expense	3.41
7	Whether to carry bulk items	3.91			

Source: The Report of Urban Transport Travel Information Service Platform Based on a Variety of Modes of Transport Coupling.

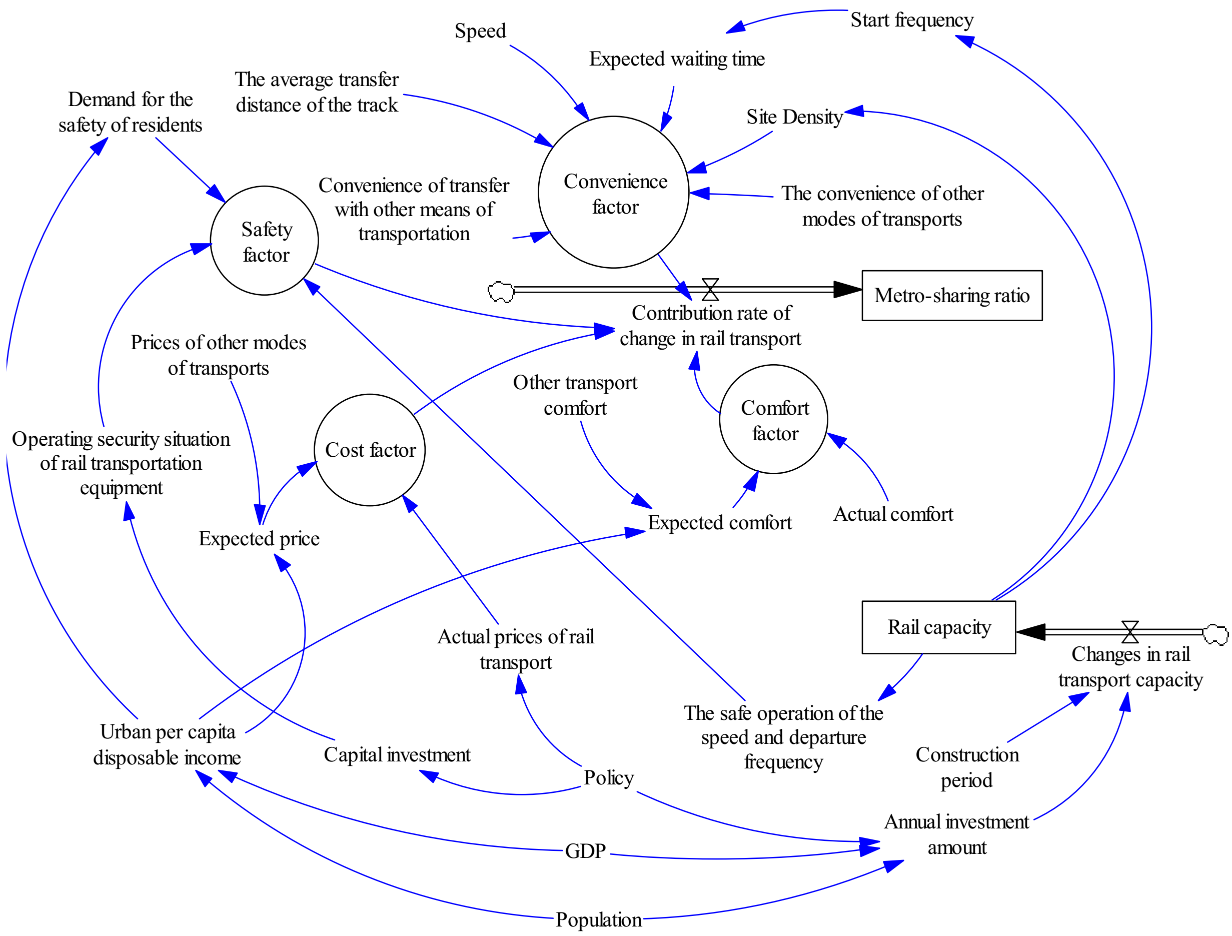

Figure 3: Separated analysis flow of sub-system based on influencing factors for rail transit.

3.2 Separated analysis on influencing factors for rail transit

The flow chart involving separation ratio of rail transit is as follows: Safety factor of flow figure:

Annual Investment Quota → Policy → Capital Investment → Rail Transit Operation Equipment Safety Situation →Safety Factor → Rail Transportation Separation Ratio Change→ Rail Transit Separation Ratio

Convenience factor of flow figure:

Annual Investment Quota → Rail Capacity Change → Rail Transit Capacity → Site Density→ Rail Transit Separation Ratio Change → Rail Transit Separation Ratio

Annual Investment Quota → Rail Capacity Change → Rail Transit Capacity → Site Density → Start Frequency → Expected Waiting Time→ Rail Transit Separation Ratio Change → Rail Transit Separation Ratio

Comfort factor of flow figure:

Actual Comfort Degree → Comfort Factor →Rail Transit Separation Ratio Change →Transit Separation Ratio

Annual Investment Quota → Rail Capacity Change → Rail Transit Capacity →Actual Comfort Degree → Comfort Factor →Rail Transit Separation Ratio Change → Rail Transit Separation Ratio

Cost factor of flow figure:

Actual Comfort Degree→ Rail Capacity Change → Rail Transit Capacity→ Rail Transit price→ Rail Transit Separation Ratio Change → Rail Transit Separation Ratio

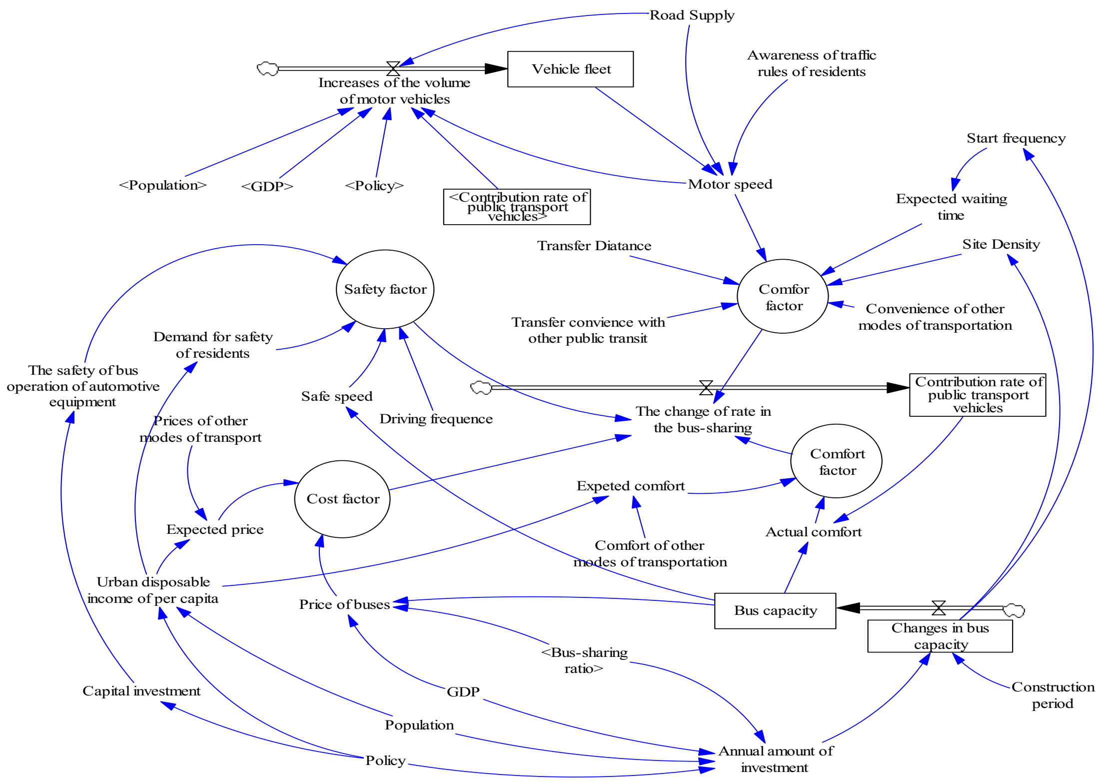

Figure 4: Separated analysis flow of sub-system based on influencing factors for bus.

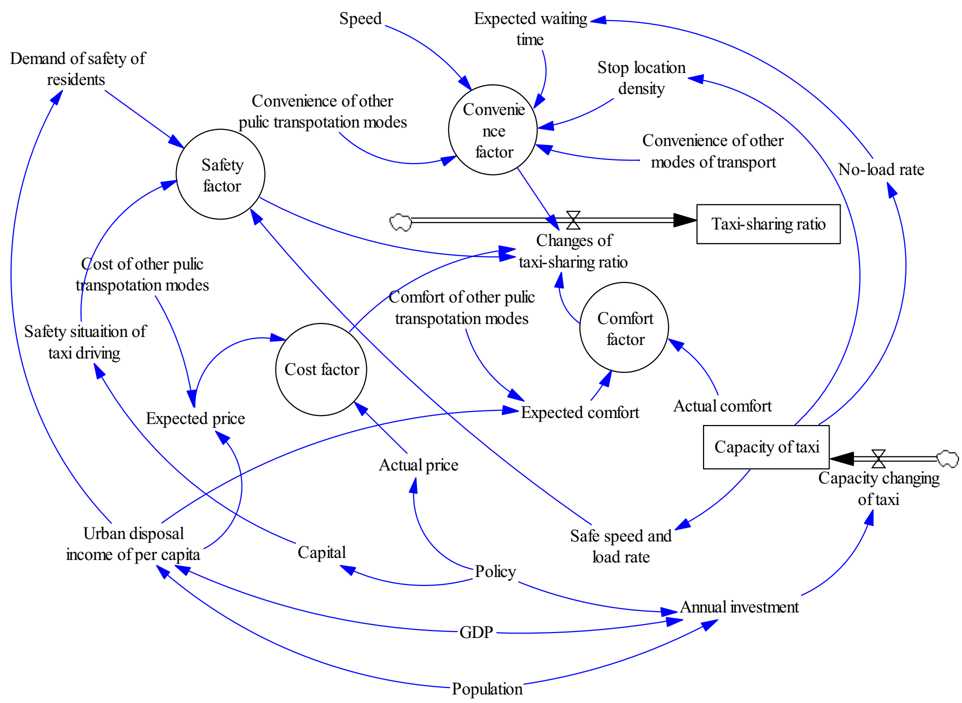

Figure 5: Separated analysis flow of sub-system based on influencing factors for taxi.

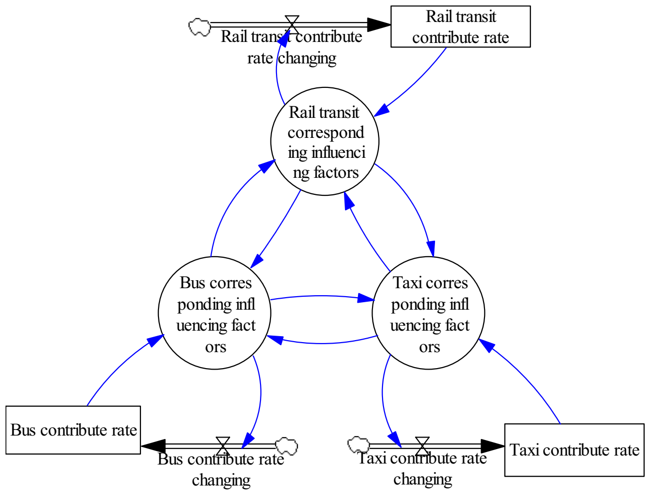

Figure 6: Three public transportation modes interaction based on influencing factors.

3.3 Separated analysis on influencing factors for bus

By the same analysis method of system dynamics under the thought of urban public transport system, and also with the similar influencing factors, we can get the figures of bus separated analysis on influencing factors (Figure 4).

3.4 Separated analysis on influencing factors for taxi

By the same analysis method of system dynamics under the thought of urban public transport system, and also with the similar influencing factors, we can get the figures of taxi separated analysis on influencing factors (Figure 5).

3.5 Three public transportation modes interaction

Figure 6 shows the relations between each of the three public transportation mode as follows:

Rail Transit Contribution Rate→ Rail Transit Corresponding Influencing Factors→ Bus Corresponding Influencing Factors→ Bus Contribution Rate→ Bus Contribution Rate Changing

Bus Contribution Rate→ Bus Contribution Rate → Rail Transit Contribution Rate→ Rail Transit Contribution Rate Changing→ Rail Transit Contribution Rate Changing

Rail Transit Contribution Rate→ Rail Transit Corresponding Influencing Factors→ Taxi Corresponding Influencing Factors→ Taxi Contribution Rate→ Taxi Contribution Rate Changing

Taxi Contribution Rate→ Taxi Corresponding Influencing Factors→ Rail Transit Corresponding Influencing Factors→ Rail Transit Contribution Rate→ Rail Transit Contribution Rate Changing

Bus Contribution Rate→ Bus Corresponding Influencing Factors→ Taxi Corresponding Influencing Factors→ Taxi Contribution Rate→ Taxi Contribution Rate Changing.

4 Coupling model of residents' choice

4.1 Descriptions of three transportation couplings based on system dynamics

Within the city transportation system, there exist interactions between different forms of public transportation through different factors (not limited to the four factors mentioned above) following similar pattern. Thus the dynamics relationship maintained can be described as couplings among sub-systems. In this process, different factors influence the sub-systems through the travellers' choices of travelling methods (i.e. type of transportations).

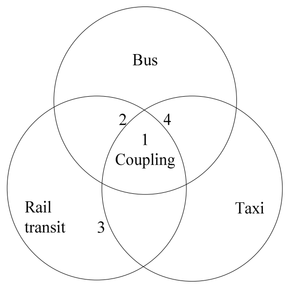

Figure 7: Coupling relationship among buses, rail transit, and taxis.

4.2 Coupling Model of transportation choice for residents

The coupling value of travellers' choice is influenced by the separation ratio of three types of transportation, while the separation ratios is decided by safety factor, convenience factor, comfort factor and cost factor.

Specifications of the model:

(1) Use the separation ratios of each type as independent variables, set up the general model of the coupling. We abbreviate Contribution rate as CR.

(2) Safety factor, convenience factor, comfort factor and cost factor as extra explanatory factors, and find out further relationship of the separation ration and coupling value.

$$\therefore f_1[g_1(x_{CR1}, x_{CR2}, x_{CR3})] = f_1(X_1) = f_{\text{safety}}(X_1)$$

$$= f_{\text{safety}}\begin{pmatrix} X_{\text{demand for safety of resident}}, & X_{\text{facilities situation}} \\ X_{\text{safe speed}}, & X_{\text{driving frequency}} \end{pmatrix}$$

(3) The influence of safety ratios on separation ratios can be shown on safety requirement of travellers, safety conditions of operating vehicles, safe driving speed and driving frequency.

$$Set\ X_n = g_n(x_{\text{CR}1}, x_{\text{CR}2}, x_{\text{CR}3})$$

$$f_2[g_2(x_{CR1}, x_{CR2}, x_{CR3})] = f_2(X_2) = f_{\text{Convenience factor}}(X_2)$$
$$= f_{\text{Convenience factor}}\begin{Bmatrix} X_{\text{Transfer convenience with other public transit}}, \\ X_{\text{Transfer distance}}, X_{\text{Road length}}, X_{\text{Transfer capacity}} \\ X_{\text{Expected waiting time}}, X_{\text{Vehicle numeber}} \end{Bmatrix}$$
$$f_3[g_3(x_{CR1}, x_{CR2}, x_{CR3})] = f_3(X_3) = f_{\text{Comfort factor}}(X_3)$$
$$= f_{\text{Comfort factor}}\left(X_{\text{Actural comfort}}, X_{\text{Expected comfort}}\right)$$
$$f_4[g_4(X_{\text{Transfer capacity}})] = f_4(X_4)$$
$$= f_{\text{Cost factor}}(X_4) = f_{\text{Cost factor}}\left(X_{\text{Actural price}}, X_{\text{Expected price}}\right)$$
$$f_{\text{coupling}}(x_{CR1}, x_{CR2}, x_{CR3})$$
$$= f\begin{Bmatrix} f_1[g_1(x_{CR1}, x_{CR2}, x_{CR3})], f_2[g_2(x_{CR1}, x_{CR2}, x_{CR3})] \\ f_3[g_3(x_{CR1}, x_{CR2}, x_{CR3})], f_4[g_4(x_{CR1}, x_{CR2}, x_{CR3})] \end{Bmatrix}$$

(4) Then we can calculate convenience factor, comfort factor, and cost factor in the same method as above.

5 Conclusions

The public transport coupling model is quite commonly used. Based on the model and the simulation on statistic data in Beijing, current level of public transport coupling in Beijing can be evaluated exactly, and its factors can be determined, so that some measurements can be implemented to improve this situation. In addition, this mode could be used to evaluate other cities' coupling level and help to improve accuracy by modifying the factors in different cities.

This model can also be applied to compare the public transport coupling among various cities. Because the separation ratio is a kind of data that can be collected objectively, it is a tool for the comparison. In fact, due to varied starting points and development modes for different cities, the comparison resulting from the separation ratio and the four key factors depending in this model will be revised respectively. Based on the analysis of Beijing public transport coupling model, we will apply the result to analyze specific cities.

In this paper, we discussed the model of residents travel mode coupling between public transports based on the separation ratio and factors, and public transport coupling in cities and its mechanism. But without necessary data verification, we only did the qualitative analysis. Thus, deeper function relations should be researched, as can be used for public solution coupling verification. Meanwhile, this paper only considered coupling analysis among bus, rail and taxi. In addition, urban transportation system is a complex and large system. How to achieve its coupling with the external factors and contributing to the sustainable development of urban economy and society requires in-depth study of the practical significance of the important subject.

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