



Evaluation of Urban Traffic Congestion Management Programs Based on System Dynamics and Ideal Solution Methods

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SUMMARY: *In this study, system factors that can reflect urban traffic congestion are screened in an all-round way, and an urban transportation system dynamics model covering multiple subsystems is constructed. The analytical equations of each subsystem module are established to improve the reliability of the model structure and the simulation of urban traffic congestion management. The evaluation index system of urban traffic congestion is established, and the weights of the indexes are calculated using the objective weighting method (CRITIC), and the traffic congestion index is calculated by combining with the method of the distance between superior and inferior solutions (TOPSIS), so as to measure the ideal solution distance of each management scheme and judge the mitigation effect on urban traffic congestion. In the system dynamics simulation experiments of the three management schemes, the urban vehicle diversion equilibrium degree of the congestion charge scheme with [10,15] yuan is optimal [0.01,0.09]. Meanwhile, the traffic congestion index of this scheme is only 0.14 by using TOPSIS calculation, which is the best capacity of traffic congestion management.*

KEYWORDS: *system dynamics; CRITIC; TOPSIS; traffic congestion index; urban traffic congestion; management scheme; ideal solution*

1 Introduction

In the context of rapid urbanization, the scale of the city has been upgraded, and private cars have become rapidly popular in the city; at the same time, economic and social development and scientific and technological progress and other factors have greatly increased the frequency of traffic in the city, and the demand for urban transportation has been increasing [1-3]. In this situation, the long-standing traffic problems in cities spread and deteriorate rapidly. In some urban centers, the average speed of motor vehicles has dropped to 8 to 10 km/h [4]. Traffic problems not only waste time and damage physical and mental health, but also cause economic losses of up to hundreds of billions of dollars per year; traffic accidents lead to tens of thousands of injuries and deaths each year, with direct property losses exceeding one billion dollars; traffic pollution accounts for more than 80% of the atmospheric pollution in large cities, with the direct consequences of the greenhouse effect, haze weather, and the creation of a variety of diseases; and traffic congestion leads to fuel consumption that is 30% more than usual [5-9]. Some studies have indicated that from the current state of development of urban transportation in China, the year 2030 will be the high period of urban transportation problems or the outbreak of urban crisis in China [10]. Countries have gained certain governance effects by increasing subway and light rail transportation, controlling the use of private cars, congestion charging, and investing in intelligent transportation systems to alleviate traffic congestion in various

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governance ways [11, 12]. By evaluating the management scheme, the urban traffic congestion management scheme can be further optimized.

System dynamics models can simulate different urban development strategies, such as increasing public transportation inputs, optimizing urban layout, etc., to assess which strategy can better alleviate traffic congestion and improve the livability of the city. Kayisu et al [13] emphasized that system dynamics is able to identify the chain of causality, i.e., positive and negative feedback loops as well as the delay effect in an urban transportation system, which adequately correlates the transportation environment with Zhang [14] developed a system dynamics model for the formation mechanism of traffic congestion in Chinese cities based on the system dynamics theory, and input the management measures into the model, among which the “sparse area combination” management policy is effective and sustainable. He and Li [15] used a system dynamics approach to simulate the effect of traffic congestion management in Chongqing, and drew a causal loop diagram and a stock-flow diagram, and found that the license plate restriction policy has a certain traffic congestion relief effect, and the railroad transportation can effectively relieve traffic congestion in a short period of time. Khosravi et al. [16] constructed a causal loop model of transportation and a dynamic model of the city using system dynamics, focusing on the three factors, namely, air quality, energy consumption, and traffic mobility, and conducted a study of urban traffic demand management policies. , to make a macro assessment of urban transportation demand management policies. Suryani et al [17] combined system dynamics simulation and scenario analysis to simulate and improve urban traffic congestion under dynamic changes in the environment, respectively. Increasing traffic mobility accessibility and decreasing daily traffic flow can reduce traffic congestion by 57.6%-69%.

And the ideal solution method (TOPSIS) is a comprehensive evaluation method, it is through the normalized data normalization matrix, to find out the optimal target and the worst target among multiple targets, calculate the distance between each evaluation target and the ideal solution and the anti-ideal solution respectively, to obtain the closeness of each target to the ideal solution, and then rank them according to the magnitude of the closeness of the ideal solution, which serves as the basis for evaluating the strengths and weaknesses of the targets. Hao et al [18] used fuzzy hierarchical analysis to calculate indicator weights and combined TOPSIS and gray correlation to assess urban traffic congestion, and proposed a hybrid decision-making method to make up for the limitations of the one-sidedness of the TOPSIS technique. Magableh and Mumani [19] combined discrete event simulation, TOPSIS, and preference selection indices to evaluate congestion management schemes for picking up and dropping off children in school zones during peak hours and selected the optimal management scheme based on several performance metrics. Zhuo et al [20] set up evaluation indexes including traffic capacity, average vehicle delay time, intersection safety, carbon emission and detour distance, and introduced TOPSIS based on combination weight improvement to evaluate the advantages and disadvantages of three traffic organization schemes for urban planar interchanges. Zhu et al [21] used entropy weight-TOPSIS to assess the level of coordinated traffic development of urban bus and metro from the levels of infrastructure, travel network and operation service to provide theoretical support for urban bus route planning. Zhang et al [22] dynamically evaluated the traffic safety facility layout scheme through the road traffic congestion feature analysis model, calculating the contribution of urban traffic safety facilities to traffic flow, entropy weight-TOPSIS model, and driver dynamic psychological feedback to provide optimization support for accident safety reduction in traffic congestion.

The system dynamics model can simulate the dynamic changes of traffic, while the TOPSIS technology can evaluate the traffic state and realize the multi-objective decision optimization. The combination of system dynamics model and TOPSIS can provide a comprehensive

assessment of the effectiveness of traffic congestion management by analyzing multiple influencing factors of traffic congestion and analyzing multidimensional data. Li et al [23] constructed a multidimensional dynamics model based on system dynamics and a multi-criteria decision-making framework based on TOPSIS, the former is used to analyze and simulate the variables of Shanghai's traffic congestion management and emission reduction policies, the latter The former was used to analyze and simulate the variables of Shanghai's traffic congestion management and emission reduction policies, and the latter to evaluate the short-term and long-term effects of the policies. The study points out that Shanghai's “dual license plate restriction” policy reduces traffic congestion, carbon emissions, and pollution, and emphasizes the challenges of a single management plan in the context of traffic congestion, carbon emissions, and pollution.

Reducing traffic congestion is the key to improving the well-being of residents and promoting harmonious urban development. With the goal of selecting the most effective urban traffic congestion management scheme, this study comprehensively considers the elements affecting urban traffic congestion and establishes a system dynamics model as one of the technical means to judge the feasibility of the scheme. The subsystem variables of the system dynamics model are used to establish the modular structure equations to ensure the computational judgment ability of the model without requiring the precision of the parameters. The objective assignment method (CRITIC) is introduced to calculate the weights of urban traffic congestion characterization indexes to determine the importance of each index in influencing traffic congestion. The distance between each solution and the ideal solution and negative ideal solution is solved by the distance between superior and inferior solutions method (TOPSIS), and the advantages and disadvantages of the management schemes are evaluated by calculating and comparing the traffic congestion index.

2 Analysis of urban transportation system modeling and congestion solving methods

2.1 System Dynamics Modeling Goals and System Elements

2.1.1 Modeling objectives

As people's lives become more and more affluent, urban transportation continues to develop, more cars, fewer roads have become the most direct source of traffic congestion in major cities. Congestion not only causes people's travel time, travel costs a lot of waste, and frequent congestion will also affect the city's image, reduce the quality of urban residents living, and even damage the overall quality of life and comfort of the country, looking for effective means and methods of congestion should not be delayed, the coordinated development of urban transport and optimization of congestion control strategy is the focus of the study of the system dynamics model. In this study, we link the subsystems of the system dynamics model according to the logical main line from congestion-causing mechanism to congestion control measures, and the main objectives are:

- 1) To analyze and sort out the causes of urban traffic congestion and the interrelationships between various elements in a macro way by system dynamics method;
- 2) On the basis of clarifying the structure and mechanism of causal feedback within the elements, select the main factors to form a system model of urban traffic congestion, and establish the causal feedback diagrams of the relevant elements of the sub-modules such as the social development sub-module, the traffic demand sub-module, the traffic supply sub-template, the traffic operation sub-module, the traffic participants sub-module, and the traffic policy sub-

module;

3) Using the model and the existing urban transportation system related data, run the system dynamics model to predict the change trend of the city's transportation supply and demand in the long term;

4) According to the urban traffic data, change some variables and parameters in the model, carry out different traffic policy simulation, observe and analyze the results;

5) Based on the simulation results, propose practical and feasible policy recommendations for urban congestion control.

2.1.2 System boundaries and model elements

1) System boundary

Determining the system boundary is actually screening out the less important factors in the system, so as to determine the main, more important internal elements of the system. The determination of the model boundary needs to follow the principles of purpose, simplicity and effectiveness, and its general steps include:

a) Select the relevant state variables and categorize and arrange them according to the state variable carriers;

b) Determine which state variables control the study variables;

c) Determining the interactions between all state variables and screening for unrelated state variables;

d) Adjusting and finalizing satisfactory system boundaries.

The system boundaries of this study broadly include: urban population, gross domestic product (GDP) of the city; the amount of residents' travel, the amount of urban material flow; the amount of private car ownership, the amount of travel by each mode of transportation; the mileage of urban roads, the length of rail transit lines; the road carrying capacity; transportation policy; environmental pollution and other aspects.

2) Model Elements

In this study, the system dynamics model elements mainly include the following:

Transportation internal elements:

a) Transportation demand elements

The main elements include: total resident travel, urban material flow, motor vehicle ownership, small car travel, small car sharing rate, surface bus travel, freight vehicle travel, motor vehicle travel, and other elements.

b) Transportation supply elements

Mainly includes: urban road mileage, urban transportation infrastructure construction, public transportation sharing rate, road grade structure, rail transit operation length and other elements.

c) Traffic operation factors

Mainly includes: urban road carrying capacity, traffic load, average travel speed of road network, traffic congestion and other elements.

Transportation external elements:

a) Urban development factors

Mainly including: urban population, urban built-up area, urban industrial structure and other elements.

b) Socio-economic factors

Mainly includes: city gross product, per capita GDP, living standards of residents and other elements.

c) Resource and environmental factors

Mainly including: urban land resources, average vehicle exhaust emissions, natural weather,

energy supply and other elements.

Aspects of transportation subject:

a) Transportation travelers

Mainly includes: traveler quality, travel distance, travel mode, travel time and other elements.

b) Transportation managers

Mainly includes: traffic management level, government pressure to control congestion, policy improvement rate, traffic enforcement, traffic planning level and other elements.

Transportation policy:

a) traffic restriction policy

b) Number restriction policy

c) goods restriction policy

d) Congestion charging policy

e) Public transportation priority policy

2.2 Framework of the system dynamics model and establishment of analytical equations

2.2.1 System module framework

Transportation system is included in the social system, and at the same time plays an indispensable role in the social system. Developed transportation is beneficial to social development, and social development is also beneficial to transportation development. Similarly, the future social economy determines the development trend of transportation supply and demand, and conversely, the level of the transportation system also affects the future social and economic development. Figure 1 is the modular framework of system dynamics, transportation supply and demand with the level of urban development and urban economic development interact with each other and stimulate each other. Transportation supply and demand is also affected by energy, environment, transportation policy and the main body of the traffic, and the traffic supply and demand situation directly determines the traffic operation status, oversupply, the traffic operation, oversupply, traffic congestion. Only supply and demand to achieve a balanced development, the road will not be congested, but also does not cause a waste of road resources, in order to make the urban economy, and even the whole social system in a benign operation of the development of the state.

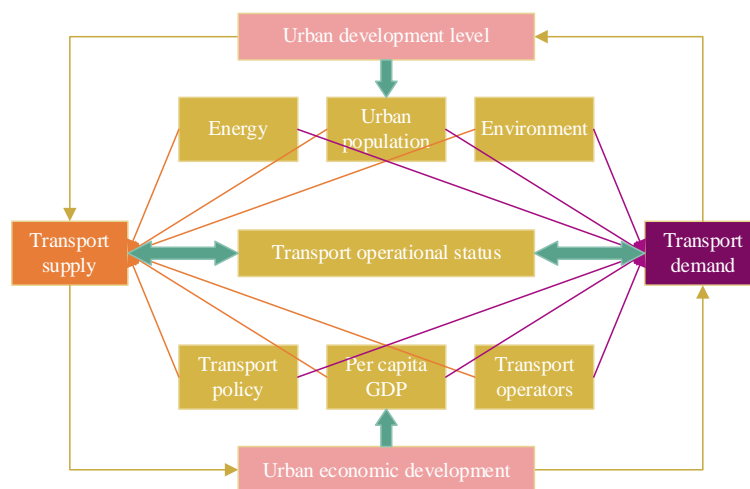


Figure 1: The module framework of system dynamics

2.2.2 Establishment of analytical equations for each module

Since the resultant operation of the system dynamics model mainly depends on the model structure and does not require much data for the variables, the structural equations between the variables in each module need to be determined in order for the system dynamics model to operate accurately. The research system of urban traffic congestion management policy consists of several subsystems: the urban development subsystem containing the city's economic scale and population scale, the urban transportation travel subsystem, the road carrying capacity subsystem, the environmental subsystem and the congestion management policy subsystem. Each subsystem is analyzed as follows:

1) Urban economy and population system

One of the basic subsystems for quantitative analysis in the urban traffic congestion management policy research system is the urban development subsystem. It contains two parts: population size and urban GDP. An increase in urban population size leads to a subsequent increase in the total number of resident trips, which ultimately affects the total travel demand in the city. Among the urban residents' trips, the mobile population's trips also occupy a considerable proportion, and for this reason, the rate of growth of the total urban population takes into account the natural growth rate and the net migration rate. According to the city's actual situation of the statistical yearbook data, the use of SPSS regression software or related data processing means, you can get the value of the relevant variables of the total urban population.

City GDP as a factor of economic development and the level of the city's development of the level of variables, it will directly affect the degree of urban motorization, thus affecting the level of development of urban transportation. The level of a city's economic strength directly determines the proportion of investment in infrastructure, which determines the intensity of investment in the construction of rail transit and the intensity of investment in the development of the bus line network.

There are two level variables in this subsystem, which are the total population of the city and the city's GDP, and the rate variables are the annual growth of the population and the annual growth rate of the city's GDP. The auxiliary variables include population growth rate, GDP growth rate, traffic congestion impact coefficient and environmental pollution impact coefficient. The main structural equations are as follows:

Level equation:

$$TP_t = TP_{t-1} + \int_{t-1}^t (TPI)dt \quad (1)$$

$$TP_t = TP_{t-1} \times \int_{t-1}^t (BR_t + NMR_t)dt \quad (2)$$

In the formula

TP_t - total population of the city at the moment t .

TPI_t - urban population growth at moment t .

BR_t - the net population growth rate at moment t , calculated from the birth and death rates.

NMR_t - the net migration rate of the population at moment t , calculated from the in-migration and out-migration rates.

$$GDP_t = GDP_{t-1} + \int_{t-1}^t (GDPI)dt \quad (3)$$

$$GDPI_t = GDP_{t-1} \times GDPR_t \quad (4)$$

$$GDPR_t = GDPIR_t \times (1 - C_{ER}) \times (1 - C_{CR}) \quad (5)$$

$$PCG_t = GDP_t \div TP_t \quad (6)$$

where

GDP_t - gross domestic product at moment t .

$GDPI_t$ - incremental GDP at moment t .

$GDPIR_t$ - the raw growth rate of GDP at moment t .

$GDPR_t$ - the growth rate of GDP at moment t after accounting for environmental and congestion effects.

C_{ER} , C_{CR} - coefficient of environmental pollution impact, coefficient of traffic congestion impact.

PCG_t - gross per capita product at moment t .

2) Urban residents' travel demand subsystem

Due to the rapid development of the economy, the number of private cars in the city is in the trend of increasing year by year, which leads to the proportion of private car travel, even if the city roads are already in a state of serious congestion, private car travel is still the first choice of some residents. Therefore, the government has introduced restrictive policies on private car purchasing and traveling, so that the number of private cars does not grow endlessly, and this relationship is expressed by the variable of private car influence coefficient in the model. Similarly, in order to encourage residents to shift from private car travel to public transportation, bus priority policies and policies to promote the development of rail transit will be introduced to increase the density of the bus network and the length of rail transit operations to attract passengers.

The urban transportation travel subsystem is the focus and core part of the whole model, in which the horizontal variables are private car ownership, bus network density and rail transit operation length. The auxiliary variables are mainly the total number of residential trips and the total number of motor vehicle trips. The main structural equations are as follows:

$$PCN_t = PCN_{t-1} + \int_{t-1}^t (PCG - PCS)dt \quad (7)$$

$$BD_t = BD_{t-1} + \int_{t-1}^t BDI dt \quad (8)$$

$$RM_t = RM_{t-1} + \int_{t-1}^t RMI dt \quad (9)$$

where

PCN_t - t moment private car ownership.

PCG_t - t moment private car increment.

PCS_t - t moment private car scrapping.

BD_t - t moment transit line length.

BDI_t - t momentary transit line network length increment.

RM_t - t moment total rail transit operating miles.

RMI_t - incremental rail transit operating mileage at moment t .

Auxiliary equations:

$$TN_t = TP_t \times N_\alpha \quad (10)$$

$$PCT_t = TN_t \times PTR_t \quad (11)$$

$$BT_t = TN_t \times BTR_t \quad (12)$$

$$RT_t = TN_t \times RTR_t \quad (13)$$

$$MVT_t = PCT_t / PN + BT_t / BN \quad (14)$$

$$TDN_t = PCT_t / PN \times PS + BT_t / BN \times BS \quad (15)$$

where

TN_t - the total number of trips made by urban residents at the moment of t .

N_α - the number of trips per capita of urban residents.

MVT_t - total motor vehicle trips at t moment.

TDN_t - transportation demand.

PCT_t, BT_t, RT_t - private car trips, surface bus trips, rail trips at moment t .

PTR_t, BTR_t, RTR_t - private car trips, surface bus trips, rail transit share at moment t .

PN, BN - average number of passengers carried by private cars, average number of passengers carried by buses.

PS, BS - average distance traveled by private cars, average distance traveled by buses.

The private car sharing rate, surface bus sharing rate and rail transit sharing rate will vary with the total number of private cars, length of bus line network and length of rail transit line network, which is expressed by introducing a table function with the following formula:

$$PTR = WITH\ LOOKUP(PCN, (PTR)) \quad (16)$$

$$BTR = WITH\ LOOKUP(BD, (BTR)) \quad (17)$$

$$RTR = WITH\ LOOKUP(RM, (RTR)) \quad (18)$$

3) Urban road supply subsystem

The horizontal variable of the road supply subsystem is the total mileage of urban roads, the rate variable is the increment of road mileage, and the auxiliary variables include the comprehensive correction coefficient of main roads, the comprehensive correction coefficient of secondary roads, the comprehensive correction coefficient of branch roads and the

comprehensive correction coefficient of expressways. The main structural equations are as follows:

$$RM_t = RM_{t-1} + \int_{t-1}^t RMI dt \quad (19)$$

$$RMI_t = RMI_{t-1} \times RMG_t \quad (20)$$

$$RSN_t = RM_t \times \gamma \times \beta \times \sum_{i=1}^4 C_i \times N_i \times g_i \times a_i \quad (21)$$

In the formula

RM_t - total road length at moment t .

RMI_t - increment of road length at t moment.

RMG_t - t moment road length growth factor.

RSN_t - t moment road supply.

γ - road network layout discount factor.

β - level of service of road network.

C_i - theoretical capacity of the i th class of roads.

N_i - average number of lanes of the i th class of road.

g_i - the proportion of roads of category i in the hierarchy of urban road network.

a_i - the comprehensive correction coefficient of the i th class of roads.

Among them, the growth coefficient of urban road length is related to the amount of road investment, which is expressed through the table function.

$$RMG = WITH\ LOOKUP(RIA, (RMG)) \quad (22)$$

In the formula

RIA - the amount of investment in urban roads.

4) Transportation pollution subsystem

In the transportation environment pollution subsystem, the level variable is the urban NO_2 stock, which is jointly determined by two rate variables NO_2 increment and NO_2 dissipation. The NO_2 increment is calculated from the total motor vehicle trips and its pollution contribution. The main equations are as follows:

$$NOC_t = NOC_{t-1} + \int_{t-1}^t (NOG - NOD) dt \quad (23)$$

$$NOG_t = MVT_t \times W \times O \quad (24)$$

$$NOD_t = NOC_t \times D \quad (25)$$

In the formula

NOC_t - stock of NO_2 in the city.

NOG - annual NO_2 increment.

NOD - annual NO_2 dissipation.

W - average annual NO_2 emissions from vehicles.

O - motor vehicle NO_2 contribution.

2.3 Comprehensive characterization of traffic congestion state based on CRITIC-TOPSIS method

In order to comprehensively reflect the real-time situation of traffic congestion state at a certain level, this paper comprehensively characterizes the traffic congestion state under the background of different management schemes with the Traffic Congestion Index (TCI) based on the screened traffic congestion state characterization indicators in the corresponding demand levels. The CRITIC method is used to determine the weights of the traffic congestion state indicators, and the distance between superior and inferior solutions (TOPSIS) method is used to calculate the negative ideal solution proximity, and the negative ideal solution proximity of the traffic congestion state indicators expresses the value of the TCI, and the traffic congestion index takes the value between 0.0 and 1.0, and the larger the traffic congestion index is, the more serious the traffic congestion state is.

2.3.1 CRITIC method for determining indicator weights

The CRITIC method is an objective weighting method that determines the weights based on the differences and comparisons of the values of the characterization indicators. It is not the case that the larger the number of the characterization indicator value indicates the more important, but the scientific characterization is completely based on the magnitude of the difference between the values of the characterization indicators and the correlation between the characterization indicators. In the CRITIC method, when the standard deviation of the indicator is certain, the greater the difference between the indicator values, the greater the weight of the indicator; the greater the degree of correlation between the indicators, the lower the weight of the indicator. Assuming that there are n road sections to be characterized each road section has p characterization indicators, forming the original indicator data matrix:

Assuming that there are n samples to be characterized and p characterization indicators, the original indicator data matrix is formed:

$$X = \begin{pmatrix} x_{11} & \cdots & x_{1p} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{np} \end{pmatrix} \quad (26)$$

where X_{ij} denotes the value of the j th characterization indicator of the i th sample.

1) Dimensionless processing

In order to eliminate the impact of the characterization results due to the different dimension, it is necessary to pre-process the characterization indicators. CRITIC weighting method generally uses forward or reverse processing to reflect the differences in the indicators. The object set after the dimensionless processing using equation (26) is:

$$A = (a_{ij}) = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1p} \\ a_{21} & a_{22} & \cdots & a_{2p} \\ \vdots & \vdots & & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{np} \end{pmatrix} \quad (27)$$

The conversion formula is

$$A = \frac{X - X_{\min}}{X_{\max} - X_{\min}} \quad (28)$$

$$X_{\min} = \min \{x_{1j}, x_{2j}, \dots, x_{nj}\}, X_{\max} = \max \{x_{1j}, x_{2j}, \dots, x_{nj}\}$$

2) Indicator variability

$$\begin{cases} \bar{a}_j = \frac{1}{n} \sum_{i=1}^n a_{ij} \\ S_j = \sqrt{\frac{\sum_{i=1}^n (a_{ij} - \bar{a}_j)^2}{n-1}} \end{cases} \quad (29)$$

S_j represents the standard deviation of the j th indicator. The standard deviation is used to reflect the difference between the values of each characterization indicator, the greater the difference, the greater the information carried by the indicator, the stronger the characterization of the indicator itself, and more weight should be assigned to the indicator.

3) Conflict of indicators

$$R_j = \sum_{i=1}^p (1 - r_{ij}) \quad (30)$$

r_{ij} denotes the correlation coefficient between the characterization indicators i and j . The degree of correlation between the values of the characterization indicators and the direction of correlation reflect the degree of correlation of each characterization indicator. The greater the degree of correlation between two indicators, the smaller the difference between them, and the smaller the proportion of the two indicators in the system of characterization indicators.

4) Information quantity

$$C_j = S_j \sum_{i=1}^p (1 - r_{ij}) = S_j \times R_j \quad (31)$$

The larger C_j is, the more information the j th characterization indicator represents, the more valuable it is, the greater the strength of characterization in the system of characterization indicators, and the greater the weight.

5) Objective weight

So the objective weight W_j of the j th characterization indicator is

$$W_j = \frac{C_j}{\sum_{i=1}^p C_j} \quad (32)$$

2.3.2 Calculation of Traffic Congestion Index by TOPSIS Method

The TOPSIS method generally determines the optimal choice by being closest to the ideal solution and farthest from the negative ideal solution. When quantitatively describing the traffic congestion state, the value of TCI is expressed by the proximity of the index value of the object to be characterized to the negative ideal solution, and the larger the value, the more serious the traffic congestion state of the object to be characterized.

1) Construct the weighting matrix

The weight coefficients of the characterization indicators obtained by using the entropy value method are multiplied with the column vector of the normalization matrix P to obtain the weighting matrix $V = (v_{ij})$, see Eq. (33), and normalization is carried out using Eq. (34) to obtain the normalization matrix B .

$$V = (v_{ij}) = \begin{bmatrix} w_1 P_{11} & w_2 P_{12} & \cdots & w_m P_{1m} \\ w_1 P_{21} & w_2 P_{22} & \cdots & w_m P_{2m} \\ \vdots & \vdots & & \vdots \\ w_1 P_{n1} & w_2 P_{n2} & \cdots & w_m P_{nm} \end{bmatrix} \quad (33)$$

$$B_{ij} = \frac{v_{ij}}{\sqrt{\sum_{i=1}^n (v_{ij})^2}} \quad (34)$$

2) Determine the optimal and worst options for TOPSIS

$$\text{Positive Ideal Solution Set } D^+ = B_{\max} = \max \{b_{i1}, b_{i2}, \dots, b_{im}\} \quad (35)$$

$$\text{Negative ideal solution sets: } D^- = B_{\min} = \min \{b_{i1}, b_{i2}, \dots, b_{im}\} \quad (36)$$

3) Calculate the proximity distance of each characterization object to the optimal solution and the worst solution

The distance scale between the object to be characterized and the positive ideal solution is L^+ , and the distance scale between the section to be characterized and the negative ideal solution is L^- .

$$L_i^+ = \sqrt{\sum_{j=1}^m (b_{ij} - d_i^+)^2} \quad (37)$$

$$L_i^- = \sqrt{\sum_{j=1}^m (b_{ij} - d_i^-)^2} \quad (38)$$

4) Calculate the traffic congestion index for each characterization object

$$TCI_i = \frac{L_i^-}{L_i^+ + L_i^-} (i = 1, 2, \dots, n) \quad (39)$$

TCI_i is the traffic congestion index TCI of the i th characterization object, the index takes the value between 0.0 and 1.0, the closer to 1.0, the more congested the traffic operation state of the object to be characterized, and the closer to 0.0, the smoother the traffic operation state of the object to be characterized.

3 Simulation study of urban traffic congestion management program

3.1 Parameter Estimation and Model Testing

3.1.1 Parameter estimation

In the process of system dynamics modeling, we often need to numerically estimate the parameters, and the relationship between the factors of system dynamics is composed of the feedback relationship of the internal structure of the system, this kind of causal loop relationship mainly depends on the structure of the system itself rather than the specific value of the parameters, so when numerically estimating the parameters, we don't overly pursue the parameter estimation of the numerical accuracy, and make estimation to meet the basic requirements of the model itself based on the parameter accuracy of the model. Therefore, when estimating the parameters numerically, we do not pursue the precision of the parameter estimates, but estimate them on the basis of ensuring the precision of the parameters of the model itself, so as to satisfy the basic requirements of the model itself.

The estimated values of some parameters are determined by looking up the relevant historical data from the National Data Network, C City Statistical Yearbook and C City Traffic Management Bureau, analyzing the relationship between the variables through regression, etc. After completing all the parameter settings in the model, we also need to test the model to ensure the accuracy of the constructed model.

Table 1 shows the results of parameter setting in the dynamics model of urban traffic congestion system. The parameter of total urban population takes the value of 7.051 million, the parameter of urban GDP takes the value of 1,329.4 million yuan, the parameter of private car ownership takes the value of 904,830,000 cars, the parameter of public transportation network density takes the value of 0.947m², the parameter of rail transit operation length takes the value of 504.382km, the parameter of total mileage of urban roads takes the value of 595.495km, the parameter of urban stock takes the value of 5.051m² The birth rate parameter takes the value of 0.895%, the death rate parameter takes the value of 0.307%, and the net migration rate parameter takes the value of 0.658%.

Table 1: Parameter setting of the system dynamics model

Parameters or initial values	Value	Organization
Total urban population	7.051	Millions
City GDP	13.294	Billion yuan
Number of privately-owned cars	90.483	Ten thousand vehicles
Bus network density	0.947	Per square meter
Railway operation length	504.382	Km
Total mileage of urban roads	595.495	Km
Urban stock of NO ₂	5.051	Per square meter
Birth rate	0.895	%
Mortality rate	0.307	%
Net migration rate	0.658	%

3.1.2 Model testing

The system dynamics model is built on the basis of real problems, so we need to examine the accuracy and validity of the model in order to say that the model really has realistic reference value. The model is gradually improved by debugging the model, constant evaluation of factors and indicators and re-modification. In this paper, we choose the mental model test method to judge whether the established traffic congestion system dynamics model of City C passes the mental model test by comparing the differences between the real values of variables and the simulated values of the model in 2020-2024, so as to judge the establishment effect.

Figure 2 takes the total city population, city GDP, and city NO₂ stock as an example to compare the real parameter values of the three variables with the model simulation values during 2020-2024. The orange bars in the figure represent the model simulation values and the yellow bars represent the real values. The error between the real and simulated values of the total urban population during the five years is within the range of [0.018,0.055], the error range of the urban GDP is 0.019~0.036, and the error of the urban NO₂ stock is between 0.021~0.054. The overall comparison reveals that the error between the real and simulated values for each year is less than 0.060, which is negligible. It can also be judged that the established system dynamics model can be used to obtain effective simulation results to help make a realistic judgment of urban traffic congestion.

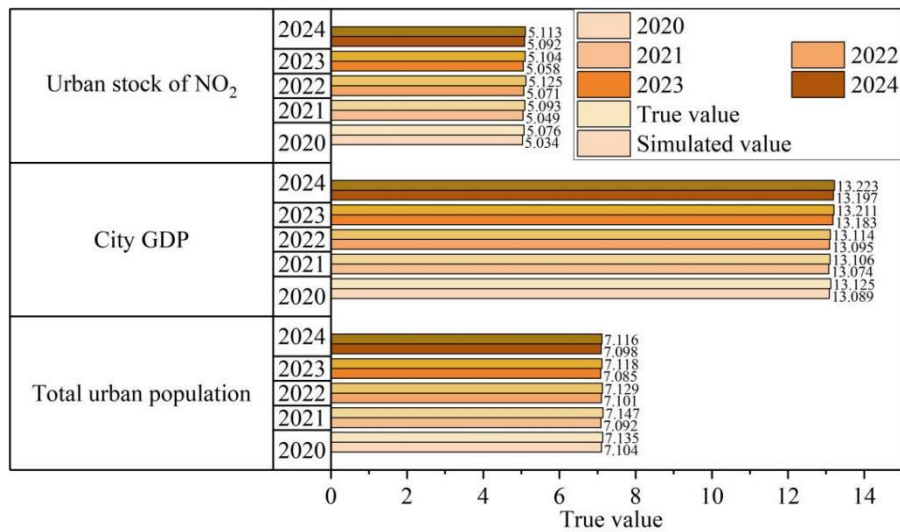


Figure 2: Comparison of actual values and simulated values of three variables

3.2 Analysis of simulation results of dynamics of urban traffic congestion management intervention system

The economy of City C has made certain achievements up to now, however, it is also an unavoidable objective fact that the residents' economic level varies greatly, which directly leads to the difference in affordability. Therefore, this paper divides the residents of City C into six levels according to the per capita disposable income, which are low-income level households, lower middle-income level households, middle-income level households, upper middle-income level households, high-income level households, and high-upper income level households. Because system dynamics can change the relevant variables in the model, so as to achieve the purpose of analyzing the impact of various different variable values on other variables, so this paper uses system dynamics to construct a model under three kinds of governance programs, three governance programs respectively by changing the value of congestion pricing, vehicle purchase tax rate and government subsidies for online car government to carry out the simulation of the urban congestion governance interventions, and the results obtained are as follows described.

3.2.1 Simulation results of traffic congestion with congestion pricing

This section examines the degree of equilibrium of vehicle diversion for residents of various income levels when different levels of congestion charge are imposed. The closer to 0.00, the more balanced the vehicle traffic distribution is, and the less congested the road is. Figure 3 shows the simulation results of vehicle flow balance under different levels of congestion charge. The five columns corresponding to different levels of congestion charge represent the average degree of equalization of vehicle diversion on each road in City C from 2020 to 2024 in the order from left to right. It can be seen that when the congestion charge is levied at [10,15] yuan, residents of six income levels will avoid the toll road when traveling, and each of them will choose the road that best suits their own situation, and at this time, the equilibrium degree of vehicle diversion ranges from 0.01 to 0.09, which is closest to the equilibrium level of 0.00, and the congestion on the road is most desirable.

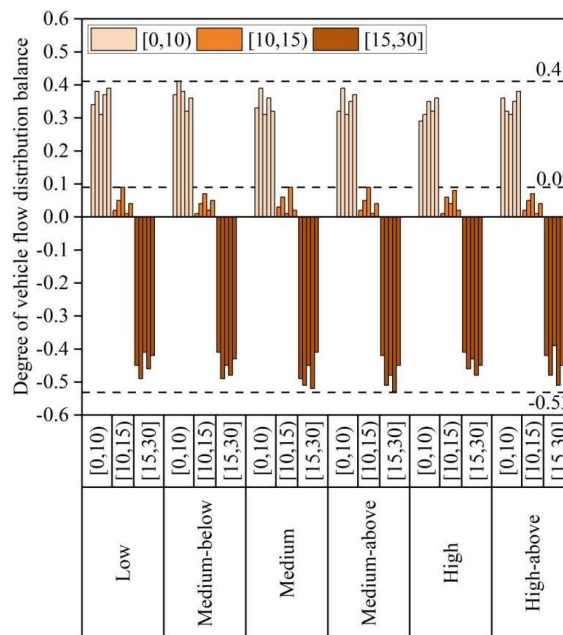


Figure 3: Vehicle diversion due to congestion fee collection

3.2.2 Simulation results of traffic congestion with vehicle purchase tax collection

Under the scenario of levying vehicle purchase tax, the vehicle purchase tax rate is categorized into four levels, which are 0.00, 0.025, 0.05, and 0.075. The level of the vehicle purchase tax rate will affect the amount of private cars purchased, which in turn will affect the amount of private car trips and traffic congestion. This section examines the degree of vehicle diversion equilibrium for residents of all income levels when different rates of vehicle purchase tax are levied. In the paper, the degree of vehicle diversion equalization is used as a measurement index, and Fig. 4 shows the simulation results of the degree of vehicle diversion equalization on urban roads under the levy of different vehicle purchase taxes.

In a longitudinal comparison, when a vehicle purchase tax of 0.05 is levied, residents at all six income levels choose to buy private cars and use them to travel the least, and the degree of vehicle diversion equilibrium ranges from about 0.11 to 0.43, which is closer to 0.00 compared to the other tax rates. However, focusing on the sensitivity of residents at different income levels to changes in tax rates, it can be seen that residents at higher income levels and those at higher upper income levels are less sensitive to tax rates, and fewer of them do not buy private cars because of changes in tax rates.

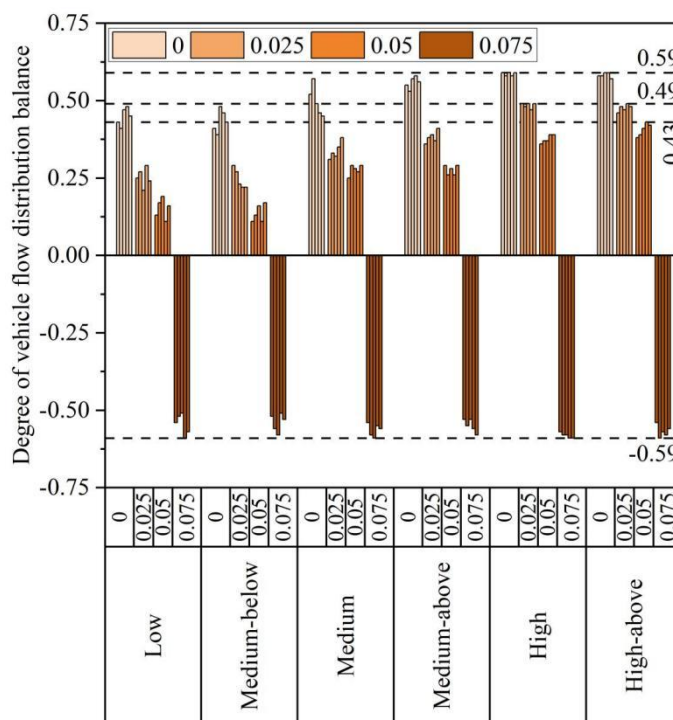


Figure 4: Vehicle diversion due to the imposition of vehicle purchase tax

3.2.3 Traffic Congestion Simulation Results of Implementing Government Subsidies for Internet Rental Cars

In the scenario of implementing a government subsidy for internet taxi, the government subsidy for internet taxi is categorized into three levels, which are [0,10], (10,20], and (20,30]. The level of subsidy for internet taxi will affect the amount of private car trips, which in turn will affect the amount of motor vehicle trips on the road and traffic congestion. This part investigates the degree of vehicle diversion equilibrium for residents of various income levels when different government subsidies for internet rides are applied. In the paper, the degree of vehicle diversion equilibrium is used as a measure, and Figure 5 shows the results of the simulation of the degree of vehicle diversion equilibrium on urban roads under different government subsidies for

internet car rental. Overall, as the government subsidy for internet car rental increases from [0,10] yuan to (10,20) yuan and then to (20,30) yuan, the maximum equilibrium degree of vehicle diversion decreases from 0.45 to 0.36 and then to 0.24, which is getting closer and closer to 0.00, and the traffic congestion situation is gradually relieved. Comparing the specific situation of residents of each income level, it can be seen that the government subsidy of online taxi has the greatest impact on the travel of residents of middle-income level as well as residents of upper middle-income level.

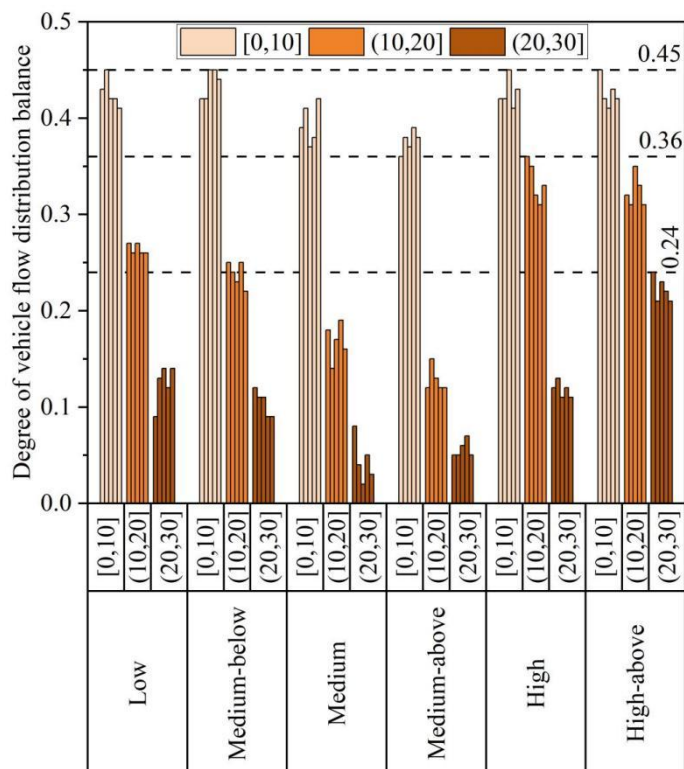


Figure 5: Implementation of government subsidies for vehicle diversion

3.3 Evaluation of governance programs based on the CRITIC-TOPSIS approach

3.3.1 Determination of weights of traffic congestion evaluation indicators

According to the urban traffic congestion evaluation index system, the judgment matrix of each index is constructed, and the weights of each evaluation index in Table 2 are calculated by CRITIC method. The evaluation indexes of urban traffic congestion are divided into 3 major categories, among which the evaluation weight of road section is 0.27, the evaluation weight of road network is 0.50, and the weight of traffic flow is 0.23. Among the single indexes corresponding to the major categories of indexes, the indexes of the road network loading degree have the highest weight of 0.32, followed by the index of the average delay of road network of 0.18.

Table 2: Weighting of traffic congestion evaluation indicators

Target layer	Major indicator	Weight value	Individual indicator	Weight value
Evaluation of Urban Traffic Congestion	Section Evaluation	0.27	Load factor	0.13
			Average travel speed	0.05
			Vehicle travel time	0.06
			Delay ratio	0.03
	Road network evaluation	0.50	Road network load factor	0.32
			Average network delay	0.18
	Traffic flow	0.23	Number of vehicles/per hour	0.12
			Number of people passing through/per hour	0.11

3.3.2 Evaluation of the effectiveness of the three management options in reducing urban traffic congestion

The TOPSIS method is used to calculate the distance D^- to the ideal solution D^+ and the negative ideal solution for the congestion charge scheme, the vehicle purchase fee scheme, and the government subsidy scheme for online car rental, and to calculate the urban traffic congestion index TCI under the three schemes to select the best management scheme to alleviate traffic congestion in City C. The congestion charge scheme = 0.0021, the distance $D^- = 0.0008$, and the urban traffic congestion index TCI = 0.14.

The distance from the congestion fee program to the ideal solution $D^+=0.0021$, the distance to the negative ideal solution $D^-=0.0008$, and the urban traffic congestion index TCI=0.14; the distance from the vehicle purchase fee program to the ideal solution $D^+=0.0054$, the distance to the negative ideal solution $D^-=0.0049$, and the urban traffic congestion index TCI=0.63; and the implementation of the government subsidy for internet car rental The distance from the program to the ideal solution $D^+=0.0036$, the distance to the negative ideal solution $D^-=0.0025$, and the urban traffic congestion index TCI=0.39.

Judging from the comparison of the distances to the ideal solution and the negative ideal solution, as well as the magnitude of the value of the urban traffic congestion index, the mitigation effect of urban traffic congestion of the congestion fee program > the mitigation effect of urban traffic congestion of the implementation of the government subsidy program of online car rental > the mitigation effect of urban traffic congestion of the program of the vehicle purchase fee. The possible reasons for this are: 1) the levy of congestion fee program has an immediate effect on the private car trips of residents of all six income levels, and is able to incorporate the travel behavior of all urban residents into the adjustment during traffic congestion management; 2) the implementation of government subsidies for online car rental has an immediate effect on most residents who choose to take a taxi to travel, especially for the middle-income and upper middle-income levels, and is able to incorporate the travel behavior of most urban residents into the adjustment during traffic congestion management. Most of the urban residents' travel behavior is included in the adjustment; 3) the levy of vehicle purchase fee program does not have an immediate impact on the residents' private car travel behavior, and the impact on the high-income and upper-middle-income residents who mainly rely on the private car for their trips is relatively small, and it is difficult to regulate the travel mode of the urban residents during the management of traffic congestion, so the management effect is not as good as that of the other two programs.

Comprehensive comparison, City C wants to ease the level of urban traffic congestion, in the choice of options should be given priority to the congestion fee program, followed by the

implementation of the government subsidies for online taxi program.

4 Conclusion

In this study, we innovate the solution selection of urban traffic congestion management schemes from the two aspects of system dynamics model construction and the application of ideal solution method. The system dynamics model of three management schemes, namely, congestion charge, vehicle purchase tax, and government subsidy for net car, is established, and the vehicle diversion equilibrium degree of the city is close to the most ideal 0.00 when the congestion charge of [10,15] yuan is levied, as calculated through simulation. The distance of this scheme to the ideal solution $D^+=0.0021$, the distance to the negative ideal solution $D^-=0.0008$, and the urban traffic congestion index $TCI=0.14$, which is the best effect of traffic congestion mitigation among all schemes.

By simulating the impact of implementing a governance scheme on various subsystems of the city and calculating the urban traffic congestion, it allows the relevant managers to visualize the application feasibility of the governance scheme, and provides a clear and explicit reference for the final implementation and adjustment of the governance scheme.

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