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Construction and Application of Urban Traffic Congestion Control Decision-Making Simulation Platform

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Abstract: The traditional urban traffic congestion control method is dominated by artificial experience. The continuous development of big data and information technology provides intelligent methods and means for urban traffic congestion control. This paper proposes to construct an urban traffic congestion control decision simulation platform by using a “multi-layer” technical framework and the “data-simulation-service” technical process. In the application case of Changcheng District, Foshan, three core technologies are elaborated: 1) origin-destination estimation technology using Internet navigation data and electronic data at checkpoints; 2) the customized development technology of congestion strategy module; 3) automatic output of simulation results. The result shows that the platform can provide intelligent, rapid, and intuitive decision-making support for urban traffic congestion control. **DOI:** 10.13813/j.cn11-5141/u.2023.0003-en

Keywords: traffic simulation; traffic congestion management; dynamic OD estimation; city-level; TransModeler

0 Introduction

In March 2022, the Ministry of Transport and the Ministry of Science and Technology proposed in the “Medium- and Long-term Development Planning Outline for Scientific and Technological Innovation in the Transportation Field (2021–2035)” to improve the technical level of comprehensive urban traffic congestion management. Meanwhile, the outline also requires to promote the coordinated development of smart transportation and smart cities and make breakthroughs in technologies. The technologies include urban traffic demand forecasting and evaluation simulation, traffic operation state perception, urban traffic multi-agent simulation and decision-making, and data-driven traffic congestion control and guidance. Finally, the intelligent management level of urban traffic “holographic perception + collaborative linkage + dynamic optimization + precise regulation” can be improved [1].

The technical means of urban traffic congestion control in China has transformed from extensive to refined approaches, but it has always been dominated by artificial experience. In recent years, although the means have also been supplemented by quantitative analysis methods such as traffic data, models, and simulations, there is no uniform standard for the basic data, model systems, and related parameters. Due to the strong technicality of the traffic simulation models, technicians often can only show the analysis results to the decision-makers, and it is common to modify the analysis results of the models for established evaluation conclusions or program tendencies. Therefore, the decision-making business of traffic congestion control lacks the support means of urban integrity, authority, and intelligence. With the rapid development of big data and information technology, digital decision-making auxiliary technology will play an increasingly important role in urban traffic. Dynamic traffic data with strong continuity and high sample coverage provide stable data input for traffic analysis. Multi-dimensional simulation technology can deduce the operation state, mechanism, and law of urban traffic, and predict future traffic situations. Human-machine intelligent interaction technology guarantees the application for traffic decision-making assistance. This paper integrates multivariate traffic data and employs the traffic simulation software TransModeler to build a city-level dynamic traffic simulation model, which is embedded in the decision-making simulation platform of urban traffic congestion control. Taking the Chancheng District of Foshan City as an example, it expounds on the specific application of a series of key construction technologies in the urban traffic congestion control platform.

1 Overall design of decision-making simulation platform in urban traffic congestion control

1.1 Functional objectives

The decision-making simulation platform of urban traffic congestion control (hereinafter referred to as the “simulation

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platform") is oriented to support the decision-making needs of urban traffic congestion control. It also integrates multivariate big data to establish a traffic congestion control decision-making simulation system based on big data. As a result, the integrated technical process of "data-simulation-service" is realized to provide intelligent decision-making support means for urban traffic congestion control. The main functional objectives of the simulation platform are as follows:

1) "Multi-dimensional + automated" collection of urban traffic supply-demand data and operation data

It is an important goal of the simulation platform to comprehensively collect multi-dimensional data such as urban traffic supply facilities, demand distribution, and system operation, and to digitally characterize the temporal and spatial distribution and problems of traffic congestion. Additionally, unlike the static models, since the simulation platform is dynamically updated with the supply and demand of the city, it is necessary to realize the automatic collection, processing, and analysis of data to ensure efficient and stable access to massive dynamic data.

2) "City-level + multi-level" simulation and evaluation of traffic supply, demand, and operation

The simulation platform is different from the simulation case study of a single road section or node but builds a large-scale simulation platform at the entire city level to simulate the entire urban traffic operation. Various traffic congestion control solutions within the city level can be simulated and digitally evaluated on the platform. Meanwhile, according to the different types of congestion control schemes and implementation effects, the simulation platform can evaluate the implementation effect of the congestion control scheme from multiple levels such as the overall region, key sections, and local nodes.

3) "Multi-scenario + customized" support for decision-making of urban traffic congestion control

The operation of simulation software is often more professional, and it is not easy for traffic decision-makers and business personnel to understand and adopt. Therefore, it is necessary to provide a customized traffic congestion control module to realize the simplified editing of various traffic congestion control schemes and the evaluation and comparison of traffic congestion control schemes in the interface of the simulation platform. Finally, the on-site decision-making of traffic congestion control can be accurately and quickly supported.

1.2 Platform framework

The decision-making simulation system of urban traffic congestion control adopts a "multi-layer" technical framework composed of the hardware foundation layer, basic data layer, simulation model layer, and decision-making application layer, as shown in Fig. 1.

1) The hardware foundation layer integrates physical resources such as computing resources, storage resources, network resources, and traffic simulation software to form a dynamically scalable high-performance computing environment and large-capacity storage environment to meet the needs for the storage, analysis, and query of massive data.

2) The basic data layer constructs the basic database of the simulation platform through the automatic collection and fusion of multivariate data. The database includes traffic supply-demand data and operation data such as traffic facility information, land-use information, population and employment distribution, dynamic traffic OD, and road network operation state, as well as traffic detection data from the transportation department (such as traffic at checkpoints obtained by video, coil, or microwave).

3) The simulation model layer takes the input of the basic data layer as the basis and simulates the traffic facilities, traffic management and control information, traffic demand, and traffic operation by the simulation software. Meanwhile, a macro-meso-micro integrated urban traffic simulation model is built to meet the requirements of different levels of traffic evaluation indicators.

4) The decision-making application layer provides various business scenarios of traffic congestion control, and simulates, evaluates, and displays different types of traffic congestion control schemes to support traffic congestion control decision-making.

2 Technical process

The simulation platform is a typical digital intelligent transportation decision-making auxiliary system, which can automatically realize the whole technical process of data input-simulation computing-decision evaluation (Fig. 2).

2.1 Collection and input of basic data

The basic data of the simulation platform is divided into static data and dynamic data. Static data includes the urban land-use information, transportation facility layout, and population and employment distribution. Land-use information can be collected through the urban planning department, transportation facility networks (road network and bus network) is collected through the urban transportation department, and population and employment data is obtained based on the population and economic census data or Internet location data. Static data mainly imports from vector files and raster data and achieves regular updates.

Dynamic data generally includes time-segmented traffic OD data, road network operation data, and traffic data at checkpoints. Through the direct connection with the data interface of Internet operators and traffic management departments, input and update channels of dynamic data are established.

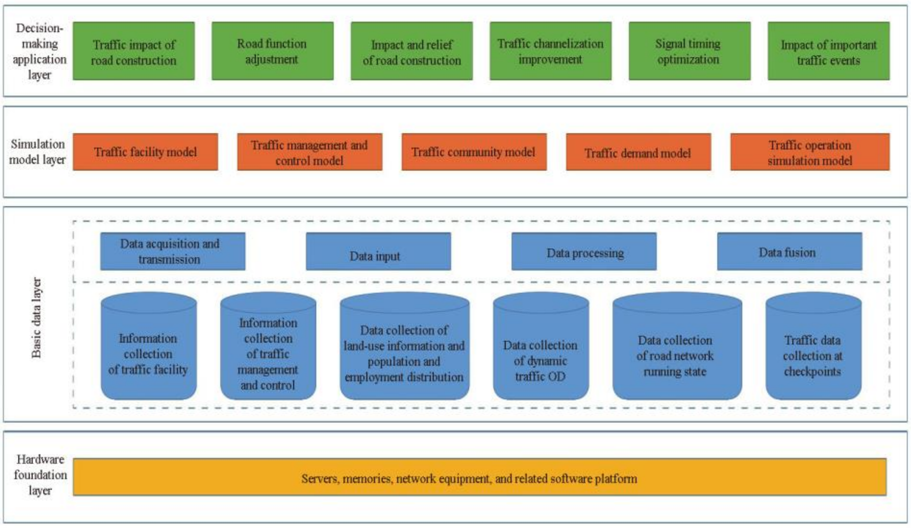


Fig. 1 Platform framework design

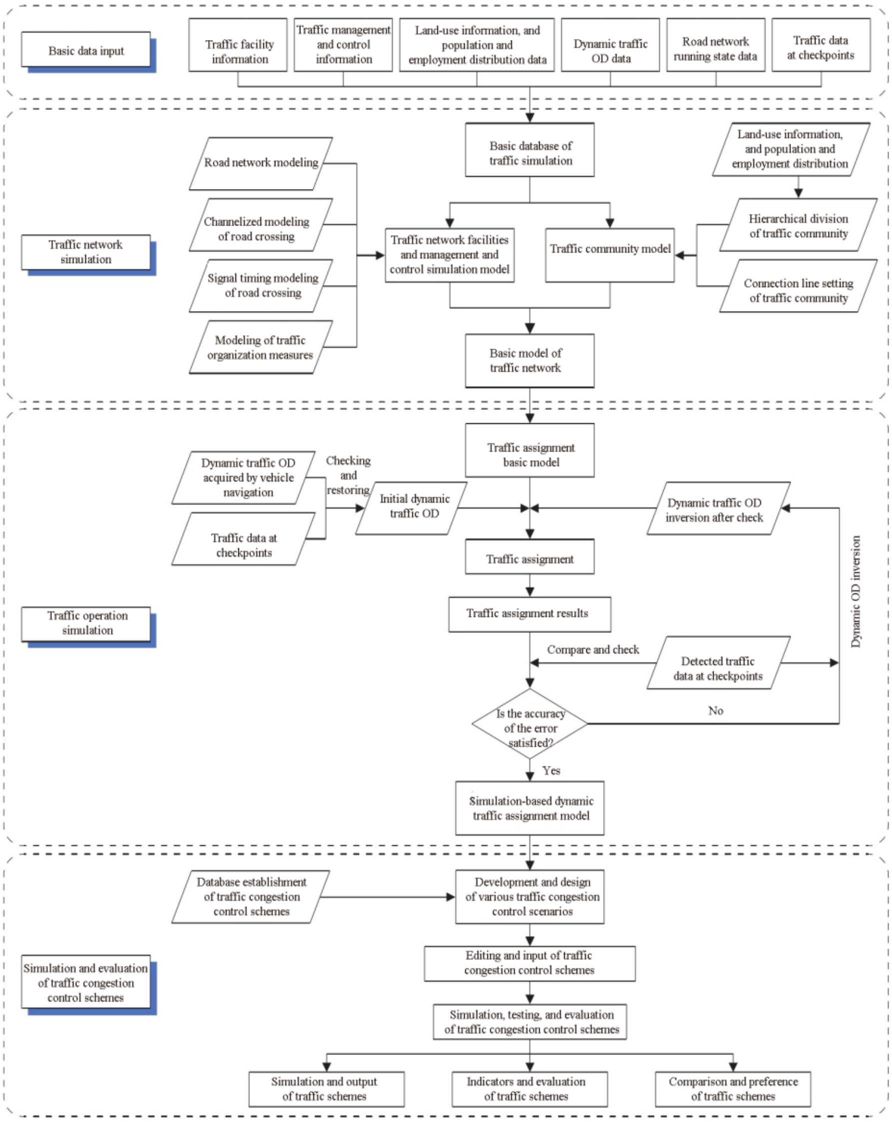


Fig. 2 Technical process of platform construction

2.2 Building of traffic simulation model

The traffic simulation model is the core of the platform to realize the functions of supply-demand and operation simulations, inferential prediction, and plan evaluation in traffic decision-making. The construction of the simulation model includes the traffic network simulation modeling and traffic operation simulation modeling, and it is achieved by the traffic simulation software TransModeler. Thanks to the utilization of the dynamic traffic assignment (DTA) algorithm for micro-simulation, TransModeler has built city-level traffic simulation models in Detroit, Phoenix, Lake County, and Columbus, and the simulation modeling range exceeds 1 000 km^2 [2]. Additionally, TransModeler supports traffic simulation with mixed micro, meso, and macro resolutions, which can ensure the computational efficiency of large-scale road networks without losing the accuracy and breadth of simulation operation information. Therefore, TransModeler provides effective technical support for the construction of the city-level traffic simulation platform.

Traffic network simulation includes three parts: modeling of traffic network facilities (road grade, lane number, and channelization of road crossings), traffic management and control modeling (signal timing scheme at road crossings and traffic organization measures), and construction of traffic communities. Traffic operation simulation aims to assign the dynamic traffic OD (usually OD at the time of 5–15 min) to the road network to fit the urban traffic operation state.

2.3 Supporting decision-making application of traffic congestion control

To efficiently support the decision-making business of urban traffic congestion control, the platform provides a dedicated supporting subsystem for the decision-making application to realize automatic simulation evaluation of traffic congestion control schemes. The decision-making system of traffic congestion control designs various business scenarios of traffic congestion control based on the secondary development function of the TransModeler software. Meanwhile, the editing, simulation, and evaluation of the traffic congestion control schemes, and the traffic operation output are completed through simplifying customized modules to realize the evaluation and comparison of the schemes.

3 Key technologies

3.1 Case background

Chancheng District is the center of politics, economy, science, education, culture, and health of Foshan City. In recent years, its economic development has improved rapidly, and the scale of the urban area has continued to expand. The number of motor vehicles and the traffic volume have increased dramatically, with the number of vehicles per thousand people being 430 in 2021, ranking first among the five districts [3]. At the same time, the traffic congestion in Chancheng District is increasingly prominent. The delay index of traffic congestion during peak hours of the year is 1.83, and the average speed of main roads during the peak hours is 20.2 $km \cdot h^{-1}$. To control and alleviate urban traffic congestion, Chancheng District established a joint meeting office for traffic congestion control, with the core members composed of traffic construction and management departments. Regular joint meetings are held to discuss and make decisions on relevant measures, countermeasures, and plans for traffic congestion control in the district. From 2021 to 2022, this district constructed a decision-making analysis system of traffic congestion control to support intelligent traffic congestion control decision-making through big data analysis and simulation deduction. The decision-making simulation system of traffic congestion control is the core of the whole system to simulate the traffic supply-demand and operation in the district, evaluate relevant traffic congestion control schemes, and finally support the formulation of traffic congestion control decision-making.

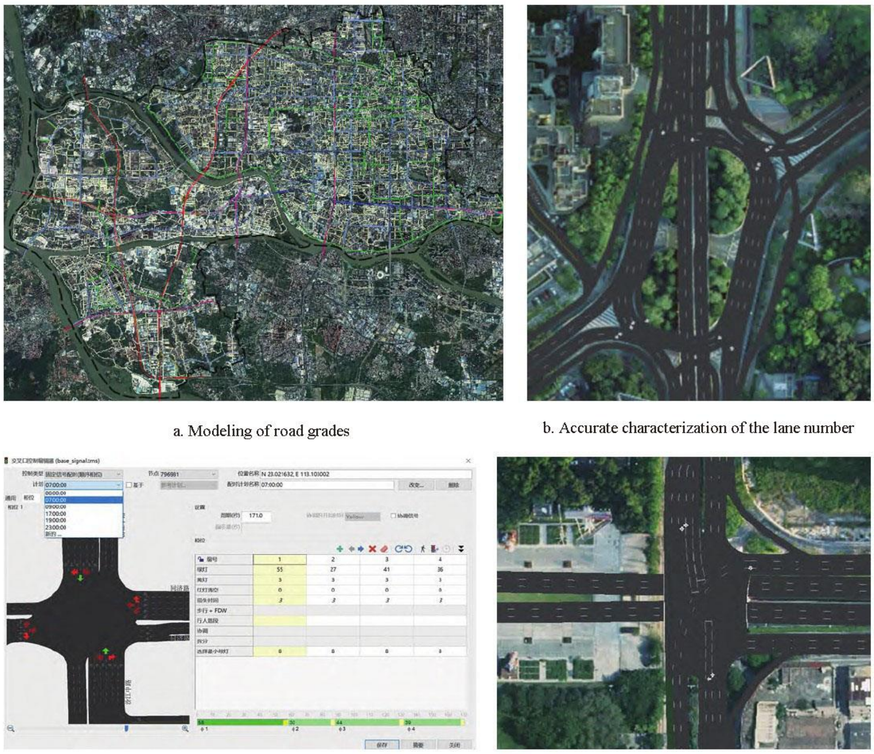
The core range of the traffic simulation model is the whole Chancheng District of 154 km^2, and the high-definition satellite imagery is taken as the input data to carry out the refined modeling of the road network for micro-simulation operation. In the level of road sections, the attributes such as the road grade, road width, lane number, and bus lanes are ensured to be consistent with reality. In the level of nodes, the channelization of crossings, lane functions, signal timing schemes (273 signal control crossings and multiperiod signal timing schemes throughout the day), and setting of 13 waiting areas are ensured to be consistent with the current situation, as shown in Fig. 3.

3.2 Dynamic traffic OD by integrating Internet navigation data and electronic data at checkpoints

The platform obtains the dynamic traffic OD by integrating Internet navigation data and electronic data at checkpoints and solves the problem of OD data source for the large-scale regional dynamic simulations.

The acquisition of dynamic traffic OD in a large-scale road network is always difficult. Traditional road network OD estimation methods based on fixed-point detection data feature low detector coverage and low accuracy in large-scale road network applications. With the development of vehicle navigation and mobile positioning technology, wide-area and continuous vehicle trajectory data together with fixed-point detection data provides technical support for large-scale road network OD estimation [4]. During OD acquisition, this paper adopts the technical method of two restorations to ensure the accuracy of traffic OD estimation in large-scale road networks as much as possible (Fig. 4).

1) First restoration. First, the Internet navigation data is employed to obtain the initial traffic sample OD and collect



a. Modeling of road grades

b. Accurate characterization of the lane number

c Input of multiperiod signal timing schemes

d Channelization of crossings and setting of waiting areas

Fig. 3 Traffic simulation model of Chancheng District, Foshan

the traffic flow trajectory to obtain the sample traffic flow on the road section. Then the sample traffic flow data is compared with the full sample flow data detected at checkpoints to obtain the sample expansion coefficient and then the prior OD matrix. The generalized least squares method is also adopted for OD estimation. The specific algorithm can refer to the scaled probe OD as the prior OD matrix model (SPP) proposed by Yang et al. [5]. In this paper, the sample traffic trajectory data is directly utilized in OD restoration to obtain the prior OD matrix. The prior OD accuracy is guaranteed, and the complexity of traffic assignment calculation and parameter calibration is also avoided to improve the OD estimation efficiency of large-scale road networks.

2) Second restoration. Based on the OD inversion module of TransModeler, the OD matrix obtained by the first restoration is the initial value of the second restoration. Combined with the electronic data at checkpoints and the traffic survey data of the key road sections, the OD within the research scope repeatedly goes through multiple inversions until the accuracy requirement of the error is met. Finally, the traffic OD matrix in different periods is obtained for the simulation-based dynamic traffic assignment. In this paper, with the aid of the built-in OD inversion module in the traffic simulation software, the OD estimation accuracy of large-scale road networks is effectively improved by considering the travel behavior of drivers based on the traffic assignment theory and algorithm.

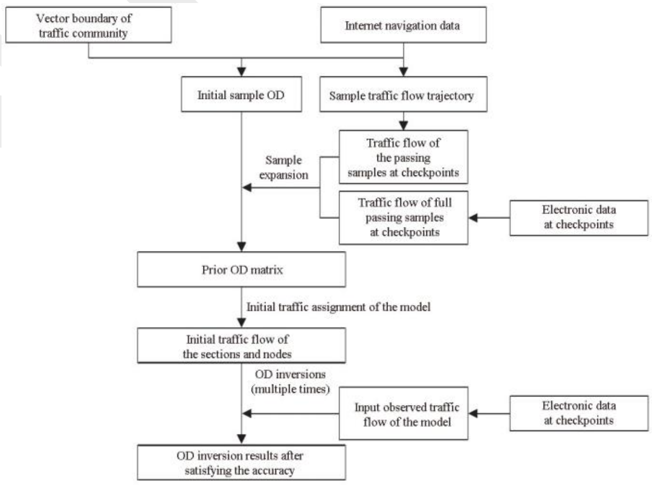


Fig. 4 Dynamic OD estimation technology

Fig. 5 shows the OD inversion results of the traffic simulation model at morning peak hours in Chancheng District, Foshan City, and the results can better meet the accuracy requirements of the simulation model.

3.3 Customized development of congestion control decision-making auxiliary module

To better support the congestion control in Chancheng District, this paper constructed a decision-making auxiliary system integrating data, simulation, and service. Based on the simulation software TransModeler, a multi-scenario decision-making auxiliary customization module of traffic congestion control was developed to realize business decision-making support with a friendly interface and convenient operation.

The system includes two parts of the business end and the display end. 1) The traffic simulation model TransModeler is embedded in the business end for business personnel to test the traffic congestion control schemes. The traffic congestion control schemes mainly include six business scenarios: road construction, road function adjustment, road enclosure construction, traffic channelization improvement, signal timing optimization, and traffic important events, which can be a single scenario or a combination of multiple scenarios. To reduce the difficulty in adopting professional simulation software, the simulation editing operations corresponding to the six common business scenarios are embedded into the simulation platform in the form of customized modules through secondary development. Finally, the input operation of traffic congestion control schemes is simplified and visualized (Fig.6). 2) The display end is a large screen for traffic congestion control decision-making. Visual output is realized for different traffic congestion control schemes, and the optimized selection of traffic congestion control schemes is finally completed according to the simulation evaluation indicators.

3.4 Automatic output of simulation results

The simulation platform developed a one-click output system for the simulation results and report of the traffic congestion control schemes, which improved the maneuverability, visibility, and rapidity of traffic congestion control decision-making.

The business end developed a simplified output window that supported the one-click packaging output of multiple simulation evaluation indicators (Fig. 7). The two types of output templates of the road network and node were preset in the output setting window to match the evaluation requirements of different traffic congestion control schemes. For example, road construction will affect the operation of road sections and road crossings within a certain range, and it is necessary to output indicators such as the road traffic flow, average vehicle speed, traffic flow density, traffic volume at crossings, delay level, and service level. This needs to select the “road network” in the output settings for this scenario. As the single-point improvement evaluation object of the crossing is generally the crossing and each inlet, the “node” is selected to output multiple indicators such as the delay, queue length, and service level to the backend database spontaneously.

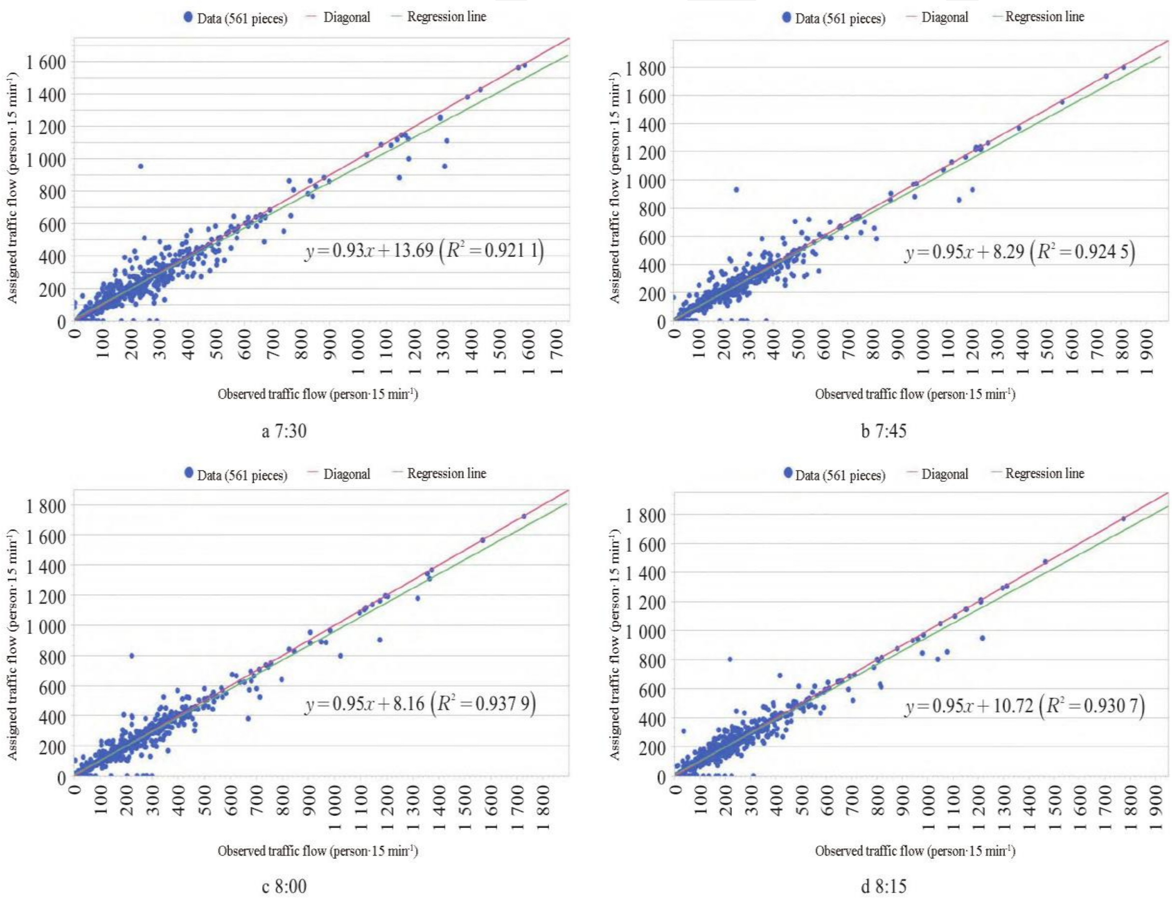


Fig. 5 Comparison of flows between estimated OD flow and observed flow at different time

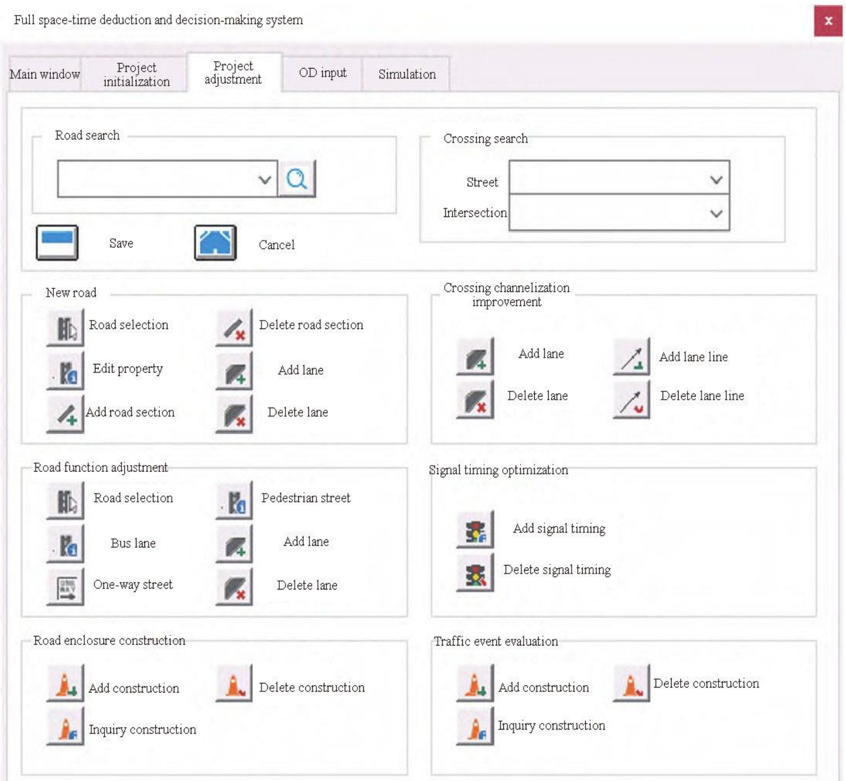


Fig. 6 Interface of a customized module for traffic congestion control plans

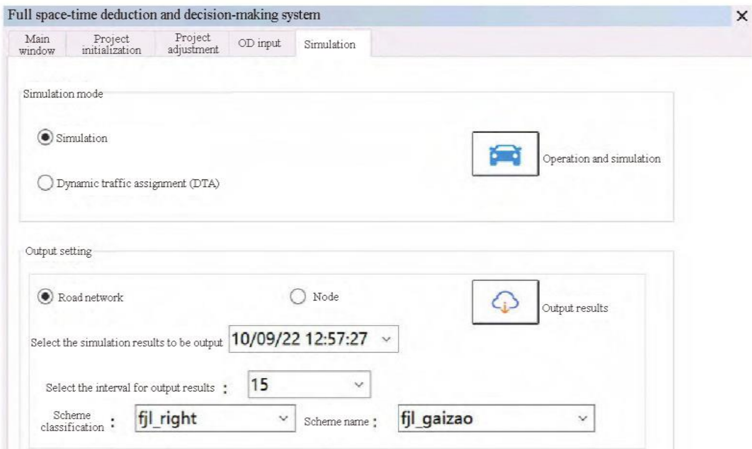


Fig. 7 Simulation output settings

The display end is a large screen for traffic congestion control decision-making to visually display the backend data. Business personnel chooses the test results of any two traffic congestion control schemes, and the indicators can be visually compared on the large screen for traffic congestion control decision-making. Similarly, the large screen for traffic congestion control decision-making also has two output styles of "road network evaluation" and "node evaluation", which correspond to the output template types. Additionally, business personnel can directly download the comparison report of schemes on the large screen as the supporting material for traffic congestion control decision-making (Fig. 8).

4 Conclusions

Traffic congestion control has always been the core of urban traffic planning, construction, and management departments. With the rapid development of big data and information technology, this paper proposed to build a simulation platform with a "multi-layer" technical framework and a "data-simulation-service" technical process. By taking Chancheng District of Foshan City as an example, a

a. Road network evaluation

b. Node evaluation

Fig. 8 Comparison and display of different schemes

large-scale city-level traffic simulation was carried out. Meanwhile, many key technologies were developed, such as dynamic traffic OD acquisition based on Internet navigation and electronic data at checkpoints, customized development of traffic congestion decision-making auxiliary module, and automatic output of simulation results. As a result, intelligent, rapid, and intuitive decision-making support is provided for urban traffic congestion control, and new development ideas and solutions are presented for urban traffic congestion control.

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