# Research on the Application of Digital Twin Technology in Smart Road Tunnel

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**Abstract-** With the development of advanced information technology, data-driven smart road tunnel construction has become an inevitable trend of industry development and transformation. Although the smart road tunnel has made rapid progress in the application of functions, there is no unified understanding in the overall connotation and overall structure, so more in-depth research is needed. The proposal and development of digital twin technology provides a new idea and way for the rapid development of intelligence. Based on the characteristics of digital twin technology in smart road tunnel, this paper analyzes the relevant functional requirements of smart road tunnel from three perspectives of data perception, data processing and multi-scenario application, and then puts forward the general framework and logical architecture of digital twin technology application in smart road tunnel, and designs and discusses multiple application scenarios of intelligent traffic management, traffic operation monitoring, vehicle-road cooperative service and traffic simulation service under smart road tunnel. Demonstrates the practicality of combining BIM technology and digital twins and finally gives suggestions for the development of digital twin technology in the application of smart road tunnel In order to provide reference for the rapid development of wisdom in the future.

**Keywords-**Smart road tunnel, digital twin, technology framework, integrated platform

## 1. INTRODUCTION

Development of road tunnels has an important significance for the evolution of urban agglomeration space structure, people's livelihood development and national economic development. By the end of 2021, China's road tunnel mileage has exceeded 160,000 kilometers, ranking first in the world for nine consecutive years and covering nearly 100% of cities with more than 200,000 population [0]. The continuous growth of social and economic production and transportation scale and road tunnel mileage puts higher requirements and challenges on the construction and operation of road tunnels. With the development of advanced information technology, data-driven smart road tunnel construction has become an inevitable trend in industry transformation. The issuance of relevant policies has further promoted the development of smart road tunnel, such as "Action Plan for Promoting Intelligent Transportation Development" [2] and "Notice on Accelerating the Pilot Project for New Generation National Traffic Control Network and Smart Expressway " [3].

With the development of new technologies such as the Internet of Things, artificial intelligence, and mobile interconnection, countries attach great importance to applying new-generation

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information technology to the construction of smart road tunnels and their maintenance and operation [4]-[6]. Smart road tunnel pilot projects have been carried out in many places in China, such as Shanghai, Jiangxi, Hebei, Hubei [7], while the active promotion of new generation smart road tunnels and 5G smart road tunnels marks that China's smart road tunnel development has gradually shifted from exploration to rapid development [8]. At the same time, some scholars have pointed out that although China's smart road tunnels have made great progress in functional application, there is still no unified understanding on its overall connotation and overall framework, and more in-depth research is needed [8]. Wang et al. [9] proposed an overall framework for smart road tunnels from five aspects: technology, business, data application and deployment to promote the development and construction of smart road tunnel. Cen et al. [10] proposed a technical system for smart road tunnel technology sets and performance requirements from a technical system perspective, and applied this technical system to actual engineering verification. Although these studies have played an important role in top-level design for smart road tunnel, there is currently no research on how to systematically comb through the overall framework of smart road tunnel or how they can be specifically applied to various scenarios.

Proposal and development of digital twin technology provides new ideas and ways for the development of smart road tunnel. Digital twin technology is to realize the digitalization of product life cycle from design, production to service, with characteristics such as virtual-real mapping, two-way interconnection and data-object fusion [11], and has been gradually applied to road tunnel field [12]. The core concept of digital twin is consistent with the ultimate goal of smart road tunnel, that is, to improve the efficiency of road tunnel construction and maintenance. Therefore, it can combine the two together and apply digital twin technology for smart road tunnel construction, driving the development of new generation smart road tunnel. Based on analyzing digital twin technology related to smart road tunnel technologies in this paper, we analyze related functional requirements for smart road tunnels. Then, we propose an overall framework and logical architecture for applying digital twin in smart road tunnel according to these requirements. Finally we give some suggestions on how to apply digital twin in smart road tunnel based on different application scenarios so as to provide reference for future development of smart road tunnel.

## 2. Analysis of Features and Requirements of Smart Road Tunnel

### 2.1. Existing Technology Analysis

By sorting out the existing literature on the smart road tunnel and analyzing related smart road tunnel projects, it is concluded that the current smart road tunnel has the following characteristics:

(1) In terms of hardware, smart road tunnel makes full use of advanced Internet of Things technologies, such as intelligent sensors, two-dimensional code, RFID (Radio Frequency Identification Devices), ETC (Electronic Toll Collection), Electronic non-parking toll collection system) to enhance the all-factor perception function of vehicles and road surface;

(2) The monitoring system composed of Beidou positioning, high-definition video and multi-

source sensors, coupled with the communication network system with 5G as the core, can realize smart road tunnel data collection and high-quality transmission [13];

(3) Application of BIM (Building Information Modelling) and GIS (Geographic Information System) to achieve the basis of virtual space traffic simulation;

(4) Smart road tunnel fully integrates intelligent road tunnel data resources, use artificial intelligence methods such as deep learning to establish analysis models, prediction models, auxiliary decision support models, etc., and improve the operation of road tunnel network research, judgment, prediction and early warning capabilities;

(5) Multi-party data coordination platforms such as mobile terminal and web terminal are adopted to facilitate the timely release of traffic information and relevant warning information;

(6) A small number of smart road tunnels also adopt UAV tilt photography, intelligent lighting and other technologies to promote intelligent construction and maintenance of road tunnel.

### 2.2. Demand Analysis

(1) Accurate perception ability is an important prerequisite for realizing smart road tunnel, so smart road tunnel needs to be able to perceive multi-source heterogeneous data. In the life-span construction process of road tunnel, various errors, such as equipment errors, personnel operations and environmental impacts, will affect the design, construction, operation and maintenance processes of road tunnel, which is not conducive to the improvement of dynamic optimization efficiency of smart road tunnel. Therefore, at the level of infrastructure, it is necessary to install advanced sensors for all-round intelligent perception of road tunnel, so as to improve the efficiency of dynamic optimization and decision-making of road tunnel.

(2) Intelligent storage and fusion processing of perceived multi-source heterogeneous data are required for the perceived multi-source heterogeneous data. Therefore, a public data resource pool needs to be established to break through data barriers, so that different departments can share data, realize data fusion, and facilitate subsequent data processing.

(3) At present, many researches on smart road tunnel are oriented to a single application scenario, such as traffic operation monitoring, traffic planning and design, vehicle-road collaborative service, etc., while few researches on smart road tunnel are oriented to multiple application scenarios. If you want to integrate different application scenarios, it is necessary to carry out systematic architecture design of smart road tunnel first, and carry out unified design for different application scenarios. Different modules can have specific design methods. Secondly, it is necessary to develop an integration platform for unified management of data and applications in the whole life cycle of collection, design, construction, operation and maintenance, so as to realize the integration of services in different application scenarios based on a unified architecture.

At the same time, the integrated platform is also a collection of functions of various service systems such as data management and analysis, pavement monitoring and simulation, data mining and remote control [11]. It can not only realize information visualization, but also realize intelligent autonomous decision-making through embedded intelligent algorithms, so as to further improve the operation efficiency of smart road tunnel.

## 3. DIGITAL TWIN AND ITS APPLICATION ARCHITECTURE IN SMART ROAD TUNNEL

Digital twin is the multi-physical and hyper-realistic dynamic simulation mapping of physical entities in the information space. It realizes the high-fidelity description, simulation, prediction and feedback of entities through sensors and controllers, and constantly approximates physical entities through self-learning [14]. The core concept of digital twin is to improve efficiency, which is consistent with the purpose of smart road tunnel. Therefore, digital twin technology can be applied to smart road tunnel, so as to improve the construction and operation management efficiency of smart road tunnel. At present, many scholars have studied the application of digital twin technology in smart road tunnel. Wang et al. [15] proposed the application scenarios of digital twin technology in smart road tunnel from four aspects: three-dimensional visual operation and maintenance, operation monitoring of special sections, visual reconstruction of traffic accidents, and monitoring and warning of "two passengers and one danger". Du et al. [8] proposed the physical architecture and logical architecture of the smart road tunnel, and proposed the key problems and prospects of the application of digital twin technology in the smart road tunnel. However, few studies pay attention to the overall application architecture of digital twin technology in smart road tunnel and some key specific application scenarios, such as traffic operation monitoring, traffic planning and design, vehicle-road collaborative service, and how to apply digital twin technology.

To solve such problems, this study proposed the overall framework for the application of digital twin technology in smart road tunnel, as shown in Fig.1, including "4 horizontal", "4 vertical" and "N platform". Among them, "4 horizontal" refers to the four levels of digital business application, application support, public data resources and infrastructure, and "4 vertical" refers to the organizational security system, policy system, standard system and security system. Under the guarantee of these systems, specific business applications can be carried out, namely "N platform", including typical applications such as traffic operation monitoring, traffic planning and design, and vehicle-road collaborative services.

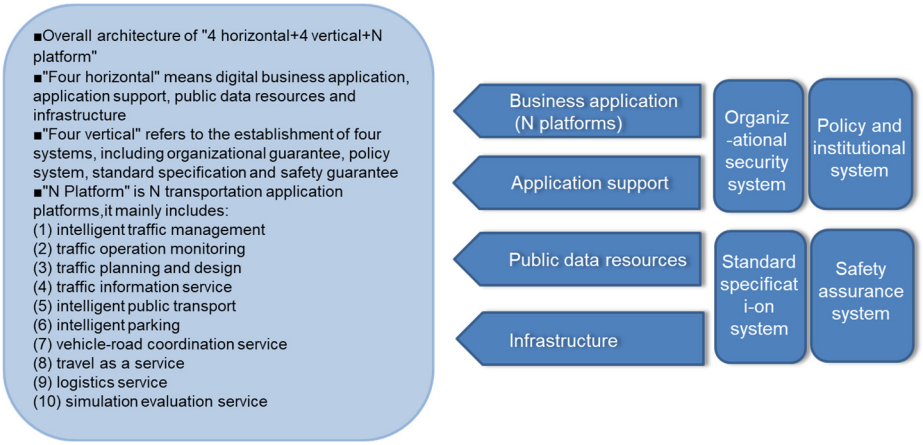


**Fig.1** Overall application architecture of digital twin in smart road tunnel

In view of the requirements of smart road tunnel and the overall application architecture based on digital twin in smart road tunnel, this paper also proposes the smart road tunnel logical architecture based on digital twin as shown in Fig.2. Its core is to realize the closed loop of smart road tunnel physical system and information system and realize various business functions through the guarantee of different systems. The lowest level of infrastructure includes computing infrastructure (cloud computing, edge computing, end computing, etc.), network infrastructure (4G/5G network, metropolitan backbone network, satellite communication system, communication infrastructure, etc.), and sensing terminals (video surveillance, lidar, signal, etc.). Through the perception and collection of the underlying infrastructure, the data are transferred to the general business service layer and classified into four categories: core data, basic data, business data and application data. The classified data will support the development of general services, including but not limited to spatio-temporal information services, model algorithm services, computational analysis services, etc. Finally, the application system layer supports the application and corresponding platform by calling different common services, such as road tunnel traffic data fusion model, traffic situation analysis, traffic planning model, etc. The infrastructure layer needs to cover the data perception of the whole life cycle of smart road tunnel, and the application platform based on digital twin needs to ensure good compatibility and portability, so as to recommend the application of digital twin in smart road tunnel and the industrialization development of smart road tunnel[16].

On the basis of the overall application architecture and logical architecture, some typical digital twin traffic models can be established, as shown in Fig.2, including:

- Traffic data fusion model: allows data fusion of different traffic sensors and forms uniform traffic flow data, including traffic flow, speed, etc.;
- Traffic situational analysis model: analyzes and forecasts traffic according to the historical data and real-time traffic model;
- Signal control model: based on real-time traffic flow data, and prediction of traffic flow, optimizes intersection signal timing, including single point, line and region, the optimal timing plan;
- Traffic planning model: forecasts the network traffic based on the four phases of transportation planning method, combined with transportation mobile Internet data;
- Intelligent road model: forms the road HD dynamic map and assists vehicles to drive safely according to the real-time intelligent road perception data;
- Traffic flow microscopic simulation model: simulates real-time operation of traffic flow by comparing the pros and cons of different scheme;
- Accident analysis model: analyzes traffic accident and evaluates road safety;
- Decision-making model: recommend cost-effective excellent project.

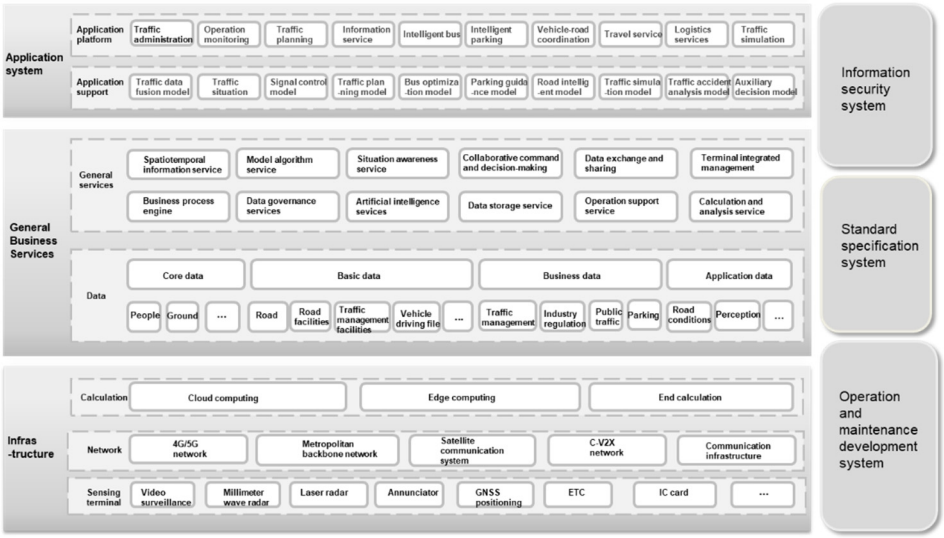


**Fig.2** Logical architecture of smart road tunnel based on digital twin

## 4. TYPICAL PLATFORMS AND APPLICATIONS

Based on the overall application architecture and logical architecture proposed in Section 2, and considering the requirements analysis of smart road tunnel summarized in Subsection 1.2, this section summarizes four typical application platforms in smart road tunnel and shows how digital twin supports the development of these typical applications.

### 4.1. Intelligent Traffic Management Platform

Intelligent traffic management platform is a traffic command and control platform for public security and traffic police departments. The platform is equipped with major functions such as comprehensive traffic situation perception, real-time traffic visualization command and dispatch, scientific research and judgment of big data, precise traffic information service, etc., which can realize the "emotional indication, emotional supervision and propaganda" of the public security traffic system, so as to further realize the orderly, safe, smooth, economic and green operation of the road traffic system.

Digital twin functions include: 1) traffic total factor data collection, situation insight; 2) Use augmented reality technology to realize synchronous visualization of traffic scene; 3) Give traffic model deduction and optimization control scheme; 4) Use artificial intelligence for emergency decision making. The functions of the intelligent traffic management platform based on digital twin are shown in Fig.3. The combination of BIM and digital twins allows intelligent traffic management platforms to improve their ability to deal with unexpected hazards in road tunnel operations. Shanghai North Transverse Corridor will be erected after the construction of the application, which is expected to be a major enhancement of the road tunnel traffic network.

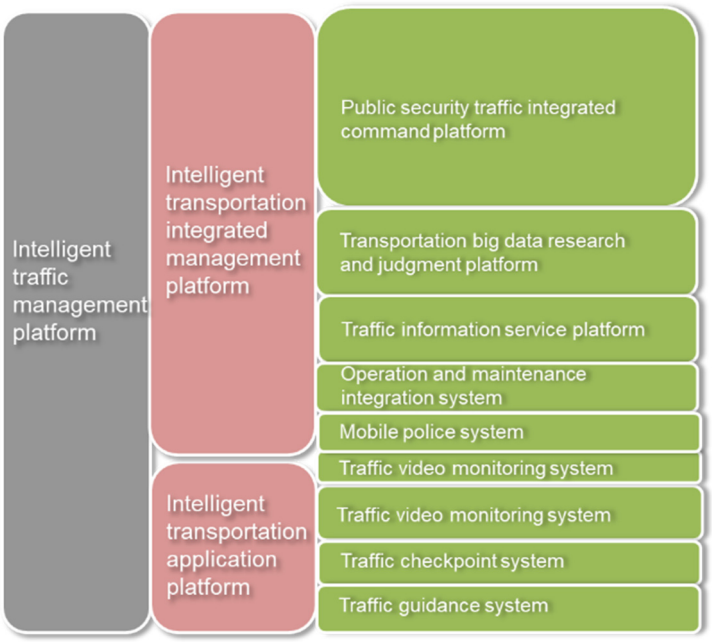


**Fig.3** Intelligent traffic management platform

### 4.2. Traffic Operation Monitoring Platform

The traffic operation monitoring platform is a daily supervision platform for local transportation bureaus, which can use big data, Internet + and so on, to establish real-time data collection and data sharing, realize real-time monitoring and early warning of transportation; improve the transportation service level, promote open sharing of transportation data resources, realize the coordination of emergency command; provide support for the operation monitoring of ground transportation, rail transit, interprovincial passenger transport and dangerous goods transport, and improve the efficiency and management level of government transportation monitoring and management[17].

The digital twin functions of traffic operation monitoring platform include: 1) real-time display of operation supervision; 2) traffic model deduction and optimization of travel; 3) artificial intelligence assistance of traffic policy; 4) BIM management of full life cycle of road; 5) synchronous visual supervision of road tunnel bridge, tunnel, ramp and toll gates; 6) pre-simulation evaluation of scheme; 7) augmented reality display of travel information service. The functions of the traffic operation monitoring platform based on digital twin technology are shown in Figure 4.

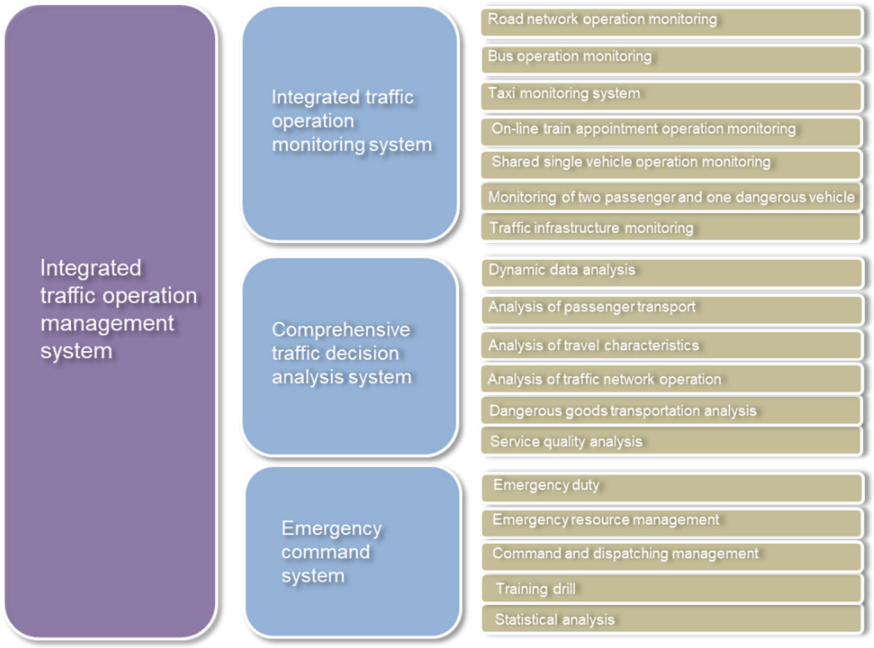


**Fig.4** Traffic operation monitoring platform

### 4.3. Vehicle-road Collaborative Service Platform

The vehicle-to-road-co-service platform is used by the vehicle-to-road co-operation service company, and needs to share data with the relevant departments of government transportation. Through the construction of roadside communication unit RSU covering the whole region, combined with the on-board communication unit OBU to realize C-V2X broadband between the vehicle and vehicle and road, so as to realize low-delay information interaction. At the same time, based on the edge calculation, the collected traffic information is processed, and the driving safety warning information and travel induction information are released to the vehicle in real time, so as to improve the traffic safety, realize the balanced and smooth flow of the road network, and provide comprehensive data support for driverless vehicles[18].

The digital twin functions of the vehicle-road collaborative service platform include: 1) realize the road system of digital twin of vehicle-road cooperation combined with the construction of high-definition map of automatic driving; 2) realize the real-time monitoring and risk determination of vehicle-road cooperative road state; 3) provide the traffic environment display of augmented reality AR for connected vehicles; 4) realize the road test supervision of autonomous driving vehicles; 5) the simulation test of digital twin automatic driving. The functions of the vehicle-road collaborative service platform based on digital twin technology are shown in Figure 5.

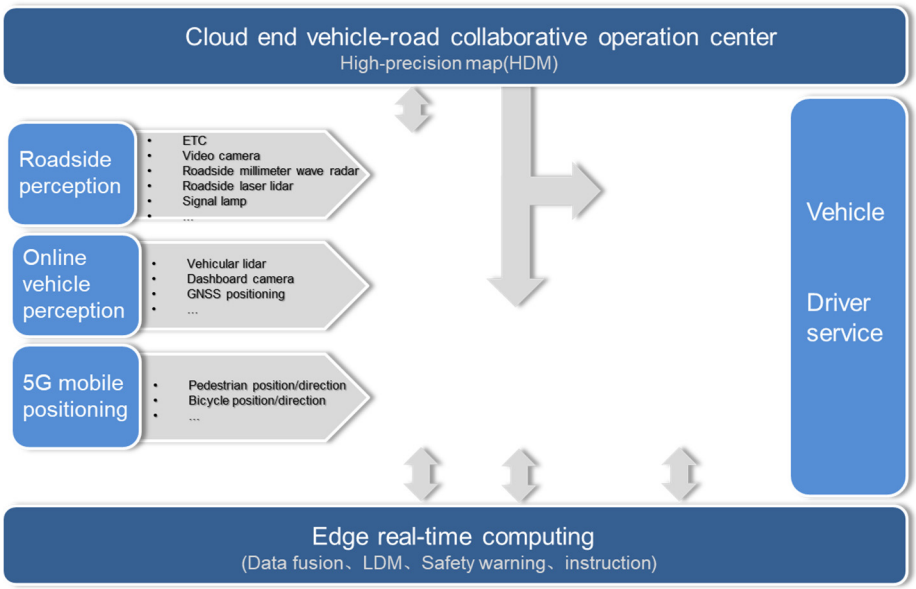


**Fig.5** Vehicle-road collaborative service platform

### 4.4. Traffic Simulation Service Platform

The traffic simulation service platform is a platform shared by all transportation related departments under the smart city. By establishing a mathematical model, the traffic simulation can truly map the physical traffic operation state, and then predict the future state of the traffic operation. According to the use of traffic simulation, traffic simulation is mainly divided into macro traffic simulation, micro traffic simulation and pedestrian simulation. Using BIM and CIM data, combined with GIS system data, high-definition map data is incorporated under conditions, establish traffic simulation model, and incorporate real-time traffic flow parameter data to form the mapping of logistics traffic in virtual space (parallel traffic), and realize the basis of traffic simulation in virtual space.

The digital twin functions of the traffic simulation service platform include: 1) evaluate the traffic planning and organization scheme of the regional network; 2) evaluate the macro network traffic service level and capacity; 3) simulate and make long-term and short-term prediction of the dynamic traffic changes of the network; 4) evaluate and analyze the macro traffic regulation and management policies; 5) provide relevant support for the study of urban macro traffic strategy; 6) evaluate whether the road marking signs and geometric canalization are scientific and reasonable; 7) evaluate the service level of existing high-speed infrastructure; 8) evaluate and predict the emergency traffic plan under the special traffic demand. The functions of the traffic simulation service platform based on digital twin technology are shown in Figure 6.

The combination of digital twin and BIM technology, on the other hand, can realize the visualization and supervision in the traffic simulation service platform, and establish the parameters of road tunnels (e.g., traffic flow, infrastructure configuration, etc.) into a refined data model, so as to grasp the changes of traffic in a timely manner.

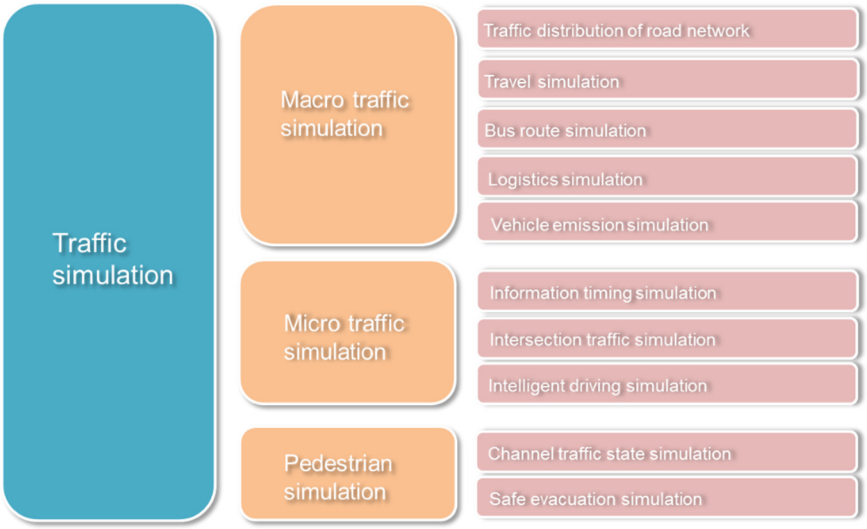


**Fig.6** Traffic simulation service platform

## 5. Conclusion

By sorting out the existing technologies and development needs of smart road tunnel, this paper interprets the connotation and framework of smart road tunnel technology based on digital twin technology. The main conclusions are as follows:

(1)Combined with the characteristics of smart road tunnel technology, the needs of the road tunnel development of intelligent technology are clarified, and the necessity of digital twin technology application in smart road tunnel is explained;

(2)Put forward the overall architecture and logical architecture of the application of digital twin technology in smart road tunnel, and clarified the interactive relationship between all levels;

(3) For four typical applications (intelligent traffic management, traffic operation monitoring, vehicle-road collaborative service and traffic simulation service), how the digital twin technology supports the operation and maintenance of the four types of platforms is discussed respectively. and demonstrated the application value of combining digital twin and BIM technology.

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