Received 18 April 2023, accepted 9 May 2023, date of publication 11 May 2023, date of current version 17 May 2023.
Digital Object Identifier 10.1109/ACCESS.2023.3275559

RESEARCH ARTICLE

Design of Highway Intelligent Transportation System Based on the Internet of Things and Artificial Intelligence

YANG CUI[1] **AND DONGFEI LEI**[2]
[1]School of Measurement and Communication Engineering, Harbin University of Science and Technology, Harbin 150080, China
[2]School of Civil Engineering, Harbin University, Harbin 150086, China
Corresponding author: Yang Cui (cuiyanghit@126.com)

ABSTRACT At present, the transportation industry is developing rapidly. Studying intelligent highway systems in the Internet of Things (IoT) context is of practical significance. This paper aims to promote the comprehensive integration of modern information technology with transportation facility management and operation management. Firstly, the fundamental nature and laws of IoT and intelligent transportation are studied. Based on the current situation, the feasibility of developing intelligent transportation based on the IoT technology of the highway is analyzed. Secondly, the design requirements of the highway Intelligent Transportation System (ITS) are analyzed. Then, the overall architecture of the highway ITS is designed by comprehensively using various advanced information, communication, and control technologies guided by demand analysis and relying on the technology platform of the IoT. It is identified as three layers: a perceptual layer, a transport layer, and an application layer. Finally, the main application function design of the highway ITS is carried out. The results show that: 1) the efficiency and effectiveness of the maintenance management system in dealing with emergencies before equipment failure is much higher than that of the traditional highway management system; 2) after using the updated system, user experience satisfaction and executive experience satisfaction have improved. It is more ideal than traditional highway traffic processing methods; and 3) expectation of the public for the innovative system designed here is 4.8. It reveals that the proposed intelligent transportation system meets the expectation of the majority of the public for highway traffic management. The purpose of this paper is to promote the development of transportation informatization and intelligence, improve the efficiency of the transportation system, and enhance the safety of transportation through IoT information technology.

INDEX TERMS Internet of Things, artificial intelligence, smart city, intelligent transportation, system design.

I. INTRODUCTION

At present, human society has ushered in the Fourth Industrial Revolution with information technology as the primary carrier. Information is beginning to become the main factor of production for social development [1]. In the traditional Internet era, the types of information and the means of obtaining information can no longer adapt to the development of the times. As the in-depth expansion of information technology, the Internet of Things (IoT) has gradually received attention and promotion. It has been progressively applied in many fields, such as smart cities, intelligent transportation, smart grid, smart home, modern agriculture, and the logistics industry [2]. The IoT builds an intelligent network with extensive coverage between objects and people to achieve topology and mapping of the physical world to the virtual world to establish an organic connection between the two. Then, human society will move towards comprehensive informatization [3].

In recent years, with the upgrading of the intelligent transportation system (ITS) and the increasingly perfect road

The associate editor coordinating the review of this manuscript and approving it for publication was Rahim Rahmani.

planning, traffic in many large and medium-sized cities has been greatly improved. Due to the development of the economy and the improvement of people's living standards, highway intelligent transportation combined with IoT and artificial intelligence (AI) has become the best choice to improve traffic [4].

IoT is defined as a network that connects any object to the Internet for information exchange and communication through information sensing equipment such as radio frequency identification, infrared sensor, global satellite navigation system, and laser scanner according to the agreed protocol to realize intelligent identification, positioning, tracking, monitoring and management. As a new technology integrating wireless communication technology, microelectronic sensor and embedded system, IoT is gradually used in ITS and other related fields that need data acquisition and detection, thus bringing a new upgrade to urban intelligent transportation. The ITS based on IoT can collect the vehicle and road information in the whole city in real-time, and intelligently and dynamically calculate the optimal command and dispatching plan and vehicle route. According to experts' research, the number of deaths in traffic accidents alone can be reduced by more than 30% each year and the efficiency of vehicles can be improved by more than 50% [5] after the adoption of intelligent transportation technology to improve the level of road management.

According to the above research status and the existing problems of the ITS, a new idea is provided for constructing an efficient ITS. First, the basic concepts of the IoT and the technologies related to AI are expounded. The feasibility of developing intelligent transportation based on IoT technology on the highway is analyzed. Second, the design requirements of the highway ITS are analyzed. Then, the overall architecture of the highway ITS is designed comprehensively using various advanced technologies guided by the needs analysis. It is determined to be three layers composed of the perception layer, transmission layer, and application layer to innovatively and completely construct a new ITS.

II. LITERATURE REVIEW

The research status of the ITS is as follows. Kaffash et al. proposed that the amount and availability of data in ITS led to the need for data-driven methods, and the application of big data algorithms further enhanced the intelligence of applications in the transportation field. The big data algorithm in ITS has a wide range of applications, including but not limited to signal recognition, target detection, traffic flow prediction, travel time planning, travel route planning, and vehicle and road safety. This study aims to provide a bibliography, comprehensively review the application of ITS, and review the most recognized models of big data used in the context of ITS. Dynamic pricing plays a crucial role in modern ITS, which can solve congestion control, peak load reduction, and mobility management of traditional or electric vehicles in a cost-effective way [6]. Saharan et al. conducted an extensive analysis on the use of dynamic pricing technology in the relevant literature of ITS, enabling them to compare the application of one technology with the advantages of other technologies. They discussed in depth the problems solved by dynamic pricing technology, the importance of various evaluation parameters, the limitations of dynamic pricing technology and its application. The study also introduced different classification methods used to explore various issues of dynamic pricing in a structured way, and proposed the challenges and future research directions of ITS dynamic pricing [7]. Lv et al. improved the ITS through deep learning, which can significantly reduce the data transmission delay of the system, improve the prediction accuracy, effectively change the path in the face of congestion, and inhibit congestion diffusion. Although there are some deficiencies in the experiment, it still provides an experimental reference for the later development of the transportation industry [8].

IoT-based ITS must fully consider various types of infrastructure and traffic objects. By building the perception network of basic traffic, various types of intelligent management service systems can be developed. Yang et al. pointed out that IoT-based ITS needs to take into account all infrastructure projects, transportation vehicles and reasonable transportation objects, build a reasonable network of basic transportation systems, and develop various intelligent management service systems. Through the introduction of IoT theory and related technologies, a certain framework of an ITS based on IoT will be formed to realize the smooth operation of intelligent transportation in all regions of the city [9]. Liu and Ke introduced the application status of transportation IoT and designed an ITS based on the national standard of IoT six-domain model. The system mainly includes the user domain, service provision domain, perception control domain, object domain, resource exchange domain and operation and maintenance control domain, and analyzes the application of transportation IoT. It includes four systems, including a parking management system, traffic guidance system, public transport management system and public security management system, which provides a reference basis for the design of traffic IoT system [10].

To sum up, the design of ITS at this stage is mostly about the transformation or upgrading of a certain link in the system and how to better integrate the IoT concept and AI technology into the overall transportation system. There is a lack of research on the comprehensive upgrading and optimization of the system. Under the guidance of demand analysis, this paper designs the overall architecture of highway ITS by comprehensively using various advanced technologies and determines it to be composed of three layers: perception layer, transmission layer and application layer. In addition, a new ITS has been innovatively and completely constructed to study and analyze the feasibility of developing intelligent transportation on highway based on IoT technology.

III. MATERIALS AND METHODS

A. AN OVERVIEW OF THE IOT

1) DEFINITION OF THE IOT

The definition of IoT is that things are connected. The study of the IoT began with and differed from the Internet [11]. The core of the IoT is to extend the node form of the network to everything. It is connected using a cable and an optical cable. The IoT mainly enables object connections over a wide area through wireless forms [12].

2) THE ARCHITECTURE OF IOT TECHNOLOGY

The IoT can connect things. It mainly relies on specific communication protocols. An essential function of the communication protocol is to unify the format of various information [13]. The purpose of connecting things is for multiple applications in production and life [14]. Therefore, the essence of the IoT is to form a communication network of massive data collectors and sensing devices following the communication protocol of the agreed format. Then, it is connected to the Internet and various networks. Communication and exchange of information can be performed to realize an interactive physical network of intelligent, automated positioning, tracking, recognition, monitoring, and other functions of the connected objects [15]. From the composition, the IoT can be divided into three levels: the perception layer, the network transmission layer, and the information processing application layer, as shown in Figure 1.

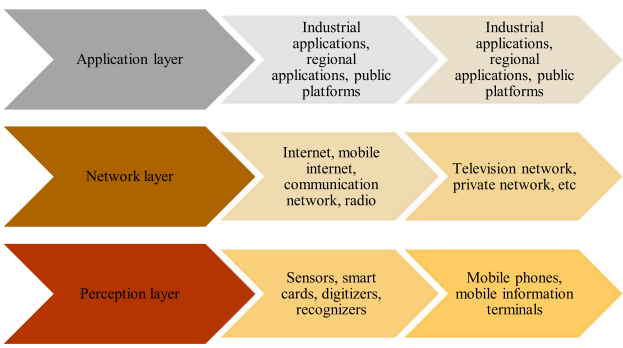

FIGURE 1. The architecture of IoT technology.

The perception layer is the collection system of basic information of the IoT. Every object is an objective being. This objective existence, in turn, derives the unique properties inherent in the object that distinguish it from other objects [16]. The physical attributes of the network layer are from the perspective of various network forms, such as the Internet, wireless communication networks, local area networks, and exclusive networks. The technical properties of the network layer are the various communication protocols that make up the efficient and correct operation of various physical networks. The application layer interfaces the IoT and the user [17]. According to the application of the IoT in different industries, the data collected by the perception layer will be transmitted through the network layer and processed, classified, screened, and processed into relevant formats for end users according to the needs of industrial applications. Its implementation relies heavily on various database technologies, professional software, and mobile applications [18].

B. OVERVIEW OF AI

AI has been a newly revitalized technological force in recent years. It is a new technological science that studies and develops theories, methods, technologies, and application systems for simulating, extending, and expanding human intelligence. The current development of AI is extremely rapid, from simple intelligent recognition to intelligent robots that can respond similarly to human intelligence, AI is undergoing continuous evolution of self-innovation. In short, AI is a simulation of the information process of human meaning and thinking. It is not human intelligence, but can think as humans and may also surpass human intelligence. The application of AI in highway inspection is a future trend, which will bring immeasurable benefits and convenient services to avoid highway accidents, and bring huge impetus to the innovation of smart highways.

The application of AI in highway inspection can make the search for road fault problems simple and efficient. The inspection vehicle utilizes intelligent inspection equipment installed on it to collect and capture high-definition images of highway faults at speeds above 60km/h, efficiently completing maintenance inspection tasks. The intelligent inspection equipment and backend services of the inspection vehicle can be applied to conduct inspections, locate, take photos, and inspect at any time. In this process, based on AI image recognition, various technologies such as high-definition image acquisition, 5G, Beidou, and big data analysis are combined to complete the integrated work of road fault detection, collection, viewing, confirmation, and reporting. It fully solves the problems of omissions, insufficient safety and accuracy faced by manual inspections.

Currently, many road inspection companies are turning their attention to AI detection robots. They liberate testing personnel and equipment through various means, and conduct comprehensive inspections of highways from multiple directions and levels. The AI detection robot integrates equipment such as ground penetrating radar, flatness gauge, and deflection instrument, and can adapt to various fault situations for detection and inspection. Meanwhile, AI is used as the processing center for information data to obtain three-dimensional (3D) mapping and stitching images of internal faults. Then, based on the detection results, the heat map of the target area and components is created for abstract analysis. The fault source is explored through deep learning of multi-dimensional hierarchical analysis of fault features. Later, manual intervention is conducted to optimize this well-trained fault source model. Based on AI, the features of highway fault data are extracted and data training is performed to provide the driving force for highway detection and fault analysis calculation. Then, it can achieve more intelligent fault detection and implementation plans to cope with more road inspection businesses.

C. THE MEANING OF INTELLIGENT TRANSPORTATION

Professor Li Deren, an academician of the Chinese Academy of Sciences and the Chinese Academy of Engineering, defines the smart city as ‘‘smart city = digital city + IoT + cloud computing’’ [19]. He believes the connotation of the smart city is the integration of the three concepts of a digital city, the IoT, and cloud computing, as demonstrated in Figure 2.

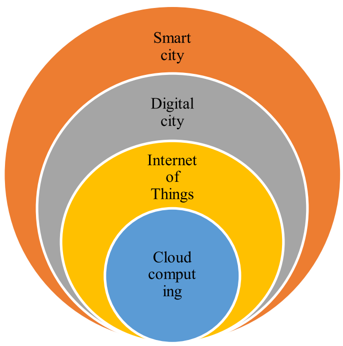

FIGURE 2. **Composition of a smart city.**

Intelligent transportation = digital transportation + IoT + cloud computing. Therefore, the transportation system can interconnect, communicate, perceive, analyze, predict, decide, and control in the city, region, and even a wider time and space range. Intelligent transportation fully protects people’s transportation safety, effectively exerts the efficiency of transportation infrastructure, and maximizes the efficiency and management level of transportation system operation. So, it serves the increasing public mobility and sustainable socio-economic development of transport needs [20].

From the definition of intelligent transportation, it is based on the premise of digital transportation. The concepts of digital and intelligent transportation have a solid consistency to some extent [21]. The outstanding feature of intelligent transportation is the collection, processing, release, exchange, analysis, and utilization of transportation system information as the basic functions. Intelligent transportation enables real-time, diverse, targeted information services and intelligent decision support for transportation participants [22].

D. DEMAND ANALYSIS OF HIGHWAY ITS

Demands analysis is the starting point for system development and design. It is the key to the success or failure of the system. Insufficient analysis of various demands can lead to insufficient functionality and system design capabilities. This, in turn, leads to a surplus of capacity and the waste of inputs [23]. The system demands are analyzed from the two aspects of user and technical demands to improve the adaptability and feasibility of the design of the highway ITS.

1) ADMINISTRATIVE AUTHORITIES

The main function of the industry authorities is to formulate industry rules and regulations. It provides macro-management of highway operators’ entry, operation, and exit management [24]. Therefore, the real-time highway intelligent traffic information demand is mainly reflected in the highway traffic management department. Figure 3 shows the demand analysis.

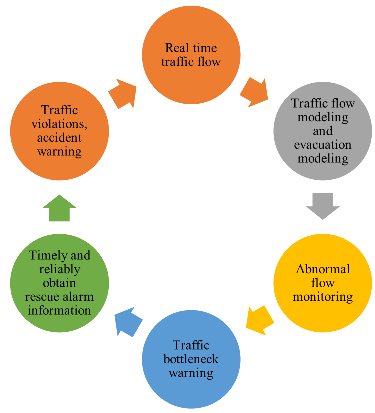

FIGURE 3. **Demand analysis of administrative departments.**

2) HIGHWAY OPERATOR

Through the effective management of assets such as highway facilities and equipment, highway-operating enterprises provide high-quality services to the general public and enterprises with transportation demands and obtain corresponding investment returns or operating income [25]. The relevant demands analysis is shown in Figure 4.

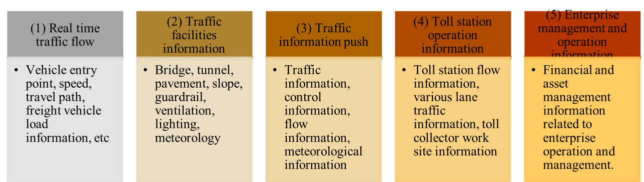

FIGURE 4. **Operator demand analysis.**

3) HIGHWAY SERVICE DEMANDER

Serving the service demand side is the ultimate purpose of highway operation. Their demands represent the direction of intelligent transportation efforts and development [26]. Their main demands analysis is shown in Figure 5.

4) HIGHWAY DERIVATIVE SERVICE PROVIDERS

Highway derivative services refer to other value-added services related to highway traffic, such as navigation, insurance, financial support, vehicle leasing, and other commercial enterprises [27]. The demands analysis diagram is shown below.

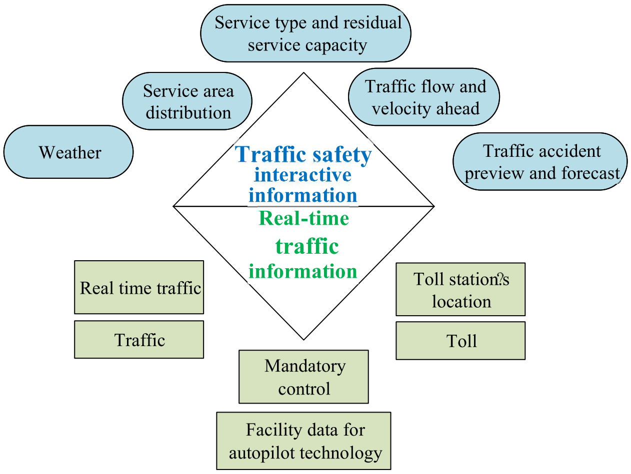

FIGURE 5. **Demand analysis of the demander.**

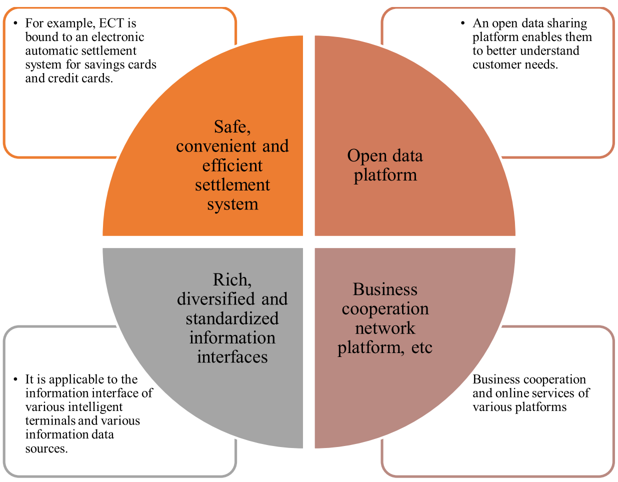

FIGURE 6. **Analysis of derived service demands.**

5) TECHNICAL DEMANDS

The intelligent transportation information system of highways must have the characteristics of openness, compatibility, dynamics, overall, and intelligence to truly realize intelligence. The characteristics of the five aspects are the basic prerequisites for the intelligent operation of the system. Without these five characteristics, it is impossible to achieve the intelligence of the system [28].

E. AI TECHNOLOGY FOR HIGHWAY INTELLIGENT TRANSPORTATION

The Highway Intelligent Transportation Big Data Artificial Intelligence Center takes the sharing, exchange, development, and service of traffic data resources as the main line. Meanwhile, all kinds of data scattered across subsystems are brought together to eliminate information silos. Information barriers between systems are broken to realize the overall link from the grass-roots application, middle-level monitoring and evaluation management, and high-level decision-making. The "integrated" data platform covering data collection, data management and application, and data service functions is built to support the situation monitoring and intelligent decision-making of highway operation [29]. The main completed work and implemented functions are as follows.

1) DATA PLANNING AND DESIGN SYSTEM

The data planning and design system realizes the unified planning of various information resources in the data center and designs the correlation relationship of various data types. The reports and rules of various data types are customized to ensure the orderly association and integrated management of data resources [30].

2) DATA ACQUISITION SYSTEM

The data of each subsystem is collected by import and exchange. Each task of data acquisition is scheduled, monitored, and counted. Data acquisition systems can also perform automatic error correction for data acquisition tasks.

3) DATA SHARING AND EXCHANGE PLATFORM

The data sharing and exchange platform focuses on each subsystem's information exchange and sharing needs and breaks down data silos based on SOA architecture through front-end machines, database docking, and Web Services [31]. Then, the management of information resources between the various subsystems of intelligent transportation is realized.

4) DATA MANAGEMENT AND ANALYSIS SYSTEM

Data management and analysis system realizes the integration, processing, and unified management of various data types. It flexibly organizes various types of report data, indicator data, and text materials in the form of thematic topics [32]. For all professional users, various types of data comprehensive analysis applications are achieved, including query retrieval, temporal analysis, data drilling, visual display, GIS, and other functions through a series of analysis configurations.

5) DECISION SUPPORT DATD

Through various visual technical means such as GIS maps, reports, and timing animations, decision support data provides various theme-oriented statistical analysis services for decision-making, such as comprehensive information display, hot spot monitoring, and comprehensive analysis [33].

6) MOBILE APP DATA SERVICE APPLICATION

For all kinds of users, based on the mobile intelligent terminal (support Android, WP, and IOS systems), mobile APP data service applications can realize the active push of various data services to meet the needs of data service acquisition.

The various perceptual information of the highway ITS involves a wide range. Various signals and information modes are different. Standardized processing must be carried out to meet the needs of information fusion. The technical indicators of various signals are standardized, and the value of each indicator attribute is uniformly transformed into a range by constructing a transformation function [34]. The interval-type standardized function is:

$$a_i = U_{d_i}(x_i) = \begin{cases} 1 - \frac{\max\{m_1^i - x_i, x_i - m_2^i\}}{\max\{m_1^i - x_i, M_i - m_2^i\}} & x_i \notin [m_1^i, m_2^i] \\ 1 & x_i \in [m_1^i, m_2^i] \end{cases} \quad (1)$$

In Eq. (1). $d_i = [m_i, M_i]$ is the threshold for metric i. $d_i = [m_i, M_i]$ indicates that the value range of d_i is between m_i and M_i. x_i is the property value of the indicator (measured value). m^* is a fixed value. $[m_1^i, m_2^i]$ is a fixed interval.

F. INTELLIGENT TRANSPORTATION CLOUD PLATFORM BASED ON THE IOT AND AI

According to the results of user needs and technical requirements analysis, this paper starts from the overall architecture of the system and the interactive functions realized combined with the technical, functional characteristics of IoT technology system perception, information processing, and communication. It carries out preliminary framework construction and the main available application layer design of highway ITS based on the IoT. From the overall functional structure perspective, the entire system can be divided into three levels: the perception layer, the network and transport layer, and the application layer, as shown in Figure 7.

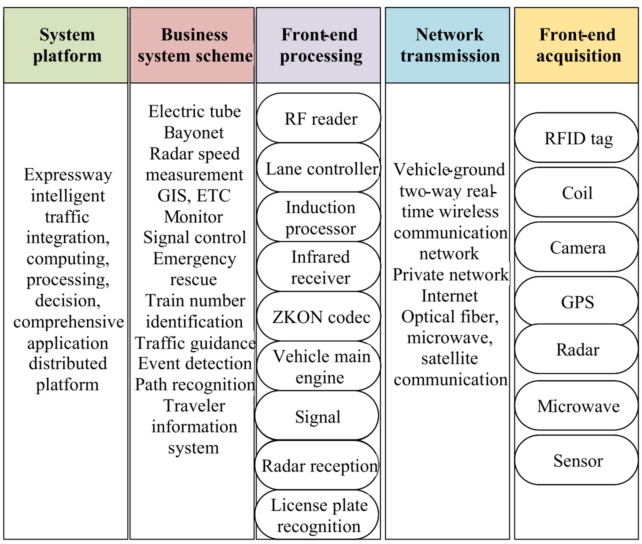

FIGURE 7. The overall architecture of intelligent highway transportation.

The highway ITS designed here is a distributed and open platform integrating functions such as integration, operation, processing, decision-making, and comprehensive application. It relies on the current advanced data acquisition technology, powerful database technology, and efficient distributed computing technology to integrate various information facilities and equipment, forming an intelligent system that can collect data, process information by itself, make self-decision-making, and actively push and publish.

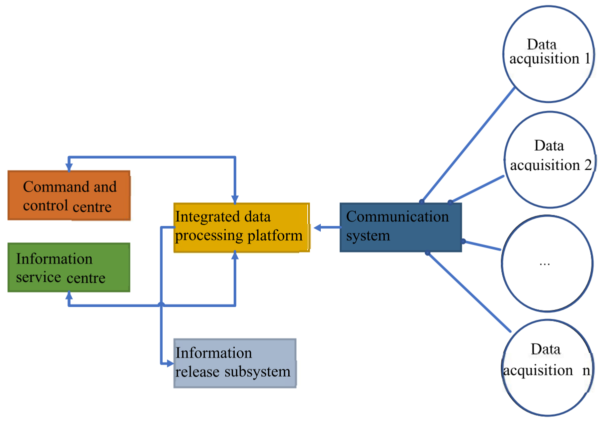

FIGURE 8. The network structure of ITS.

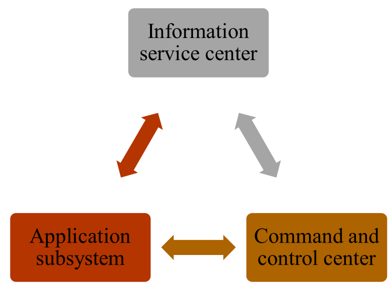

FIGURE 9. Hierarchical architecture of ITS.

The entire network function topology space of the highway ITS comprises three levels: data acquisition subsystem, data comprehensive processing platform, and information release subsystem, as presented in Figure 8.

The highway ITS designed here can divide the network into three levels from the function: application subsystem, information service center, and command and control center. These three levels are also three functional modules for different information demands. The roles and functions of information centers and command and control centers are relatively clearly defined. The application subsystem contains several subsets. It is a collection of all applications except the information service center and the command and control center, as shown in Figure 9.

In Figure 9, the three levels have four functions. The first is to carry out hierarchical and centralized processing of the collected traffic information. The second is to have an advanced intelligent command and control center. The third is to have a wide range of information collection, aggregation, processing capacity and a stable and reliable software and hardware facility configuration and operation environment. The fourth is that the information collection and release system has a fault self-test function and can timely inspect and maintain these facilities.

The cloud-based comprehensive service platform mainly consists of three major parts: data aggregation and sharing, intelligent management, and intelligent services. Massive real-time collected traffic data are stored. Besides, cloud

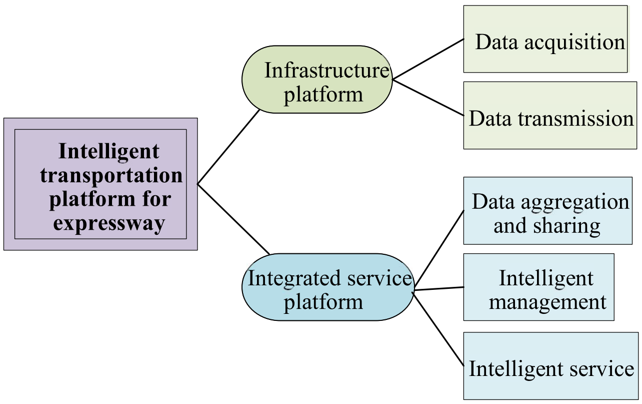

FIGURE 10. Framework model of expressway intelligent transportation platform.

TABLE 1. Traffic data collection table.

Information Type	Electromechanical system	Information acquisition
Image information	Road and toll station monitoring system	Pavement condition Car condition Traffic flow operation status Meteorological information
Traffic flow information	Road and toll station monitoring system Toll system	Traffic Traffic density Vehicle speed Vehicle queue length Vehicle type discrimination
Traffic environment information	Road monitoring system Tunnel system Road monitoring system	Pavement condition Brightness inside and outside the tunnel Bridge condition Slope condition
Traffic incident information	Road and toll station monitoring system	Traffic accident Vehicle breaks down Road construction
Traffic operation control data	Road and toll station monitoring system	Traffic incident response Variable information release and guidance Lane control
Vehicle charging data	Toll station monitoring system	Labor charge data Electronic charging data Vehicle license plate data

computing technology is adopted to aggregate, process, and interactively share massive traffic data to form an efficient comprehensive traffic database, providing intelligent services for applications on cloud platforms. An integrated expressway intelligent transportation operation service system has been constructed to provide comprehensive and accurate information on expressway operation status for highway managers, providing monitoring, management, and decision-making basis. The system provides accurate and rich travel guidance information for highway travelers, and offers safe, efficient, comfortable, and fast traffic information services [35]. Once the highway is in an abnormal traffic state, the cloud-based comprehensive service platform provides decision support for highway managers. It can achieve coordinated emergency handling among highway-related departments such as the highway traffic police department, the highway emergency rescue department, and the highway maintenance department. Besides, it can ensure the safety and smoothness of highway traffic, avoid or reduce secondary traffic anomalies, and improve the efficiency of collaborative management [36]. Figure 10 is a framework model for a cloud platform:

Data acquisition is to utilize radio frequency identification technology, on-board intelligent terminals, and other sensing devices and technologies in IoT technology, and integrates a large number of electromechanical transportation systems in highways, realizing the interaction of people, vehicles, roads, and the environment, and collecting traffic data in a timely, comprehensive, and accurate manner. It provides effective basic data for the safe operation and management of highways and effective service information for travelers. The data acquisition system mainly collects six types of dynamic data in the highway, including images, traffic flow, traffic environment, traffic events, traffic operation control, and vehicle pricing. Table 1 displays its various data collection tables:

Regarding the application of intelligent transportation data collection, this section mainly takes the tunnel system's internal and external brightness lighting system as the testing instruction. After sending the power on and measurement commands, it is essential to wait for a measurement time more than 120ms to read the illuminance value. The data obtained by sending power on, measuring instructions, reading illumination values, and processing data programs is float type. Hence, first, the float type results are stored in a zero-time storage area in the form of hexadecimal numbers using a memory replication method to facilitate subsequent data processing and transmission. The code designed for this system is as follows:

```
Data [0]=0 × 01;
if (!I2C_WriteNByte(I2C1, Data, 1))
Data [0]=0 × 11;
flag = I2C_WriteNByte(I2C1, Data, 1);// Sending measurement commands
if (!flag){
Delay_m3(300);// Waiting for more than 120ms
if (flag){
```

```
GPIO_SetBit3(GPIOB, GPIO_Pin_0);
} else {
illhumi = ((Data [0] < < 8)+Data [1])/(1.2*2);
memcpy (buf, sillhumi, 4);
usRegInputBuf [0] = (buf [0] < < 8) | buf [1];
usRegInputBuf [1] = (buf [2] < < 8) | buf [3];
}
} else {
usRegInputBuf [0] = 0 × 0000;
usRegInputBuf [1] = 0 × 0000;
}
```

The illumination value returned to the host is a 16-digit number, which is then converted to decimal to be the illumination result. According to the chip instruction manual, the result in continuous H-resolution mode 2 needs to be divided by 1.2 to obtain an accurate illuminance with a resolution of 0.51×. Therefore, accurate illuminance is obtained by dividing the data read from the I2C bus by 1.2.

The intelligent transportation infrastructure layer platform is actually an information collection and transmission layer. It completes data collection during the construction, operation, and maintenance periods through various types of infrastructure on the highway, providing reliable basic data resources. During the construction period, the main tasks are to complete data collection for project management, measurement and payment, design changes, experimental data, and on-site video monitoring. During the operation period, the platform mainly completes data collection for road section monitoring, tunnel monitoring, vehicle pricing, environmental testing, fire monitoring, vehicle testing, slope testing, and bridge health monitoring. During the maintenance period, it is to complete the collection of information on the condition of highways, bridges, and tunnels, as well as the operation and maintenance of electromechanical equipment. Then, the collected data are transmitted to the cloud computing platform through the network to achieve data aggregation, fusion, and sharing.

G. HIGHWAY INTELLIGENT TRAFFIC NON-STOP TOLL SYSTEM

The working principle and process of the highway non-stop toll collection system designed here are as follows. When the vehicle is driving to the non-stop toll lane, the speed is reduced to less than 20km/h according to the speed limit prompt electronic sign, entering the vehicle detection and perception range. First, the read and write antenna starts when the vehicle passes the trigger coil and enters the communication range. The read and write antenna communicates with the non-stop toll in-vehicle system to determine whether the vehicle's electronic tag is valid. If both the conditions for the validity of the electronic tag and sufficient balance are met, the transaction is made. The transaction is successful, and the system control railing is raised. The traffic signal light turns green, and the transaction information is displayed on the fee card. If it is judged that the trading conditions are not met, immediately alarm and keep the lane closed until the vehicle leaves the detection coil sensing range. After the vehicle passes through the drop bar to sense the ground sense coil, the passage railing automatically falls back. In addition, the traffic signal light turns red, and the system saves the transaction record. The transaction is uploaded to the non-stop toll system server, and the system re-enters the standby state to wait for the next car to enter. Figure 11 shows the principle and composition.

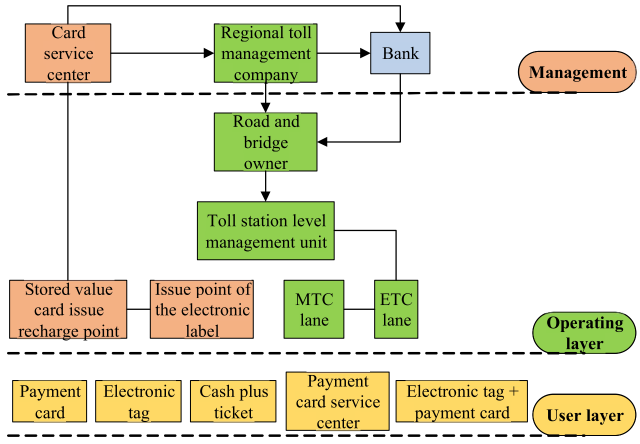

FIGURE 11. Operating framework diagram of the non-stop toll collection system.

The entire settlement system includes three levels, management, operation, and user. The whole architecture of the system is divided into two parts: a one-card service system and a regional toll collection system from the perspective of business functions. The one-card service system refers to the background support settlement system and payment card issuance and user service system of networked charging. The regional toll collection system includes a four-level structure of lane, toll center, toll sub-center, and toll station systems.

H. HIGHWAY INTELLIGENT TRAFFIC GUIDANCE SYSTEM

The main function of the highway intelligent traffic guidance system is to guide vehicles to pass safely and efficiently according to dynamic and real-time traffic situations. Dynamic and real-time traffic conditions include sudden traffic accidents, highway infrastructure roads, bridges, and tunnels. Then, information and program support is provided for traffic management decisions.

The dispatching system monitors and detects the operation status of regional traffic flow in real-time. It quickly collects various traffic flow operation data and analyzes the traffic flow operation characteristics timely. Besides, the dispatching system intelligently and adaptively predicts changes in traffic flow and formulates the best response measures and programs, which are released to the public through various channels timely. Figure 12 shows the traffic guidance process.

There are several main methods of vehicle positioning technology: map matching positioning, Global Positioning System (GPS), racking positioning, inertial navigation

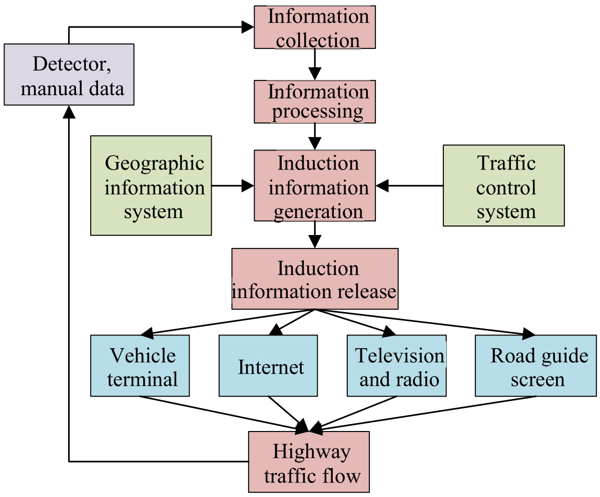

FIGURE 12. Traffic guidance flowchart.

system, and tuned radio frequency positioning. The function of the vehicle positioning system is to determine the vehicle's precise position in the road network.

This section analyzes the accuracy of the plane and elevation values of the overall realistic 3D model of the highway survey area. Inspection points within the survey area are selected according to the method of uniform sampling points in the general area and enhanced density collection in areas with large terrain fluctuations. The 3D coordinates of each inspection point measured are set to (X, Y, Z). They are compared with the encrypted 3D coordinates (X′, Y′, Z′) of the corresponding point coordinates of the same name in the real scene 3D model constructed using the unmanned aerial vehicle system. The difference between the measured and true values of the coordinates in the 3D model is calculated.

Root mean square error (RMSE) is an important indicator that reflects the accuracy of errors. Therefore, this paper analyzes the accuracy of realistic 3D models constructed based on AI systems by calculating the RMSE of planes and elevations. The calculation equation is as follows:

$$m_x = \sqrt{\frac{\sum (X' - X)^2}{n}} \tag{2}$$

$$m_Y = \sqrt{\frac{\sum (Y' - Y)^2}{n}} \tag{3}$$

$$m = \sqrt{(m_X)^2 + (m_Y)^2} \tag{4}$$

$$m = \sqrt{\frac{\sum (Z' - Z)^2}{n}} \tag{5}$$

n represents the number of checkpoints; m represents the calculated RMSE.

I. SWOT ANALYSIS MODEL

SWOT analysis mainly focuses on the analysis of internal and external competitive environments and conditions. It includes S-Strength, W-Weakness, O-Opportunity, and T-Threat. SWOT analysis identifies the strengths/weaknesses and opportunities/threats of design based on the definition of a competitive strategy for intelligent transportation on highways. Finally, all types of strength, weaknesses, opportunities, and challenges related to research objectives are listed, and a matrix is adopted to arrange them. The relationship between the influencing factors is determined based on system analysis, and decision-making conclusions are drawn through analysis. Through this method, it is possible to conduct a comprehensive, systematic, and accurate analysis of the actual situation of research objectives to formulate sound plans, policies, and strategies.

This paper conducts a SWOT analysis for the design of intelligent transportation systems for highways based on IoT and AI, as shown in Table 2 below:

TABLE 2. Swot analysis of intelligent transportation.

Strengths	Weaknesses	Opportunity	Threat
Large capital scale	Insufficient information openness	Policy opportunities	Incomplete information security
Low operational risk	Lack of uniform specifications	Green travel	Information leakage
Special fund support	Insufficient control	Increased environmental requirements	Public welfare of toll roads
Enhanced brand influence	The level of intelligent transportation needs to be improved	Active intelligent transportation market	Weak human resource base

IV. RESULTS

A. SWOT ANALYSIS AND COMPARISON

The SWOT analysis method is adopted to analyze and judge the environment in which the intelligent transportation business development is located, and the following strategies are available for selection:

SO strategy: under the condition of coexistence of internal advantages and external opportunities, it is essential to adapt to a favorable policy environment, seize opportunities, utilize the advantages of intelligent transportation to expand its main business, and increase research, development, and investment in the intelligent transportation business.

WO strategy: under the condition of the coexistence of external opportunities and internal weaknesses, external opportunities should be utilized to compensate for internal weaknesses. Enterprises should actively respond to existing policies, establish corresponding contacts with each other and strengthen better cooperation with government departments. Moreover, they must strengthen internal management, conduct personnel training, and timely acquire advanced management knowledge. Besides, they should improve the personnel assessment, salary and treatment system, attract high-tech talents to join, ensure high-quality and efficient management results, and solve the problem of fundamental weaknesses in human resources.

ST strategy: under the condition of coexistence of internal advantages and external threats, enterprises should utilize internal advantages to avoid external threats. Existing assets need to be fully utilized. The development model and related products of intelligent transportation projects should be combined with smart cities and the intelligent transportation industry. It can minimize the risk of information leakage from intelligent businesses based on their technological advantages while diversifying their development.

WT strategy: under the condition of the coexistence of internal weaknesses and external threats, internal weaknesses should be reduced and external threats should be avoided. Enterprises should strengthen evaluation work and early planning as early as possible. Based on a reasonable grasp of national policies, they can also effectively grasp their entry into new industries to resolve the crisis better. Moreover, they can transform from a highway enterprise with a relatively single core business to a diversified enterprise to achieve sustainable enterprise development.

B. COMPARISON OF HIGH-SPEED EMERGENCIES IN NEW ITS

A comparative test is conducted on the new ITS designed here. The system proposed here is implemented for one month for a small range of applications. The degree of occurrence of real-time information acquisition, number of traffic accidents, road congestion time, and maintenance efficiency of highway facilities is collected and compared with the degree of occurrence of each project before implementation.

First, for the comparison of real-time information acquisition time, the time when real-time events occur on site and the time when the system prompts are compared to compare the efficiency of information acquisition before and after using the intelligent transportation platform. Then, for the comparison of the number of traffic accidents, the number of traffic accidents before and after using the intelligent transportation platform is calculated monthly. Next, real-time statistical records of road congestion are used for comparison. Video surveillance during congested highway sections is selected for comparison before and after using the platform. Finally, regarding the efficiency of highway facility maintenance, the experiment compares the arrival time of maintenance workers before using the intelligent transportation platform with the response time of the early warning system. It can ensure that maintenance workers arrive at the scene early in case of an accident. The comparison results are revealed in Table 3.

In terms of real-time information acquisition, the information that users want can be obtained within ten minutes from the previous half-hour acquisition. The frequency of traffic accidents has dropped from 75 to 38. Road congestion time has been reduced from 45 hours to 30 hours. Highway facility maintenance has shifted from about an hour ago to using a facility warning system. Repairs are done well in advance of facility failures. On the whole, the efficiency and results of dealing with emergencies are much higher than those of traditional highway management systems.

TABLE 3. Actual situation of different projects before and after use.

	Real-time information acquisition/hour	The number of traffic accidents/times	Road congestion time/hour	Highway facility maintenance efficiency/hour
Before use	0.5	75	45	Arrive within 1 hour
Intelligent transportation	0.16	38	30	Facility early warning system

C. COMPARISON OF THE USE OF NEW ITS AND THE EXPERIENCE OF MANAGEMENT PERSONNEL

The classification test of user satisfaction is collected for the new ITS designed here. After the system proposed here is applied in a small area for one month, the data collection and comparison of the experience population of the expressway ITS is divided into users and managers. Figure 13 reveals the comparison results.

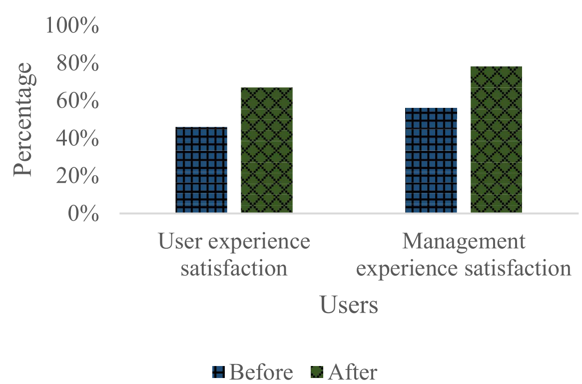

FIGURE 13. Satisfaction of the user's experience before and after.

From Figure 13, user experience satisfaction increases from 46% to 67% after using the ITS. Executive experience satisfaction increases to 78% from 56% previously. It is more ideal than the traditional high-speed traffic processing method. The feedback effect of each user group is also high.

The questionnaire form of the implementation intention of the ITS here is also distributed in large quantities through online solicitation and circle of friend sharing. People's comments and opinions on the current highway treatment system are investigated. The questionnaire also includes the

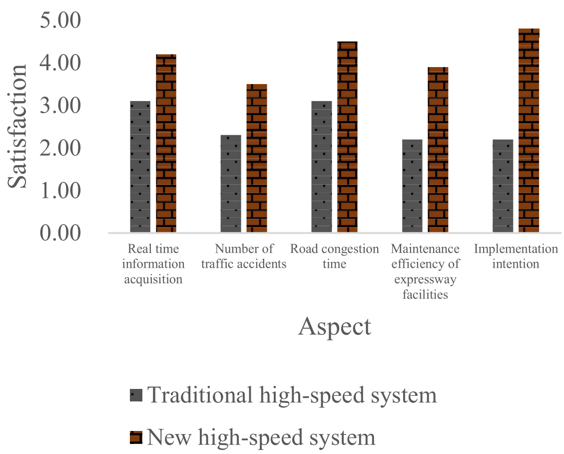

FIGURE 14. User intent survey.

intention to implement the innovative system reported here. The specific situation is shown in Figure 14.

From Figure 14, in all aspects of highway traffic incidents, the expectation of users' satisfaction with traditional systems is lower than that of ITS here. Moreover, on the two expectations of continuing to implement the conventional transportation system and implementing the innovative system designed here, the average user expectation value of the former is 2.2. The expectation value of the latter reaches 4.8. It indicates that the ITS proposed here meets most of the public's expectations for high-speed traffic management.

V. CONCLUSION

The design and construction of intelligent highway transportation systems help realize transportation's informatization and intelligence. It plays a massive role in improving the transportation system's efficiency, enhancing the safety of traffic travel, and increasing the public perception of the highway industry. This paper is based on the improvement of the service capabilities of the highway industry. The necessity and urgency of building intelligent transportation and construction's importance and leading role are studied. The results show that: (1) the efficiency and effectiveness of the maintenance management system in dealing with emergencies before equipment failure is much higher than that of the traditional highway management system. (2) After using the updated system, user experience satisfaction increases to 67%, and executive experience satisfaction increases to 78%. It is more ideal than traditional high-speed traffic processing methods. (3) In terms of the two expectations of continuing to implement the conventional transportation system and implementing the innovative system designed here, the average user expectation of the former is 2.2, and the latter is 4.8. It suggests that the ITS proposed meets the expectations of the majority of the public on high-speed traffic management.

Here, the characteristics, substance, and development process of IoT technology and intelligent transportation technology are systematically analyzed. The highway ITS designed here is based on IoT and AI technology. This system has more advanced sensing technology, more powerful information processing capability, and more abundant terminal applications than the current widely used traffic information system. This is a breakthrough and exploration in IoT and intelligent transportation. It aims to play an active role in the future design and research of highway command transportation systems.

REFERENCES

[1] J. Min, Y. Kim, S. Lee, T.-W. Jang, I. Kim, and J. Song, "The fourth industrial revolution and its impact on occupational health and safety, worker's compensation and labor conditions," *Saf. Health Work*, vol. 10, no. 4, pp. 400–408, Dec. 2019.

[2] A. Nauman, Y. A. Qadri, M. Amjad, Y. B. Zikria, M. K. Afzal, and S. W. Kim, "Multimedia Internet of Things: A comprehensive survey," *IEEE Access*, vol. 8, pp. 8202–8250, 2020.

[3] S. Kumar, P. Tiwari, and M. Zymbler, "Internet of Things is a revolutionary approach for future technology enhancement: A review," *J. Big Data*, vol. 6, no. 1, pp. 1–21, Dec. 2019.

[4] D. Jiang, "The construction of smart city information system based on the Internet of Things and cloud computing," *Comput. Commun.*, vol. 150, pp. 158–166, Jan. 2020.

[5] H. Zhang and X. Lu, "Vehicle communication network in intelligent transportation system based on Internet of Things," *Comput. Commun.*, vol. 160, pp. 799–806, Jul. 2020.

[6] S. Kaffash, A. T. Nguyen, and J. Zhu, "Big data algorithms and applications in intelligent transportation system: A review and bibliometric analysis," *Int. J. Prod. Econ.*, vol. 231, Jan. 2021, Art. no. 107868.

[7] S. Saharan, S. Bawa, and N. Kumar, "Dynamic pricing techniques for intelligent transportation system in smart cities: A systematic review," *Comput. Commun.*, vol. 150, pp. 603–625, Jan. 2020.

[8] Z. Lv, S. Zhang, and W. Xiu, "Solving the security problem of intelligent transportation system with deep learning," *IEEE Trans. Intell. Transp. Syst.*, vol. 22, no. 7, pp. 4281–4290, Jul. 2021.

[9] J. Yang, J. Zhang, and H. Wang, "Urban traffic control in software defined Internet of Things via a multi-agent deep reinforcement learning approach," *IEEE Trans. Intell. Transp. Syst.*, vol. 22, no. 6, pp. 3742–3754, Jun. 2021.

[10] C. Liu and L. Ke, "Cloud assisted Internet of Things intelligent transportation system and the traffic control system in the smart city," *J. Control Decis.*, vol. 32, pp. 1–14, Jan. 2022.

[11] Y. Ding, M. Jin, S. Li, and D. Feng, "Smart logistics based on the Internet of Things technology: An overview," *Int. J. Logistics Res. Appl.*, vol. 24, no. 4, pp. 323–345, Jul. 2021.

[12] C. Suppatvech, J. Godsell, and S. Day, "The roles of Internet of Things technology in enabling servitized business models: A systematic literature review," *Ind. Marketing Manage.*, vol. 82, pp. 70–86, Oct. 2019.

[13] L. Yu, B. Nazir, and Y. Wang, "Intelligent power monitoring of building equipment based on Internet of Things technology," *Comput. Commun.*, vol. 157, pp. 76–84, May 2020.

[14] Z. Lv and H. Song, "Mobile Internet of Things under data physical fusion technology," *IEEE Internet Things J.*, vol. 7, no. 5, pp. 4616–4624, May 2020.

[15] W. Viriyasitavat, L. D. Xu, Z. Bi, and D. Hoonsopon, "Blockchain technology for applications in Internet of Things—Mapping from system design perspective," *IEEE Internet Things J.*, vol. 6, no. 5, pp. 8155–8168, Oct. 2019.

[16] A. Rejeb, J. G. Keogh, and H. Treiblmaier, "Leveraging the Internet of Things and blockchain technology in supply chain management," *Future Internet*, vol. 11, no. 7, p. 161, Jul. 2019.

[17] K. O. M. Salih, T. A. Rashid, D. Radovanovic, and N. Bacanin, "A comprehensive survey on the Internet of Things with the industrial marketplace," *Sensors*, vol. 22, no. 3, p. 730, Jan. 2022.

[18] B. B. Sinha and R. Dhanalakshmi, "Recent advancements and challenges of Internet of Things in smart agriculture: A survey," *Future Gener. Comput. Syst.*, vol. 126, pp. 169–184, Jan. 2022.

[19] F. Zantalis, G. Koulouras, S. Karabetsos, and D. Kandris, "A review of machine learning and IoT in smart transportation," *Future Internet*, vol. 11, no. 4, p. 94, Apr. 2019.

[20] Y. Wu, H.-N. Dai, H. Wang, Z. Xiong, and S. Guo, "A survey of intelligent network slicing management for industrial IoT: Integrated approaches for smart transportation, smart energy, and smart factory," *IEEE Commun. Surveys Tuts.*, vol. 24, no. 2, pp. 1175–1211, 2nd Quart., 2022.

[21] Z. Karami and R. Kashef, "Smart transportation planning: Data, models, and algorithms," *Transp. Eng.*, vol. 2, Dec. 2020, Art. no. 100013.

[22] B. Jan, H. Farman, M. Khan, M. Talha, and I. U. Din, "Designing a smart transportation system: An Internet of Things and big data approach," *IEEE Wireless Commun.*, vol. 26, no. 4, pp. 73–79, Aug. 2019.

[23] K. Zheng, E. Yao, J. Zhang, and Y. Zhang, "Traffic flow estimation on the expressway network using toll ticket data," *IET Intell. Transp. Syst.*, vol. 13, no. 5, pp. 886–895, May 2019.

[24] Z. Liu, H. Jia, and Y. Wang, "Urban expressway parallel pattern recognition based on intelligent IoT data processing for smart city," *Comput. Commun.*, vol. 155, pp. 40–47, Apr. 2020.

[25] W. Ko, S. Park, J. So, and I. Yun, "Analysis of effects of autonomous vehicle market share changes on expressway traffic flow using IDM," *J. Korea Inst. Intell. Transp. Syst.*, vol. 20, no. 4, pp. 13–27, Aug. 2021.

[26] K. Shaaban, M. Elamin, and M. Alsoub, "Intelligent transportation systems in a developing country: Benefits and challenges of implementation," *Transp. Res. Proc.*, vol. 55, pp. 1373–1380, Jan. 2021.

[27] Z. Cheng, J. Yuan, B. Yu, J. Lu, and Y. Zhao, "Crash risks evaluation of urban expressways: A case study in Shanghai," *IEEE Trans. Intell. Transp. Syst.*, vol. 23, no. 9, pp. 15329–15339, Sep. 2022.

[28] J. Wang, M. Wang, Q. Liu, G. Yin, and Y. Zhang, "Deep anomaly detection in expressway based on edge computing and deep learning," *J. Ambient Intell. Humaniz. Comput.*, vol. 13, pp. 1293–1305, Oct. 2020.

[29] D. Tien Bui, N.-D. Hoang, and V.-H. Nhu, "A swarm intelligence-based machine learning approach for predicting soil shear strength for road construction: A case study at Trung Luong National Expressway Project (Vietnam)," *Eng. With Comput.*, vol. 35, no. 3, pp. 955–965, Jul. 2019.

[30] Z. Cheng, W. Wang, J. Lu, and X. Xing, "Classifying the traffic state of urban expressways: A machine-learning approach," *Transp. Res. A, Policy Pract.*, vol. 137, pp. 411–428, Jul. 2020.

[31] M. Naz, F. A. Al-Zahrani, R. Khalid, N. Javaid, A. M. Qamar, M. K. Afzal, and M. Shafiq, "A secure data sharing platform using blockchain and interplanetary file system," *Sustainability*, vol. 11, no. 24, p. 7054, Dec. 2019.

[32] I. M. A. Chen, "IMG/M V. 5.0: An integrated data management and comparative analysis system for microbial genomes and microbiomes," *Nucleic Acids Res.*, vol. 47, no. D1, pp. D666–D677, 2019.

[33] S. Ai-min, "Discussion on countermeasures and intelligent operation mode of division construction for the expressway passenger and freight transport system," *China J. Highway Transp.*, vol. 33, no. 5, pp. 1–7, 2020.

[34] J. C. S. Wood, "Comments on 'determination of background, signal-to-noise, and dynamic range of a flow cytometer: A novel practical method for instrument characterization and standardization,'" *Cytometry A*, vol. 97, no. 4, pp. 423–428, Apr. 2020.

[35] A. Boukerche, Y. Tao, and P. Sun, "Artificial intelligence-based vehicular traffic flow prediction methods for supporting intelligent transportation systems," *Comput. Netw.*, vol. 182, Dec. 2020, Art. no. 107484.

[36] L. Xiao and Z. Wang, "Internet of Things: A new application for intelligent traffic monitoring system," *J. Netw.*, vol. 6, no. 6, p. 887, Jun. 2011.