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CPS-Based Operation Management System for Closed Test Ground of Intelligent Connected Vehicles

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Abstract: With the wide application of new generation information technology, Intelligent Connected Vehicles industry is booming, and the management and application of its closed test ground becomes a key issue. This paper draws on the concept of industrial Internet, based on the information physical system, puts forward the operation and management tool centered on the vehicle, road and cloud integration fusion sensing and control. The article firstly explains the key technology and development status of Intelligent Connected Vehicles and closed test ground, and analyzes the challenges of operation and management; then introduces the related theories of information physical system and industrial internet; then elaborates the management system constructed based on this system, which covers the overall architecture, test scenario and standard regulation management, equipment and facility management, test business management, and safety supervision business; finally, it looks forward to the future expansion plan. Finally, it gives an outlook on the future expansion plan. The study aims to solve the complexity and uncertainty of the application services of Intelligent Connected Vehicles closed test ground, improve the operation and management efficiency, and provide reference for the construction and management of Intelligent Connected Vehicles test ground.

1. Introduction

Vehicles are gradually developing in the direction of digitalization, networking and intelligence, and the traditional test ground is also being upgraded and transformed. Intelligent Connected Vehicles test ground not only builds or renovates road scenes including simulated tunnels, simulated rain and fog, simulated schools, simulated bus harbors, traffic circles, intersections, zigzag intersections, parking lots, etc., but also builds new infrastructure such as intelligent traffic signals, C-V2X networks, intelligent cameras, millimeter-wave radar, LIDAR, edge computing equipment EMC, roadside unit RSU, big data cloud control platform, high-precision positioning base station, meteorological environment monitoring station and other infrastructures[1]. Accordingly, Intelligent Connected Vehicles test ground not only faces traditional operation and management requirements such as site management, personnel and vehicle management, and test management[2], but also ushers in a large number of emerging challenges such as infrastructure management, test equipment management, and test data management[3, 4].

With the application of cloud computing, big data, Internet of Things, artificial intelligence, mobile Internet and other new-generation information technologies popularized at an extremely high speed, everything in the world can be sensed, communicated, and manipulated, which makes people and things smarter and more accurate in manipulation, and the triadic fusion of the human society-information world-physical world has brought information services into the era of pervasive computing and network which is triggering a new revolution[5]. The information - physical system, also known as the cyber - physical system (CPS), essentially aims to construct a closed - loop empowerment system. This system is based on the automatic data flow between cyber space and physical space, covering functions such as state sensing, real - time analysis, scientific decision - making, and accurate implementation. It is designed to address the complexity in the manufacturing process and service applications, as well as the uncertainties therein. By doing so, it can enhance resource allocation efficiency and achieve resource optimization[6].

CPS through the integration of advanced sensing, computing, communication, control and other information technologies and automatic control technology, builds a complex system in physical space and information space, such as people, machines, objects, environment, information and other elements of the mutual mapping, timely interaction, efficient collaboration, to achieve on-demand response to the allocation of resources within the system and the operation of the rapid iteration, dynamic optimization[6]. CPS is a comprehensive technology system to support the deep integration of informationization and industrialization. German Industry 4.0 takes CPS as the core technology of Industry 4.0, and the Industrial Internet proposed by the U.S. is also mainly based on CPS, and Made in China 2025 proposes that “intelligent manufacturing based on information-physical systems, such as intelligent equipment and intelligent factories, is leading the transformation of manufacturing methods”. In addition to industrial manufacturing, CPS is also widely used in major fields such as electric power and transportation[7]. China's National Innovation Center for Intelligent Connected Vehicles believes that CPS can effectively solve the cooperative control problem of Intelligent Connected Vehicles and Intelligent Transportation[8], which is used as the research basis for the reference architecture.

The four core technologies of CPS are ‘hardware, network, platform, software’, which in the field of industrial manufacturing and Intelligent Connected Vehicles, respectively, in the form of industrial Internet, vehicle, road and cloud integration and fusion control system, a comparative analysis is shown in Table 1.

Table 1 Presentation analysis of CPS in IM field and ICV field

CPS Cores	industrial manufacturing	Intelligent Connected Vehicle
hardware	Perception and automation. The essence of perception is the digitalization of the physical world, and automatic control is the information world reacting on the physical world. Such as distributed control systems, data acquisition and monitoring systems are common perception and automatic control systems in industry.	Intelligent connected vehicles (with sensing, decision-making and control capabilities) and other transportation participants, roadside infrastructure (e.g., smart traffic lights, roadside units, cameras, millimeter-wave radar, LIDAR, etc.), and other related supports, such as high-precision positioning base stations and meteorological and

		environmental monitoring stations, etc.
network	Industrial Networks. The information network connecting industrial production equipment/systems and various elements such as materials, products, and people, such as fieldbus, Ethernet, and wireless networks.	Communication networks throughout all parts of the entire system, such as CAN bus and in-vehicle Ethernet in the vehicle, and C-V2X networks for vehicle-vehicle, vehicle-road and vehicle-cloud.
platform	Industrial Cloud and Intelligent Service Platform. A highly integrated, open and shared data service platform, which is a cross-system, cross-platform and cross-field data distribution center, data storage center, data analysis center and data sharing center. Based on the industrial cloud service platform to promote the development, integration and open sharing of basic data and tools such as specialized software libraries, application model libraries, product knowledge bases, test and evaluation libraries, and case expert libraries.	Cloud control infrastructure platform, a highly integrated, open and shared data service platform that integrates various data, services, users and other types of resources from vehicle-side, road-side, public information service platforms, and third-party platforms, with resource connectivity and data openness, data storage, processing and analysis. Based on the intelligent networked vehicle cloud control infrastructure platform, it provides tools and capabilities such as fusion sensing, collaborative decision-making, collaborative control, traffic control and domain big data empowerment. [9]
software	Industrial software, which is the modeling, coding and tooling of the laws of industrial R&D and design, production and manufacturing, operation and management, service and other full-life-cycle links, is the carrier of industrial knowledge, technology accumulation and experience system, and is the core of realizing industrial digitization, networking and intelligence.	Cloud control application platform, serving R&D and testing, vehicle safety and control, traffic supervision, traffic law enforcement, travel and insurance services [8, 9] and other intelligent connected vehicle R&D and application links, empowering automobile manufacturers, parts suppliers, scientific research institutes, vehicle owners, shared mobility service providers, and relevant management departments.

In the field of industrial manufacturing, the key to the implementation of the Industrial Internet is to realize the integration of OT control technology and IT information technology. OT technology is mainly used to interact with the real world, which can be defined as the software and hardware technology that monitors or controls all kinds of end devices, processes and events in the enterprise, including data acquisition and automatic control technology[10]; IT technology is mainly used to solve business problems. The integration of the two aims to reduce costs, optimize business processes, and reduce process risks. By bridging real-time device data and business-related data, interconnectivity and interoperability can be realized, enabling faster implementation of development and integration. There may be two routes and modes for the integration of them[11]: first, on the basis of the existing technology, products, networks, and system architectures remain unchanged, data convergence is driven by the standard unification, which can be called the "stock grafting type convergence"; second, the underlying technology system of the OT and IT is promoted to deconstruct based on the cloud side and end, and re-packaging is realized on the basis of the deconstruction and convergence, which can be called the "stock grafting type convergence". The second is to promote the deconstruction of the underlying technology system of OT and IT based on the cloud, edge and end, and re-packaging and realizing convergence on the basis of deconstruction, which can be called "digital native convergence. In the current engineering practice, the stock grafting type fusion is widely used. Therefore, it is appropriate to construct an operation management tool for Intelligent Connected Vehicles test ground based on the experience of the fusion of OT operation technology and IT information technology in the industrial manufacturing field.

In view of the fact that CPS is widely used in both the Intelligent Connected Vehicles field and the industrial manufacturing field, and that the operation and management of Intelligent Connected Vehicles closed test ground is extremely similar to the applications of production process control and enterprise operation management in the industrial manufacturing field, in order to solve the complexity and uncertainty in the process of test service of Intelligent Connected Vehicles closed test ground, to improve the efficiency of resource allocation, and to realize the optimization of resources, we will design an operation and management tool of Intelligent Connected Vehicles closed test ground with the site equipment management, test service management, etc. as the clues of application requirements, take CPS as the core structure, make full use of the operation and management experience in the field of industrial manufacturing and the concept of integration of OT and IT, and design the operation and management tools for Intelligent Connected Vehicles closed test ground.

The subsequent chapters of this paper will focus on this operation management tool to carry out in-depth discussion: Chapter 2 analyzes the management needs of closed test grounds, sorting out specific needs in various aspects, including site management, regulatory scene management, personnel and vehicle management, etc., and clarifying the research direction; Chapter 3 builds the framework of operation management system for closed test grounds, introducing the system architecture based on SoS-level CPS and the key support capabilities of cloud control infrastructure platform; Chapter 4 elaborates on the application of site equipment management, covering the functions and operation mechanisms of various subsystems, such as road-side sensing, traffic signals, high-precision maps and positioning, etc.; Chapter 5 focuses on test service management applications, introducing various test service management functions based on IT technology; finally, Chapter 6 summarizes the research results, analyzes the advantages and limitations of the system, and looks forward to the future research direction.

2. Closed test ground management needs analysis

Assisted driving, vehicle-road collaboration, autonomous driving and other functions are gradually on board, giving rise to various emerging testing needs in closed test grounds, driving the construction of closed test grounds for intelligent network connection. According to incomplete statistics, there are more than 50 closed test grounds in the country, of which more than 30 have the ability to test Intelligent Connected Vehicles, and the role of the test ground has gradually changed from providing a venue to providing comprehensive testing services [12].

Table 2 Requirements for operation and management of closed test ground for ICVs

No.	Requirements	Detailed descriptions
1	Scene Management	Management of dynamic test areas, vibration and noise test roads, flooded roads, water-related roads, simulated rain and fog, simulated tunnels and other roads and their rules such as driving speed, driving direction, and traffic flow limit.
2	Regulatory scenario management	raffic signal recognition and response, road traffic infrastructure and obstacle recognition and response, pedestrian and non-motorized vehicle recognition and response, peripheral vehicle driving status recognition and response, automatic emergency avoidance, vehicle positioning and other regulatory scenarios management.
3	human and Vehicle Management	Driver and non-driver admission and safety training management, vehicle access management, etc.
4	Test Management	Including risk management and traffic flow management, such as monitoring the location of test vehicles, vehicle speed, monitoring fatigue driving, monitoring driver distraction, avoiding cross-testing, making good safety isolation in the test area, controlling the test vehicle flow and so on.
5	Infrastructure Management	Network and power lines, intelligent traffic signals, C-V2X network, intelligent cameras, millimeter-wave radar, LiDAR, edge computing equipment EMC, RSU, big data cloud control platform, high-precision positioning base station, meteorological and environmental monitoring stations, and other infrastructure real-time monitoring, real-time control, abnormal alarm, fault repair and other operations management.
6	Test Equipment Management	Management of test equipment such as dummy, dummy vehicle, mobile flatbed vehicle and other targets, driving robot, road test data acquisition system, high-precision positioning data acquisition system, vehicle-mounted data acquisition terminal and other test equipment.
7	Test Business Management	Closed-loop process management such as test business reservation, task status monitoring, and account management.
8	Test Data Management	Test data acquisition/collection, storage, pre-processing, processing and analysis, report output and other works.

It is appropriate to regard the intelligent connected vehicle test ground as a factory providing comprehensive testing services. The five elements of factory management, namely, ‘human, machine, material, method, and environment’, correspond to the ICV test ground:

1) Human, refers to all the personnel in the test ground, including management personnel, business personnel, testing personnel, quality personnel and so on;

2) Machine, referring to infrastructure equipment such as intelligent traffic signals, RSUs, radars, etc. and testing instruments and equipment such as dummies and dummy cars, etc. used in the testing process;

3) Material, which refers to all objects in the testing process, including cars and their parts, etc;

4) Method, refers to the rules and regulations and operating methods to be observed in the

testingprocess, including inspection specification standards, test cases, and various operating procedures;

5) Environment, including the test ground, meteorological environment, etc..

Through the expert opinion survey, the main operation and management requirements of the intelligent connected vehicle test ground are sorted out as shown in Table 2.

Intelligent connected vehicle test ground operation and management is also similar to that of the industrial manufacturing field, especially in the discrete production industry. In the field of industrial manufacturing, the application scenarios of product development and design, production process control, cooperative resource allocation, and enterprise operation management are all extremely mature. Among them, production process control (including planning management, process management, equipment management, material management, quality management, safety and environmental management, etc.) and enterprise operation management (including order management, financial management, etc.) almost include the requirements of the operation and management of the test ground for intelligent connected vehicles listed in Table 1. Therefore, it is appropriate to draw on the mature management experience in the industrial manufacturing field for the operation and management of the intelligent connected vehicle test ground.

3. Framework of closed test ground operation management system

CPS can be deepened from unit-level, system-level, and system-of-systems-level (SoS).

A unit-level CPS is the smallest system with sensible, communicable, interactive, computable, and self-decision-making functions, and an industrial robot, an intelligent machine tool, or an intelligent networked car are the smallest units. For example, an intelligent connected vehicle, as a unit level, includes perception systems such as camera and radar and control actuators such as brake and throttle, intelligent decision-making units such as ADAS for assisted driving system and ADS for autonomous driving system, and networks such as CAN, in-vehicle Ethernet, and C-V2X. Multiple unit - level CPSs realize automatic data flow over a larger range and in a wider field, as well as interconnection and interoperability through the network, thus forming a system - level CPS. For example, the entire vehicle - road cooperative system, which includes intelligent connected vehicles, road - side sensing facilities, positioning base stations, etc., achieves interconnection and cooperative control through networks such as C - V2X and satellite communication.

Multiple system-level CPSs or organic combinations with unit-level CPSs form SoS-level CPSs. The entire ICV closed measurement ground management system is a SoS-level CPS, whose system architecture is shown in Figure 1, including ICVs, roadside sensing systems, traffic signal control systems, high-precision positioning systems, simulated rain and fog systems, meteorological environment monitoring systems, access control systems, information dissemination systems. Through C-V2X, Ethernet, satellite and other networks, the closed measurement ground management system for ICVs utilizes a big data platform to realize cross-system and cross-platform interconnectivity and interoperability, facilitating the fusion and processing of heterogeneous data from multiple sources, realizing comprehensive sensing, in-depth analysis, scientific decision-making and precise execution of information in the whole domain, and supporting real-time monitoring of equipments, traffic signal control, site management, and management of regulatory scenarios, personnel and vehicle management, test management, test data management and other applications.

Among them, the base of the operation and management system of the closed test ground is the cloud control infrastructure platform, including network, computing, storage and other resources. The base is the big data center with support capabilities such as V2X Server, high-precision map, fusion perception, collaborative decision-making, collaborative control, traffic control, etc. It provides data application services through middleware such as process support, mobile framework, presentation support, decision-making support and GIS. The big data center realizes cross-platform and cross-system heterogeneous pooling and sharing and publishing of equipment status and control data, video data, traffic flow data, geographic location data and other data.

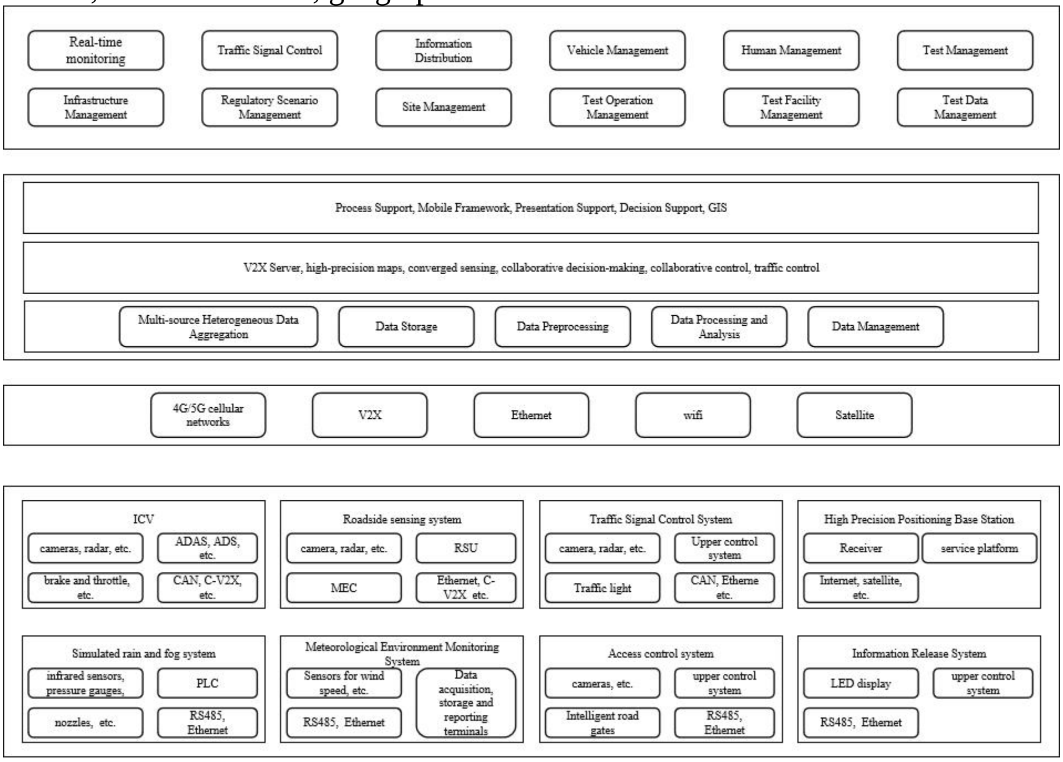

Figure 1 Closed test ground operation management system architecture based on SoS-level CPS

4. OT-based device management applications

The equipment management application based on OT mainly includes roadside sensing, traffic signals, positioning base stations, meteorological and environmental monitoring stations, information release screens and other equipment[13].

4.1. Roadside sensing subsystem

Figure 2 Intersection with roadside sensing devices and traffic signal control system

Roadside sensing subsystem, as shown in Figure 2, mainly includes roadside unit RSU, intelligent camera, LiDAR, millimeter-wave radar, edge computing equipment and other terminal equipment, as well as other ancillary facilities such as roadside poles and pole-holding chassis. Intelligent cameras are responsible for sensing vehicles, pedestrians, target traveling direction, and environmental visibility within the viewing angle; radar can also detect pedestrians and vehicles, and at the same time accurately detect the size, location, and speed of obstacles; edge computing equipment mainly performs roadside sensing fusion computation and sends the fusion results to the intelligent network link roadside unit RSU. RSU also acquires the traffic signals and broadcasts the information to the intelligent network link roadside unit RSU through the C-V2X network to broadcast the information to the ICV and report it to the cloud control infrastructure platform.

4.2. Traffic signal control subsystems

Traffic control sub-system equipment mainly includes coordinated control type traffic signal controller, traffic detector (such as video, radar, etc.), traffic signal light, etc. Combined with the software accompanying the sub-system, it can design and edit parameters such as phase, control scheme, day plan scheduling of intersection traffic signal controllers, and realize the graphical operation and preview function; it can read the program from the traffic signal controllers or send the designed program to the controllers, and the controllers will run the new program in the next cycle; the traffic control subsystem communicates with the RSU of roadside sensing subsystem and the cloud control platform through the network to realize interconnection and interoperation.

The following codes, as shown in figure 3 and figure 4, are sample messages for RSM and SPAT informations to be reported to the cloud control platform.


```
{
    "rsuId": "",
    "rsuEsn": "",
    "rsuName": "",
    "rsms": [
        {
            "refPos": {
                "lon": 0,
                "lat": 0,
                "alt": 0
            },
            "Participants": [
                {
                    "ptcType": {
                        "region": 0,
                        "id": 0
                    },
                    "ptcSubType": 0,
                    "ptcId": 0,
                    "source": "",
                    "pos": {
                        "lon": 0,
                        "lat": 0,
                        "alt": 0
                    },
                    "speed": 0,
                    "heading": 0
                }
            ]
        }
    ]
}
```


Figure 3 RSM code sample

```
{
    "name": "",
    "Intersections": {
        "intersectionId": {
            "region": 0,
            "id": 0
        },
        "status": "",
        "phases": [
            {
                "phaseId": 0,
                "light": "",
                "timing": 0
            },
            {
                "phaseId": 1,
                "light": "",
                "timing": 0
            }
        ]
    }
}
```

Figure 4 SPAT code sample

4.3. High precision map and positioning base station

High-precision maps and positioning subsystems are the basic support for intelligent connected vehicles. The data content of the high-precision map includes basic road surface information (such as road markings, arrows, ground markings, pedestrian crossings, etc.), road accessory information (such as electronic signage, signal lights, electric police, road facilities, video surveillance, intelligence boards, etc.), other accessory facilities (such as gantries, barriers, bus stops, etc.), and the intelligent network infrastructure (such as RSUs, cameras, millimeter-wave radar, etc.), and so on. The high-precision positioning base station can provide real-time navigation, fast positioning, accurate timing and other service functions for the test ground. Typical application scenarios include realizing high-speed real-time decimeter-level and low-speed real-time centimeter-level positioning functions for intelligent vehicle monitoring and driving control; realizing centimeter-level positioning functions for real-time digitization of the state of road infrastructure; and supporting the centimeter-level surveying and mapping needs of high-precision electronic highway maps.

4.4. Meteorological environment monitoring subsystem

Meteorological environment monitoring sub-system includes visibility, temperature and humidity, rainfall, wind speed and direction, infrared and other sensors and recording terminals for data collection, storage and processing and reporting, which can accurately and timely detect meteorological and road surface environmental conditions and report them to the cloud control platform through the network, which will process and analyze them and send them to the roadside RSUs or the information release screen as needed.

4.5. Information release subsystem

The information release subsystem, as shown in Figure 5, includes LED screen control host and upper control software, which is connected to the cloud control platform through fiber optic network and open interface. It supports automatic release of weather information, road condition information, test information, vehicle information and other data, and can receive control commands from the cloud control platform or sub-systems, and process and execute them.

Figure 5 Information release screen of unmanned test area

5. IT-based test service management application

The IT-based test service management application is oriented to the business requirements of intelligent network testing, providing test task management (business audit, business status monitoring, business progress management, equipment binding, single-service test statistics), test ledger management, test area management, test vehicle management, tester management, test equipment management, regulatory scenario management, test case configuration, V2X data processing and preservation, test program management, test records, test alarms and other functional management contents. The flow of test task management is shown in the Figure 6.

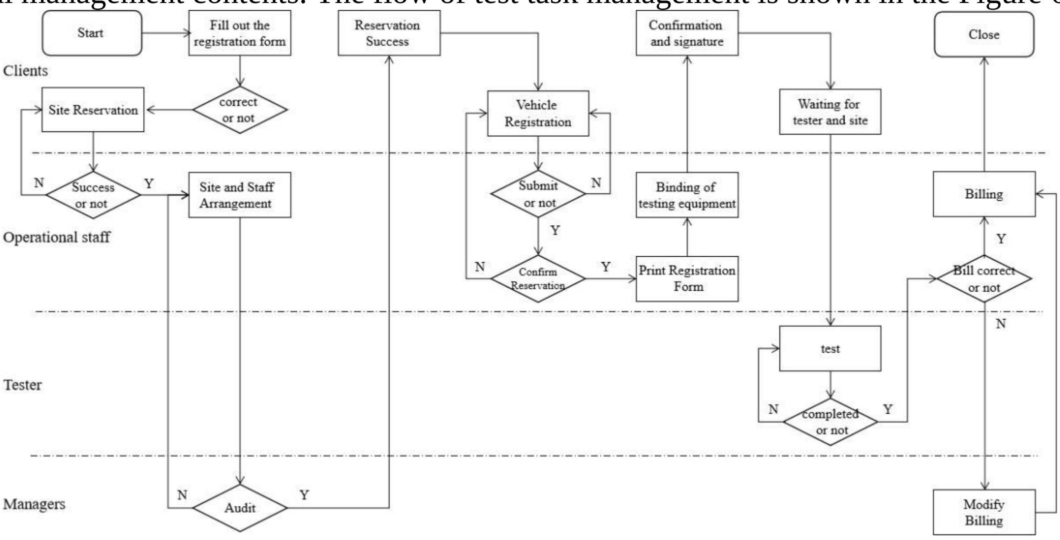

Figure 6 The flow of test task management

6. Conclusion

This paper constructs a comprehensive set of operation and management programs for closed test ground of smart connected vehicles by drawing on the mature concept of industrial Internet and CPS technology, which is of great significance to promote the development of smart connected vehicle industry. The results of the study show that while upgrading the technology and expanding the functions of the closed test ground for intelligent connected vehicles, it faces a lot of operation and management problems, covering many aspects such as safety hazards, management efficiency, data quality and so on. The CPS-based vehicle-road-cloud integrated fusion sensing control operation management tool provides an effective way to solve these problems. The tool realizes real-time perception, accurate decision-making and efficient control of various resources at the test ground by integrating information from vehicles, roads and the cloud.

In the process of system design and realization, the constructed IoT four-layer architecture lays a solid foundation for the overall management system. The test scenario and standards and regulations management module guarantees the standardization and scientificity of testing through the establishment of scenario libraries and strict compliance with standards and regulations; the equipment and facilities management module realizes comprehensive monitoring and maintenance of infrastructure and test equipment; the test business management module carries out refined management of the testing process and data, effectively improving the testing efficiency and quality; and the safety supervision business module provides strong guarantee for the safe operation of the test ground. The safety supervision business module provides a strong guarantee for the safe operation of the test ground. From the practical application point of view, the system has significant advantages and application value. On the one hand, it can improve the operation and management efficiency of the test ground, rationally deploy resources, and reduce testing time and cost; on the other hand, by strengthening the monitoring and data analysis of the testing process, it can help to improve the technical level and safety of intelligent connected vehicles and accelerate their commercialization process.

However, this study still has some limitations. In terms of system design, although most of the operation and management requirements have been taken into account, the scalability and adaptability of the system need to be further optimized in the face of evolving intelligent connected vehicle technologies and increasingly complex test scenarios. In terms of practical validation, the effect of the system's practical application in large-scale test grounds has not yet been comprehensively evaluated, and subsequent research can refine and improve the system through actual case analysis and data monitoring,continuously improve the cyber-physical-social systems[14], and adopt advanced encryption technologies to protect sensitive test data for transmission and static protection of sensitive test data with advanced encryption technology to solve the problem of data security and privacy protection[15].

Looking ahead, with the continuous innovation of intelligent connected vehicle technology and the rapid development of the industry, the management demand of closed test grounds will continue to be upgraded. The operation and management solution proposed in this study can be used as a basic framework to further expand the system functions and improve the level of management intelligence by combining cutting-edge technologies such as artificial intelligence and 5G communication. At the same time, we will strengthen cooperation with other research institutions and enterprises in the industry to jointly explore new modes and methods for the management of closed test grounds for intelligent connected vehicles, and contribute to the healthy development of the intelligent connected vehicle industry.

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