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Analysis on the development status of intelligent and connected vehicle test site

Peng Zhi, Rui Zhao, Haoran Zhou, Yanwu Zhou, Nam Ling, and Qingguo Zhou*

Abstract: With the development of automobile intelligence and connectivity, Intelligent and Connected Vehicle (ICV) is an inevitable trend in the transformation and upgrading of the automotive industry. The maturity of any advanced technology is inseparable from a large number of test verifications, especially the research and application of automotive technology require a large number of reliable tests for evaluation and confirmation. Therefore, the ICV Test Site (ICVTS) will become a key deployment area. In this paper, we analyze the development status of ICVTS outside and within China, summarize the shortcomings of the existing test sites, and put forward some targeted suggestions, in an effort to guide the development and construction of ICVTS towards the path that seems to be most promising.

Key words: Intelligent and Connected Vehicle (ICV); automatic driving; Internet of Vehicles (IoV); test site

1 Introduction

With the acceleration of the new round of technological revolution and industrial transformation, intelligent technologies, such as Artificial Intelligence (AI)[1, 2] and big data[3, 4], have penetrated extensively into the automotive industry. Automotive products and automotive industry are undergoing a major change—Intelligent and Connected Vehicles (ICV)[5]. Relevant data show that in 2020, 3.032 million ICVs were sold in China, an increase of 107% year-on-year, and the penetration rate remained at about 15%. It is estimated that by 2025, ICV sales will account for 50% of all car sales[6–8]. Just like the change from mobile phones to smartphones, ICV will bring great convenience to our lives. It fundamentally avoids traffic accidents caused by drivers' irregular driving behavior[9] and has a profound impact on reducing traffic congestion and accident rates, and the city's future traffic planning. Therefore, ICV will effectively alleviate multiple global issues, such as traffic congestion, energy, environment, and safety[10]. In ICV, human drivers will be replaced by computer systems[11], and ICV will be separated from the active control of humans. Therefore, the safe and reliable operation of the ICV system and its subsystems are essential. However, the core technologies involved in ICV are not yet mature. An important reason is the lack of a road test environment that meets ICV requirements to prove its key technologies. Therefore, speeding up the road test for ICV is imminent. It is an essential guarantee for road safety and an important measure to promote the development of the ICV industry. However, due to the increased complexity of new components and systems, ICV testing and verification have become different from the past. Therefore, the ICV test requires a specific test site and experimental environment[12]. The construction of ICV Test Sites (ICVTS) will become one of the critical tasks of ICV research. In recent years, in order to promote the development of ICV technology in China, the government and enterprises have actively carried out

• Peng Zhi, Rui Zhao, Haoran Zhou, and Qingguo Zhou are with the School of Information and Engineering, Lanzhou University, Lanzhou 730000, China. E-mail: zhip13@lzu.edu.cn; zhaor19@lzu.edu.cn; zhouhr19@lzu.edu.cn; zhouqg@lzu.edu.cn.
• Yanwu Zhou is with the Beijing Zuosi Information Consulting Co., Ltd., Beijing 100085, China. E-mail: zyw1976427@pday.com.
• Nam Ling is with the Department of Computer Science and Engineering, Santa Clara University, Santa Clara, CA 95053, USA. E-mail: nling@scu.edu.
* To whom correspondence should be addressed.
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the construction and operation of ICV demonstration zones. At present, although the construction of ICVTS has been somewhat effective, there are still problems, such as inconsistent construction standards, unclear rules, and lack of breakthroughs and innovations in business models and data open models[13−15], which restrict the development of the ICV industry in China. To help the development and construction of ICVTS towards the path that seems to be most promising, we analyze the development status of ICVTS outside and within China, summarize the shortcomings of the existing test sites, and put forward some targeted suggestions.

2 Development status of ICVTS

2.1 ICVTS

ICV is a complex[16] of autonomous driving technology[17] and Internet of Vehicles (IoV) technology[18]. ICV is equipped with cameras, millimeter-wave radar, lidar, and other sensors, and integrates communication technology[19−22], AI technology[23, 24], planning algorithms[25], and control algorithms[26] to realize the sharing and interaction of surrounding sensing information, such as cars, roads, and people. As a result, ICV has functions such as environment perception and intelligent decision-making, thereby providing safe, comfortable, energy-saving, and efficient driving experience for drivers and passengers[27]. As shown in Fig. 1, it is the architecture diagram of ICV.

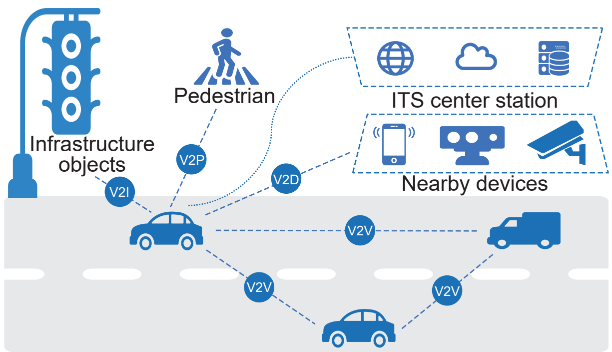

Fig. 1 Architecture of ICV. ICV communicates with other vehicles, pedestrians, infrastructure objects (such as traffic lights, signs, roadblocks, or lane marks), and nearby devices (such as sensors, cameras, or personal devices).

In the process of automobile Research and Development (R&D), optimization, and production, testing is an important part of it. In particular, field testing is extremely important for detecting possible problems in the safety, comfort, handling, and other aspects of the vehicle[28]. In view of the complexity of the ICV function, the Traditional Vehicle Proving Ground (TVPG) can no longer meet its test requirements, so the test needs to be carried out in a dedicated field, that is, ICVTS. By simulating the different environments that ICV may encounter in real-world and relying on advanced technology facilities, such as the Internet of Things (IoT), AI, and big data, ICVTS tests and verifies the technical standards, operating data, and software algorithms of the ICV system, thereby shortening the development of ICV cycle. A complete ICVTS should meet the requirements of rich test scenarios, complete test functions, perfect communication capabilities, high test data reliability, good test confidentiality, and strong test specificity. The construction of ICVTS should be different from the TVPG. The focus of the test is to assess the vehicle's perception and adaptability to the traffic environment. The construction and development of ICVTS can provide bases and suggestions for the standardization process of ICV, and promote the industrialization process of ICV.

2.2 Development status outside China

Road testing and demonstration operations are the bases for the industrialization and commercialization of global ICV. The United States, the European Union, Japan, and other automotive developed countries and regions attach great importance to the demonstration operation of ICV. They carry out the construction of ICVTS and prove the technical capabilities of the key systems in the actual operation of ICV by simulating various roads and scenarios. Figure 2 shows several well-known test sites outside China.

2.2.1 Mcity test facility

Mcity is the world's first autonomous driving test site designed for testing Autonomous Vehicle (AV) and IoV technologies, including Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I). It covers an area of about 0.13 km^2, and the total length of the

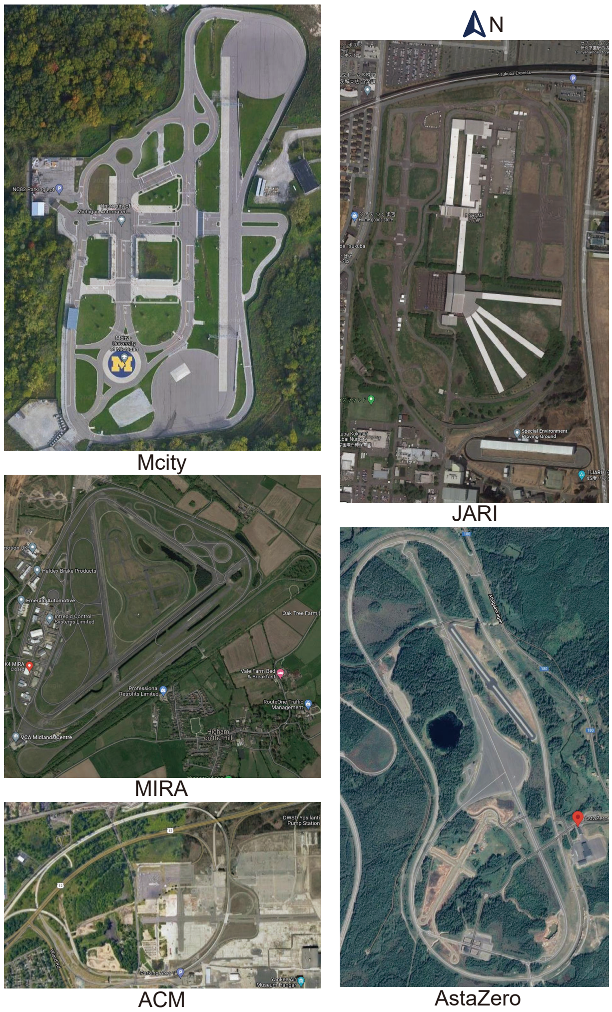

Fig. 2 Overview of the test sites on Google Map.

experimental road is 6.8 km. Mcity contains three simulated road scenes, namely highways, urban roads, and suburban roads. Its experimental area is divided into two areas: the high-speed test area used to simulate the highway environment, and the low-speed test area used to simulate the urban and suburban areas. Mcity's test content mainly includes automatic braking, sign recognition, Vehicle-to-Everything (V2X), and so on. It can flexibly replace road markings, traffic signs, exterior building walls, etc., according to test requirements. At the same time, Mcity reserves some areas for unknown scene testing. In addition, being located in the Great Lakes region of the United States, Mcity has ideal conditions for extreme cold testing in winter. However, due to the limited area of the site, the layout of the scene is relatively simple, and there is still a gap with the actual traffic scene. For example, the longest straight road in Mcity cannot meet the requirements of automatic driving tests at speed of more than 70 km/h.

2.2.2 MIRA proving ground

The Motor Industry Research Association (MIRA) proving ground is located in the UK and is one of the largest and most comprehensive independent test sites in the world. MIRA covers an area of 3.5 km^2, and the test road is 93 km long. It has 24 types of test roads, which are mainly divided into high-speed ring roads, dynamic squares, long straight-line performance roads, and stable handling performance roads. MIRA is upgraded and reconstructed based on TVPG, focusing on the connected test environment, and supports the test requirements of various communication equipment according to the different ICV communication standards. At present, MIRA's testing and research are mainly for traditional vehicles, electric vehicles, connected vehicles, and AVs. The test content includes emergency braking, lane-keeping, automatic parking, automatic steering, etc. MIRA accepts test applications worldwide, and its users may come from all over the world. Therefore, users can adjust according to different standards of different countries, such as traffic signs, traffic lights, etc. At the same time, MIRA also has the testing capability of virtual simulation.

2.2.3 AstaZero test site

Located in Sweden, active safety test area (namely AstaZero) is a test site designed and constructed for the development of future traffic safety for active safety testing. It is the world's first full-scale road safety test site. The total area of AstaZero is 2 km^2, including 0.25 km^2 of paved road. The test area is composed of multi-lane road area, highway area, urban area, rural road, and main test center, which can simulate almost all actual traffic conditions. The rural road is 5.7 km long, half of which allows a maximum speed of 70 km/h, and the other half allows a maximum speed of 90 km/h. AstaZero test content covers a comprehensive range, including vehicle dynamics, driver behavior, V2V/V2I function, functional reliability, communication technology, etc. AstaZero has strong comprehensive capabilities, complete test scenarios and test functions, and has significant advantages especially in simulation tests for Advanced Driving Assistance System (ADAS)[29] scenarios. But it also has certain limitations. At present, its road facilities are relatively simple, and it lacks special scenes, such as tunnels and high-speed straight roads. Facilities, such as tunnels, fog, and rainwater generators, will be added in the next phase of construction.

2.2.4 JARI test facility

Japan Automobile Research Institute (JARI) test site covers an area of 3.02 km^2. It has built a separate smart car test field outside the main test field, which contains most of the main venues and buildings in its office area. Among them, JARI Ibaraki Prefecture's Intelligent Vehicle (IV) test site is part of it. JARI also has an AV test line of about 300 km on the capital expressway. JARI includes three major areas, namely a 1.8 km long V2X urban block, a multifunctional urban area, and a special environmental test area. Its road types are comprehensive and can meet a variety of testing requirements. JARI's test content includes braking performance, handling stability, handling safety, etc. Its feature is to provide a special environmental test area to simulate the interference factors in reality, such as backlighting, fog, and rain.

2.2.5 ACM proving ground

American Center for Mobility (ACM) has a smart mobility test center providing safe platforms for the integration, testing, and validation of connected, automated, and electrified vehicle and other mobility technologies. It covers an area of about 4.65 km^2, including variable road systems and customizable test environments. In addition to the conventional infrastructure, its biggest feature is that it contains a dual three-lane avenue, allowing a maximum speed of about 90 km/h. At the same time, it contains a 0.213 km curved tunnel, allowing a maximum speed of about 65 km/h. ACM is currently one of the complete test grounds.

2.3 Development status within China

Since 2015, as the national and local governments pay more and more attention to the ICV field, many places within China have begun to promote the planning and deployment of ICVTS, and there has been an upsurge in building ICVTS. According to statistics, ICVTS at the ministerial, city, and enterprise levels has been launched in more than 50 cities, opened more than 3500 km of test roads, and issued more than 700 test licenses. The total road test mileage exceeded 5.3 million km[30]. The ICVTS that has been built covers a variety of road scenes, such as urban roads and rural roads, and has relatively complete scene facilities and intelligent connected equipments. Some test sites are already equipped with 5G communication equipments, and the signals can cover the fully enclosed test area[31]. Next, this section will introduce some representative ICVTS in China.

2.3.1 National ICV Pilot Zone (Shanghai)

The National ICV Pilot Zone (Shanghai) is the first ICV demonstration zone approved by the Ministry of Industry and Information Technology (MIIT). It was approved to start construction in 2015. On March 1, 2018, Shanghai issued the first batch of ICV open road test licenses. As of the end of 2020, Shanghai has opened a total of 243 test roads with 559.87 km. ICV has carried out effective road test mileage of 396 000 km, and the number of test road mileage is among the top in China. Figure 3 shows the test data of the autonomous driving mode in the test area in 2020, including the monthly accumulated mileage and effective data volume[32]. The demonstration area covers roads of different types and levels, with 1580 test scenarios, including multiple scenarios, such as industrial areas, commercial areas, transportation hubs, and residential areas. In addition, the existing open test roads have achieved full coverage of 5G signals and high-precision map collection. At the same time, a number of infrastructure services for Intelligent Transportation (IT), such as vehicle-road collaborative application systems, holographic road perception systems, and safety supervision and monitoring platforms, have been built. However, the test area has not yet been completed, and it will be completed in 2022. It is estimated that after completion, the total size of the test site will exceed 230 km^2, and the test road mileage will exceed 900 km, which will include a 28 km highway scene.

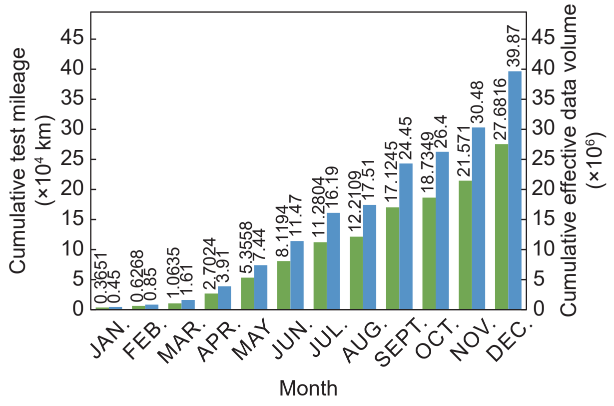

Fig. 3 Test data of the autonomous driving mode in Shanghai pilot zone in 2020. Green represents the accumulated test mileage, and blue represents the effective test data volume.

2.3.2 National Intelligent Transportation Comprehensive Test Base (Wuxi, Jiangsu)

The test base is a national-level IV and IT application demonstration project and is constructed under the guidance of MIIT and the Ministry of Public Security (MPS). It covers an area of 0.14 km^2, including highway test areas, multifunctional test areas, urban blocks, ring road test areas, and high-speed test areas. The total length of the closed test area is 3.53 km, and the road in the public test area is more than 50 km long. There are more than 150 actual road test cases composed of various road types, traffic signs, and lane lines. In addition, the test base includes a semi-open test road with a length of 10 km and a closed highway with a distance of 4.1 km. The expressway has a one-way three-lane highway and is equipped with an emergency parking zone.

2.3.3 Intelligent Vehicle Integrated Systems Test Area (Chongqing)

The Intelligent Vehicle Integrated Systems Test Area (I-VISTA) construction and operation will be carried out in three phases. The first phase of the project covers an area of 0.268 km^2. It has established an urban traffic scene test area, including 50 test scenarios, which can be summarized into four categories: road traffic, efficiency, communication and positioning capability testing, and information service. The second phase covers an area of 2.24 km^2, of which the comprehensive service area and the test road occupy 0.095 km^2 and 2.147 km^2, respectively. The test road includes various special roads, rural roads, and high-speed ring roads. The third phase of the project is an open road demonstration area for IV and IT, equipped with communication facilities required for testing and evaluation of network connectivity. At present, I-VISTA has built some test areas that form an IV engineering public service platform that covers most of the special road conditions. These areas include a 5G closed test area, a 5G controllable and fully networked test demonstration area that simulates urban and rural highspeed scenes, and an open road covering more than 85% of the road environment in the country. I-VISTA provides a rich test environment for cutting-edge technology testing and verification, key technology integration applications, and multi-scenario industrialization demonstration exploration.

2.3.4 Intelligent System Test Area in Xiangjiang New Area (Changsha, Hunan)

The demonstration area began planning and construction in June 2016 and officially opened to the public on June 12, 2018. The project covers an area of 0.82 km^2 and will be constructed in two phases. The test site is based on the 15 km^2 AI Technology Park. The completion of the first phase of the project includes three types of roads: expressway, urban and rural, of which the mileage of expressway is 3.6 km, and that of urban road is 6 km. The second phase of the project was completed in 2019. It has successively completed the construction of a 100 km intelligent expressway and a 100 km open test road, as well as the construction of a 7.8 km smart bus demonstration line, which is the first demonstration line in China. In addition, it has built more than 35 000 5G base stations. At present, the test site has attracted more than 20 industry giants, such as Huawei, Baidu, Schaeffler, and more than 340 supporting companies to settle in Changsha, which help build an ICV industrial ecological cluster in all aspects.

It can be seen from the above that each ICVTS has its characteristics, as shown in Table 1. For example, some test sites restore realistic traffic scenes by simulating the construction of traffic facilities or setting different dynamic interactive scenes. Some test sites can replace road markings and traffic signs

Table 1 Comparison of the test sites.

Test site	Urban road	Country road	Highway	Special climate or scene	Virtual environment	Flexible design
Mcity	√	√	√	×	×	√
MIRA	√	√	√	×	√	√
AstaZero	√	√	√	×	√	√
JARI	√	√	√	√	√	×
ACM	√	√	√	√	×	×
Shanghai	√	×	√	√	×	×
Wuxi	√	√	√	×	×	×
Chongqing	√	×	√	√	×	×
Changsha	√	√	√	×	×	×

according to test requirements, or have the area for unknown test scenarios to reserve space for future renovation and upgrading. In addition to testing road construction, some test sites also provide comprehensive supporting services, such as meeting rooms and lounges. In contrast, the ICVTS within China is mainly based on demonstration areas, which are currently relatively small in scale and simple in functions.

3 Problems and challenges

After years of technology accumulation and development, although the ICVTS construction has achieved certain achievements in China, there are still some problems that restrict the development of the ICV industry. This section will further explain the main problems currently existing in ICVTS within China.

3.1 Planning and construction stage

3.1.1 Ununiform construction standards

The construction standards of ICVTS in different regions are not uniform, and the construction level is also uneven, which result in large differences in key scenes, such as highways, bends, ramps, tunnels, and roundabouts in various closed test sites[33].

First of all, in terms of the road itself, China's current road infrastructure construction standards are not uniform[34], which hinders the use of ICV. Taking the irregularity and non-uniformity of road traffic labeling as an example, car companies need to constantly adjust parameters and build different models to adapt to traffic signs under different regulations when identifying traffic signs, which will cause some features in traffic signs to be ignored, such as subtle shapes and colors, then in turn affects the improvement of accuracy. At the same time, it also makes car companies spend more energy on the recognition of traffic signs. The main reason for this problem is that the intelligent transformation of road infrastructure requires cross-departmental collaboration, and the responsible party is not clear, which makes it impossible to coordinate the unification of site standards and affects the effect of its construction.

Secondly, from the perspective of overall planning, the existing test sites have a high overlap rate and the problem of repeated construction is relatively serious[14]. At the same time, because the construction of ICVTS in various places is focused on the testing requirements of basic functions, there is a lack of characteristic and differentiated scene construction, and it is impossible to focus on different aspects, such as test scenes and test items. The main reason for this problem is that the testing sites that have been built in China are promoted by different government departments, such as the MIIT, the Ministry of Transport (MT), the Ministry of Housing and Urban-Rural Development (MHURD), and the Development and Reform Commission (DRC)[15]. In addition, there are city-level and enterprise-level test demonstration sites. This blooming situation seems to have set off an upsurge in the construction of ICVTS, but it will cause many problems, one of which is the high repetition rate of the above-mentioned test site. Take the "Technical Guidelines for the Construction of Autonomous Driving Closed Sites (Interim)" issued by MT in 2018[35] as an example. It only provides good guidance for several key ICVTS identified by the MT, while other test sites do not fully comply with the guidelines. Therefore, it has not become a unified standard for the construction of ICVTS in cities within China.

3.1.2 Ununiform evaluation standards

In the previous section, the article mentioned that the existing ICVTS is authorized by different government departments. This will bring another problem, that is, each ICVTS cannot form a unified identification system and evaluation method[15]. This problem will cause companies to carry out ICV road tests in different cities and need to reapply and evaluate according to the requirements of each city, which greatly reduces the efficiency of the test and hinders the mutual acceptance of test results.

A complete test and evaluation system is a necessary condition to support the development of ICV technology. At present, as the operational safety tests for ICV are still in the exploratory stage, a complete and mature test evaluation system has not yet been formed for ICV testing[9]. Recently, cities, governments, and companies have tried to promote this, but the results are unsatisfactory. An IV technology company in Shanghai worked with the China Software Evaluation Center to formulate the “Intelligent Connected Vehicle Test Site Evaluation System”, but the adoption rate by other test centers is not high. In addition, each city within China has its own access requirements, and only Guangzhou accepts testing experience in other cities. Guangzhou makes it clear that if ICV has approved the test vehicle at other test sites, and the test time is not less than six months or the test mileage is not less than 2000 km, the car company can submit relevant test certificates, reports, and other materials. However, these materials are only used to replace the relevant materials for ICVTS testing rather than being directly allowed to test vehicles from other places to test in Guangzhou. Therefore, if the ICVTS within China wants to achieve sustained, stable, and healthy development, it is necessary to focus on solving the problems of the uniformity of the ICVTS certification system and evaluation standards, including whether the test results can be mutually recognized and how to ensure the effect of mutual recognition.

3.1.3 Limitations of TVPG based reconstruction

During the in-depth transformation of the automotive industry, many TVPGs that were originally used for automotive inspection, certification , and technical testing have also followed the pace of ICV development. The TVPG transform and upgrade the existing facilities to ICVTS in combination with ICV testing requirements. One of the more representative ones is the MIRA test site, which was founded in 1946. In 2015, MIRA started from traditional vehicle road testing to ICV test projects, providing technical support for the team researching ICV technology. In addition, the I-VISTA in Chongqing and the Intelligent Driving Test Base of MT in Beijing are all upgraded and rebuilt based on TVPG.

Reconstruction on the basis of TVPG has low construction costs and short time-consuming, but it is not easy. For example, the road length, type, and shape of the traditional test site have poor plasticity. Suppose only the partial transformation of the test site is carried out, such as the intelligent upgrade of road infrastructure, including the intelligent control of site communication signals, traffic lights, and signs. In that case, the ICVTS will be constrained from the initial overall planning and layout. And it is not conducive to the later intelligent operation and management and hinders the subsequent sustainable development[36].

3.2 Operational stage

3.2.1 Poor operating income

ICV is a product of cross-industry integration, combining traditional automotive, information technology, network communications, transportation, energy, and other advanced technologies, so its testing involves core technologies in other industries. The new requirements are put forward on a series of aspects, such as testing standards, testing tools, testing methods, and testing venues, especially for intelligent infrastructure. Higher requirements mean an increase in construction costs and an increase in the amount of investment, which will lead to capital and cost issues[33]. The government needs to consider the following information, how to use financial funds to build ICVTS, whether the current ICV is a public service, and whether the companies participating in the test pay a specific fee for road use to promote infrastructure construction further. As for the established ICVTS, the biggest problem is that there is no good business model yet. In addition, since the current ICVTS mainly does technical testing and verification, the testing income is limited and the investment return period is long. There is a lack of exploration of innovative business models. The confusion of the business model and the poor potential operating income have caused most ICVTS to work in an unsaturated state.

3.2.2 Difficulties in data sharing

The main reasons for the difficulty of ICVTS data sharing are as follows. First of all, the test standards of ICVTS in different regions are not uniform, and the specific test scenarios are also quite different. Secondly, the local ICVTS test report can only be determined to apply for a drive test license locally, and it is not accepted in other cities, which makes data sharing unnecessary. Furthermore, ICVTS data collection is also difficult. The specific manifestation is that participating companies usually require the confidentiality of vehicle test data, and even require ICVTS operators not to collect relevant data. Even if the relevant vehicle operation data and driving status data required to apply for a drive test license can be collected, it is challenging to realize data sharing, and it is even more difficult to carry out secondary development applications after data desensitization[33]. In addition, data security is a core issue that operators and participating companies care about. For example, what information can be shared among the test areas, what information must be kept secret, and how to share and ensure data security. At present, these data security issues lack a unified standard that meets the requirements of all parties. The various above-mentioned reasons ultimately lead to the unclear ICVTS data opening model and the difficulty of data sharing.

4 Countermeasures and suggestions

In recent years, ICV has made significant progress and has entered a growth phase from the R&D phase. This section will give countermeasures and suggestions for the current problems and challenges faced by ICVTS mentioned in Section 3 to provide a reference value for the construction and development of ICVTS within China, as shown in Fig. 4.

4.1 Improvement of the test and evaluation system and the standard specifications

Standard formulation is an important content and basic work of technological innovation, as well as a prerequisite and leading basis for industrialization. To maintain the healthy, stable, and sustainable development of the ICVTS within China, the first thing that needs to be done is to improve the test evaluation system and standard specifications, and promote the mutual recognition of test results from different test sites[28].

Countries, such as Japan, the United Kingdom, and Germany, have all formed unified requirements at the national level[37]. Although NDRC, MT, and MIIT

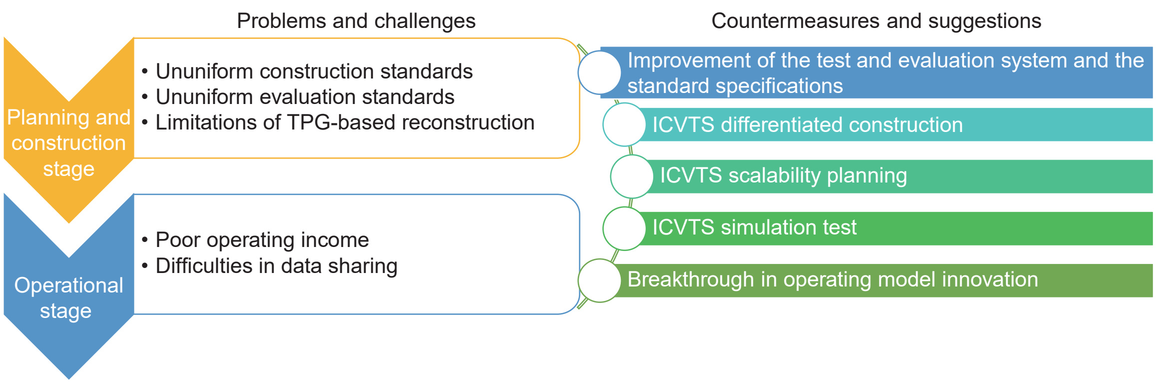

Fig. 4 Challenges and suggestions at different stages.

have taken the lead in formulating the top-level structure in China, they cannot eliminate the ICV entry barriers in various cities. Therefore, the national level should unify ICVTS construction standards in various regions, including (1) clarifying the overall requirements of ICVTS; (2) standardizing the general and specific requirements for test roads, such as road type and length requirements; and (3) standardizing the supporting service requirements, such as traffic facilities, communication equipment, and testing tools. At the same time, the combination of basic exemption items and special additional items should be used to promote mutual recognition of test results at various test sites, and to realize test data collaboration and sharing. In addition, the pace of construction of the ICV technical standard system, safety standard system, and legal system in China should also be accelerated to provide a strong guarantee for the development of ICVTS.

4.2 Balanced planning and layout

4.2.1 ICVTS differentiated construction

In order to avoid repeated investment and construction of ICVTS, ICVTS in different regions should meet the unified test requirements, and also need to combine special standards under different climate and geological scenarios, such as plateau frozen soil, high-temperature Gobi desert, and extremely cold regions[28]. However, most of the test sites are currently deployed in economically developed central and eastern cities. Figure 5 shows the distribution of test sites that have been built in China. The existing test sites within China lack special temperament geology, which is particularly critical for ICV testing under extreme climate and geological conditions. In the United States, many manufacturers choose to establish test grounds in the desert, such as the Yuma test ground. Weather conditions are the primary reason why automakers choose deserts. Stable weather is suitable for vehicle testing all year round, and low rainfall means that the interruption time of testing can be minimized. In addition, the desert area is hot in summer, and vehicle testing under high temperature conditions can be carried out. More importantly, there

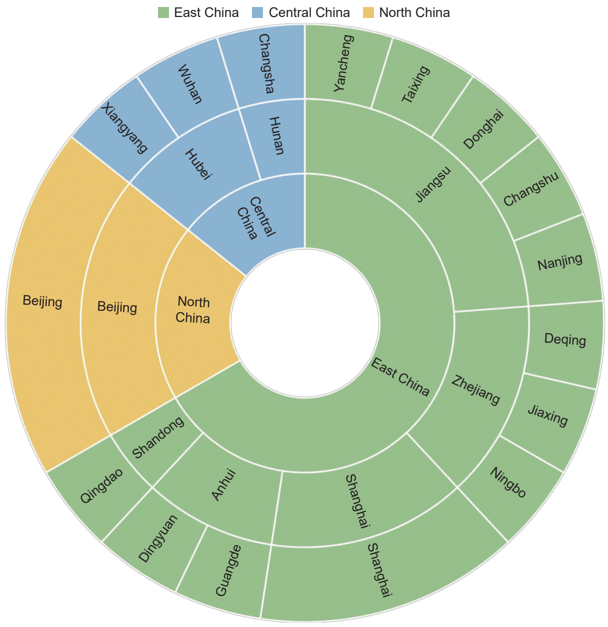

Fig. 5 Distribution of existing test sites in China.

are few people in the desert, which facilitates the confidentiality of test site information. Therefore, the national and local governments can build and deploy ICVTS with unique terrain and climate characteristics in the northwest and northeast regions of the country, use regional superior resources to drive the implementation and demonstration applications of ICV projects, and improve the ICV test scene library. The scientific layout can realize the differentiation and functional complementation of ICVTS, thereby avoiding overlapping functions, waste of resources, and vicious competition, which is conducive to the establishment of the testing environment and testing system within China[27].

4.2.2 ICVTS scalability planning

The goal of developing ICVTS is to promote the implementation of ICV, and its essence is to restore the real scene as realistically as possible. However, it is difficult to simulate the ever-changing real traffic scenes by relying only on artificially simulated test sites. Limited to relevant policies, laws, and regulations, as well as the potential safety hazards caused by public road testing, closed field testing and simulation testing are still the main methods of ICV testing. Therefore, ICVTS should also open up tests on public roads as soon as possible[38]. Firstly, we must establish an access relationship between closed testing and public road testing, and promote collaborative innovation of closed testing content and public road testing procedures. Secondly, we need to strengthen the management of public road testing, including strengthening the review mechanism for test subjects and test vehicles, clarifying the evaluation methods and assessment standards of ICV in terms of function and safety, and launching research on the impact of test vehicles on road traffic travel. In the design and planning stage, ICVTS reserves interfaces for different test requirements to facilitate future upgrades. For example, if there is no fixed marking on the road, the lane layout can be changed at any time. For instance, the establishment of traffic signal lights and signboards should take into account the requirements of laws and regulations of different countries. Various traffic elements can be moved, and traffic signs can also be replaced at any time according to test requirements. A certain area of asphalt pavement is reserved for the design and layout of scenes that are not included in the existing site, such as large parking lots. In this way, test scenarios can be adjusted on demand for testers, thereby greatly reducing the cost of later upgrades and improving facility utilization and service life[27].

4.2.3 ICVTS simulation test

In the form of ICVTS test service, attention should be paid to the construction of simulation capabilities and test databases[28]. Some situations that rarely appear in actual road conditions can be repeated from different perspectives in the simulation environment. In addition, when the ICV system changes due to upgrade, the impact of such changes can be estimated through the simulation environment. Through virtual simulation tests, the platform judges the correctness of unmanned vehicles' action execution under different road environment conditions, and evaluates its intelligent technology level and the safety, applicability, and efficiency of the future transportation system. This platform can improve ICV pre-test efficiency, reduce unnecessary losses, and accelerate industrial application.

4.3 Breakthrough in operating model innovation

To solve the conflict between ICVTS construction cost and profit, we give the following suggestions according to different stages of ICVTS development. In the early stage of ICVTS development, government intervention is needed to provide essential assistance. The government should provide preferential treatment from funding and policy. It will alleviate the initial funding pressure of ICVTS to ensure its regular operation, and encourage companies to conduct vehicle tests and collaborate in the joint construction of ICVTS. For ICVTS, first it should conduct a comprehensive survey to determine its own goals and formulate future development strategies. It helps to avoid functional conflicts with other well-developed ICVTSs, thereby forming dislocation development and facilitating complementary advantages. For example, the eastern coastal area is humid and hot in summer, thus ICVTSs there can cooperate with ICVTSs in the northeast or northwest where have icy winter to test the climate resistance of the vehicle. Besides, the start-up ICVTS should also actively strive to reach a cooperation agreement with developed ICVTSs outside and within China, invite their expert teams to assist in the planning, construction, and initial operation. Furthermore, ICVTS is a service-oriented enterprise. It needs to learn from Internet thinkings, uphold the concept of customer first, provide customers with a high-quality user experience, and establish long-term and stable cooperative relations with customers[39]. Finally, brand promotion plays a vital role in ICVTS's brand awareness, brand influence, industry leadership, and brand authority. Hosting academic seminars and publishing papers will help expand the influence of ICVTS in the academic field. The impact of ICVTS on society and schools can also be rapidly expanded by holding IV challenges. AstaZero organizes researcher exchange activities every year and jointly establishes R&D institutions with surrounding universities and scientific research institutions to provide mutual technical support and talent training.

When entering the middle stage of development, ICVTS should first try to incubate part of the technology into products, which create profits and gain more resources such as users and potential customers for the operation companies. It should also combine testing services with cutting-edge technologies and apply intelligent technologies in traditional scenarios, such as parking lots, gas stations, and charging stations. In addition, ICVTS should conduct standardized management of the data pipeline. Each ICVTS needs a data platform to collect and store information, like vehicle operating data, driving status data, and traffic data. The collected data are sorted and desensitized so that it can be used for the second time. These data can be further shared to realize the interconnection and intercommunication of data between different ICVTSs. Finally, after accumulation in the initial stage of development, customer resources should be fully exploited at this stage. ICVTS's customers are mainly automobile manufacturers, they have various test parameters and performance indicators of the vehicle, which can help ICVTS establish a unified test standard. ICVTS can establish deeper cooperative relations with customers through membership or cooperative alliances. Customers can participate in the use or management of decision-making of ICVTS according to their authority, and ICVTS can obtain the right to use test data.

In the later stages of ICVTS development, ICVTS and local government should maximize the cohesion of ICVTS as the core of the vehicle industry. Vehicle testing should serve as the platform, link, and origin to drive the integrated development of ICV technology innovation, intelligent manufacturing, application services, and entertainment. ICVTS and local government can combine big data to serve critical technologies, e.g., sensors, chips, navigation, vehicle interface, operating systems, and promote vehicle research and development and industrial application. The ultimate goal of ICVTS is to build a new industrial ecology with a reasonable structure and sustainable development through the development of an intelligent operation and management model, extend the industrial chain to the back end and the value chain to the high end, and finally build an ICV industrial cluster around ICVTS. The ICV industry chain is shown in Fig. 6.

Based on the above analysis, Gansu province has unique advantages in the construction of ICVTS. From the perspective of geographic location, Gansu is located in the northwestern region of China, with mountains, plateaus, plains, river valleys, deserts, and Gobi staggered. The landforms are complex and diverse, which can meet the needs of scene testing in different regions. Gansu has an area of about 425 800 km^2, ranking the seventh among all provinces in China. Gansu has rich land resources and low population density. It is suitable for projects with large area for test site and can effectively solve the problem of lack of highway scenes or insufficient mileage in the test sites within China. And as the center of the northwest, Gansu does not yet have ICVTS. Therefore, the construction of ICVTS in Gansu can effectively solve the problem of uneven distribution of test sites in China. From a climate perspective, China has five climate types, and Gansu has four of them. The complexity of climatic characteristics helps to improve the ICV testing capabilities under special climate and geological environments, that are currently urgently needed, which is the lack of climatic conditions in eastern cities. From an energy point of view, ICVs are mostly electric vehicles, and ICVTS data centers and simulation systems require powerful computing systems, so power consumption is high. From the perspective of regional development, Gansu gains the key to the ICV industry through the construction of ICVTS, so as to drive the development of the automobile industry and new energy industry in Gansu. It will help narrow the gap in the development of high-tech industries in the eastern and western regions and attract high-tech talents to the western region. This is also a key force to increase the province's core competitiveness and enhance the overall strength of the

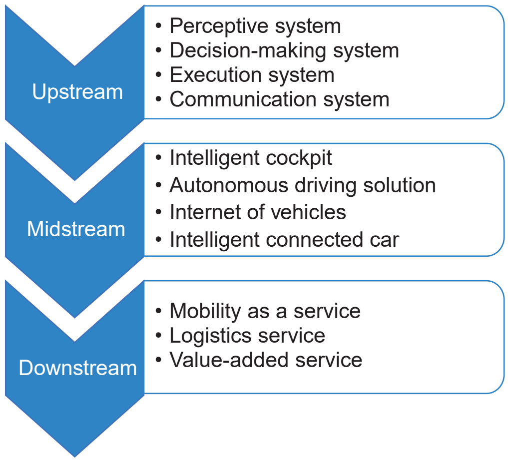

Fig. 6 ICV industry chain.

province, with good economic and social benefits.

5 Conclusion

ICVTS is an icebreaker in the development of the ICV industry. In this paper, we analyze the development status of ICVTS outside and within China, summarize the shortcomings of the existing test sites, and put forward some targeted suggestions. The development of ICVTS within China should draw on the advanced experience of the established test site, rationally plan, and scientifically deploy. The construction of ICVTS not only serves ICV, but also plays a vital role in the development of intelligent transportation and smart cities.

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Peng Zhi received the BEng and MEng degrees in computer science and technology from Lanzhou University, China in 2017 and 2020, respectively. He is currently a PhD candidate at the School of Information Science and Engineering, Lanzhou University. His research interests include computer vision, deep learning, and autonomous driving.

Rui Zhao received the MEng degree from Lanzhou University, China in 2017. Now he is a PhD candidate at Lanzhou University, who is devoted to the development of search recommendation model in the multinational company. He is currently focusing on the research of the self-driving vehicle.

Haoran Zhou received the BEng degree from Beihang University in 2018. He is currently a master student at the School of Information Science and Engineering, Lanzhou University. His research interests include autonomous driving, deep learning, and computer vision.

Yanwu Zhou graduated from the open education of TV University. He is now the director of the Production and Research Department, Beijing Zuosi Information Consulting Co., Ltd. His research interests include autonomous driving, intelligent connected vehicles, and RISC-V.

Nam Ling received the BEng degree from the National University of Singapore, Singapore in 1981, and the MEng and PhD degrees from the University of Louisiana, USA in 1985 and 1989, respectively. He is currently the Wilmot J. Nicholson Family Chair Professor (Endowed Chair) of Santa Clara University (USA) and the chair of its Department of Computer Science and Engineering (since 2010). From 2010 to 2020, he was the Sanfilippo Family Chair Professor (University Endowed Chair) of Santa Clara University. From 2002 to 2010, he was an associate dean at its School of Engineering. He is an IEEE fellow due to his contributions to video coding algorithms and architectures. He is also an IET fellow. He was named IEEE Distinguished Lecturer twice and was also an APSIPA Distinguished Lecturer. He received the IEEE ICCE Best Paper Award (first place) and the IEEE Umedia Best/Excellent Paper Awards (three times). His research interests include video coding and compression, deep learning approaches for video/image coding, deep learning approaches for video/image processing, and video/image coding for machines.

Qingguo Zhou received the BS and MS degrees in physics from Lanzhou University in 1996 and 2001, respectively, and the PhD degree in theoretical physics from Lanzhou University in 2005. Now he is a professor at the School of Information Science and Engineering. Lanzhou University. He is also a fellow of IET. He was a recipient of IBM Real-Time Innovation Award in 2007, Google Faculty Award in 2011, and Google Faculty Research Award in 2012. His research interests include safetycritical systems, embedded systems, real-time systems, and autonomous driving.