Lessons learned through automated driving bus operation and efforts using C-ITS solutions

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ABSTRACT

This paper reports on the findings obtained from the long-term operation experiment of automated driving bus being conducted in the Kashiwa-no-ha area of Japan. First, an overview of the state-level R&D projects for the social implementation of automated driving services and development of legal systems will be introduced. An overview of the Japanese government's efforts to date, such as the SIP-adus project, which has been working on the research and development towards social implementation of automated driving since 2014 under the cooperation of relevant ministries and agencies will be introduced. In addition, it will be introduced that the requirements necessary in Japan to implement Level 4 autonomous mobility services in society, mainly on the revision of the Road Traffic Act in April 2022, which paved the way for mobility services to be realized by Level 4 automated driving. Next, an overview of the long-term operation experiment of automated driving bus that the authors are working on, and the knowledge and issues obtained from the experiment will be reported. This project is commenced under the framework of the Kashiwa ITS Promotion Council. Participants include a variety of companies such as automated driving vehicle manufacturer, equipment manufacturer, insurance company, leasing company, bus operator, and developer, as well as university, community development organization, and the city hall, and are not only engaged in technology development and verification, but also created an ecosystem for social implementation and are promoting initiatives. The automated driving operation at SAE level 2 has been continued for about three years. However, in the operation so far, it has been observed that there are many cases where drivers manually intervene in the automated driving system in order to prevent the negative effects on the surrounding road users, such as other vehicles and pedestrians when passing through intersections, and to avoid obstruction of travel by vehicles parked on the street. In this paper, it will also be reported that the results of analysis of the factors that hinder automated driving obtained from the operation so far. Furthermore, in order to eliminate these impediments to automated driving bus service, it will be reported that efforts have started in 2022 in order to realize level 4 automated driving bus service by 2025 by introducing C-ITS. Finally, we will discuss the challenges and prospects of introducing Cooperative ITS into automated driving bus services in Kashiwa-no-ha.

1. INTRODUCTION

1.1. Recent initiatives on automated driving in Japan

In Japan, pioneering efforts in research and development of automated driving technology were seen in the 1990s. However, the full-scale and large-scale efforts were started in 2014, when the "Public-Private ITS Initiative/Roadmaps" [1] was formulated as a national strategy for automated driving, and under it, cross-ministerial and public-private collaboration has been conducted to research and develop automated driving technology and develop a framework for social implementation. This initiative follows the establishment of the Strategic Innovation Programme (SIP) based on the “Japan Revitalization Strategy”, which were approved by the Cabinet in 2013. In the first phase of the SIP, which started in 2014, the

“SIP Automated Driving System” was implemented with the aim of realizing the expected timeframe for the market and service realization of automated driving systems, as set out in the 'Public-Private ITS Concept and Roadmap'. In addition, “SIP-adus (SIP Automated Driving for Universal Services)” has been implemented in the second phase of the SIP, which started in 2018.

In these programs, research and development of automated driving technologies, particularly in the areas of “Technologies for using the traffic environmental data”, “Safety assurance technologies”, “Cyber security” and “Creation of an architecture for geographical data for automated driving”, which are considered to be collaborative areas, was carried out under a cross-agency, industry-academia-government collaboration structure. In addition, field operational tests of automated driving technologies have been conducted in various regions nationwide.

As a result of these efforts, a Japanese car manufacturer was the first in the world to obtain Level 3 type approval from the Ministry of Land, Infrastructure Transport and Tourism (MLIT), Japan in November 2020, and the market launch of Level 3 automated driving system was achieved in March 2021 [2]. In addition, a driverless automated mobility service using a remote automated driving system (Level 3) has started operation in Eiheiji-town, Fukui prefecture, in a limited Operational Design Domain (ODD) [2].

Besides, a company has been established to develop and distribute high-precision 3D maps, based on the achievements of the SIP projects involving industry -academia-government collaboration. By the end of 2018, this company have developed and started commercial distribution of high-precision 3D maps of approximately 30,000 km of expressways and motorways across the country. In addition, an automated driving evaluation environment in cyberspace has been established to enable the evaluation of automated driving systems in a virtual space, similar to real-world conditions [3].

1.2. Initiatives to realise Level 4 automated mobility services in Japan

In Japan, legal and institutional arrangements have also been developed to promote research and development of automated driving technology and to realize social implementation of automated driving services, as shown in Table 1.

Table 1 - Institutional Arrangements on Automated Driving

Year	Development of legal framework
2016	Formulation of the "Guidelines for Public Road Trials on Automated Driving Systems"
2017	Amendments to relevant Notices based on "Safety Standards for Road Transport Vehicles"
2019	Formulation of "Road Use Permission Criteria for Public Road Demonstrations of Automated Driving"
2020	Amendments to and enforcement of the "Road Transport Vehicle Act" and "Road Traffic Act"
2022	Amendments to the "Road Traffic Act" (entered into force on April 1)

In 2016, the National Police Agency formulated the “Guidelines for Public Roadside Experiments on Automated Driving Systems” to enable demonstration tests of automated driving technologies on public roads. These guidelines clarify that demonstration tests of automated driving systems can be carried out on public roads without special permission or notification, for example by ensuring that the safety driver is in the driver's seat of the experimental vehicle and can perform the necessary operations in an emergency. In addition, the road-use permission criteria for public road demonstrations have also been improved by specifying requirements for remote automated driving systems and for automated vehicles that are operated by a device shaped differently from a conventional steering wheel and brake during manual operation.

In 2020, amendments to the “Road Transport Vehicle Act” and the “Road Traffic Act” made it legally possible to realize SAE driving automation level 3. As a result, as mentioned above, the world's first Level 3 passenger car was put on the market in 2021 and a Level 3 automated driving mobility service was launched in Eiheiji-town, Fukui prefecture.

In 2022, the “Road Traffic Act” was amended again, and the legal system was developed to realise driverless automated driving mobility services, SAE driving automation level 4. Specifically, a new permit framework was established for those who intend to perform automated driving without a driver, named “Specified Automated Operation (SAO)”, which is equivalent to Level 4. Table 2 provides an overview of the permit framework for SAO. It is stipulated that this permit framework will start in April 2023, and it is expected that Level 4 automated driving mobility services will be launched from April onwards in Japan.

Table 2 – Overview of the Specified Automated Operation [4]

(1) Permission for Specified Automated Operation (SAO)
・ Parties seeking to conduct automated driving without a driver ("Specified Automated Operation"), equivalent to Level 4, require permission from the Prefectural Public Safety Commission
・ Parties who intend to obtain a permission shall submit a "SAO Plan" to the Prefectural Public Safety Commission
・ When the Prefectural Public Safety Commission intends to grant a permission, it shall hear opinions from the mayor of the municipality whose area includes the route of the SAO
(2) Permission Criteria
・ The vehicle must be capable of SAO
・ The SAO must be performed in compliance with the ODD*
・ Smooth and reliable implementation is expected for the measures which the SAO implementer or the SAO staff must implement under the Road Traffic Act
・ The SAO conducted according to the SAO plan is not likely to significantly interfere with other traffic
・ The SAO is for the purpose of transporting people or goods and is recognized as contributing to the convenience or welfare of local residents
* ODD: Operatinal Design Domain(Specific conditions under which an automated driving system is designed to operate (the traveling route, the time of day, weather, etc.))
(3) Obligations of a Permission Holder ("SAO Implementer")
・ SAOs must comply with the plan for SAO and the conditions attached to the SAO permission
・ Installation of remote monitoring equipment and assignment of a person ("SAO Supervisor") who perform the remote monitoring (except when the SAO Supervisor is on board)
・ The SAO implementer must provide education to the SAO staff, etc.
(4) Obligations of SAO Supervisors
・ Monitor the state of the operation of the remote monitoring
・ In the event of a traffic accident, taking measures to notify the fire department and to send a person responsible for on-site measures to the scene
・ In the event of a traffic accident, reporting the date and time of traffic accidents to police officers, etc.
(5) Administrative Disposition
・ The Prefectural Public Safety Commission may issue instructions, revoke or suspend permission, etc., when a SAO Implementer, etc., violates laws and regulations
・ The chief of a police station may suspend the validity of a permission provisionally in the event of a traffic accident or other incident in a SAO

In addition, research and development under a project of the Ministry of Economy, Trade and Industry (METI) and Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has started since 2021 for the social implementation of Level 4 automated driving mobility services. The project, named “Project on Research, Development, Demonstration and Deployment (RDD&D) of Autonomous Driving toward the Level 4 and its Enhanced Mobility Services (RoAD to the L4)” has started including four themes for research, development and demonstration. The four themes are: “Realisation of Level 4 automated mobility services under the limited ODD”, “Expansion of ODD and vehicles”, “Practical application of advanced logistics systems on expressways” and “Establishment of automated mobility services in mixed traffic environment.” Furthermore, field operational tests are being actively conducted in various regions to realize the Government's goal of implementing Level 4 automated mobility services in 50 locations by 2025 and in 100 locations by 2027.

2. OVERVIEW OF AUTOMATED BUS OPERATION IN KASHIWA-NO-HA

2.1. Framework of the initiative

A long-term demonstration experiment for automated driving bus operation in the Kashiwa-no-ha area of Kashiwa City, Chiba prefecture began in November 2019. This long-term demonstration experiment is being conducted with two main objectives. The first is to develop and verify automated driving technologies. The second objective is to verify how automated mobility can be operated as a sustainable mobility in urban development. For this reason, the implementation structure of this long-term demonstration of automated driving bus is being carried out with the participation of a diverse range of stakeholders who participate in the “Kashiwa ITS Promotion Council”, as shown in Table 3. In other words, unlike other demonstration experiments conducted over a short period of time, in order to provide a sustainable automated mobility service, not only companies with technical resources but also parties with non-technical resources such as Kashiwa City Hall, the Urban Design Centre, which is responsible for promoting urban development in Kashiwa-no-ha, a property development company, an insurance company, a car leasing company and others are participating in the project. This has enabled initiatives to improve the social acceptance of automated mobility by holding test-ride events for residents, as well as examining how automated mobility should be implemented in urban development.

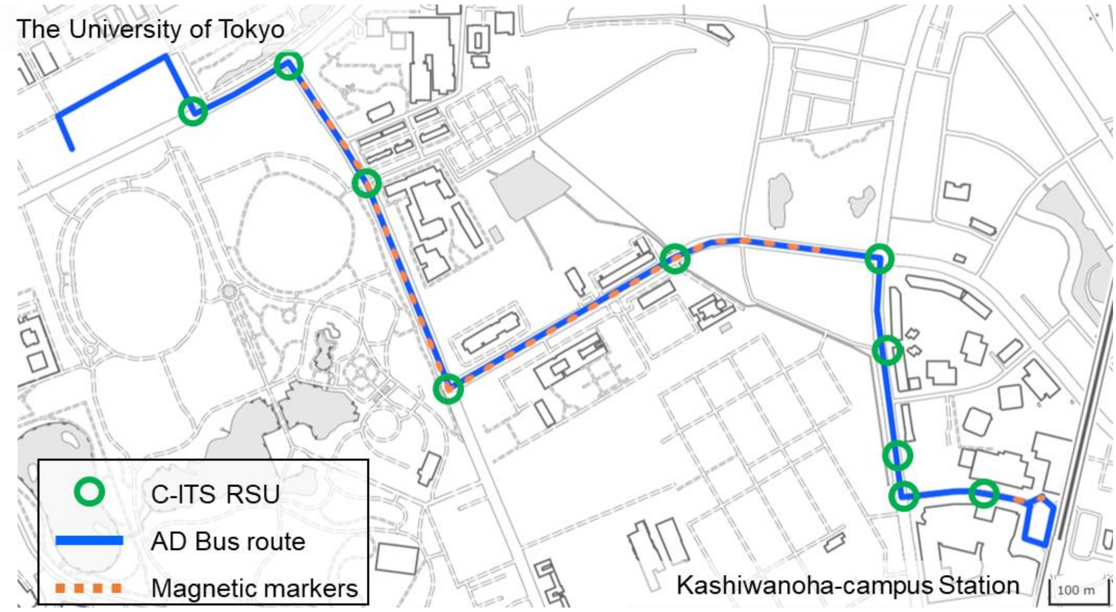
Table 3 - Contributors to the long-term demonstration experiment of automated driving bus

Participants contributing mainly to technical considerations
Bus operator
Automated bus development company
Remote monitoring system provider
Magnetic positioning system development company
Companies developing Cooperative ITS RSU
Participants contributing mainly to non-technical considerations
Kashiwa City Hall
Urban Design Center Kashiwa-no-ha
Insurance company
Car leasing company
Property development company
Consulting company
Leading Organization
The University of Tokyo

From 2021, based on the previous initiatives for the operation of automated driving bus, new R&D activities are carried out under the CooL4 (Cooperative Level 4 Automated Mobility Service in mixed traffic environment) project, as a part of the project, “RoAD to the L4.” The CooL4 consortium, which includes The University of Tokyo, Nagoya University, AIST and others, is developing and verifying technologies under the automated driving bus operation in Kashiwa-no-ha [5].

2.2. Operation of automated bus

Figure 1 shows the route of the automated driving bus service in Kashiwa-no-ha. The Kashiwa-no-ha area is located approximately 30 km from central Tokyo. The Kashiwa-no-ha area is served by Kashiwanoha-campus Station on the Tsukuba Express line, which connects central Tokyo and Tsukuba City by train. The University of Tokyo, Chiba University and the National Cancer Centre Hospital East are located near Kashiwanoha-campus Station.



Source: Geographical Survey Institute map with relevant information added by the author

Figure 1 – Route of automated driving bus operation

Automated driving bus is operated as part of a shuttle bus service between Kashiwanoha-campus Station and the Kashiwa campus of the University of Tokyo, carrying actual passengers and making three round trips a day. The passengers are students, faculty and staff, as well as people who have business at the Kashiwa campus. In addition to this, one shuttle bus service is operated daily for trial rides, making a total of four round trip shuttle bus services a day from Monday to Friday. In addition, extra test-rides are also operated when there is a particular request.

The trial operation of automated driving bus in Kashiwa-no-ha as long-term demonstration experiment has continued for more than three years and two months as of January 2023. It is one of the longest running demonstration tests with passengers on board. No accidents have reported with the automated driving system during the period of operation.

2.3. Technologies used in automated driving bus

An automated driving bus converted from a small size bus was used at the beginning of operation in 2019. That fleet was replaced by the automated driving bus converted from a conventional medium-sized bus in January 2021. Both vehicles are equipped with a driving automation system that automates a part of driving tasks, enabling Level 2 automated driving with a safety driver in the driver's seat. Specifically, the recognition module of the automated driving system uses the various sensors shown in Table 4 to localize self-position and recognize obstacles, while the decision-making module calculates how the vehicle should be controlled based on the recognition information. Based on the calculation results, the control module manipulates the steering wheel, accelerator/brake and blinker to implement automated driving.

Table 4 - Various sensors on automated driving bus

Sensors equipped on automated driving bus
LiDAR (forward, rear, side×2)
Obstacle-detection camera
Signal recognition camera
Stereo camera
Millimeter-wave radar
Magnetic marker detection sensor
Gyro sensor
GNSS antenna
Communication antenna

Gradual improvement has been made to the driving automation system. The RTK-GPS and high-precision gyro sensors are used for localisation of self-position of automated driving bus. However, when the roadside trees along the road are overgrown in summer and when the vehicle passes under some buildings, the accuracy of localization using RTK-GPS and high-precision gyro sensors alone is not sufficient. Therefore, magnetic markers are installed in sections where accuracy is insufficient, and improvement of driving automation system was made to the use of a magnetic positioning system in April 2020. Magnetic markers are used not as target trajectories but as landmarks for self-position estimation, and for research, development and verification purposes, magnetic markers are placed in a grid pattern in some sections in addition to the usual point sequence arrangement [6].

The base fleet upgrade to medium-sized buses in January 2021 included enhanced traffic signal recognition cameras and object detection sensors on the side. In conjunction with this, other detection and driving functions were also improved. A display has also been added to the vehicle. This display allows the passengers to see the image of automatic steering and the sensing status during automated driving. Figure 2 shows the image of the display. In addition, remote monitoring functions have been installed to detect passengers who stands up or walking during bus running and to announce warnings based on recognition using camera images to prevent passengers from falling over [7].

From 2022, initiatives on connection with traffic signals and with cameras and sensors of C-ITS roadside units on the route have also been started as described in section 4.

(Photo: S.Suzuki)

Figure 2 - Image of a display installed in the automated driving bus

3. MANUAL OVERRIDE DURING AUTOMATED BUS OPERATION

3.1. Situations where manual overrides take place

When an automated driving bus is in operation, a safety driver belongs to a bus operator company which is operating a route bus in the Kashiwa-no-ha area is in the driver's seat. In case the situations cannot be managed by the automated driving system, the safety driver manually overrides the automated driving system. In this operation at Kashiwa-no-ha, even within the ODD, manual override is performed whenever the safety driver, based on his/her experience, deems it necessary. Therefore, locations where manual override occurs are considered to be where challenges can be identified for automated driving systems. The authors analyzed the locations where manual override is performed and found that most of manual overrides occur in the locations shown in Table 5.

Table 5 - Locations where manual overrides are frequently performed

Category	Situation
Signalized intersection	Points where there are a lot of interaction with other road users and where drivers are expected to exercise caution in their decisions
Unsignalized intersection	A point where there are bus stops, residences and parks in the vicinity and where drivers are expected to exercise caution in their decisions
Unsignalized intersection	A point where there are pedestrian crossings, parking entrances and exits, and bus stops and where drivers are expected to exercise caution in their decisions
Point of departure and arrival	Points where switching from automated to manual operation and from manual to automated operation

3.2. Factors leading to manual overrides

There are three types of manual override: steering, accelerating and braking. The highest number of manual overrides per round trip by type, recorded in the period January 2022 to September 2022, was for accelerating, followed by steering and the lowest number of manual overrides for braking as shown in Figure 3.

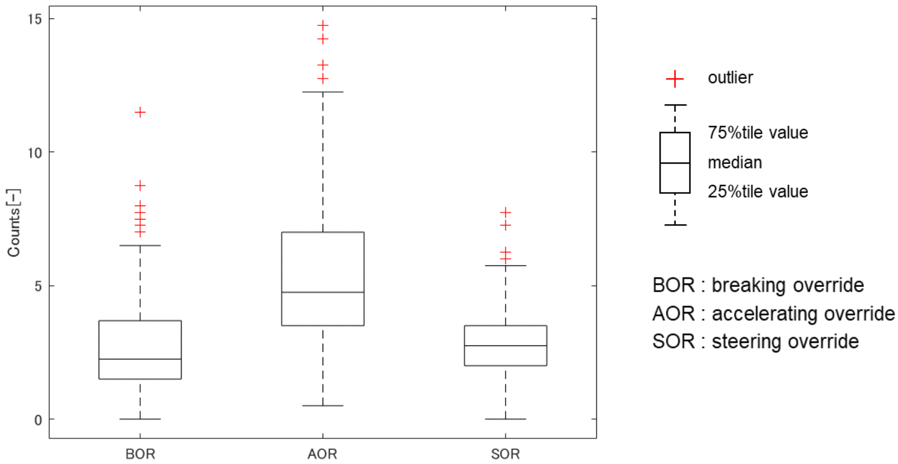


Figure 3 – Comparison of three types of overrides per round trip [8]

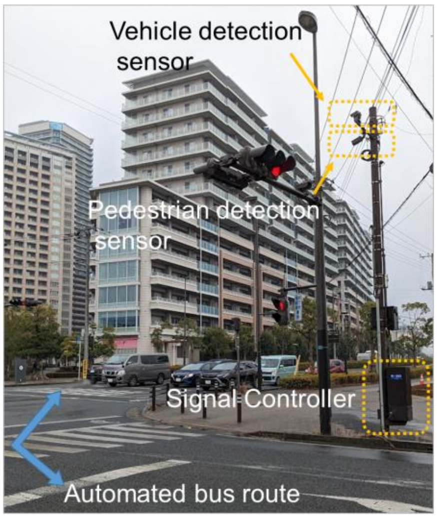
The reasons for the high number of manual overrides on accelerator operations may be due to the following reasons. For example, when passing through an intersection, the driver communicates somehow with surrounding vehicles, cyclists and pedestrians and predicts their behaviour based on experience. Then, after confirming and ensuring safety, the driver promptly exits the intersection, also taking traffic smoothness into consideration. However, the driving automation system cannot communicate with surrounding vehicles, cyclists and pedestrians, and compared to the driver, the acceleration and deceleration control performed while confirming and ensuring safety is more discreet on the safety side. This may cause a difference between the driver's decision making and the that of the driving automation system, and the driver is likely to perform manual overrides in accelerator control in many cases.

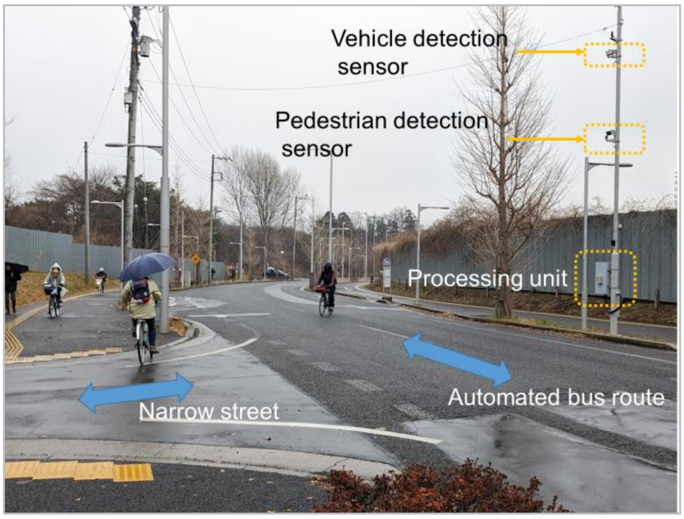
The authors also analyzed the surrounding road environment when manual override was performed, using the images of the drive-recorders [8]. As a result, it was learned that in many cases, manual overrides in braking occurred in front of the driving path, when a pedestrian crossing takes place or a vehicle enters the path, by initiating deceleration in advance. In these cases, manual overrides in braking control by the driver is considered to be caused by a difference between the driver's experience-based behaviour prediction and the decision making of the driving automation system.

4. INSTALLATIONS OF COOPERATIVE ITS

4.1. Outline of additional Cooperative ITS installations

As described in section 3., a number of manual overrides were performed at signalised and non-signalised intersection in the Kashiwa-no-ha automated driving bus operation, and further improvements were required to achieve Level 4 driving automation. Therefore, under the CooL4 project funded by METI, some roadside units (RSUs) were installed in a test field of the University of Tokyo's Kashiwa Campus and functional verification was carried out. In addition, in 2022, RSUs equipped with sensors and communication devices were installed by parties of Kashiwa ITS Promotion Council for verification of functions to expand the physical range within which automated driving bus can detect approaching vehicles and so on and to enable them to acquire signal information. Images of RSU are shown in Figure 4. The locations of the RSUs are shown in Figure 1.





(Photos: S.Suzuki)

Figure 4 - Images of RSU

Each RSU is equipped with LiDAR and/or cameras and has the capability to detect pedestrians, cyclists, running vehicles and parked vehicles and transmit this information to the automated driving bus via a common communication device.

4.2. Cooperative ITS services for road users

Table 6 shows the outline of the C-ITS services provided to road users using introduced RSUs.

At signalized intersections, signal information is transmitted to the automated driving bus via communication equipment to improve the bus's decision-making on acceleration and deceleration operations, thereby improving the accuracy of safety confirmation and realizing efficient deceleration operations. In addition, sensors such as LiDAR, cameras and millimetre-wave sensors are used to detect vehicles, cyclists and pedestrians inside and outside intersections, and transmit this information to the automated driving bus, thereby enhancing the automated driving bus's perception of traffic environment at intersections. These technologies provide services that ensure efficient fuel consumption in an automated driving bus and services that prevent passengers from falling over in the cabin. They also provide safe driving assistance services that include surrounding road users by reducing the likelihood of collisions between automated buses and pedestrians, cyclists and other vehicles.

RSUs installed beside pedestrian crossings at an unsignalized intersection detects pedestrians and cyclists in the vicinity of the pedestrian crossing, including those in blind spots from the approaching automated driving bus, and transmit information to the automated driving bus to prevent sudden deceleration. RSUs installed at another unsignalized intersection at the exits of a narrow street detects running out vehicles and cyclists, and pedestrians crossing the road. And it provides information to the automated driving bus to prevent sudden deceleration. RSUs installed in areas where there are many parked vehicles can detect pedestrians and vehicles jumping out of blind spots caused by parked vehicles, as well as the departure of parked vehicles, and transmit the information to the automated driving bus to prevent sudden deceleration. At bus stops, the system detects vehicles approaching from behind when the automated driving bus starts and transmits the information to the automated bus, thereby improving safety when the bus starts from bus stop.

These technologies also provide services that prevent passengers from falling over in the cabin and safe driving assistance services that include surrounding road users.
The idea is that these C-ITS services by RSUs will be provided not only to buses equipped with automated driving systems, but also to vehicles equipped with C-ITS on-board units. In other words, other road users are being considered to be able to enjoy the C-ITS services using RSUs, mainly on safe driving assistance.

When introducing driving automation system utilizing Cooperative ITS RSUs, after checking and verifying the functions and communications, the safety driver of the automated driving bus is given the experience they need to get used to the improved system behaviour using additional Cooperative ITS's information. This is because, when implementing Level 2 automated driving, the driver needs to be fully aware of the tendency of decisions and behavior of the automated driving system, for making appropriate manual overrides to ensure safety. As of December 2022, the verification of the transmission of signal information and of its reflection to the automated driving system has been completed. And safety drivers' familiarization experience of improved system is in the process of being implemented. For other Cooperative ITS RSUs, the functional and communication verification stage is still in the process, and safety driver familiarization experience will be conducted as soon as it is completed.

Table 6 - Outline of the installed C-ITS services using RSUs

Type	Function
Signal information provision	Signal information is provided from RSU to automated driving bus in order to enable correct recognition of the current status and remaining signal time without the influence of the dazzling sunset or street trees
Right and left turn support	To prevent interference with oncoming straight vehicles when turning right and with crossing pedestrians and cyclists when turning right/left, vehicles, pedestrians and cyclists are detected by RSU and right/left turn assistance information or object information is provided to the automated bus
On-street parking avoidance support	For on-street parking avoidance support, the RSU detects on-street parked vehicles and oncoming vehicles and provides information on on-street parking avoidance suport and object information to the automated driving bus
Pedestrian detection support at unsignalized pedestrian crossing	To prevent interference with pedestrians and cyclists at unsignalized pedestrian crossings, pedestrians and cyclists are detected by RSU and information on pedestrian crossing detection support and/or object information is provided to the automated driving bus
Support for detection of running out vehicle from side street	To prevent interference with vehicles runnig out of the side street, the RSU detects the vehicles and provides object information to the automated driving bus

5. CONCLUSION

Firstly, this paper provides an overview of the research and development of automated driving technology in Japan and the efforts made towards its social implementation. In Japan, research, development and social implementation in the cooperative field, such as development of high-precision 3D maps and automated driving evaluation environment in cyberspace were promoted through cooperation between industry, government and academia in accordance with the roadmap set by the Government of Japan. In addition, legal systems were developed to enable social implementation of SAE driving automation level 3 and level 4.

Secondly, the long-term operation experiment of a Level 2 automated driving bus, which has been continuously conducted in the Kashiwa-no-ha area for more than three years, was described. This long-term operation has been realized with contributions from a diverse range of participants, not only to carry out technical verification, but also to verify sustainable operation and social implementation. It was also reported that improvements are being made to the driving automation system sequentially in order to resolve issues learned in the course of continued operation. Specifically, it is described that introduction of a magnetic positioning system, improvements to the operation automation system in conjunction with vehicle renewal, and the introduction of Cooperative ITS.

Future challenges include the verification of the use of the Cooperative ITS in the driving automation system, which has been installed and verified since 2022, in actual operations. Besides, the improvement of automated driving technology, the establishment of an operation implementation framework and the evaluation of the impact of automated bus driving on surrounding traffic environment in order to meet the Permission Criteria for obtaining a permit of Specified Automated Operation with a view to realizing Level 4 automated mobility service within fiscal year 2025.

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