Outline of Large-scale Field Operational Test

Masato Minakata (Toyota Motor Corporation)

1 Back Ground

In SIP-adus, various research and development measures have been organized around five major themes since 2016, and a large-scale field operational test (FOT) is set as a deployment milestone.

Overseas FOTs include the Smart City Challenge in the United States, a demonstration experiment on automated driving technology in the entire city in Columbus, Ohio. In Europe, the AdaptIVe Project, the largest comprehensive automated driving demonstration experiment, is being carried out in the context of the Seventh Framework Programme (FP7) by EU member states. Similarly, in the United States, Waymo and Uber are conducting social demonstration experiments on civic mobility services using automated driving vehicles. Demonstration experiments on public roads are also being conducted in various countries around the world.

The FOT environment for automated driving on public roads in Japan has already become comparable to that of other countries thanks to the cooperation of the National Police Agency, the Ministry of Land, Infrastructure, Transport, and Tourism and other organizations. As long as there is a driver in the driver's seat, FOTs can be carried out without applying for permission with the government agencies.

2 Overview

Our way of thinking about large-scale does not, in any way, refer to the number of vehicles participating in a FOT. The meaning we attribute to the large-scale expression is " way of approaching comprehensive themes", "implementation over a wide area", and "internationally open".

2.1. Objectives

The objectives of large-scale FOTs are

1) Stimulating research and technological development by providing the necessary places and infrastructure.
2) Industry, government and academia evaluation, from many viewpoints, of the common themes raised at these open opportunities to identify problems.
3) Judging whether to put SIP-adus research results into practical use.
4) Inviting overseas manufacturer participation and leading international cooperation and standardization.
5) Using public relations to promote automatic driving systems and foster social acceptance.

2.2. Themes

SIP-adus carried out large-scale FOTs covering the five major themes of ① dynamic maps, ② human machine interface (HMI), ③ cybersecurity, ④ pedestrian accident reduction, and ⑤ next-generation urban transport. These five major themes are the fundamental technologies in the cooperative areas of the industry, and are indispensable for the social implementation of automated driving systems. It is therefore important to confirm the effectiveness and practicality of these cooperative areas via the FOTs.

2.3. Implementing Organization

Under the Promotion Committee, a plan for large-scale FOTs was studied by the large-scale FOT planning task force. Based on that plan, the National Energy and Industrial Technology Development Organization (NEDO) acted as the administrative secretariat to manage the overall operation of the large-scale FOTs and administer public experiment funding on a per theme basis. The organization granted funding implemented its FOT plan, including the recruitment and the management of FOT participants.

2.4. Participants

SIP-adus recruited domestic and overseas automakers, automobile parts and system suppliers, universities, research institutes, and venture companies to openly participate in the dynamic map and HMI FOTs with expectation of receiving feedback from wide range of the perspectives. The preparation of some experimental equipment and the infrastructure necessary for the FOTs were carried out by the SIP-adus and provided to the participants. In total, 22 domestic and overseas groups participated in the FOTs (Fig. 1).

Fig. 1 Participants in SIP-adus Large-scale FOTs

2.5. Area

FOT on the public roads are indispensable for currying out the demonstration experiments for practical application.

In the large-scale FOT, SIP-adus planned the use of highways and ordinary roads, primarily in the Kanto region, and reached prior agreement with the stakeholders in the relevant regions to carry out the test on public roads for the first time in Japan. In addition, SIP-adus conducted a FOT in Okinawa to verify the social acceptance for an automated driving bus as the next-generation of urban transport. To solve the increasingly serious problem of limited mobility due to the shortage of transport services and logistics in depopulated areas, the social acceptance of mobility services based on road-vehicle cooperation using michi-no-eki roadside rest areas as a starting points was evaluated in semi-mountainous areas where super aging is advancing rapidly. For some FOTs, the test courses were also used from the point of view of ensuring safety.

2.6. Period

The SIP-adus large-scale FOTs started in October 2017, with the implementation period determined separately for each theme. All experiments were completed in December 2018.

Dynamic Maps

Yoshiaki Tsuda, Yukishiro Saito, Yukio Takahashi (Mitsubishi Electric Corporation)
Shinya Muroyama, Kazuki Hirao (Aisan Technology Co., Ltd.)
Sosuke Hirano, Junichi Kamichika (Increment P Corporation)
Kiyohiro Yamauchi, Yumi Takehana (Zenrin Co., Ltd.)
Shintaro Osaki (Toyota Map Master Incorporated)
Ryota Kataoka, Miho Shikata (Pasco Corporation)

ABSTRACT: Through the large-scale field operational test (dynamic maps), we designed static information update data for dynamic maps necessary for automated driving systems and location referencing methods to link static information with dynamic information, and collaborated with test participants to evaluate these static information update data and location referencing methods. Based on the static information evaluation results, we created map updating guidelines. We also determined that information usage intent varied by automated driving level. Our findings indicate that linking static information and other information can be effective for automated driving system vehicle control, and we verified dynamic map theory through actual field operational testing.

1 Introduction

Dynamic maps are high-accuracy 3D maps overlaid with constantly changing information regarding nearby vehicles, the status of traffic signals, and other driving conditions. Dynamic maps are composed of four layers, as shown in Fig. 1: static information, semi-static information, semi-dynamic information, and dynamic information. Static information is the high-accuracy 3D map itself. It is composed of actual features, such as carriageway lines, street signs, and traffic signals, and virtual features, such as lane links, carriageway links, and intersection areas. Semi-static information consists of future road transport information such as traffic congestion forecast information, scheduled traffic restrictions information, and weather forecast information. Semi-dynamic information is composed of road traffic information such as accident information and traffic congestion information. Dynamic information consists of traffic signal information and information regarding physical objects on or near roads, such as the positions of nearby vehicles and pedestrians. Location referencing methods have been defined to link these four layers, from static information to dynamic information.

Section 2 of this article provides an overview of the large-scale field operational test (dynamic maps) (the field operational test). Section 3 presents the methods used to evaluate map data updates, semi-dynamic information (traffic flow information and lane-specific restriction information) and dynamic information (e.g., traffic signal information, crosswalk pedestrian information), and the results of these evaluations. Section 4 contains a summary of our results.

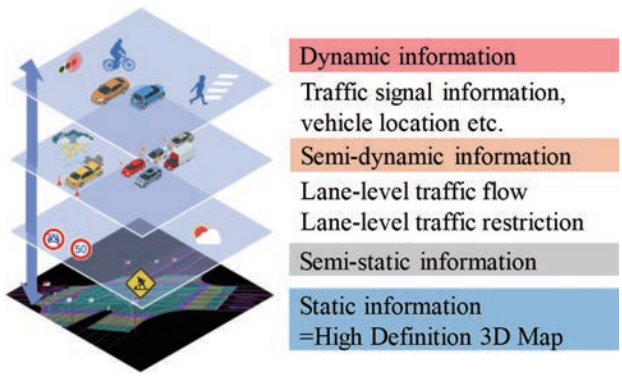


Fig. 1 Dynamic map four layer structure

2 Overview of the Dynamic Map Field Operational Test

2.1. Dynamic Map Field Operational Test Schedule

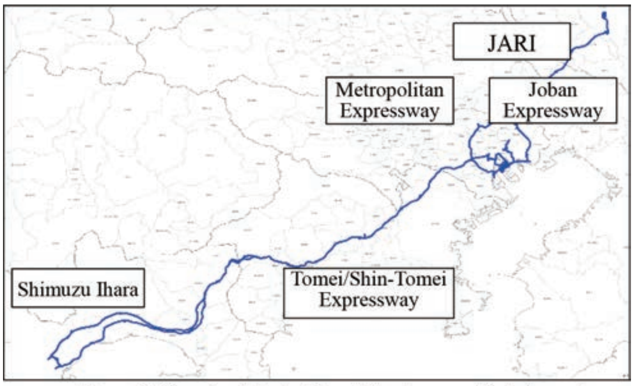
With the participation of test participants, over the 15-month period from October 2017 to December 2018, this test verified the specifications and accuracy of prototype dynamic maps, the linking of information such as dynamic information and semi-dynamic information with static information, and the system used to distribute this information. Table 1 shows the schedule of the Dynamic Map Field Operational Test.

Table 1 Dynamic Map Field Operational Test schedule

Major category	Category	2017				2018												2019		
		9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Preparation/ Provision/ Evaluation	Static data :300km	■	■	■																
	Static data :758km				■	■	■	■												
	Static data :updated data										■	■	■	■						
	Semi-dynamic data														■	■	■			
	Dynamic data														■	■	■			
Conclusion	Static data							■	■											
	Dynamic data																■	■	■	
Meetings/ Events	Dynamic Map FOT WG	○			○		○	○		○		○			○	○	○		○	
	SIP-adus WS			★												★				

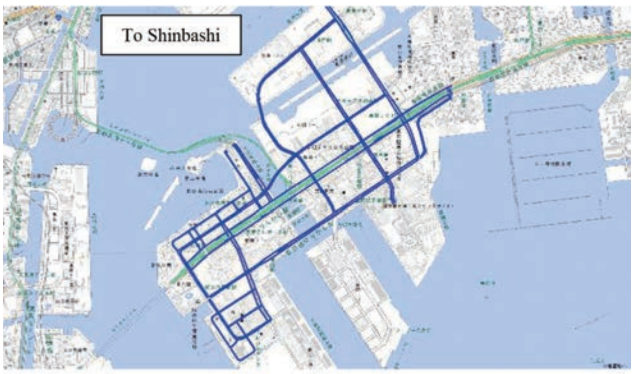
2.2. Field Operational Test Area

In order to implement this field operational test, static information was prepared for routes starting from the Japan Automobile Research Institute urban area simulation test course and extending to the Shimizu Ihara Interchange via the Joban Expressway, Metropolitan Expressway, Tomei Expressway, Shin-Tomei Expressway, and other roads, as well as for the Odaiba area, as shown in Figs. 2 and 3.



* Geospatial Information Authority of Japan light color map used for background map

Fig. 2 Dynamic Map Field Operational Test Area (Expressways)



* Geospatial Information Authority of Japan light color map used for background map

Fig. 3 Dynamic Map Field Operational Test Area (Odaiba Area)

2.3. Field Operational Test Participants and Implementation System

The twenty participants shown in Table 2, including Japanese and foreign motor vehicle manufacturers, suppliers, and universities, took part in the field operational test. A total of ten dynamic map field operational test working group sessions were held. The working group discussed verification test contents, evaluation methods and evaluation contents, and verification test equipment configurations.

Table 2 Dynamic Map Field Operational Test Participants

Japanese automotive manufacturers	7
Foreign automotive manufacturers	3
Japanese suppliers	3
Foreign suppliers	3
Universities/other	4

2.4. Equipment and Software Used in the Field Operational Test

The following equipment and software was used to distribute (1) static information, (2) semi-dynamic information, and (3) dynamic information in this verification test.

(1) Static information (map data and map update data)

Static information map data and map update data were distributed to test participants on DVD. Incremental map update data alone was also distributed via LTE to verify envisioned actual operation.

(2) Semi-dynamic information (traffic flow information and lane-specific restriction information)

Traffic flow information generated from probe information acquired from vehicles was distributed via LTE. Lane-specific traffic restriction information was also distributed using ETC 2.0 roadside wireless devices in actual operation.

(3) Dynamic information (traffic signal information, crosswalk pedestrian information, vehicle detection information)

Dynamic information was distributed via two distribution methods that are in actual operation. Advanced infrared beacons were used to distribute traffic signal information. ITS wireless roadside devices were used to distribute traffic signal information, crosswalk pedestrian information, and vehicle detection information.

LTE smartphones, ETC 2.0 vehicle-mounted devices, 760 MHz receivers, and receiving terminals for storing data output from receiving terminals were lent to test participants in order to receive information types (1) through (3). Figures 4 to 7 show the testing systems and devices used in the field operational test.

API software and dynamic map viewers installed in receiving terminals were used to verify received data. Figure 8 shows an example of traffic signal information for the Odaiba area displayed on the dynamic viewer.

Test participants installed these devices and software in test vehicles, drove on actual roads, and conducted evaluation verification.

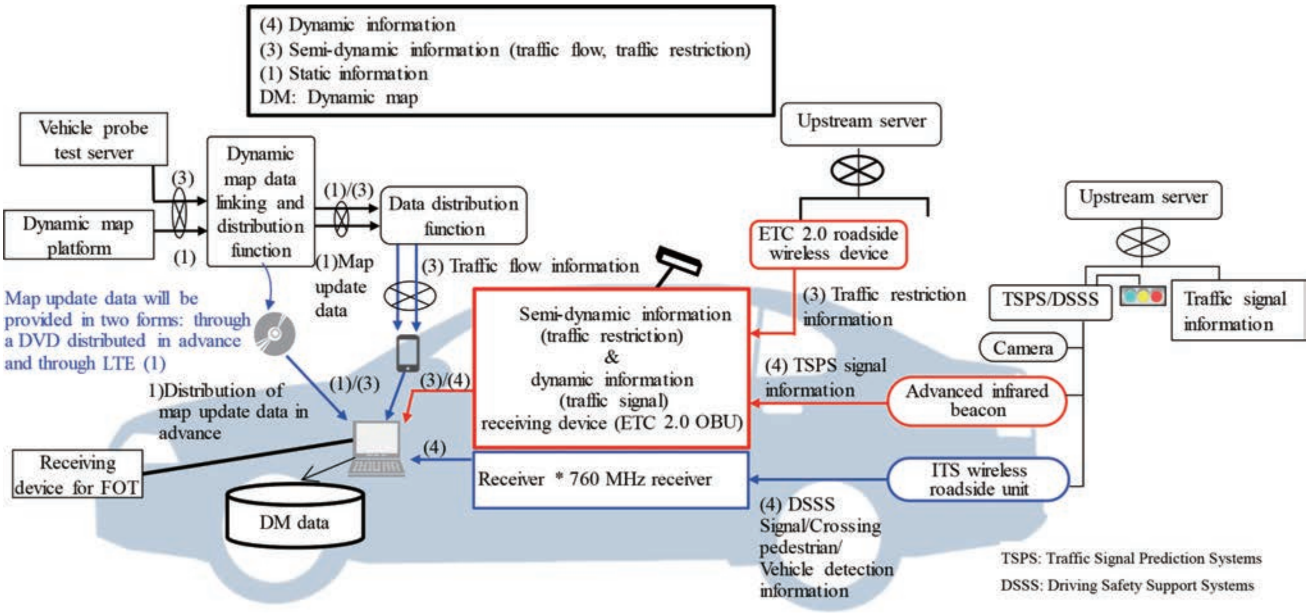
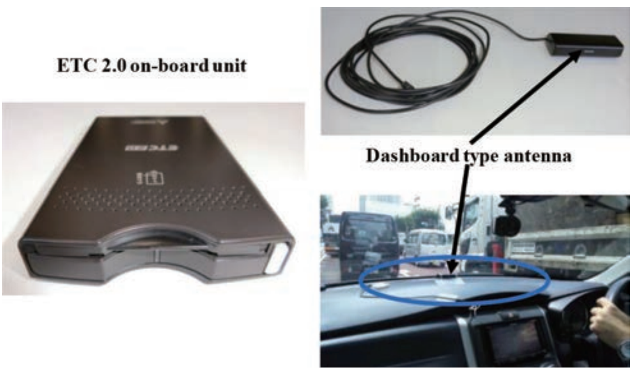


Fig. 4 Equipment and Software Used in the Field Operational Test



Source: Mitsubishi Electric Corporation

Fig. 5 ETC 2.0 Vehicle-Mounted Device

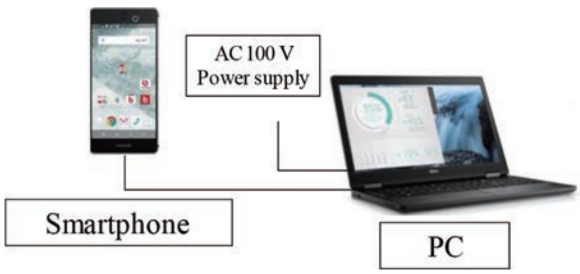
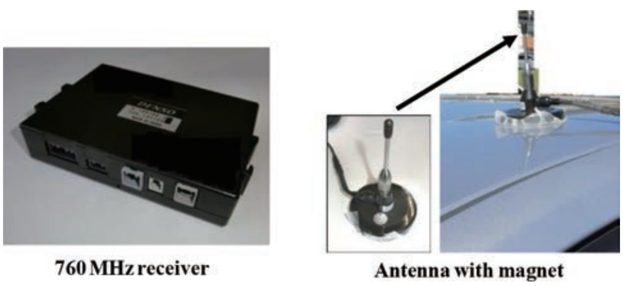


Fig. 7 Receiving Terminal



Source: DENSO CORPORATION

Fig. 6 760 MHz receiver

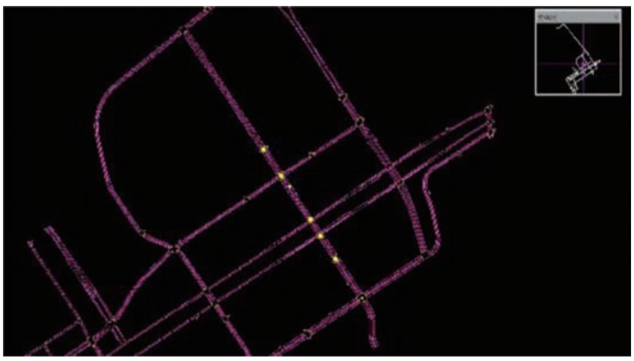


Fig. 8 Example of Traffic Signal Information for the Odaiba Area Displayed on the Dynamic Viewer

3 Evaluation Methods

3.1. Static Information

The five types of map update data shown in Table 3 were created based on factors such as static information improvement requests, and map update evaluation was performed.

As the map update data example in Fig. 9 shows, map update data was prepared for areas in which there were road extensions or changes to road shapes.

Table 3 Locations for Which Map Update Data Was Created

Target road	Update location, etc.
Ordinary road	Odaiba – Toyosu/Shimbashi section = Positioning of partial update
Ordinary road	Additional CRP design = Positioning of feature addition update
Ordinary road	Odaiba Tokyo International Exchange Center/Miraikan area = Positioning of new road addition update
Expressway	Two large-scale correction areas * Horikiri/Kosuge Junction (inner lanes) * Itabashi/Kumano Town (inner and outer lanes) = Positioning of partial update
Expressway	Harumi Interchange = Positioning of new road addition update

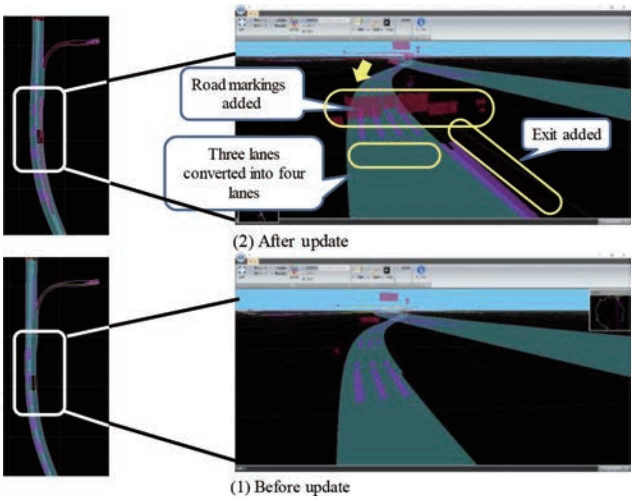


Fig. 9 Example of Map Update Data (Metropolitan Expressway - Horikiri/Kosuge Junction Inner Lanes)

3.2. Semi-Dynamic Information

(1) Overview of traffic flow information

With regard to traffic flow information, the project coordinated with a separate SIP-adus project to distribute two types of traffic flow information—the road-specific and lane-specific information shown in Table 4—via LTE. Figure 10 shows an example of the displayed traffic flow information.

Table 4 Overview of Traffic Flow Information and Information Distribution Area

	Overview of traffic flow information	Distribution area
Road-specific traffic flow information	Road-specific traffic flow information generated from probe information. Traffic flow information for each lane with the same start and end points was replicated and supplied.	Joban Expressway: Misato toll booth – Yatabe Interchange Tomei Expressway: Yoga IC – Atsugi Interchange Ordinary road: Odaiba/Big Sight-mae
Lane-specific traffic flow information	Lane-specific traffic flow information generated from probe information.	Metropolitan Expressway: Tanimachi Junction -> Hamazakibashi Junction (one-way)

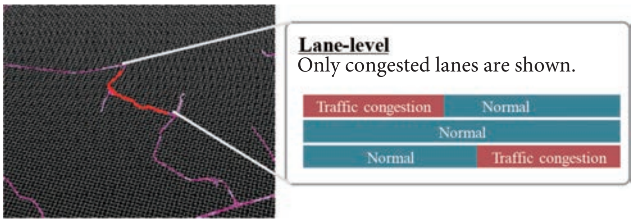


Fig. 10 Traffic Flow Information (Lane-Specific) Display Example

(2) Overview of Lane-Specific Restriction Information

A test system was created to test the use of lane-specific restriction information distributed by ETC 2.0 roadside devices in dynamic maps. This test system was then provided to test participants. When participants passed ETC 2.0 roadside devices on actual roads, they received lane-specific restriction information and evaluated the linking of static information and lane-specific restriction information (see Fig. 11).

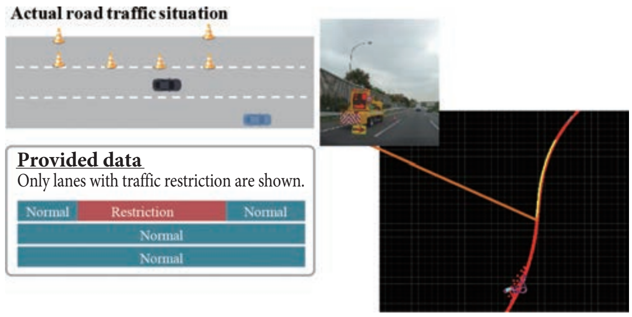


Fig. 11 Lane-Specific Restriction Information Display Example

3.3 Dynamic Information

A test system was created to test the use of traffic signal information and other information provided by advanced infrared beacons and ITS wireless roadside devices in dynamic maps. This test system was then provided to test participants. When participants passed intersections on actual roads, they received TSPS/DSSS information and evaluated the linking of static information and traffic signal and other information (see Fig. 12).

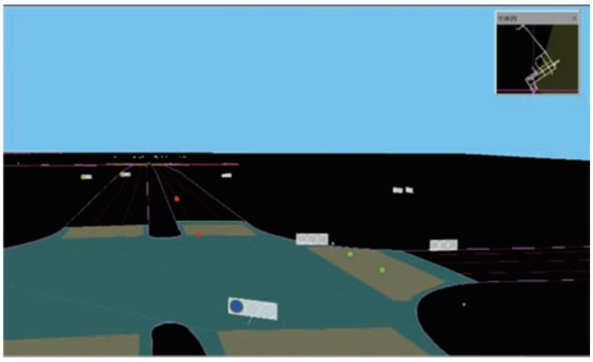


Fig. 12 Dynamic Information Display Example

4 Evaluation Results

Evaluations were performed on static information, semi-dynamic information, and dynamic information.

4.1 Static Information Evaluation Results

We determined that high-accuracy 3D map usage intent varied by automated driving level. We found that level 2 and higher automated driving systems used high-accuracy 3D maps, and that feature and attribute information usage intent for level 4 and higher automated driving systems varied by company. Table 5 shows the results of the static information evaluation.

Table 5 Static Information Usage Intent

Automated driving level	High-accuracy 3D map usage	Update frequency
Level 1	-	-
Level 2	✔	Data updated as necessary when incremental updates become available. Data updated roughly once every six months for batch updates.
Level 3	✔	
Level 4	✔ (includes competitive area elements)	
Level 5	✔ (includes competitive area elements)	

4.2 Semi-Dynamic Information Evaluation Results

(1) Traffic flow information evaluation results

We determined that traffic flow information usage intent varied by automated driving level. For level 3 and higher automated driving systems, some participants indicated that lane-level traffic flow information was necessary. Table 6 shows the traffic flow information evaluation results.

Table 6 Need for Traffic Flow Information

Automated driving level	Traffic flow information (road-specific)	Traffic flow information (lane-specific)
Level 1	✔	-
Level 2	✔	-
Level 3	-	✔
Level 4	-	✔
Level 5	-	✔

(2) Lane-specific restriction information evaluation results

We determined that lane-specific restriction information usage intent varied by automated driving level. For level 2 and higher automated driving systems, some participants indicated that lane-specific restriction information was necessary. Table 7 shows the lane-specific restriction information evaluation results.

Table 7 Need for Lane-Specific Restriction Information

Automated driving level	Lane-specific restriction information
Level 1	-
Level 2	✔
Level 3	✔
Level 4	✔
Level 5	✔

4.3. Dynamic Information

We determined that dynamic information usage intent varied by automated driving level. We also found that traffic signal information was required for all automated driving levels. We found that for level 1 and 2 automated driving, participants planned to use crosswalk pedestrian information and oncoming vehicle information as information for drivers, while for level 3 and above automated driving, the information was necessary for vehicle control. Table 8 shows the dynamic information evaluation results.

Table 8 Need for Dynamic Information

Automated driving level	Traffic signal information	Crossing pedestrian information	Oncoming vehicle information
Level 1	✔	-	-
Level 2	✔	-	-
Level 3	✔	✔	✔
Level 4	✔	✔	✔
Level 5	✔	✔	✔

5 Summary

Through the large-scale field operational test (dynamic maps), we designed test systems to link the dynamic map static information update data and static information necessary for automated driving systems with dynamic and other information, and collaborated with test participants to perform evaluations.

Based on the evaluation results, we created map updating guidelines. We also determined that information usage intent varied by automated driving level.

Our findings indicate that linking static information and other information can be effective in automated driving system vehicle control, and we verified dynamic map theory through actual field operational testing.

This research and development work was carried out with the collaboration of Program Director Seigo Kuzumaki, members of SIP-adus, the large-scale field operational test (dynamic maps) participants, as well as Dynamic Map Platform Co., Ltd., Mitsubishi Research Institute, Inc., Sumitomo Electric Industries, Ltd., and NTT DOCOMO, INC., which were involved in the preparation of test systems.

References

(1) Automated Driving System Map Data Specification Proposal Ver. 1.1 (2016)
(2) Automated Driving System Map Data Encoding Specification Proposal (Test Data Encoding Specifications) Ver. 1.0 (2016)
(3) Dynamic Map Semi-dynamic/Semi-static Information Data Specifications (Proposal) Ver. 1.0 (2016)
(4) Recommended Specifications for High-accuracy Maps Used for Automated Driving (November 2016, Japan Automobile Manufacturers Association, Inc.)
(5) Materials Related to New Advanced Digital Road Surface Information for Advanced Driving Support (Japan Digital Road Map Association)

About the author

1) Yoshiaki Tsuda is the chief engineer of the Information Technology Systems Department at Mitsubishi Electric Corporation’s Kamakura Works. He is engaged in research and development of social infrastructure systems such as ITS, DSRC, and high-accuracy 3D maps.

HMI

Keita Hosaka (Tokyoto Business Service Co., Ltd.), Makoto Itoh (University of Tsukuba), Toshihisa Sato (National Institute of Advanced Industrial Science and Technology), Satoshi Kitazaki (National Institute of Advanced Industrial Science and Technology)

ABSTRACT: In the HMI large-scale experimental demonstration, the results of research and development (knowledge and systems) are verified by corporate participation (in actual use). In FY 2017, a baseline for readiness was derived through public road experiments in which (1) the feasibility of driver monitoring systems (DMS) in the real world was verified, and (2) data with variability for use as a baseline in the readiness index was acquired. In FY 2018, the relationship between how and what information on system functions is conveyed to the driver and handover performance are being verified experimentally on a test course. Also, various controlled driver conditions, DMS output, and handover performance will also be verified experimentally on the test course.

1 HMI Large-Scale Experimental Demonstration

We conducted the experimental demonstration with enterprises as participants to verify the SIP-adus Human Factor deliverables (knowledge and system) in an environment closer to real-world situations. The data obtained was shared between the organizers and the participants, and will prove useful for further research and development by the individual companies. Furthermore, it is used as reference for "the JAMA HMI guidelines", "ISO TC22/SC39", and "UN-R79".

2 Large-Scale Experimental Demonstration in FY 2017 (Task B: Evaluation of driver condition, development of DMS)

2.1. Purpose

The FY 2017 experiment was conducted on public roads on to define driver readiness.

The purpose of the experiment was to derive the readiness component index during manual driving to serve as a baseline. The methodology for the experiment involved having each subject drive for about two hours in a vehicle equipped with the DMS prototype for commercial vehicles (manual driving) from the SIP large-scale experimental demonstration highway course. For the evaluation items, we analyzed the relationship between the DMS output and driving information to derive the baseline readiness index (Fig. 1).

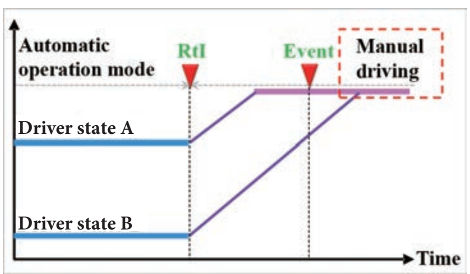


Fig. 1 Conceptual diagram of readiness

The baseline in the readiness index is considered to be variation in readiness during manual driving. Specifically it is necessary to consider internal driver factors driver attributes (age, sex, driving frequency, etc.), and driver state (presence or absence of focus on driving, drowsiness, fatigue) and external factors such as congestion or other road traffic environment changes and traffic environment complexity, and quantitatively verify the relationship between these values and the DMS output.

The research questions in "Evaluation of Readiness Component Indicators in Practical Use" are as follows.

RQ1: Does the relationship between driver condition (DMS output) and the surrounding environment monitoring behavior change during manual driving?

RQ2: Can the DMS detect changes in state based on the awareness of the driver?

2.2. Implementation Plan

The participating companies performed the five items below.

(1). Pre-experiment preparation state

(2). Preparation of vehicle used in the experimental demonstration

(3). Experimental demonstration

(4). Post-processing of vehicles used for the experimental demonstration (removal of equipment)

(5). Submission of experimental data

The experimental conditions are as follows.

- Experimental vehicle

  Manually operated commercial vehicles

- Subjects

  Each participating company selected nine or more people who, as much as possible, are average drivers (three aged from 20 to 39, three aged from 40 to 59, and three aged 60 or older).

- Route and driving time

A combination of two to three hours of long-distance highway driving defined in SIP experimental demonstrations and half-an-hour to one hour of highway driving around Tokyo was used. The order of the routes was balanced, and a break time was set for safety.

The items measured in the experimental demonstration are as follows.

- Driver, vehicle, traffic environmental data
  Vehicle (CAN) information, GPS information, video images around the vehicle
- DMS output
  Gaze, eyelid opening, blinking, saccades
- Other items
  Interviews concerning the driver's state.
  The staff member riding along observed and recorded the surrounding environment and equipment operation.

2.3. Outline of Implementation

The FY2017 large-scale experimental demonstration was conducted at six participating companies, with experiments carried out between November 2017 and March 2018 (Table. 1). There were a total of 61 subjects (50 male subjects (82%) and 11 female subjects (18%)). By age, 25 subjects (41%) were 20 to 39 years old, 24 (39%) were 40 to 59 years old, and 12 (20%) were 60 or older.

Table 1 Outline of implementation

Participating Companies	Total number of subjects	Running experimental period	Total distance
Company A	9	Nov. 27, 2017 to Dec. 8, 2017	About 2,241 km
Company B	20	Dec. 4, 2017 to Dec. 18, 2017	About 3,583 km
Company C	9	Jan. 19, 2018 to Jan. 26, 2018	About 2,225 km
Company D	9	Jan. 25, 2018 to Jan. 31, 2018	About 2,826 km
Company E	9	Jan. 31, 2018 to Feb. 22, 2018	About 2,066 km
Company F	5	Mar. 13, 2018 to Mar. 20, 2018	About 815 km
Total	61		About 13,756 km

2.4. Implementation Result

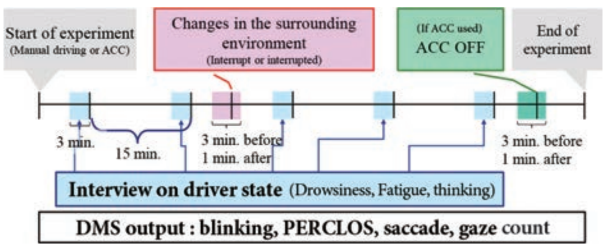


Fig. 2 Diagram of calculation of evaluation index

To verify the relationship between changes in driver condition or ambient environment and the DMS output, data was extracted and verified as shown in Fig. 2.

For the driver status, drowsiness, fatigue, and thinking were clearly ascertained from interviews at 15 minute intervals, and the relationship between the value and the DMS output was verified.

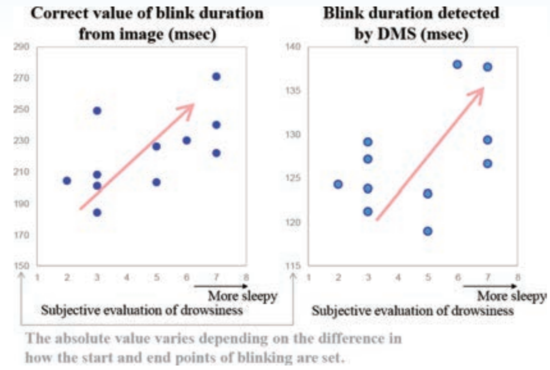


Fig. 3 Investigation of feasibility of DMS: blinking detection

In the context of studying the feasibility of DMS, we examined the relationship between the subjective evaluation of drowsiness and DMS output. Fig. 3 above compares the correct answer (graph on the left) calculated from images and the DMS output (graph on the right). Regarding the subjective evaluation of drowsiness, results with high correlation were obtained in 'blink duration' rather than 'PERCLOS'. A similar tendency was found in both the correct values from images and the data from the DMS output.

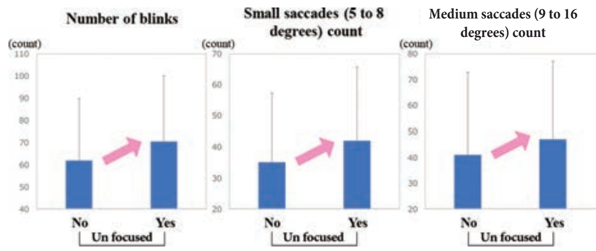


Fig. 4 Investigation of feasibility of DMS: detection of saccades

Next, we examined the relationship between thinking and DMS output. Fig. 4 above verifies the relationship of the DMS output (blink count, saccades (small), saccades (medium)) in terms of whether the driver is thinking or not. In the case of thinking (≒ conscious but exhibiting inattentiveness), it was confirmed form the DMS output that the number of blinks and the occurrence of smaller saccades increased.

From these results, the following findings were obtained.

- It was confirmed that the DMS operates in a real-world environment and detects the driver condition.
- Sufficient fluctuation (variation) in readiness was acquired as a baseline for the readiness index.

3 FY 2018 Large-Scale Experimental Demonstration (Task A: Study of prior driver knowledge and establish guidelines on system functions)

3.1. Purpose

Verify the relationship between how and what information on system functions is conveyed to the driver and handover performance (driver and vehicle behavior) in vehicles with automation corresponding to level 2 or 3. Specifically, we examine the usefulness about requests to intervene (RtI), the meaning of RtI indications, and examples of scenarios requiring intervention to achieve a proper handover.

3.2. Experiment Scenario

The subjects were separated into two groups with different prior knowledge (Table 2) and performed subtasks (SuRT) in the low speed range (approximately 30-50 km/h). An RtI was generated at the object avoidance event (TTC: 6 seconds), and the driver's behavior was measured.

Table 2 Two groups with different degrees of prior knowledge

	Group with little prior knowledge	A Group with a lot of prior knowledge
Common teaching	• Description of experiment contents • Explanation about automatic driving vehicle • Explanation of how to use the automatic driving vehicle system • Explanation of subtask during automatic operation	
Teaching of RtI	• Description of RtI	• Description of RtI • Explanation of display of RtI • Scenes where RtI occurs (3 scenes)

4 FY2018 Large-Scale Experimental Demonstration (Task B: Evaluation of driver condition, development of DMS)

4.1. Purpose

Verify the relationship between controlled driver states, DMS output, and driving handover performance in vehicles with automation corresponding to level 2 or 3. The controlled driver states are conscious but exhibiting inattentiveness, distraction, and drowsiness.

4.2. Experiment Scenario

For the conscious but exhibiting inattentiveness and distraction state experiments, the three sessions of manual driving, automatic operation only, and automatic operation with subtask execution were carried out. Subtasks implemented Nback (1 back, 2 back) for the conscious but exhibiting inattentiveness state and SuRT (difficult) for the distraction state. In the experiment, an RtI was generated before switching from automatic operation to manual driving (TTC: 6 seconds), and automatic operation (low speed) and subtasking were performed with a preceding vehicle present. The preceding vehicle changed lanes one second after the occurrence of the RtI, and the object avoidance behavior of the driver and the DMS output were measured (Fig. 5).

For the drowsiness state experiment, the two sessions of manual driving and automatic operation were carried out. The automatic operation (low speed) was performed with a preceding vehicle present. The RtI is generated 25 min after the start of driving, or when the examiner observing the subject determines that the driver alertness is decreasing. The preceding vehicle changed lanes one second after the occurrence of the RtI, and the object avoidance behavior of the driver and the DMS output were measured (Fig. 5).

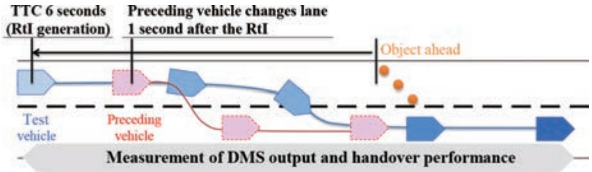


Fig. 5 Description of RtI event

5 FY 2018 Implementation Plan for Large-Scale Experimental Demonstration

In the large-scale experimental demonstration of FY 2018, experiments were carried out efficiently. The methodology involved participating companies selecting two either carry out the two tasks as a joint experiment or as separate experiments.

The experiment conditions were as follows.

- Automatic operation level of test vehicle
  Corresponding to level 2 (hands on the steering wheel) or level 3 (hands off the steering wheel)
- Experiment site
  Test course (company test course or shared test course)
- Subjects
  10 people or more

The items measured in the experiment are as follows.

- Vehicle behavior data and in-vehicle environmental data
- DMS output (Task B only)
- Questionnaire
  We conducted the questionnaire before and after the experiment.

6 Conclusion

In the FY 2017 experimental demonstration, (1) the feasibility of DMS in the real world was verified, and (2) data with variability for use as a baseline in the readiness index was acquired.

In the FY 2018 large-scale demonstration experiment, we sought to elucidate the following two points. The first (Task A) is the relationship between how and what information on system functions is conveyed to the driver during automatic driving and handover performance. The second (Task B) is the relationship between the controlled driver states and the DMS output, and the operation handover performance.

Information Security

Ken Okuyama (PwC Consulting LLC)

ABSTRACT: A field operational was conducted based on the information security evaluation method for vehicle systems established in FY 2017. In FY 2018, a larger scale information security field operational test will be conducted with an increased number of participants. The evaluation and implementation approach were reviewed and will be finalized as Information Security Evaluation Guidelines for vehicle systems.

1 Project Overview

The Cross-ministerial Strategic Innovation Promotion Program (SIP) Automated Driving System / Large Scale Field Operational Test: Information Security Field Operational Test conducted research and analysis on cybersecurity threats related to automated driving, developed a cybersecurity evaluation method/protocol at the vehicular level aimed towards international standardization and formulated a plan to conduct technical research through black box testing of the vehicle systems provided by the participants in the field operational test.

This document summarizes the details of the information security trial research conducted based on the information security evaluation method that was developed and the management of the field operational test.

2 Information Security Trial Research

2.1. Objectives and Scope

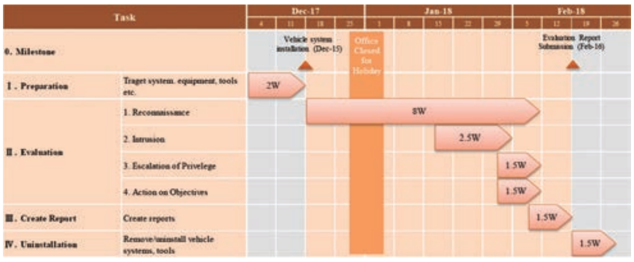
In the information security trial research, an evaluation was conducted for vehicle systems based on the evaluation method described in the draft of the Information Security Evaluation Guideline formulated in FY 2017.

Through the evaluation trial based on the guideline, the practicality and validity of the Information Security Evaluation Guideline was assessed. At the same time, vulnerabilities in the tested vehicle systems that could potentially lead to cyberthreats were tested from an attacker's viewpoint, and advice was given for any issues discovered that required remediation.

2.2. Evaluation Period and Schedule

The evaluation was conducted over eight weeks; from the setup of vehicle systems to be evaluated, to reporting the evaluation results. Within this period, seven weeks were spent on obtaining the firmware during the reconnaissance phase. Due to time constraints, only part of the work related to escalation of privileges and action on objectives were conducted.

Evaluation Period: 15th December, 2017 to 9th February 2018 (36 days)



2.3. Details of the Evaluation

2.3.1. Evaluation Items

The specific evaluation items covered in this project are listed in the table below. The evaluation items that were covered are marked with "○", items that were not covered because they did not fulfill the prerequisites are marked with "×", and items that were not covered due to lack of features or required applications are marked with "-".

Category1	Category2	Items	Coverage
1.Reconnaissance	1.1 HW Research	1.1.1 I/F research before device removal	○
		1.1.2 I/F research after device removal	○
		1.1.3 I/F research after chip removal	○
		1.1.4 Research on hidden I/F	✖
		1.1.5 I/F connection	○
		1.1.6 Binary extraction	○
		1.1.7 Binary protection feature confirmation	○
		1.1.8 Reverse engineering	○
	1.2 SW Research	1.2.1 Application communication channel research	○
		1.2.2 External vehicular Wi-Fi communication interception	○
		1.2.3 Internal vehicular Wi-Fi communication interception	-
		1.2.4 Bluetooth communication interception	○
		1.2.5 BluetoothLE communication interception	-
		1.2.6 TCU communication interception	-
		1.2.7 Browser, HTML engine research	-
		1.2.8 CAN message communication interception	-
		1.2.9 Application communication interception	○
2.Intrusion	2.1 Passive attack with user intervention	2.1.1 DrivebyDownload attack	-
		2.1.2 File attachment attack	-
	2.2 Passive attack without user intervention	2.2.1 Attack using automatic connection to external Wi-Fi	○
		2.2.2 Attack using fake server	○
		2.2.3 Attack using remaining development environment	○
	2.3 Active attack exploiting vulnerability	2.3.1 Attack via Bluetooth	○
		2.3.2 Attack via BluetoothLE	-
		2.3.3.Attack via TCU	-
		2.3.4 Attack via internal vehicular Wi-Fi	-
	2.4 Active attack using information obtained through communication interception	2.4.1 Spoofing attack	✖
		2.4.2 Replay attack	-
3. Escalation of Privelege	3.1 Circumvement of protection feature	3.1.1 Circumvement of code execution prevention feature	✖
		3.1.2 Circumvement of sandbox	✖
	3.2 Obtaining high privelege	3.2.1 Escalation of privelege by attempting known attack	✖
		3.2.2 Circumvement of forced access control (MAC)	○
4.Action on Objectives	4.1 Information leakage	4.1.1 Leakage of confidential information (sending to external)	✖
	4.2 Disruption of service	4.2.1 Disruption of vehicle service (feature)	✖
	4.3 Unauthorized operation (control related)	4.3.1 Falsification of firmware related to control	✖
		4.3.2 Malicious use of control features	✖
	4.4 Unauthorized operation (information related)	4.4.1 Falsification of application related to information	○
		4.4.2 Malicious use of features related to information	✖

2.3.2. Format of the Evaluation Report

The results of trial research were reported and covered the following items;

(1) Evaluation results
(2) Criticality
(3) Evaluation details
(4) Evaluation procedure
(5) Assumed risk
(6) Condition for successful attack
(7) Improvement plan

The criticality of the items was judged based on the following criteria:

· **High**

Cases where failing to remediate a discovered vulnerability could lead to a highly critical cybersecurity compromise that would severely impact business operations (e.g. product recall, disruption of business operations). In addition, the attack leading to the compromise does not require high technical capability or cost. Necessary measures such as vulnerability remediation must be implemented immediately.

· **Medium**

Cases where failing to remediate a discovered vulnerability could lead to a highly critical cybersecurity compromise that has considerable impact on business operations (e.g. significant deterioration of business performance). An attack leading to the compromise requires some degree of technical capability and cost. Implementing measures such as vulnerability remediation as necessary is recommended.

· **Low**

The discovered issue in the system does not have any immediate impact on cybersecurity, but implementing appropriate measures is expected to provide an improvement in the cybersecurity level. It is recommended to implement certain measures in the future.

· **Info**

The discovered issue in the system may have some impact on cybersecurity. It is recommended to consider implementing certain measures considered.

2.4. Summary of the Trial Research

Through the trial research, it was discovered that the reconnaissance phase of the developed evaluation procedure required a longer period than originally expected. This was recognized as an improvement point for the future management of field operational tests. Variation in evaluation results for multiple systems was also recognized as an issue to be addressed in future field operational tests.

The actual evaluation results will not be disclosed in this document as they contain highly sensitive information related to the tested systems.

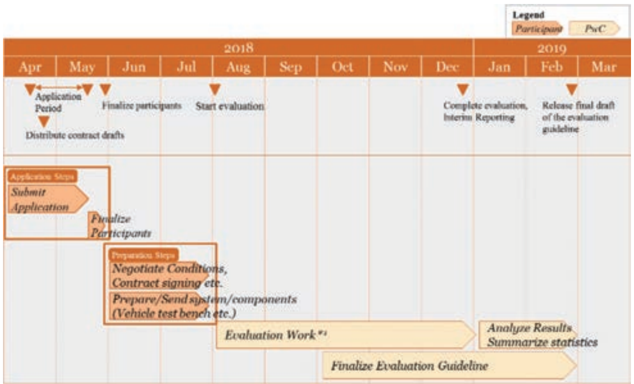
3 Management of Information Security Field Operational Test

The field operational test will be planned and managed taking into consideration the previously explained trial research results and with an increased number of vehicle systems to be evaluated.

3.1. Field Operational Test Management Plan

3.1.1. Field Operational Test Schedule

The schedule of the field operational test in FY 2018 is as follows:



*1 Evaluation work will be conducted for two months within the set period (August - December) for each participant.

3.1.2. Preparation for Field Operational Test

For the field operational test, participating companies were requested to provide the following items and/or services.

· Contract Phase

- Property loan agreement, non-disclosure agreement

· Items related to evaluation target system

- Vehicle system, vehicle system components, telematics service (ECU, service account, server, application)

· Preparation for evaluation work

- Set up of evaluation target system (initial connection, functionality check)

3.1.3. Confidential Information Handled in Field Operational Test and Scope of Disclosure

Scope of disclosure for the confidential information handled in the field operational test was restricted as shown in the following table. PwC and the individual participants shall sign a non-disclosure agreement to apply and ensure stricter confidentiality management.

Category	Item	Details	Author	Scope of disclosure			
				Participants	NEDO (Obligation for non-disclosure)	Program Director or other related parties of SIP-adus (Obligation for Non-disclosure)	No restriction (Publicly Disclosed)
Project Status	1. Names of Participants	Status of applications by candidate companies to participate in the field operational test	PwC	○ (Only total number of participants for other companies)	○	✖ (Only total number of participants)	✖
	2. Detailed Information of each Participants	Specific requirements, contractual conditions etc. for each companies applied to participate in the field operational test	PwC	○	✖	✖	✖
	3. Anonymous status of progress of each participants (For reporting to related Working Groups etc.)	Status on progress of preparation for the evaluation (contract signing etc.). Company names will be made anonymous.	PwC	○	○	○	✖
Evaluation Target System	4. Vehicle System / Components	Vehicle system and components to be evaluation	Partici-pants	○/ PwC	✖	✖	✖
Evaluation Method	5. Specific Evaluation Method for each Participants	Create, summarize and share evaluation method specific to each vehicle system as necessary	PwC	○	✖	✖	✖
	6. Evaluation Guideline (Final Version)	Evaluation guideline reflecting the results of the field operational test	PwC	○	○	○	○
Evaluation Results	7. Evaluation Report (Company specific)	Report summarizing the evaluation results including, - Details of the evaluation procedure including the technologies and equipment used, - Details of the evaluation result (highly sensitive as it may contain vulnerability information)	PwC	○	✖	✖	✖
	8. Summary Report (Statistics of the evaluation results)	Field operational test results, feedbacks from the participants on the project etc. modified for public disclosure.	PwC	○	○	○	○

3.2. Reviewing the Evaluation Method

As previously mentioned, several issues were found through the trial research and the evaluation method for the field operational test was reviewed to reflect the necessary improvements.

3.2.1. Review of Evaluation Method in the Reconnaissance Phase

The reconnaissance phase, which turned out to be the most time consuming phase of the trial research, was reviewed as follows:

- Hardware reverse engineering work will be contracted to a third party vendor with specialized skills and timing will be concentrated in the initial period of the phase. This will allow the reconnaissance phase to be completed in four weeks (one month).

3.2.2. Review Evaluation Method in the Intrusion Phase and Onwards

The intrusion phase was reviewed so that a deep-dive into the procedures from intrusion to action on objectives phase will be performed based on the following prioritization.

- Priority

1. Active attacks through cellular network
2. Passive attacks through cellular network
3. Active attacks through Wi-Fi
4. Passive attacks through Wi-Fi
5. Active attacks through Bluetooth
6. Passive attacks through Bluetooth

Intrusion will be attempted using all attack methods against all external communication interfaces within the standard evaluation period of one month. The escalation of privilege and action on objectives phases are evaluated after successful intrusion into the vehicle embedded system. Therefore, it can be assumed that a successful intrusion through one external interface produce the same results for the other interfaces.

3.3. Planning of Evaluation Guideline Update

Through the management of the field operational test, the evaluation guideline is to be finalized as follows:

3.3.1. Implementation of Threat Analysis

The field operational test aims to evaluate the robustness of the vehicle systems against attacks from three communication interfaces: cellular, Wi-Fi and Bluetooth.

Alternatively, as the number of target areas for the penetration tests to be conducted within a limited timeframe is expected to increase in the future, threat analysis will be integrated into the evaluation guidelines in order to enable prioritization of the targets.

3.3.2. Refinement of Evaluation Criteria

The evaluation criteria and the elements used as input for the evaluation are defined as follows to ensure a reproducible evaluation method.

(1) Evaluator Skill

Identify necessary skills of an evaluator. Self-check shall be conducted by the evaluator, then cross-checked by the responsible manager.

(2) Procedures based on Guideline Evaluation Items

Clarify procedures described in the guideline. Based on work evidence and results, evaluate that each evaluation items were conducted with minimal variation.

(3) Evaluation Workload

Set the standard evaluation period at two month (forty working days) with two staff members and perform the evaluation accordingly.

Manage the field operational test based on this set evaluation workload and evaluate the validity of the elements through the test results, to reflect any necessary improvements into the evaluation guideline.

4 Conclusion

In the Information Security Field Operational Test, a penetration test will be conducted based on the vehicle cybersecurity evaluation method that was developed.

Based on the test results, the Information Security Evaluation Guideline will be summarized to contribute to the standardization of the penetration testing method for vehicle security evaluations.

About the author

1) Ken Okuyama, Technology Consulting Manager, Cybersecurity, PwC Consulting LLC

Pedestrian Collision Reduction

Kosuke WATABE (Nippon Koei Co., Ltd.)

ABSTRACT: The goal of this project is the reduction of pedestrian collisions. For this purpose, various demonstration experiments with attention evaluation tools were conducted using communication technology (V2P). In the demonstration experiments, functionality and effectiveness were verified under the actual traffic conditions, and the impact of promoting the social value of the provided service was examined. The service transmits alerts, conveys information, and provides notifications of the presence of an intersection between cars and pedestrians, and was assigned a certain evaluation. This report presents the overall process and the results of the project for the two years of FY 2017 and FY 2018.

1 Introduction

This research aimed to demonstrate the effectiveness of pedestrian collision reduction support technologies under actual traffic conditions, and to achieve the promotion of social value for said technologies by carrying out verification tests and validations of mutual warning functions in portable devices that incorporate vehicle-to-pedestrian (V2P) communication technologies, high precision pedestrian positioning technologies, and action prediction technologies. Systems using these technologies provide services such as transmitting alerts, conveying information, and providing notifications of the presence of an intersection.

This is a two-year project running from FY 2017 through FY 2018. In order to determine the effectiveness of the V2P technologies and the issues to solve, we are conducting several experiments and considering measures in scenarios where the technology is effective at reducing pedestrian accidents.

Experiments to examine the reliability of V2P devices were carried out during FY 2017. In FY 2018, a survey was conducted among the public, and the effectiveness of the devices was evaluated and verified in scenarios requiring support.

V2P assistive technology was applied separately to the developed products (mobile terminals) of the counterparts involved, based on the assumption that two-way communication was established between the service for pedestrians and in-vehicle devices.

2 Project Process

2.1. Preparation for Experiments

The first step of this project was to examine the reliability of V2P devices, and we started by designing experiment plans. To conduct experiments effectively, various scenarios were introduced and divided into two categories, A) scenarios requiring support and B) scenarios not requiring support. Category A) consists of five scenarios: (A1) pedestrian crossing an uninterrupted road section, (A2) crossing an intersection with poor visibility, (A3) right turn at an intersection (both with and without traffic signals), (A4) left turn at an intersection (both with and without traffic signals), and (A5) roads without sidewalks **(Fig. 1)**. Category B) also consists of five scenarios: (B1) inside a vehicle, (B2) inside a building, (B3) on a pedestrian footbridge, (B4) on a sidewalk, and (B5) on or below an elevated structure **(Fig. 2)**.

The experiment area must have enough space to allow us to conduct the experiments for all scenarios safely. For that reason, Odaiba and Ariake in Tokyo were the final choice.

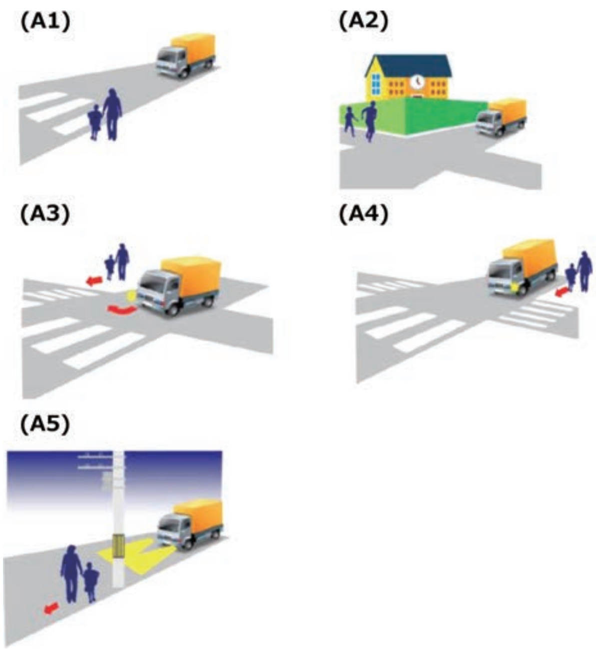


Fig. 1 (A) Five scenarios requiring support.

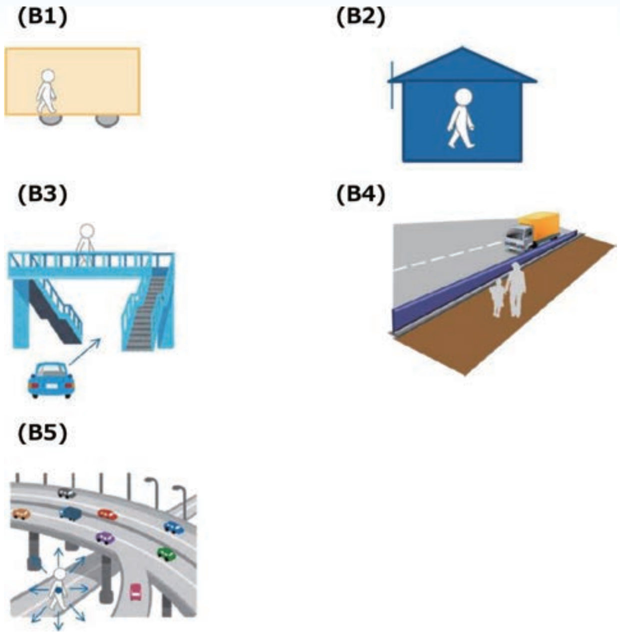


Fig. 2 (B) Five scenarios where support is not required.

Experiment plans were established as laid out below to establish assessment methods for objectively and quantitatively verifying whether the provision of information to both pedestrians and vehicles allowed each of them to avoid danger.

· Evaluation by check sheet
· Construction of a visualization system and database with which to evaluate collected data and logs

2.2. Experiments for Reliability of Devices

The experiments were carried out from February 13 to 15, 2018 with 2,604 samples collected for ten scenarios in 14 locations. A total of 150 people, including the testing staff, participated.

In the experiments, V2P communication systems were operated. These systems are composed of pedestrian devices **(Fig. 3)** and in-vehicle devices. The goals of these experiments were to achieve a correct device operation ratio of more than 80% for the scenarios requiring support, and an incorrect operation ratio of less than 20% for the scenarios where support was not required.

Pedestrians and drivers with the appropriate devices passed through each scenario, and we examined how correctly each device operated. A shotgun method was introduced in order to gain reliable sampling effectively. In addition, condition verification, trend analysis, and factorial analysis were carried out on the log data. The experiments were carried out in the same location for the same scenario multiple times, taking dependence on the surrounding environment into account, to achieve the target number of samples.

Fig. 3 V2P communication system used for verification.

2.3. Evaluation of Devices

The results of the experiments show the goals were mostly achieved **(Figs. 4 and 5)**.

The correct operation ratios in scenarios A1) and A2) tended to be slightly low. There was some excessive detection and other issues involving notification transmission and reception methods at intersections, and there is still room for improvement in the information notification methods.

In the scenarios in which support was not required, the

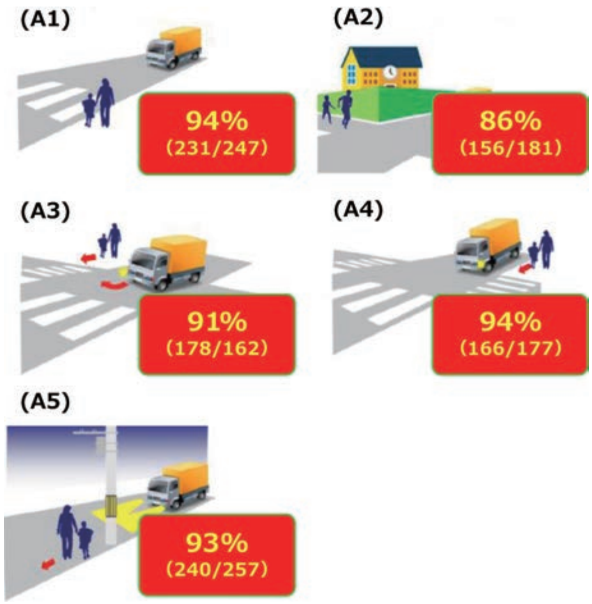


Fig. 4 Results of scenarios requiring support.

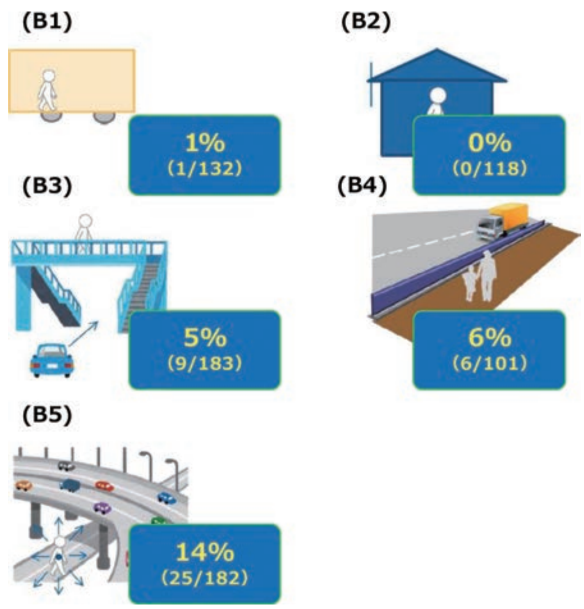


Fig. 5 Results of scenarios where support was not required.

ratio of incorrect operations was high in the scenarios related to altitude such as (B3) pedestrian footbridges and (B5) on or below elevations, with information notifications being unintentionally sent and other issues. This was attributed to the fact that the high bridge is a slope structure, and it was inferred that there was a case that it matched after altitude detection

The problems and tasks were identified for the next verification.

We also studied whether or not it would be possible to secure data by having pedestrians walk freely and undirected throughout an area for the main verification (survey), but this was found to be extremely difficult.

2.4. Experiments for Examining Behavior Change

Demonstration experiments based on general monitor tests were conducted from 22 to 23 July 2018 and in mid-November 2018.

In these experiments, we analyzed what changes in action and consciousness are observed when information such as alerts is provided to pedestrians and drivers in scenarios that require support. In scenarios A1 and A2, where many accidents between vehicles and other road users occur, experiments were also conducted in cases where no information was provided.

Since these types of accidents are common in children (especially 7 years old boys) and elderly people, we classified them as children (lower grade), adults, elderly people (65 years old and over), and carried out an evaluation demonstration experiment with thorough safety measures.

(1) Verification using test course

Using the JARI test course, we verified behavior change in a situation where the pedestrian and the vehicle approached a scene where there were many pedestrian accidents.


(A1)


(A2)

Fig. 6 Validation of behavior change (**A1, A2**).

Forty-eight pedestrians and 32 drivers cooperated in the experiments.

The car was driven at 50 km/h, and 30 km/h for Case A1 (crossing on a single road), and 30 km/h for Case A2 (intersection outside the line of sight), with the pedestrian walking at a normal pace in accordance with the approach of the car were the conditions applied.

In pedestrian experiments, the frequency of visual confirmation increased in cases where information is provided, and the average time to behavior change (stopping) tends to be longer when it is not provided. This was not limited to a particular age group, but was constant, with an especially large difference observed in the elderly (Fig. 7).

In contrast, in the experiments with drivers, the behavior leading to deceleration changed in all age groups.

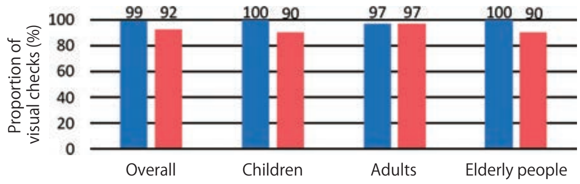


Fig. 7 Verification of pedestrian behavioral change (**A1**).

(2) Validation on public road

As in (1), the Odaiba district was used as a test site, with XXX pedestrian monitors and XXX driver monitors participating in a scenario requiring support. In a scenario where information provision is required, the monitor experiences a situation where the pedestrian and vehicle encounter one another. After that, we assessed the situation using log and camera data, and also conducted a questionnaire on the evaluations, tasks and requests concerning information provision, to examine the effectiveness of the system.

3 Conclusion

This study has made it possible to evaluate that providing information such as alerts via V2P two-way communication is effective for both pedestrians and drivers. In addition, there were needs and issues related to terminal requirements (functional requirements, requirements for weight reduction required for portability) and behavior changes. It would be greatly fulfilling if the results obtained in this research proved useful for the social implementation of this system.

① Large Scale Field Operational Tests

Advanced Rapid Transit

Daisuke Oshima, Akira Mitsuyasu, Takane Imagawa (Pacific Consultants Co., Ltd.)
Junko Ushiyama, Chiemi Tsuchiya, Masao Yamamoto (Hitachi, Ltd.)

ABSTRACT: A large-scale field operational test on the introduction of advanced rapid transit (ART) will be conducted with the aim of developing a public transportation system that is convenient and easy to use for various users, including the elderly and people with disabilities. Specifically, there are plans to: verify the effectiveness of advanced public transportation priority systems (PTPS) to reduce the time required for ART, verify the precise docking control system at bus stops to provide safe and quick boarding and alighting for all passengers, verify the effectiveness of the route map and guide information created by aggregating and integrating barrier-free information collected from people with restricted access to transportation and other people, as well as the provision of congestion forecasts by station and time based on the results of analyzing congestion around stations near a venue when events are held. A field operational test on the ART Information Center function as the foundation for realizing services utilizing ART-related information as well as organic and flexible cooperation of ART systems by collecting, managing, and providing various traffic information is also included in the plan.

1 Overview

A large-scale field operational test on ART is being carried out on the five elemental technologies (ART swiftness based on utilization of advanced PTPS, precise docking control at bus stops, ART movement support system for people with restricted access to transportation, guidance for congestion prediction and avoidance, and ART Information Center function) in order to verify the effects of the technologies developed.

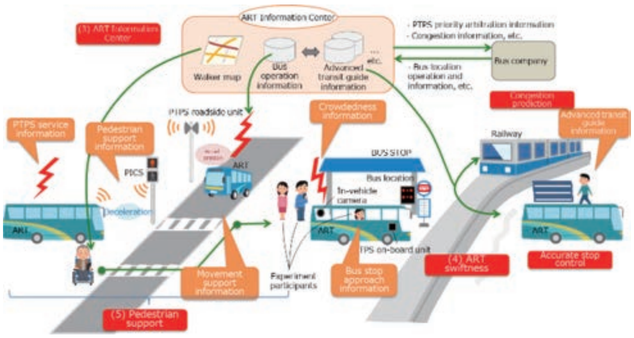


Fig. 1 Visualization of advanced rapid transit development

2 Improvement of ART Swiftness through Advanced PTPS

2.1. Purpose of test

In the context of the development of Advanced PTPS, this test verifies the extent to which advanced PTPS, which detects the approach of vehicles at an intersection and controls the priority signal accordingly, and priority arbitration for multiple vehicles simultaneously approaching an intersection, improve the swiftness of ART. In addition, this test also examines the interface that informs the bus driver of the priority status of the driver's vehicle.

2.2. Overview of test

The implementation period, place, and other details of the field operational test are shown in Table 1 and Fig. 2.

Table 1 Overview of advanced PTPS field operational test

Implementation period	Scheduled for three weekdays during the week starting November 26, 2018
Place	Tokyo Ring Road No. 2 (from Toyosu Market Entrance to Ariake Station area) (See Fig. 2)
Vehicles	Two buses (of route bus size)

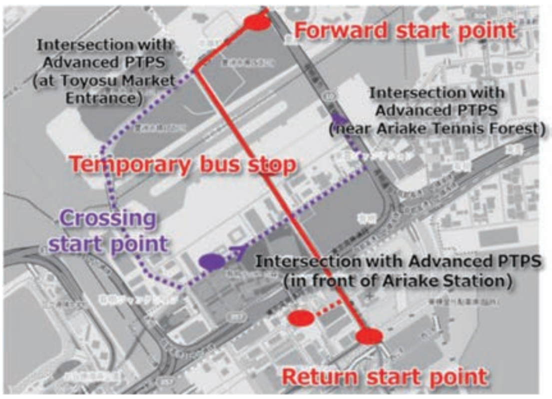


Fig. 2 Traveling route of advanced PTPS field operational test vehicles

2.3. Verification items

(1) Verification of the effect of advanced PTPS on bus operation.
(2) Verification of priority arbitration when two buses with routes that cross simultaneously approach an intersection.
(3) Verification of HMI.

3 Sensing and Control technologies Related to Precise Docking Control in Advanced Rapid Transit System

3.1. Purpose of test

This test verifies issues in the practical application of the precise docking control system based on the integration of sensing technologies such as vehicle position detection, and vehicle control technologies such as braking and steering.

3.2. Overview of test

The implementation period and other details of the field operational test are shown in Table 2 and Figure 3.

Table 2 Overview of verification test of precise docking control

Implementation period	Scheduled for about four weeks of weekdays from late November to late December 2018
Place	See Fig. 3

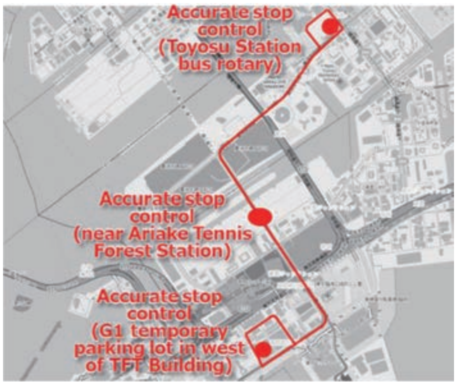


Fig. 3 Traveling route of precise docking control field operational test vehicle

3.3. Verification items

(1) Confirmation and verification of issues under real-world conditions

This test confirms and verifies various issues under various road, traffic, and communication environments by performing precise docking control on public roads and at bus terminals.

(2) Verification of ease of boarding and alighting between platform and bus

This test also verifies how precise docking control affects the ease of boarding and alighting for passengers when the height difference and gap between the ground and the step of the bus are reduced by placing a temporary platform on the sidewalk.

Fig. 4 Scenes of precise docking control

4 Pedestrian Support System

4.1. Purpose of test

4.1.1. Field operational test on provision of bus boarding information

This test examines the effectiveness of the public transportation transit guide, bus boarding guide, and crowdedness information provided as a service by the ART Information Center function.

4.1.2. Field operational test on route guidance according to individual characteristics

This test evaluates the usefulness and acceptability of the route guidance according to individual characteristics for a wide variety of users including people with restricted access to transportation through a personal navigation app utilizing information (common infrastructure information) necessary for movement, collected in FY 2017.

4.2. Overview of test

4.2.1. Field operational test on provision of bus boarding information

The implementation period and other details of the field operational test are shown in Table 3 and Fig. 5.

Table 3 Overview of field operational test on provision of bus boarding information

Implementation period	Scheduled for 5 days between October 1 and 10, 2018
Place	See Fig. 5
Participants	Several people out of about 20 people with restricted access to transportation for each day

Fig. 5 Route of field operational test on provision of bus boarding information

4.2.2. Field operational test on route guidance according to individual characteristics

The implementation period and other details of the field operational test are shown in Table 4.

Table 4 Overview of field operational test on route guidance according to individual characteristics

Implementation period	Scheduled for 5 days between October 15 and 30, 2018
Place	Toyosu Station area (Toyosu Station -> (virtual) friend's home)
Participants	Several people out of about 20 people with restricted access to transportation for each day

4.3. Verification items

4.3.1. Field operational test on provision of bus boarding information

This test uses questionnaires to verify the usefulness of providing public transportation-related information, such as transit guide information and boarding/congestion notification information while moving between Toyosu and Ariake using public transport including assumed ART buses.

4.3.2. Field operational test on route guidance according to individual characteristics

The prototype personal navigation app displays route search results according to the characteristics of the various users, including people with restricted access to transportation, and provides route guidance. This test verifies the acceptability of the route guidance according to individual user characteristics by asking people with restricted access to transportation to move around Toyosu Station while carrying a smartphone with the personal navigation app installed.

5 Guidance methods for predicting and avoiding congestion

5.1. Purpose of test

Looking ahead to the Tokyo Olympic and Paralympic Games, this test examines the method of providing congestion avoidance guidance by offering appropriate information according to individual attributes and scenarios, on the basis of the application of dynamic congestion prediction and human behavior modification processes in collaboration with the ART Information Center function. This field operational test provides information on large-scale events and verifies the effectiveness of the method through questionnaires.

5.2. Overview of test

The field operational test is conducted using the Sumida River Fireworks Festival and Jingu Gaien Fireworks Festival as large-scale events that attract hundreds of thousands of visitors. Specifically, congestion prediction information and congestion avoidance recommendation information are provided to visitors using the existing route search sites or the app (see Fig. 6). The congestion prediction information provides real-time information on the degree of congestion (such as congestion forecasts by station and time) based on the route search history. The congestion avoidance recommendation information suggests ways to avoid the congestion, such as "come to the venue earlier" and "get off the train at another station and walk a little."

Fig. 6 Example of providing information in field operational test (app information screen)

5.3. Verification items

This test conducts a web-based questionnaire for app users in order to verify the effectiveness of efforts to promote behavior modification of visitors by providing information. Specifically, this test shows the effectiveness of providing information, such as the percentage of visitors who have changed the stations or railway lines they use or the time they leave home to visit the event.

5.4. Results of verification

The tabulated questionnaire results show that about 90% of respondents who viewed the provided information answered that the information was useful, and about 20% of them answered that they had modified their original planned route. In addition, another 40% or so of respondents answered that they made a decision after reading the articles because they originally had not decided how to go to the venue, which indicates the usefulness of the provided information.

6 Functions of ART Information Center

6.1. Purpose of test

The ART Information Center plays the function of information linkage in the above-mentioned large-scale field operational test on the improvement of ART swiftness based on utilization of advanced PTPS and of the pedestrian support system (see Fig. 7).

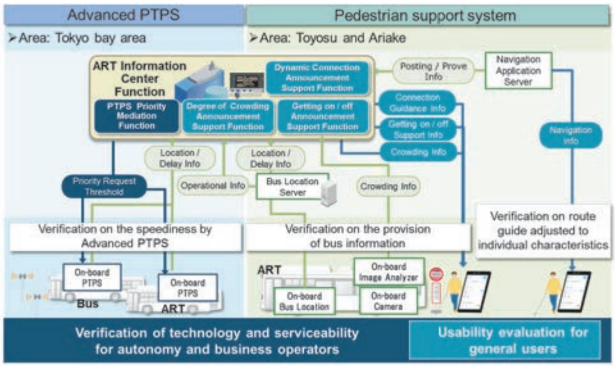


Fig. 7 Visualization of operations of ART Information Center function

6.2. Overview of test

The implementation period and other details of the field operational test are shown in Table 5.

Table 5 Overview of field operational test on functions of ART Information Center

Implementation period	October to November 2018
Place	Toyosu/Ariake area
Data collaboration destination	PTPS on-board unit, on-board video analyzer unit, bus location server, and navigation app server

6.3. Verification items

Two demonstration confirm that the functions of the ART Information Center function, including the PTPS priority arbitration function and boarding information support function, work without any problems and while providing useful information.

Feasibility Study of Advanced Automated Driving System for Public Buses in Okinawa

Takayuki Ando (Advanced Smart Mobility Co., Ltd.)

ABSTRACT: In Okinawa, traffic jams are a serious social problem that should be resolved, and there are high expectations for the development of an advanced rapid transit (ART) system using automated driving technology. This feasibility study aimed to resolve various technological- and service-related issues to facilitate the introduction of an automated ART driving system in Okinawa. Although this study found that some functions of the proposed system were feasible, such as lane keeping, velocity, approach, and lane change controls, it also found that higher recognition capabilities and higher control accuracy will be necessary before a level 4 or 5 driverless automated driving system can be adopted. In addition, issues related to cost, laws, infrastructure, and support for disabled people will also have to be resolved before this system is ready for introduction.

1 Traffic environment in Okinawa

Traffic jams in Okinawa have become a serious social problem that should be resolved. Okinawa has no railways except a monorail and the utilization rate of public transportation is extremely low(1). At the same time, car ownership has been increasing and more tourists are borrowing rental cars. In this situation, there are high expectations that an advanced rapid transit (ART) system using automated driving technology can promote the use of public transportation.

2 Experimental Conditions

2.1. Aim

The main aim of this study was to clarify potential issues created by the future introduction of automated buses in Okinawa, by examining the feasibility and acceptance of technologies, such as lane keeping control, velocity control, object detection and avoidance, approaching control, remote monitoring, and the like.

2.2. Vehicle

The small bus shown in Fig. 1 was remodeled into an automated driving bus. A steering motor was mounted on the column shaft, acceleration was automated by voltage inputs to the engine ECU, and deceleration realized by controlling the pneumatic pressure. RTK-GPS and magnetic sensor were used for localization. LiDARs, cameras, and radar were used for detection.

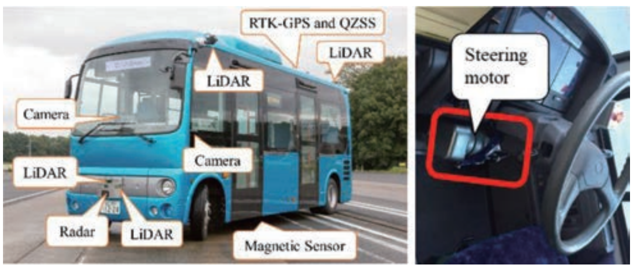


Fig. 1 Automated Driving Bus

2.3. Course

Figure 2 depicts the course of the experiment, which was conducted in Ginowan city and Kitanakagusuku village in December 2017. The length of this course is 20 km, and it includes Route 58 which is the main road on the island of Okinawa. Another experiment was conducted in Nanjo city in March 2017.

Fig. 2 Map of the Experiment Course

3 Specification and Experimental Results

3.1. Object Detection

The automated bus detected objects using LiDARs, cameras, and radar, as shown in Fig. 3. The types of objects, such as cars, bicycles, and pedestrians were identified using AI. As shown in Fig. 4, road maps were used to distinguish objects in the same lane of the bus from those in other lanes. These methods reduced the non-detection and misdetection of objects.

② Regional Tests

Feasibility Study of Advanced Automated Driving System for Public Buses in Okinawa

Fig. 3 Object Detection Using Sensors

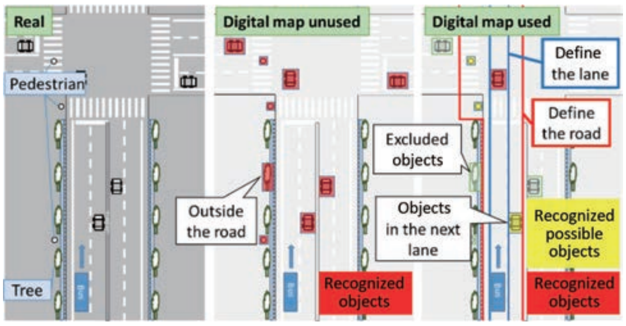


Fig. 4 Distinguishing Objects Using Road Maps

3.2. Lane Keeping Control

Lane keeping control adopted path following control(2). Figure 5 defines errors in the lateral position and yaw angle of the vehicle from the reference path. The lateral position and yaw angle were measured using RTK-GPS and the error was calculated as follows.

$$e_y = -(X - X_r)\sin\theta_r + (Y - Y_r)\cos\theta_r \quad (1)$$

$$e_\theta = \theta - \theta_r \quad (2)$$

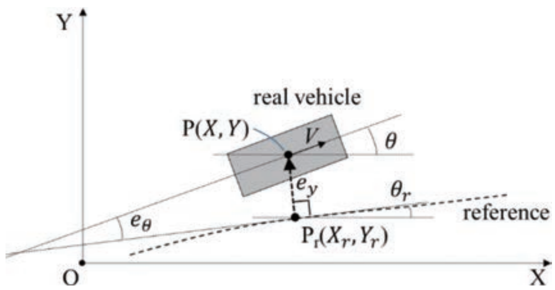


Fig. 5 Definition of Error

In Fig. 6, δ is the steering wheel angle calculated and directed by the lateral position and yaw angle feedback control. K_y and K_θ are the feedback gain of this controller, and $G_{y,\theta}$) is the transfer function of the vehicle.

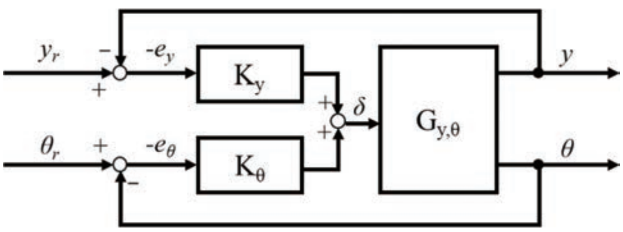


Fig. 6 Lateral Position and Yaw Angle Feedback Control

Figure 7 defines the error in the lateral position when lane keeping control is active. It shows an error of within ±0.2 m, which indicates that the bus does not deviate from its lane.

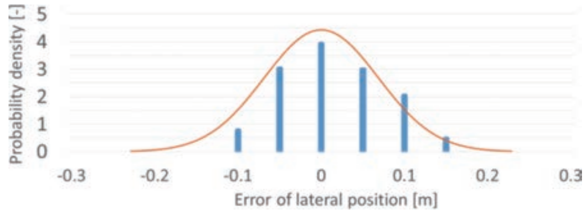


Fig. 7 Lateral Position Error

3.3. Approach Control

To make it easier for passengers to get on and off, the bus must stop closely and accurately to the bus stop. Bus stop approach control using sensors such as a LiDAR, magnetic sensors, and RTK-GPS was trialed as shown in Fig. 8.

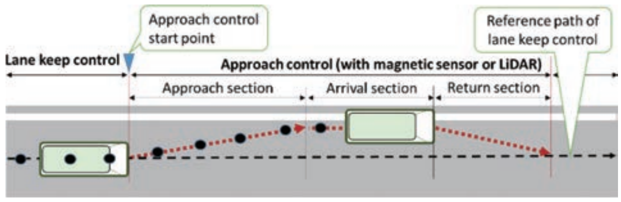


Fig. 8 Approach Control to Bus Stop

The experimental results in Fig. 9 show that the distance between the curbstone and the bus was within 4.0 cm ±2.0 cm when the automated system uses LiDAR for curbstone detection.

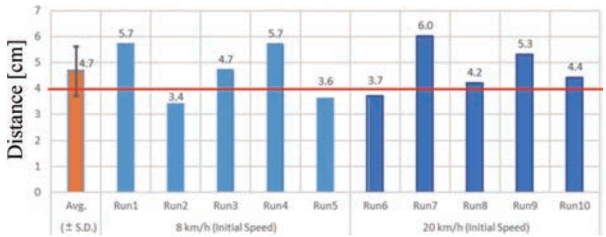


Fig. 9 Distance between Curbstone and Bus

3.4. Object Avoidance and Lane Change Control

Figure 10 shows the object avoidance and lane change control procedures when preparing to change lanes to the right.

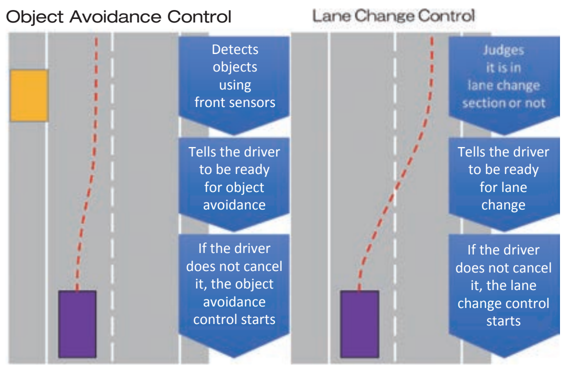


Fig. 10 Object Avoidance and Lane Change Control

The experiment found that it is difficult to change lanes when the road is crowded or the speed of the bus is much lower than other vehicles.

3.5. Velocity Control

Acceleration and deceleration commands are calculated by a velocity controller that generates a reference velocity in real time. When the bus detects an object in front of it, such as a vehicle stopped at a red light, adaptive cruise control (ACC) decelerates the bus as shown in Fig. 11.

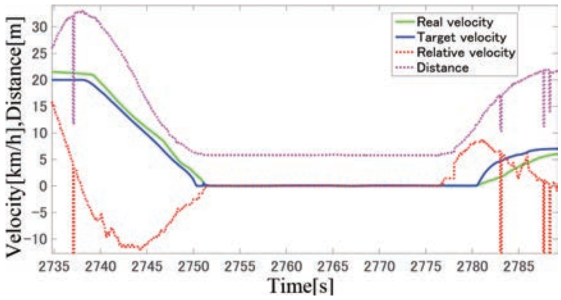


Fig. 11 ACC Results

3.6. Remote Monitoring System

The system allows a remote observer to check the vehicle position, speed, state, and whether an error has occurred. The observer can stop or start the vehicle by watching live videos taken by cameras inside and outside the vehicle.

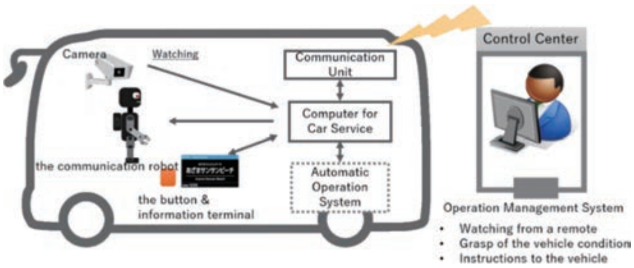


Fig. 12 Remote Monitoring System

3.7. Questionnaire results

Passengers became more positive about riding an automated bus than before the test ride. However, they identified many issues to be resolved before such a bus could be introduced, such as cost, laws, infrastructure, support for disabled people, safety, and the like.

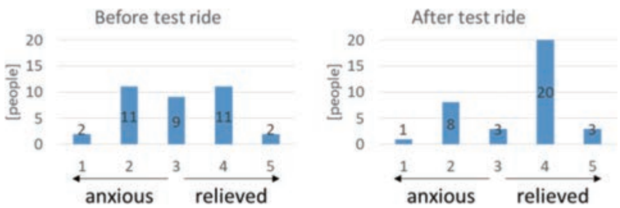


Fig. 13 Questionnaire Results

Many business operators answered that a level 2 or 3 automated driving system had few merits since the lower labor costs of a fully automated system would be necessary to pay for the introduction of the automated driving system.

3.8 Override

Unexpected steering overrides occurred 2.3 times and brake overrides occurred 4.0 times per 20 km on average. Figure 14 depicts a steering override case, in which a large bus had stopped on the bus route and there was small space to avoid it. Higher recognition capabilities and higher control accuracy are needed for a level 3, 4, or 5 automated driving system.

Fig. 14 Case of Steering Override

4 Conclusion

Although many issues related to technologies and services remain before an automated ART system can be introduced in Okinawa, some of were resolved in this feasibility study. Higher recognition capabilities and higher control accuracy are necessary requirements for a level 4 or 5 driverless automated driving system. In addition, issues related to cost, laws, infrastructure, and support for disabled people will also have to be resolved before this system is ready for introduction.

References

(1) The Japan Times: Okinawa set to launch first railway project, https://www.japantimes.co.jp/news/2014/02/20/national/okinawa-set-to-launch-first-railway-project-to-ease-chronic-traffic-jams, (February 20, 2014).

(2) T. Fukao et al.: Preceding Vehicle Following Based on Path Following Control for Platooning, Proceedings of IFAC AAC (2013).

About the author

1) Takayuki Ando, Assistant Manager, Control Development, Engineering Div., Advanced Smart Mobility Co., Ltd.

② Regional Tests

Field Operational Tests for Automated Driving Systems in Rural Areas

Ministry of Land, Infrastructure, Transport and Tourism Road Bureau ITS Policy and Program Office

ABSTRACT: Due to the progressive aging of the population in Japan in recent years, ensuring means of transportation in rural areas has become a pressing problem. In the cross-ministerial Strategic Innovation Promotion Program (SIP), field operational tests (FOTs) have been conducted for automated driving services (ADS) in rural areas where the aging of the population is progressing with particular rapidity, using roadside rest areas (called "Michi no Eki" in Japanese). These tests have been conducted nationwide since September 2017, and tests were performed in 13 locations during FY 2017. The tests are verifying the effects of ADS on road transportation in anticipation of their fully fledged introduction, as well as social acceptance, benefits to the community and so on. The test results verified that ADS could successfully and smoothly navigate even steep winding roads in mountainous areas, even when there was snow on the road. However, the test results also identified issues such as parked vehicles on the road and vehicles coming from the opposite direction. The tests also showed that participants have high expectations of ADS, felt that ADS is considerably reliable, and that the introduction of these services would have a substantial beneficial impact on communities. SIP will continue to work toward the introduction of ADS in rural areas.

1 Background

The aging of society is progressing much more rapidly in rural areas than in the nation as a whole. The aging of the population in these areas is thought to be roughly ten years ahead of the national average, with an aging index of 31% in 2010 compared to the national average of 23%. In addition, the total length of bus routes that were abolished nationwide from FY 2007 to FY 2015 comes to 13,000 km, forty percent of truck drivers are 50 years of age or older, and in 2017 alone, the number of people aged 65 or older who voluntarily surrendered their driver's licenses came to 400,000. This is around 17 times the number (approximately 20,000) who did so in 2007.

Amidst these trends, around half of all rural residents aged 75 or older leave the house less frequently after voluntarily surrendering their driver's license. Presumably these senior citizens have fewer opportunities to leave their homes and go to places that they would ordinarily frequent, such as supermarkets and other commercial facilities, hospitals, local authority offices and financial institutions.

Roadside rest areas (called "Michi no Eki" in Japan) have been constructed in 1,145 locations nationwide as of April 2018. Eighty percent of these are located in rural areas. Thirty-nine percent are located within one kilometer of a hospital or clinic, and 35% are located within one kilometer of a facility that offers public services. Forty-four percent have bus stops for express buses, route buses, and on-

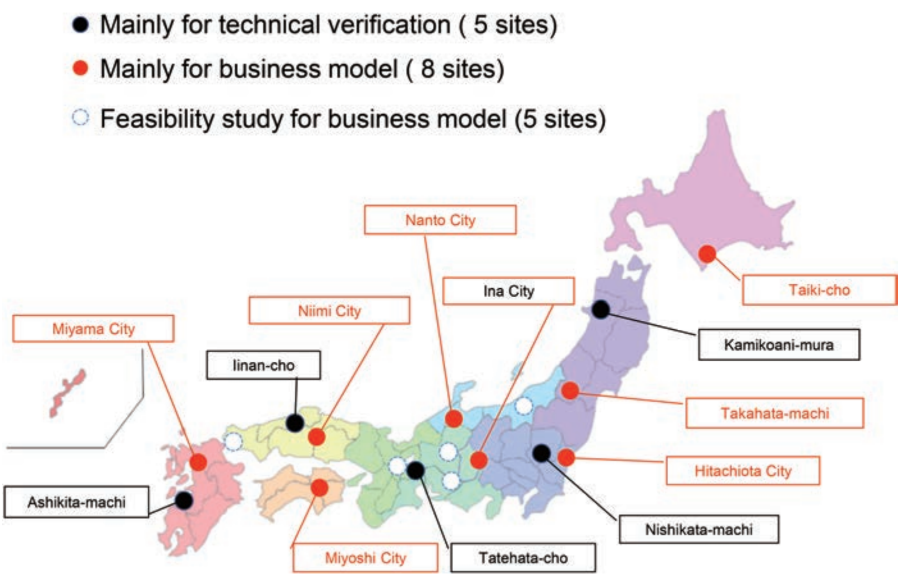


Fig. 1 Locations of FOTs in FY 2017

demand buses. Large numbers of such rest areas function as centers for transportation and community life in rural areas.

2 Purpose

Field operational tests (FOTs) are being conducted at 13 roadside rest areas nationwide in anticipation of the introduction of automated driving services (ADS). These FOTs are aiming to verify the effects on road transportation of the fully fledged introduction of ADS in rural areas by 2020 from the viewpoints of technology and business models.

3 FOTs in FY2017

At first, five locations for FOTs were selected for the primary purpose of technical verification. Eight locations were also selected for the primary purpose of studying business models. Apart from these 13 locations, another five regions were also selected for the purpose of conducting a feasibility study of business models. Figure 1 shows these locations. FOT committees were established in each location to verify research items, routes, transportation systems, to coordinate with related entities, and to conduct testing and verification.

Second, four types of vehicles were selected through an open bidding process. Various types of models equipped with different driving technologies were selected, as shown in Table 1. These vehicles are basically operated at low

Table 1 Buses selected

1) DeNA 	**Autonomous technology** • Identify own position by GPS and IMU. • Drive according to a predetermined route. • Acquire point-clouds data. Capacity: **6 (seated) (Total 10)** Speed: **10km/h**
2) Advanced Smart Mobility 	**V2I technology** • Identify own position and drive a predetermined route using GPS, magnetic markers and gyro sensors. Capacity: **20** Speed: **35km/h**

Table 2 Passenger cars selected

3) Yamaha Motor 	**V2I technology** • Drive a predetermined route by following embedded magnetic-induction lines. Capacity: **4–6** Speed: **12km/h**
4) Aisan Technology 	**Autonomous technology** • Drive a predetermined route using a high-precision 3D map. • Detect surrounding conditions by LIDAR. Capacity: **4** Speed: **40km/h**

speeds.

Third, the route of each test was set on the basis of the location of the roadside rest area. The routes travel around surrounding villages, private residences and facilities including hospitals, local authority offices, agricultural centers, and other important facilities. The total distance was a few kilometers. The routes were divided into two types of section: dedicated sections for level 4 automated driving and those for level 2 automated driving. Following the constraints defined in current regulations, the level 4 sections were set in a special manner.

Finally, the items tested were (i) the effect on road infrastructure, road management, and road transportation systems, (ii) the reliability of ADS, (iii) business feasibility, (iv) the human machine interface (HMI), especially relating to social acceptance, and (v) impacts on the local economy.

3.3. Case study – Hitachi Ohta roadside rest area.

This section introduces the FOT conducted at the Hitachi Ohta roadside rest area as one of the case studies. It was implemented for one week starting on Sunday November 19, 2017. It used the vehicle supplied by Yamaha Motor as shown in Photo 1. This is a cart type vehicle with 7 seats and a forward camera for object recognition. The total length of the route was 3.2 km, which includes 500-meter sections for level 4 automated driving. The route connects the Hitachi Ohta roadside rest area with several bus stops for passengers and farm products.

The FOT concentrated on technical aspects, namely, (i) the effects on road infrastructure and the like, (ii) the reliability of ADS, and (iii) the HMI. It was expected that ADS would find it difficult to navigate sectors with overgrown vegetation and narrow lanes. Furthermore, in terms of reliability, the FOT verified the effect of rain on the detection capability of the forward camera. One of the unique points of this FOT is the collection of agricultural crops and delivering them in cooperation with express buses. Photo 1 shows several scenes from the FOT.

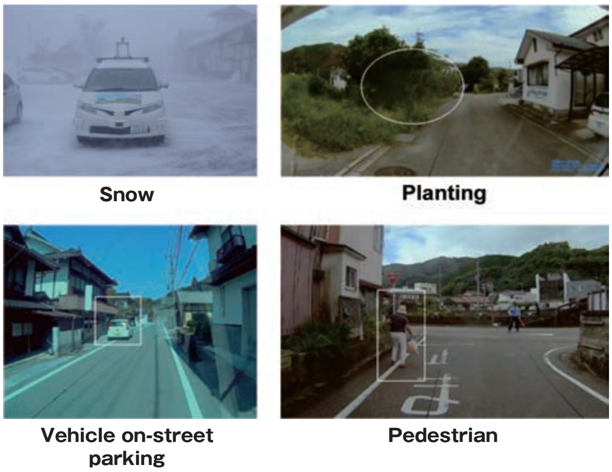


Photo 1 Scenes from FOT

4 Results of FOT

4.1. Effects on road structure, road management, and road transportation systems

(1) Road structure

The ADS was able to navigate smoothly even on steep winding roads and was not affected by road alignments. The ADS drove smoothly even in sectors with steep inclines. However, in some cases, ADS recognized the steep incline as an obstacle. Furthermore, in sectors with no sidewalks and narrow road shoulders, ADS detected pedestrians and bikers as obstacles and stopped or requested the user to drive manually.

Photo 2 Examples of obstacles

This FOT also indicated the importance of cooperation with the local community. For example, signposts that indicate dedicated ADS sections are needed to caution pedestrians and bikers not to enter the sections concerned.

At intersections with no traffic signals, when ADS detected or needed to make way for approaching vehicles, in some cases, the vehicle either stopped or required manual driving to avoid the vehicles. When approaching intersections with poor visibility and the like, ADS also required manual intervention in advance in some cases.

(2) Road management

During the FOT, cases occurred in which the ADS detected plants or weeds on the roadside and stopped or required manual driving. This shows that it is essential for road administrators to perform appropriate plant management. Also, in areas with heavy snowfall, ADS was able to drive smoothly even when the road was covered with snow or compacted snow (approximately 10 cm). In some cases, however, snow that had been pushed to the sides of the road was detected as an obstacle on the road. Road administrators will be required to remove snow appropriately for ADS.

(3) Road transportation systems

While ADS was able to merge smoothly onto and off two-lane sections of roads, on single-lane and other narrow road sections, there were cases in which the ADS regarded approaching vehicles as obstacles and stopped or required manual driving. In particular, it might be necessary to take measures for narrow road sections. Some potential solutions are to provide turnouts, to establish rules that give priority to ADS transit through cooperation with the local community, or to make such roads one-way.

Under mixed traffic environments, the ADS was able to drive smoothly when its vehicle speed was about the same as the surrounding vehicles. However, traffic congestion occurred in some cases when its speed was extremely slower. It might be necessary to introduce dedicated sections, provide turnouts, or other measures. Also, when there were parked vehicles on the road, ADS detected them, and stopped or required manual driving. As a result, it may be necessary to introduce measures in cooperation with the local community, such as posting signs indicating ADS routes and regulations prohibiting drivers from parking their vehicles.

(4) Roadside rest areas as transit centers

There were cases in which ADS detected pedestrians or two-wheeled vehicles and stopped or required manual driving. Measures will be required, such as the posting of clear signs indicating ADS routes and securing adequate spaces for two-wheeled vehicle parking.

When there was snow at the roadside rest area, in some cases, the vehicle parking spaces were not visible. The ADS detected parked vehicles as protruding into the road, and stopped or required manual driving. It might be necessary to remove snow as appropriate.

4.2 HMI including social acceptance

The research conducted questionnaire surveys with monitors who participated in FOTs as ADS passengers. The questions were related to the HMI. There were 1,240 respondents. The ratio of male responders was 60.5% and that of senior citizens aged 65 or older was 39.2%. The survey showed that 40% of respondents recognized the benefits of ADS. They hoped it would become a better developed means of daily transportation. In contrast, the most frequently mentioned concerns were unforeseeable issues and lack of maintenance. Figure 2 shows the change in attitudes about the reliability of ADS before and after riding the vehicle. The result shows that people tend to feel that ADS is more reliable after riding in the vehicle. The results from responders who experienced level 4 automated driving also show that more people felt that ADS is reliable after riding in the vehicle.

Another result showed the change in people's intention to use ADS in the future after their experience of ADS. Overall, there was a high inclination to use ADS in the future, which became even higher after riding in the ADS vehicle. People tended to worry about securing daily transportation in the future. Especially, those who intend to voluntarily surrender their driver's licenses stated that they were more likely to use ADS.

4.3 Impacts on local economy

The survey results showed that ADS would provide local people with potential benefits. For example, they could have the opportunity to go anywhere, take trips outside the home, and make use of delivery services using ADS.

5 Conclusion

These FOTs have found that, despite several technical issues that should be addressed, ADS is basically applicable to routes including roadside rest areas, hospitals, local authority offices, supermarkets, and other facilities. To achieve the government goal by 2020, it will be necessary to implement additional FOTs that basically focus on business feasibility to help local communities introduce ADS and to secure local transportation services at a reasonable cost.

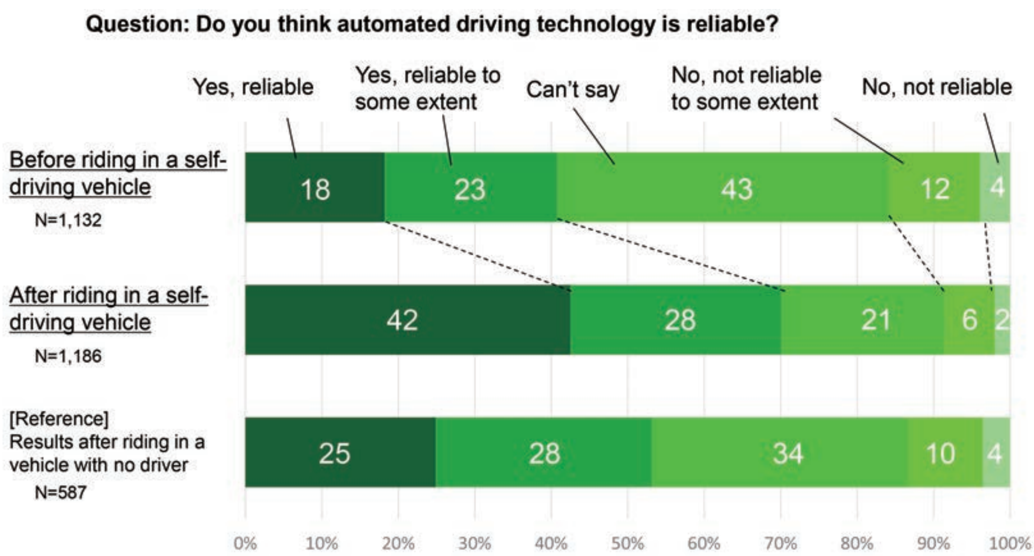


Fig. 2 Change in people's attitudes about the reliability of ADS