SIP-adus: Project Reports, 2014-2018
- Automated Driving for Universal Services -

2018

SIP

Cross-ministerial Strategic Innovation Promotion Program

Looking Back on Five Years of SIP-adus

Seigo Kuzumaki
SIP-adus Program Director
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There are many issues to solve for the realization of automated driving systems (ADS). Therefore, it was fortunate for us that ADS was picked up in the Cross-ministerial Strategic Innovation Promotion Program (SIP), which aims for industry-government-academia collaboration.

In the beginning, there was a big gap in understanding about ADS among the people involved, and each OEM has a different stance on ADS development. Through frequent and tense discussions in SIP, a consensus gradually grew to finally reach the conclusion that ADS development needs a "competition and cooperation" strategy.

Two decades of intelligent transport systems history (ITS) development have helped us collaborate with NPA, MIAC, METI and MLIT. The Cabinet Office has been working with the Cabinet Secretariat to make a roadmap of ADS and ITS. These relationships have made cross-ministerial collaboration smooth.

We have been proactive at presenting our activities at the international congresses. Ultimately, we made our presence felt with respect to *de jure* and *de facto* standardization activities in the areas of dynamic mapping and HMI. Large-scale field operational tests began in Japan in October 2017. We recruited more than 20 participants from industry and academia, not only in Japan but also in Europe. This created an opportunity for open discussion to enhance international cooperation and harmonization.

As a result of our SIP-adus activities, Dynamic Map Platform co Ltd was established in 2017. We take pride in having produced such outcome, which is not an end, but a beginning. We want to keep striving for the realization of Society 5.0 by pursuing the expansion of big data uses, such as maps and geographical information.

Lastly, I want to convey special thanks to all the members involved in SIP for their support. I would also like to dedicate this report to former Program Director, Dr. Watanabe, who passed away in the midst of his efforts to make the program a success.

Toward the Realization of Mobility in Society 5.0

Ryo Kuroda
(Deputy Director General for Science, Technology and Innovation, Cabinet Office)

The novel Society 5.0 concept was proposed as the ideal Japan should pursue in the 5th Science and Technology Basic Plan formulated by the Council for Science, Technology and Innovation (CSTI) in 2016. Society 5.0 is the human-centered society that simultaneously realizes solutions to social problems and economic growth by means of the integrated ICT technologies in cyberspace and in physical space. CSTI established the Cross-ministerial Strategic Innovation Promotion Program (SIP) for Society 5.0. The feature of SIP is to carry out activities ranging from basic research to practical application and commercialization with the cooperation of cross-ministerial government agencies, academia and industry.

SIP-adus (Automated Driving for Universal Services) is one of the eleven SIP projects. It aims to reduce traffic accidents and provide mobility as a necessary service by gathering the information from vehicles in physical space, analyzing it in cyberspace, and feeding the analyzed results back to the vehicles for safe and comfortable control. SIP-adus precisely embodies Society 5.0 in the mobility domain. Under the leadership of Program Director Seigo Kuzumaki, members of SIP-adus from industry, academia, and government have collaborated with each other and solved many of the challenges presented by advanced automated driving systems. We hope the fruitful outcomes developed in these five-year of the SIP-adus project will be widely shared and utilized as firm foundation for the future stages.

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Overview

SIP Automated Driving System Outline

Yasuyuki Koga (Cabinet Office)

ABSTRACT: SIP-adus(Automated Driving for Universal Service) started in June 2014 as a national research and development project for innovation. It has a social significance, providing a fundamental solution to suchissues as the reduction of traffic fatalities, the reduction of the environmental burden by easing traffic congestions, travel support for elderly people and other vulnerable road users, and the revitalization of rural areas. The improvement of the competitivenessof the automobile industry and the expansion of related markets are significant from an industrial point of view. Under the Steering Committee, we established the System Implementation WG, the International Cooperation WG, and the Next-Generation TransportWG. In 2016, we identified five important area of focus (1) dynamic maps, (2) human-machine interface(HMI), (3) cyber-security, (4) pedestrian accident reduction, and (5), next-generation transport. We also conducted a large-scale FOTs on these area from 2017and delivered the achievement of the research and development.

1 Significance and Targets

1.1. Background, Domestic and International Situation

Automated driving systems have been promoted through industry-academia-government collaboration in cross-field efforts made in cooperation with government departments under the framework of the Strategy Innovation Creation Program (SIP) started in June 2014. In addition to conducting comprehensive R&D starting from the development of core technologies and aiming for practical application and commercialization, the results obtained through field operational tests (FOTs) have also contributed to reviews of regulations and systems. Since automobiles are international products and also one of Japan's key industries, the projects has always been promoted with international standardization in mind.

The promotion of R&D, practical application and commercialization of automated driving has a two-sided significance for the Japanese government. It has a social significance, providing a fundamental solution to such issues as the reduction of traffic fatalities, the reduction of the environmental burden by easing traffic congestion, travel support for elderly people and other vulnerable road users, and the revitalization of rural areas. The improvement of the competitiveness of the automobile industry and the expansion of related markets are significant from an industrial point of view.

In addition to various projects promoted under the EU R&D program Horizon2020, Germany, the UK and other European countries have been working on formulating a strategy and developing technologies. In the United States, the Federal Department of Transportation (USDOT) formulated a national strategy on automated driving systems and ITS in December 2014. Since July 2015, the University of Michigan has been conducting a large-scale public road FOT near Detroit involving car manufacturers from Japan, the United States and Europe, imitating an urban area based on the M City test course.

Moreover, the joint statement between Japan and Germany on the promotion of R&D in the field of automated driving technology in January 2017 marked the beginning of international collaboration.

The number of traffic accident fatalities in our country has been decreasing for more than 10 years as a result of long-standing efforts by national and regional public organizations, related private organizations and citizens. The Tenth Fundamental Traffic Safety Program, approved in March 2016, established a national target of reducing the number of traffic accident fatalities to 2500 or less by 2020, and realizing the safest road traffic in the world. However, while the number of fatalities declined for two consecutive years, dropping to 3,694 in 2017, considerable efforts are still required to reach the national target. In particular, intersection, pedestrian, bicycle, and motorcycle accidents are major problems. An integrated approach including not only vehicles, but also improvements to the traffic environment, and the education of people, is required.

On a different note, vehicle driving functions are comprised of three elements: recognition, decision and operation. There are technologies that recognize the road environment through radars installed in vehicles (automated systems), and technologies that recognize the road environment by relying on communication between vehicles, and between vehicles and external devices (cooperative systems). To realize automated driving systems, advances in the three elements mentioned above must be achieved by integrating both types of technologies. Automated systems alone cannot solve the problem of reducing the traffic fatalities, and they must be complemented by cooperative systems.

1.2. Significance and Politic Importance

According to the Declaration to be the World's Most Advanced IT Nation: Basic Plan for the Advancement of Public and Private Sector Data Utilization approved by the Cabinet in May 2017, "the relevant ministries and private enterprises shall work together to promote the development and practical application of safe driving support and automated driving systems, as well as the utilization of traffic data, based on the Public-Private ITS Initiative/ Roadmaps 2016. In particular, they will promote efforts, including the development of institutions and infrastructure, aimed at realizing the possibility of automated driving on expressways and unmanned automatic driving in limited areas, including the necessary FOTs, by 2017."

In addition, the Comprehensive Strategy on Science and Technology Innovation 2017 formulated based on the 5th Science and Technology Basic Plan shows that it is necessary to actively promote R&D for automated driving systems to realize Society 5.0, core efforts and positioning towards the realization of full-scale cyber-physical systems, the development of dynamic maps, and so on.

Over the past 20 years, Japan has developed and introduced the world's most advanced ITS system, and the automobile industry is currently its largest export industry. As various Western countries accelerate their R&D on automated driving systems as part of their national policy, it is important for Japan to push forward with the development, practical application, and popularization of these systems. Reaching the aforementioned national target and realizing the world's best road traffic society will produce both great social and industrial value for the people.

On the other hand, many ministries are involved in the field of ITS and automated driving systems, and it must be considered not only from a technical point of view, but also based on other considerations, including social acceptance and institutional aspects. Government agencies, as well as public and private organizations, must work together to promote the development of the field.

At the beginning of the SIP automated driving system project, we were seeking collaboration in the absence of mutual public and private understanding. However, in the process of establishing the Public-Private ITS Initiative/ Roadmaps with the Strategic Headquarters for the Promotion of an Advanced Information and Telecommunications Network Society (IT Strategic Headquarters) in June 2014, the SIP Automated Driving System Steering Committee and the Headquarters were able to promote cooperative studies, as well as advance the understanding of the parties involved and foster communication. Through these discussions, institutional development was also promoted by various government departments based on automated driving measures specific to each department and in accordance with the Outline of Development of Institutions for Automated Driving (April 2018, Strategic Headquarters for the Promotion of an Advanced Information and Telecommunications Network Society, Strategic Conference for the Advancement of Public and Private Sector Data Utilization).

Regarding industry-academia cooperation, which cannot be said to always have been strong in the automotive field, SIP has created opportunities for cooperation by promoting interaction allowing the different parties to meet with one another. The industry-academia cooperation in the automotive field must now be strengthened even further.

International standardization is also important for vehicles, which are global products. It is essential for the SIP efforts aimed at maximizing effectiveness through FOTs based on a hands-on approach to generate international cooperation and gain citizen understanding and acceptance. With respect to international collaboration, we were able to demonstrate initiatives for the standardization and de-facto standardization of dynamic maps and HMI through the use of ITS Japan networks in EU (ERTICO) and US (ITS America), as well as active popularization efforts in cooperative areas of automatic operation from Japan.

1.3. Targets and Objectives

1.3.1. Social Targets

We seek to achieve national targets such as the reduction of traffic accident fatalities (2,500 people / year) and easing of traffic congestion. The timeline for these targets will be clarified by following up on the Public-Private ITS Initiative/Roadmaps 2018 and developing technologies enabling the effectiveness of traffic accident fatality reduction safety measures to be predicted. These approaches will be integrated in a PDCA cycle.

1.3.2. Technological Targets

We decided to revise the automated driving levels and definitions of the automated driving systems and driving support systems implementing these levels, taking into consideration international trends on the definition of automated vehicles including those in Europe and the United States. To avoid confusion due to differences in definitions, and to ensure international consistency, we will adopt the definitions in SAE J 3016, which was approved by SAE International in September 2016 in the US.

However, at any level, the driver can take control of the system at any time.

- Regarding the expected commercialization time, we plan to establish the technology required to implement a system that utilizes infrastructure information such as signaling information and congestion information (SAE level 2) by 2017, and a high-end system (SAE level 2) that will be a step towards SAE level 3 by 2020. We will promote R&D in cooperative areas to ensure the commercial availability of SAE level 3 systems in 2020, and SAE level 4 systems in 2025.
- We will create an internationally open R&D environment and establish a new international collaboration system to solve global problems.

1.3.3. Industrial Targets

(1) Industry creation

There is a wide range of new industry fields that can be related to automated driving systems. It is expected that the market will expand drastically not only for vehicle sensors (cameras, radars, etc.), but also for vehicle communication equipment, roadside communication equipment, portable communication equipment and other information communication equipment and digital infrastructure.

Moreover, as new platform technologies related to high precision 3D mapping technology, basic dynamic map technology, and probe information-based map update technology, evolve after automated driving systems are put to practical use and popularized, new industries will be created in various fields beside automated driving, such as information development, operation, or services utilizing high precision positioning information. In addition, the combination of HMI, security technology and advanced automotive control technology will bring a new value in the context of a cyber-physical system where machines adapt to, and support, people. New technologies and businesses, such as next-generation transportation systems, support systems for vulnerable road users and walking movement, and package-based export of regional traffic management services and infrastructure, will be created.

(2) World Share

We will lead the standardization of automated driving systems in terms of international cooperation, and establish our position as the top global player by building upon the work of our predecessors in the area of cooperative systems.

To establish concrete numerical targets (KPI), we aim to build a collaborative organization towards the further advancement of automated driving systems, which will consist of representatives from industry, government and academia and will remain even after the SIP project ends. A wide range of university experts will analyze social and industrial impacts, and determine these targets in cooperation with the IT Strategic Headquarters, the Investigation Committee for New Strategy Promotion and the Road Transportation Subcommittee.

2 Deployment Milestones

2.1. Reaching the National Target for the Reduction of Traffic Accident Fatalities

We will establish a technical foundation and execution organization to implement traffic accident countermeasures adapted to vehicles, people and infrastructure as a whole to reach the national target described in the Tenth Fundamental Traffic Safety Program.

In addition to development of driving support systems and automated driving systems, and the promotion of the practical application and popularization thereof, we will develop technology to advance the data analysis and simulation of traffic fatalities and predict and verify the effectiveness of safety measures. We will analyze the execution organization integrating multiple related parties, and use the results to establish a mechanism to progress towards the national target.

2.2. Implementation and Popularization of Automated Driving Systems

Regarding the expected commercialization time, we plan to establish the technology required to implement a system that utilizes infrastructure information such as signaling information and congestion information (SAE level 2) by 2017, and a high-end system (SAE level 2) that will be a step towards SAE level 3 by 2020. We will promote R&D in cooperative areas to ensure the commercial availability of SAE level 3 systems in 2020, and SAE level 4 systems in 2025. In the area of dynamic maps, Dynamic Map Platform Co., Ltd. was established in June 2017, and there are plans for that company to prepare high-precision maps of all expressways and all motorways by the end of 2018. This will represent a big step towards practical application.

2.3. Development in Collaboration with Tokyo Metropolis with the Tokyo Olympics and Paralympic Games in 2020 as a Milestone

Defining the Tokyo Olympics and Paralympic Games in 2020 as a milestone, work is progressing on the practical application of next-generation transportation systems that contribute to the future generations in Japan, improve accessibility (measures for vulnerable road users), and propose solutions to social acceptance and institutional issues for social implementation of the aforementioned measures in anticipation of the development of Tokyo and the aging of society. In particular, we have signed a memorandum of understanding with the Cabinet Office, the Tokyo Metropolitan Government and related parties to incorporate ART technology into the waterfront city area BRT which is under consideration by the Tokyo Metropolitan Government. Technical development, demonstration experiments and other efforts are promoted in close cooperation by the parties involved.

3 Outline of R&D

3.1. System Development and Research Subjects

Since the beginning of the SIP project in 2014, we have been advancing R&D on individual topics while promoting the establishment of teams such as the Steering Committee, the System Implementation WG, the International Cooperation WG, and the Next-Generation Transport WG. In 2016, we identified five important areas of focus: (1) dynamic maps, (2) human–machine interface (HMI), (3) cybersecurity, (4) pedestrian accident reduction, and (5) next-generation transport.

The R&D in the competitive field of automated systems for vehicles is carried out by the automobile industry itself, while SIP has mainly promoted the development and practical application of fundamental technologies and of cooperative areas (related to cooperative systems) which require collaborative public and private efforts.

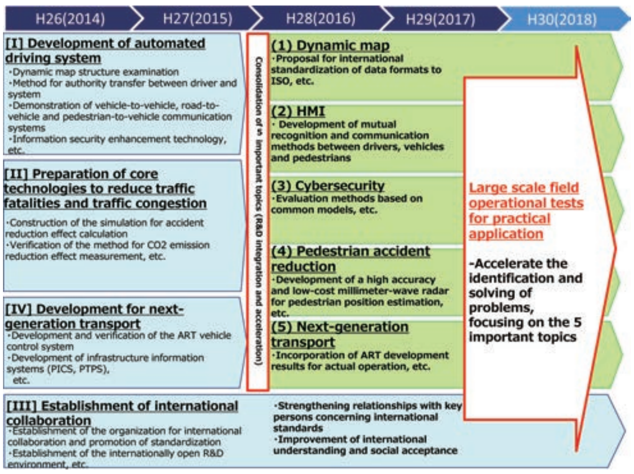

Fig. 1 Process Chart

3.2. Large-Scale FOTs

Conducting large-scale FOTs in cooperation with government departments is important to promote collaboration between industry, academia and government. The purpose of the experiments is to speed up the realization of the deployment milestones by identifying institutional, business and other problems from the R&D results obtained so far, providing feedback for development, and applying the PDCA cycle consisting of: (a) the activation of technology development, promotion of infrastructure development, (b) the prompt identification and solving of problems for practical application, and (c) a sequence of large-scale FOTs mainly focused on the five important topics started in October 2017 on 300 km of road (600 km round-trip) covering the Joban, Shuto, Tomei, and Shin Tomei expressways as well as general public roads around the Tokyo waterfront city area. The main purposes of these FOTs were the intensification of international collaboration by providing a forum for open study and discussion for participants, including overseas manufacturers, and the intensification of collaboration between industry, academia and government, transmission of the state of social demands and R&D results. Twenty-two domestic and overseas automobile manufacturers, automotive part manufacturers, universities, and other organizations participated in long-term experiments and development conducted until the end of December 2018.

4 acknowledgment

Two distinguished program directors devoted their energy to SIP-adus program to make automated driving technologies in reality. Counsellors and expert staffs has supported PD's effort with their full capacity. I would like to thank you all of them and all contributors to the program.

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Results of Research and Development

[I] Development of Automated Driving Systems

[II] Development of Basic Technologies to Reduce Traffic Accident Fatalities and Congestion, and Initiatives to Raise Social Acceptance

[III] Next-Generation Urban Transportation

[IV] Field Operational Tests

[V] International Collaboration

Overview of SIP Dynamic Map Research and Development for Automated Driving

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ABSTRACT: Dynamic maps are three-dimensional high precision maps on which various kinds of semi-static (scheduled phenomena), semi-dynamic (current phenomena), and dynamic information (real-time changes), are combined with position data for smart automated driving (AD) and advanced driver assistance systems (ADAS).

Many SIP R&D measures are carried out to achieve the early realization, wide deployment of dynamic maps, as well as reduce their cost.

Dynamic map use will not be limited to vehicles featuring AD/ADAS, but also address social needs such as the prevention or mitigation of the effects of natural disasters, advanced agriculture, or infrastructure management and maintenance. These elements are therefore also considered in SIP-adus.

The final stage of SIP R&D involves a large scale Field Operational Test (FOT) carried out by many of the stakeholders involved.

1 About Dynamic Maps

The dynamic map is one of the most important technologies for the realization of high level automated vehicles. AD system must have recognition, decision, and operation functions. Sophisticated recognition requires map and ITS information to achieve high level self-position estimation, as well as on-board sensors such as video cameras, radars, lidars, or laser scanners to perceive the vehicle surroundings. A lot of various high level research and development is carried out as part of SIP activities to create high performance and low cost dynamic maps.

Though AD systems fundamentally use high precision maps and on-board sensors, automated vehicles will be able to run more intelligently with ITS information.

2 The Structure of Dynamic Maps

Dynamic maps are maps consisting of both high-precision digital maps and ITS anticipative information. They have four layers, as shown in Fig. 1. The bottom layer is a three-dimensional digital map which contains a high precision lane level road map with road shape and topological data, as well as road objects such as road sign, road paints, traffic signal poles, and stop lines.

Above that, Layer 1 is a semi-static information layer which shows scheduled phenomenon such as traffic control plans, road construction plans, or weather forecasts. Layer 2 is a semi-dynamic information layer that shows current phenomena such as traffic accidents, traffic congestion occurring within the preceding 30 minutes, or the local weather forecast. The top layer consists of dynamic information that shows real-time changes from ITS anticipative information such as vehicle-to-infrastructure communication (V2I), vehicle-to-vehicle communication (V2V), vehicle-to-pedestrian communication (V2P), or traffic signal rotation cycles.

This information includes position data with timestamps, and is transmitted from support infrastructures to automated vehicles via V2X or mobile communication such as LTE, 4G, or 5G. These are plotted on the base layer map in the AD system, providing it with knowledge of surrounding conditions on the traveled route.

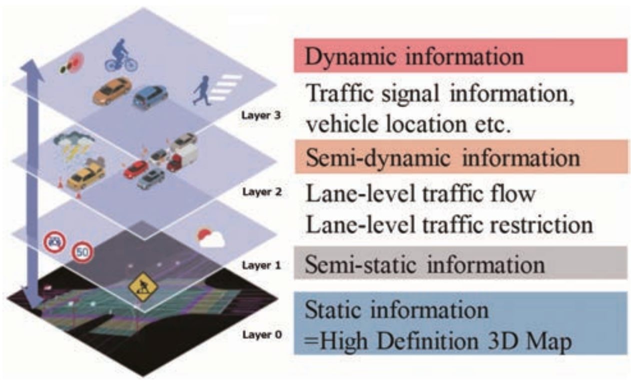

Fig. 1 Structure of a Dynamic Map

3 Research Items for Dynamic Maps

SIP research on dynamic maps cover the aspects listed below. These results are shown in item by item reports.

(1) Estimation of current SIP map specification (lane information, road objects accuracy, and so on)
(2) Development of methods for three-dimensional high precision static map creation and maintenance, including automatic mapping systems.
(3) Consideration of the semi-static, semi-dynamic, dynamic information specifications and service methods.
(4) Dynamic map application considerations and research
(5) Communication specification research on V2X
(6) ITS information service research at intersections.

3.1. Estimation of Current SIP Map Specification

Three-dimensional high precision map data for a long-distance expressway route, ordinary roads in the 2020 Tokyo Olympic and Paralympic Game stadium area, and a proving ground isolated from open roads, covering approximately 760 km, were prepared. Many of the SIP large scale FOT participants, OEMs (car manufacturers), suppliers, academic institutions, and other private firms are validating the map specification, accuracy, and other factors.

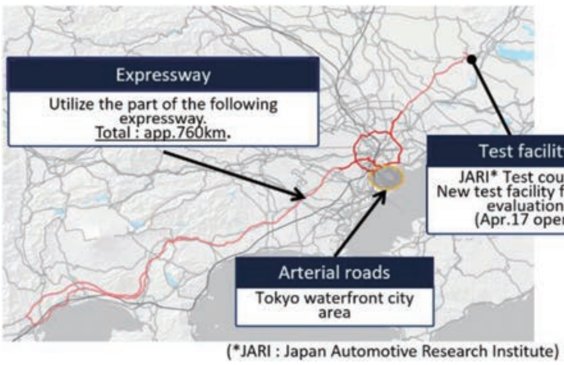

Fig. 2 Dynamic map estimation area

3.2. Development of Method for Three-Dimensional High Precision Static Map Creation and Maintenance Including an Automatic Mapping System

In order to serve accurate and low cost maps, effective map creation and maintenance methods were considered, with a particular focus automatic difference updates using AI technology and partial point cloud data gathering by road operators and contracted cargo trucks, or from ordinary vehicle probe data.

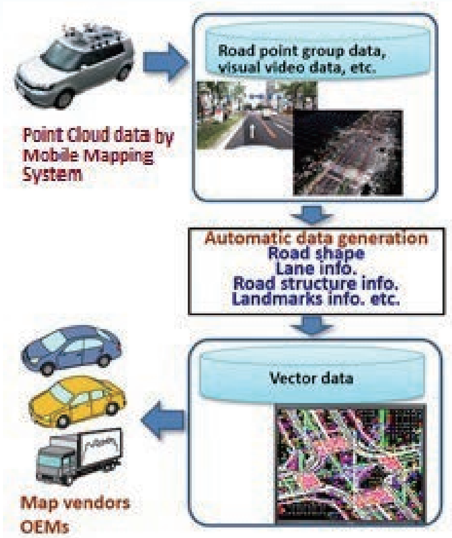

Fig. 3 Example of map database update

3.3. Consideration of Semi-Static, Semi-Dynamic, and Dynamic Information Specifications and Service Method

Road operators must have a road repair plan. Road level public traffic information services and means of data transmission such as ETC 2.0 are already available. However automated vehicles and advanced ADAS cars need lane rather than road level information as shown in Fig. 4. Ways to create or transfer lane level information from infrastructures to automated vehicles were therefore considered.

Fig. 4 Example of lane level traffic condition information

3.4. Dynamic Map Application Consideration and Research

Using dynamic maps only for automated vehicles has poor cost benefit. Therefore, other applications of dynamic maps are being considered for businesses providing map-based information service or to address social needs such as the prevention or mitigation of the effects of natural disasters, advanced agriculture, or infrastructure management and maintenance.

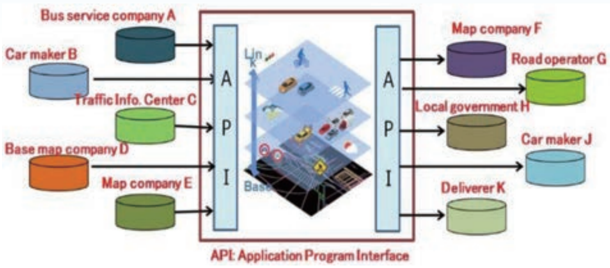

Fig. 5 Dynamic map information service platform

3.5. Communication Specification Research on V2X

Smart automated vehicles require connected car technologies that make use of V2X (V2I, V2V, V2P, 5G, probe data, so on), including existing infrastructure like second-generation electronic toll collection (ETC 2.0) on highways, advanced infrared beacons on ordinary roads, and LTE and 4G mobile communications.

Communication between automated vehicles—machine to X communication (M2X)—is needed. The results of these considerations are shown in item by item reports.

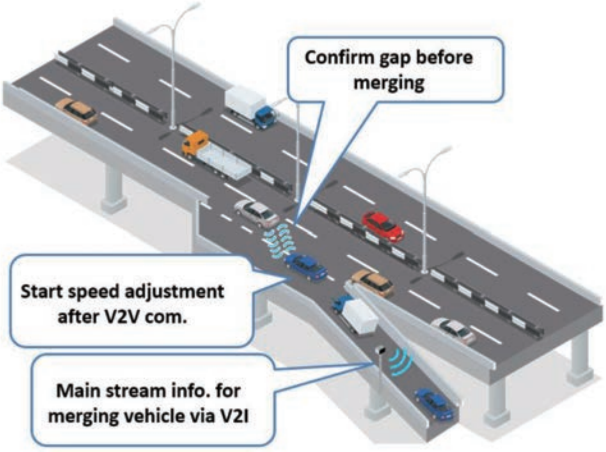

Fig. 6 Merging scenario supported by machine-to-machine communication

Fig. 7 Vehicle-to-pedestrian communication using DSRC

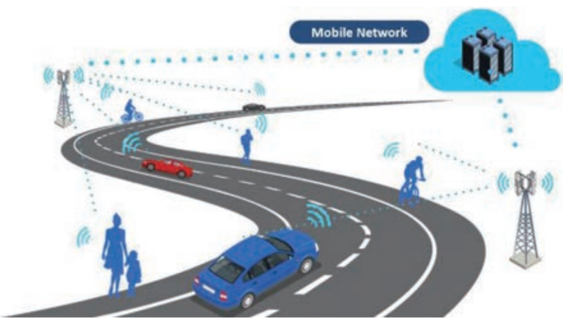

Fig. 8 Wide area communication via mobile network

3.6. ITS Information Service Research at Intersections

At intersections, automated vehicles need the following information to ensure traffic safety: real-time traffic signal information and signal rotation cycle, information on pedestrians crossing the road, oncoming vehicles, and more.

On-board sensors will not be able to acquire that information. Therefore, road-side sensors will detect pedestrians or oncoming cars, while the traffic signal rotation cycle will be obtained from the traffic management system, and the information will be sent to approaching automated vehicles via dedicated short range communications (DSRC)

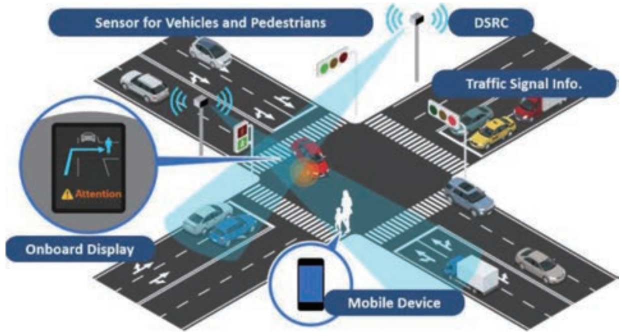

Fig. 9 ITS information services at an intersection

3.7. Communication Assets for Dynamic Maps

Various technologies, including mobile communication capable of mass data distribution and DSRC capable of handling real time information are being considered as communication methods to provide semi-dynamic and semi-static information for dynamic maps. In Japan, a number of ITS communication systems have been put into practical use since before 2000. The ETC 2.0 system for toll collection also provides information for safe driving. In addition, the advanced infrared beacons and radio communication road side units at intersections provide traffic signal information and traffic control, as well as traffic congestion information. These systems have already spread throughout Japan. Systems spread on such a large-scale are a valuable social asset. Therefore the utilization of these systems is also being considered preferentially for the distribution of dynamic map data.

4 Summary

Dynamic maps are absolutely necessary for smart automated vehicles, and SIP has put a great deal of effort in their development. We are also taking care to avoid making maps with unnecessarily high quality or maps that will not be accepted as either international or de facto standards.

Map cost reduction is also very important to ensure the widespread propagation of automated vehicles. We have been developing low-cost map maintenance methods and considering other uses such as businesses offering map-based information services or social needs such as the prevention or mitigation of the effects of natural disasters, advanced agriculture, or infrastructure management and maintenance.

Dynamic Map Prototyping and Design, and Establishment of Data Linking Functions, Distribution Functions, and Updating Methods

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Shintaro Osaki (Toyota Mapmaster Incorporated)
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ABSTRACT: Over a five year period, beginning in 2014, we deliberated the approaches to use in relation to dynamic map static information requirements, data specifications, preparation guidelines, and encoding specifications, as well as the location referencing methods used to link static information and dynamic information in the dynamic maps necessary for automated driving systems. Through the Large-Scale Field Operational Test (Dynamic Map), we conducted static information evaluation with the collaboration of test participants. Based on the evaluation results, we concluded that the essential features that make up static information are sufficient for use by automated driving systems. We also defined features for which there were numerous requests from test participants as quasi-essential features. Through this test, we found that road signs, road markings, and the like change over the course of three to four months after dynamic maps are created, and we identified a need to organize approaches to updating static information.

1 Introduction

In automated driving systems, vehicle-mounted sensors (cameras, LiDAR, etc.) serve as a vehicle's "eyes," enabling safe and comfortable vehicle control. The detection capabilities of these vehicle-mounted sensor technologies have improved in recent years, but there are limits to what they can detect. Furthermore, there is a demand for the ability to use inexpensive sensors in regular vehicles. Dynamic maps can be used as a supplementary technology for vehicle-mounted sensors. These dynamic maps can be used to supplement important automated driving functions, such as vehicle localization and path planning.

Dynamic maps are high-accuracy 3D maps overlaid with constantly changing information regarding the positions of nearby vehicles, the status of traffic signals, and so on. 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, restriction plan 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 for linking these four layers, from static information to dynamic information.

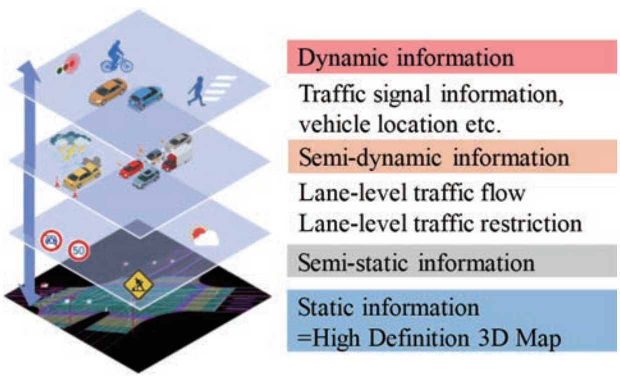

Fig. 1 Dynamic map four layer structure

In 2014, the Study of Advancement of Map Information (Information Assembly and Structuring) for Use in Studies and Investigations of the Approaches to Use in Resolving Issues Affecting the Realization of Automated Driving Systems was carried out in preparation for the creation of the high-accuracy 3D maps that comprise dynamic maps. Mobile mapping systems (MMS) were used to measure

① Dynamic Maps

Dynamic Map Prototyping and Design, and Establishment of Data Linking Functions, Distribution Functions, and Updating Methods

Tokyo's Odaiba area (approx. 65.3 km of roads), the acquisition of features was verified, and issues were identified and organized.

Based on the results of these activities, in 2015, the Study of Prototyping and Evaluation Aimed at the Creation of Dynamic Maps for Use in Studies and Deliberations on the Approaches to Use in Resolving Issues Affecting the Realization of Automated Driving Systems was carried out. Automated driving system use cases were used to create a requirement specifications proposal, an automated driving system map data specifications proposal, and a map data preparation guideline proposal.

Table 1 Overview and results of past activities

		2014	2015	2016	2017	2018	Results
(1) Study of advancement of map information (information assembly and structuring) for use in studies and investigations of the approaches to use in resolving issues affecting the realization of automated driving systems		■					Results report Odaiba measurement
(2) Study of prototyping and evaluation aimed at the creation of dynamic maps for use in studies and deliberations on the approaches to use in resolving issues affecting the realization of automated driving systems			■				Results report Requirement specifications Data specifications Map data preparation guidelines
(3) Study of prototyping and evaluation aimed at the creation of dynamic maps for use in studies and deliberations on the approaches to use in resolving issues affecting the realization of automated driving systems				■			Results report Map data encoding specifications Large-scale Field Operational Test area (300km) measurement
(4) Implementation and management of Strategic Innovation Promotion Program (SIP) for Automated Driving Systems/large-scale field operational test/dynamic map prototyping and design and establishment of center functions and updating methods, etc.	(4)-1 Evaluation of (3)				■		Large-scale Field Operational Test area (758km) measurement Consensus formation regarding essential/extended features
	(4)-2 Large-scale Field Operational Test area (758km) creation and evaluation				■		
	(4)-3 Map update data creation, distribution, and evaluation					■	Map data optimization based on results of (4)-2 (map update data creation and evaluation) Map update guidelines Consensus formation regarding dynamic map specifications through Large-scale Field Operational Test Results report
	(4)-4 Consensus formation regarding Dynamic Map Large-scale Field Operational Test				■	■	
Measures aimed at practical implementation				▲ Establishment of Dynamic Map Platform Planning Co., Ltd.	▲ Establishment of Dynamic Map Platform Co., Ltd.		

In 2016, a Study of Prototyping and Evaluation Aimed at the Creation of Dynamic Maps for Use in Studies and Deliberations on the Approaches to Use in Resolving Issues Affecting the Realization of Automated Driving Systems was carried out. It measured 50 km of ordinary roads and 250 km of highways, and, based on map data encoding specifications proposal for automated driving systems (prototype data encoding specifications), created a high-accuracy 3D map covering approximately 300 km.

Furthermore, in order to verify dynamic maps through the large-scale field operational test, a 758 km test area was created in 2017, with 20 Japanese and overseas motor vehicle manufacturers, electrical component manufacturers, universities, and other organizations participating in the project and conducting a dynamic map evaluation. In carrying out this test, test participants' feedback and results were collected and organized through dynamic map field operational test working group sessions in order to develop a de facto standard and contribute on an international scale.

In 2016, Dynamic Map Platform Planning Co., Ltd. was established, and in the following year, 2017, it became Dynamic Map Platform Co., Ltd. in preparation for commercialization. Table 1 shows an overview of these past activities.

2 Dynamic Maps

2.1. Overview of Dynamic Maps

Table 2 shows map use cases for the automated driving systems discussed by SIP-adus. The static, semi-dynamic, and dynamic information used by automated driving systems was identified based on these use cases. The location accuracy of static information was set to the equivalent of map information level 500, the location accuracy of semi-dynamic information was set to lane level accuracy, and the location accuracy of dynamic information was set to several meters. These are defined in Requirement Specifications (Proposal) Ver. 1.0.

Table 2 Map use cases

Item Number	Contents	
Use Case 1	Driving position determination	
Use Case 2-1	Driving control [highways]	Traversing toll booths
Use Case 2-2		Merging into main roadways (from interchanges to main roadways and from junctions to main roadways)
Use Case 2-3		Driving on main roadways
Use Case 2-4		Construction restrictions
Use Case 2-5a		Lane changes (from driving lanes to passing lanes)

Use Case 2-5b		Lane changes (from passing lanes to driving lanes)
Use Case 2-6		Splitting off from main roadways (from main roadways to junctions and from main roadways to interchanges)
Use Case 2-7		Stopping in emergency parking zones
Use Case 3-1	Driving control [ordinary roads]	Driving on main roadways
Use Case 3-2		Merging into through streets
Use Case 3-3a		Lane changes (from driving lanes to passing lanes)
Use Case 3-3b		Lane changes (from passing lanes to driving lanes)
Use Case 3-4		Driving straight through intersections
Use Case 3-5		Turning right at intersections
Use Case 3-6		Turning left at intersections
Use Case 3-7		Avoiding objects
Use Case 4	Parking areas	Parking within parking area lines

2.2. Static Information Data Model

The Automated Driving System Map Data Specification Proposal Ver.1.1 (the data specifications) document was created based on the requirement specifications in 2.1.

Within the static information defined in these data specifications, carriageway lines, pedestrian crossings, traffic signals, road signs, and the like are defined as actual features, while lane links, carriageway links, intersection areas, and the like are defined as virtual features. The data specifications also define the methods used to acquire actual features. Figures 2 to 6 show the acquisition definitions for road signs, traffic signals, carriageway links, and lane links. Figure 7 is an illustrative depiction of static information.

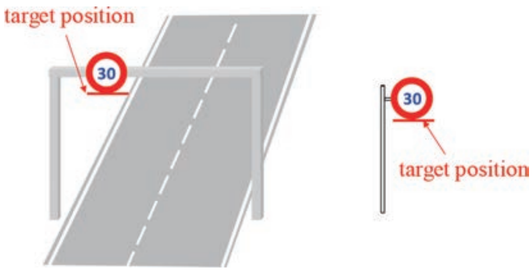

Fig. 2 Road sign acquisition position example

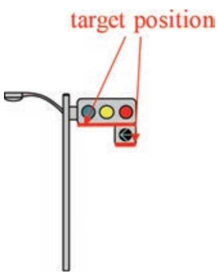

Fig. 3 Traffic signal acquisition position example

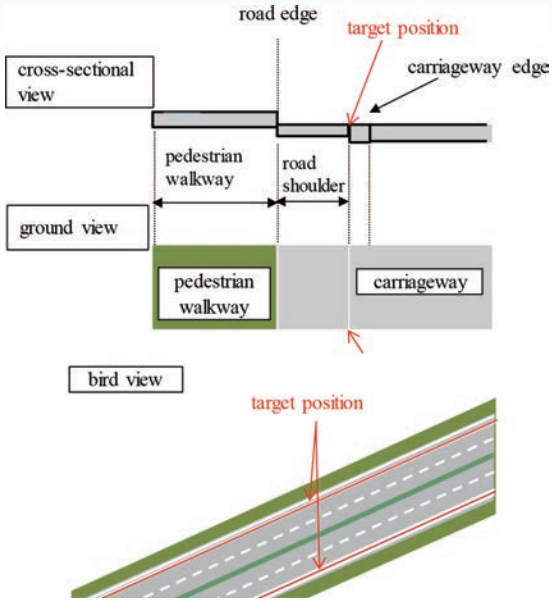

Fig. 4 Shoulder acquisition position example

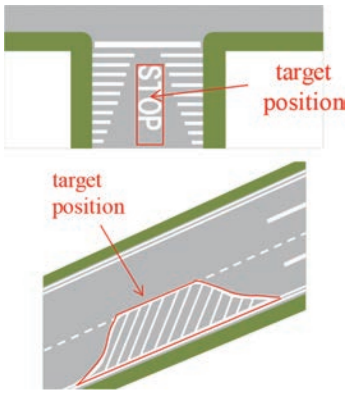

Fig. 5 Road marking acquisition position example

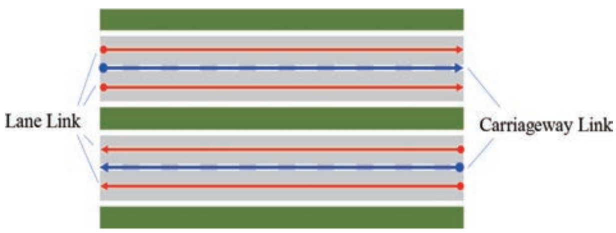

Fig. 6 Lane link and carriageway link acquisition position example

① Dynamic Maps

Dynamic Map Prototyping and Design, and Establishment of Data Linking Functions, Distribution Functions, and Updating Methods

These data specifications define attribute information and related information. The data structure is indicated in Fig. 8. The data specifications define collaborative area features and competitive area features separately (Table 3). During deliberations regarding the collaborative area, opinions were exchanged with two major overseas map suppliers, and features used globally were specified as essential features.

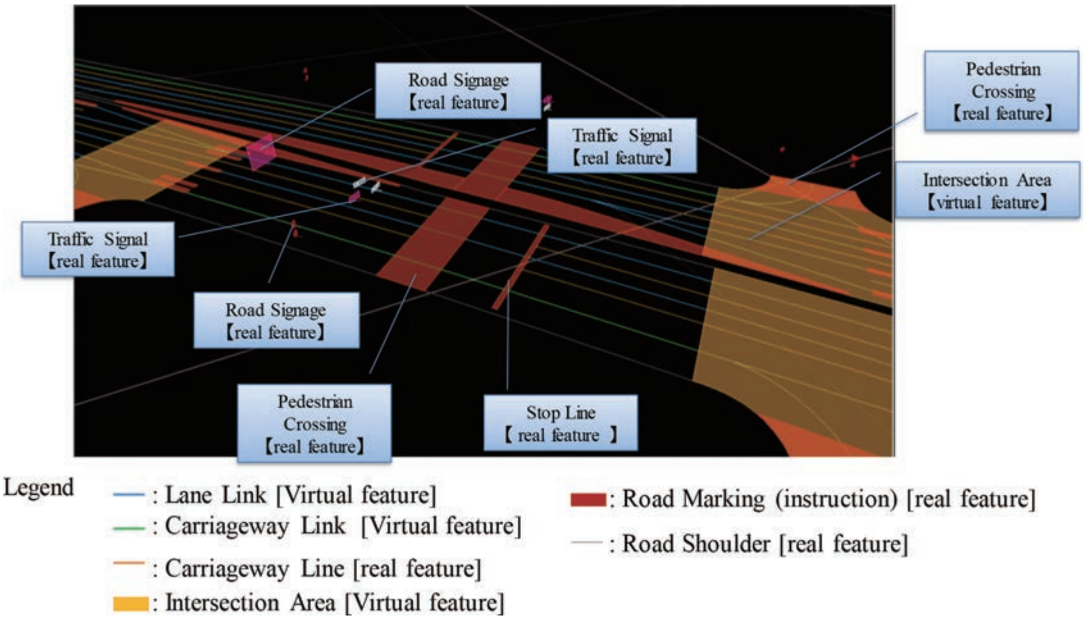

Fig. 7 Depiction of static information

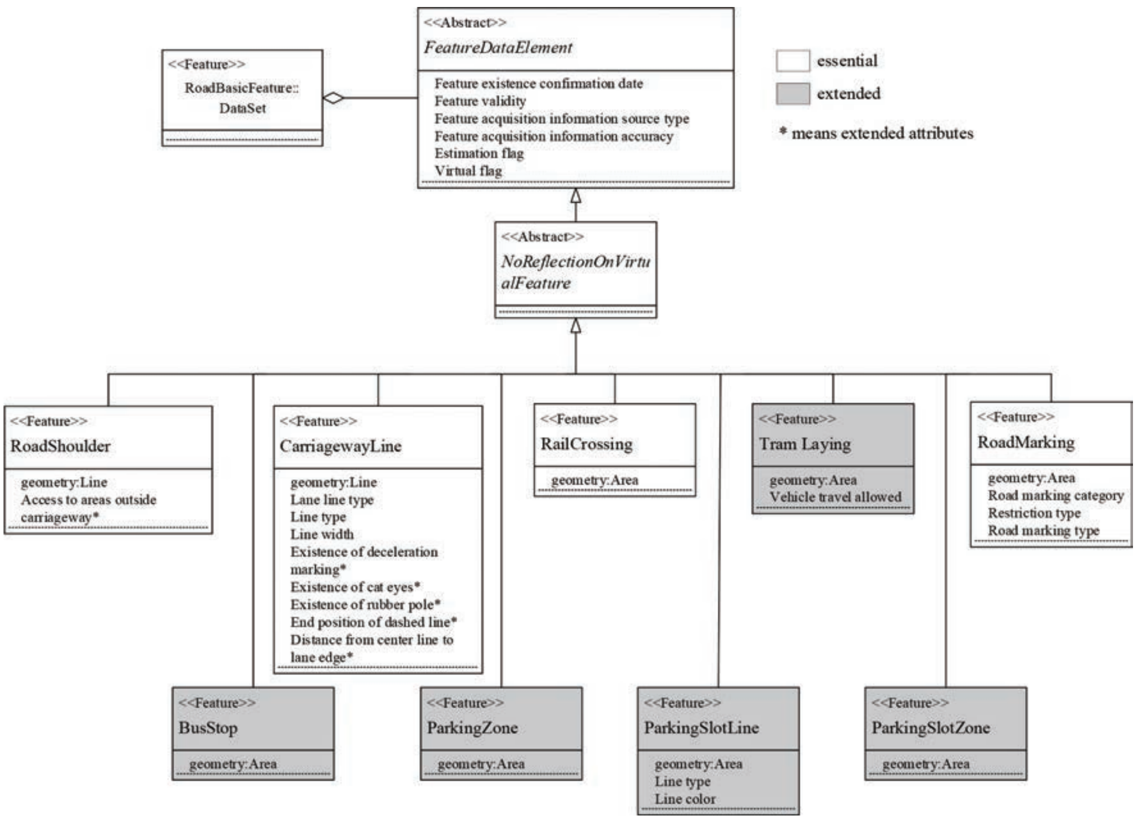

Fig. 8 Examples of definitions of feature attributes and related information

Table 3 List of essential/extended features

		Feature
Essential feature	Actual feature	・Carriageway line (carriageway center line, lane line, carriageway edge) ・Stop line ・Pedestrian crossing ・Road sign ・Shoulder ・Streetcar stop area (island) ・Toll island ・Sidewalk curb ・Emergency parking zone ・Road marking ・Streetcar stop area (marking) ・Channelizing island ・Traffic signal
	Virtual feature	・Carriageway link ・Lane link ・Intersection lane link ・Intersection area
Extended feature	Actual feature	・Grade crossing ・Railway ・Parking zone ・Parking slot ・Parking slot line ・Guardrail ・Cat's eye ・Speed breaker ・Delineator ・Rubber pole ・Road light ・Utility pole ・Kilometer post
	Virtual feature	・Node on carriageway link ・Node on lane link ・Carriageway area ・Lane area

2.3. Static Information Encoding Specifications

The Automated Driving System Map Data Encoding Specification Proposal (Prototype Data Encoding Specifications) Ver.1.0 was created based on this static information data model.

Static information is divided into four types of records, as shown in Table 4: metadata records, feature records, attribute records, and feature relationship records. Figure 9 shows an example of static information (feature record).

Table 4 Data structure of static information

	Record	Contents	Remarks
1	Metadata record	Metadata indicating geodetic system information, file information, etc.	
2	Feature record	Feature shape data, possible feature attributes, relationship types	Contains possible attribute record and feature relationship record type numbers
3	Attribute record	Feature attributes (reversible lanes, link lengths, etc.)	Uses same feature item qualifier as the feature record
4	Feature relationship record	Relationship between features (link connection information, etc.)	As above


```
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  <featureDataRecord>
    <laneLink>
                        :
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        <timeMask>0</timeMask>
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          <geometryDescription_polyline>
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            <vertex>
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              <yCoordinate>35.0641930429</yCoordinate>
              <zCoordinate>103.0030</zCoordinate>
              <zEllipsoidHeight>143.4241</zEllipsoidHeight>
              <coordinates_XY>8:-103817.5670:-
1748.7783:143.4241:103.0030</coordinates_XY>
            </vertex>
                        :
    </laneLink>
  </featureDataRecord>
```


Fig. 9 Example of static information (feature record)

2.4. Static Information Generation Method

A mobile mapping system (MMS) is used to satisfy static information location accuracy requirements. Table 5 shows the static information creation procedure.

Table 5 Static information creation procedure

	Creation procedure	Work contents
1	MMS measurement	Create measurement plan, perform thorough measurement, and generate MMS point group data (Fig. 10).
2	Post-processing and analysis	Analysis processing performs baseline analysis or optimal travel route analysis on data from fixed stations, GNSS measurement devices, IMUs, and odometers to determine vehicle position and posture. The vehicle's own position and posture are used with calibration data to determine the position and posture of digital cameras, laser measurement devices, etc.
3	Evaluation of analysis results	Evaluation is performed promptly, an accuracy management table is created, and decisions are made regarding the need for adjustment by acquiring data at a new location or using adjustment points.
4	Accuracy management using GCP	MMS-based measurement systems rely on GNSS wireless signals. Compositing and joining can be performed easily by using GCP as an overall standard, even when signal reception is poor. GCPs are used to attempt to achieve uniform accuracy by making it possible to achieve a relative accuracy of 25 cm.
5	Landmark processing	When large-scale discrepancies are found during verification using GCPs, GCPs are used to improve location accuracy. The manufacturers that supply MMS systems supply dedicated applications, which are generally used for processing.

Dynamic Map Prototyping and Design, and Establishment of Data Linking Functions, Distribution Functions, and Updating Methods

6	Accuracy management using GCP	When there are GCPs that are not used for landmark processing, those GCPs are used to verify accuracy after processing.
7	Plotting	The data that has been created is used to acquire point, line, and plane data for stipulated features. There are various methods for acquiring data, from semi-automatic feature acquisition to manual acquisition while looking at a screen. Work is performed in such a way as to meet accuracy requirements.
8	Structuring	Structuring is the assigning of meaning in order to create relationships between shapes in accordance with Automated Driving System Map Data Specifications (Proposal).
9	Attribute assignment	Necessary attributes for acquired features are stored from front-facing photographic data, on-site investigation results, and separately acquired materials, based on the Automated Driving System Map Data Specifications (Proposal).
10	Basic map data output	Data is output in the stipulated format.

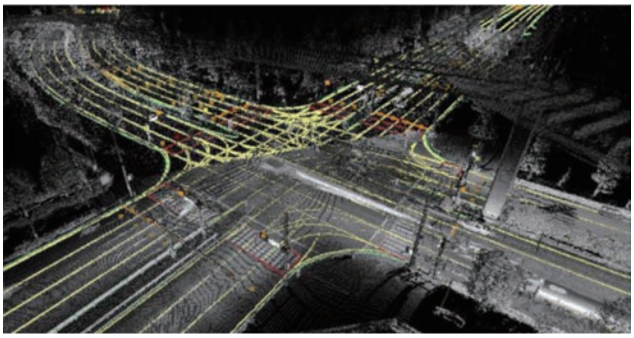


Fig. 10 Example of MMS point group data

2.5. Location Referencing Method

The location referencing method defines how static information (high-accuracy 3D maps) is linked to dynamic information, semi-dynamic information, and semi-static information.

There are four location referencing methods that can be used with dynamic maps (see Table 6). Types 1 and 2 were used for the dynamic maps in the large-scale field operational test.

Table 6 Types of location referencing methods

Type of location referencing methods	Overview	Reference figures/tables
Type 1	Distance difference from CRP	Figure 13, Table 7
Type 2	Road distance + offset from carriageway link	Figure 14, Table 8
Type 3	Expression in terms of latitude, longitude, and altitude (conventional method)	
Type 4	Expression in terms of bearing and distance	

Types 1 and 2 express location information in terms of distance from common reference points (CRPs). CRPs are virtual features defined for intersection areas. They are used as reference points for linking dynamic or other information to static information. CRPs are defined for the centers of ordinary road intersection areas (see Fig. 11) and on lane links in intersection areas of highways (see Fig. 12).

CRP specifications are stipulated in the Dynamic Map Semi-dynamic/Semi-static Information Data Specifications (Proposal).

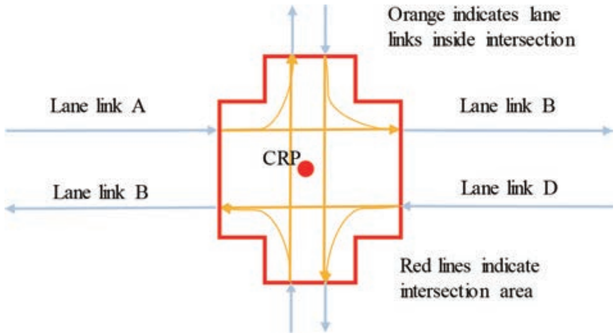


Fig. 11 Example of CRP defined for an ordinary road

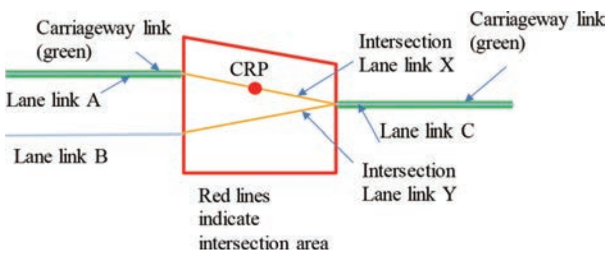


Fig. 12 Example of CRP defined for a highway

Location information expression types 1 and 2, used in the large-scale field operational test, are defined below.

1) Location information expression type 1

Location information expression type 1 is primarily used to indicate the locations of vehicles and pedestrians, etc., inside intersection areas. As shown in Fig. 13, distance differences from CRPs defined for intersection areas are expressed using rectangular coordinate systems with the structure shown in Table 7.

Fig. 13 Conceptual image of location information expression type 1

Table 7 Location information expression type 1 data elements

Item	Essential/optional	Format
CRP identifier	Essential	Unique CRP ID
x distance	Essential	Number indicates distance (m) in x direction from the CRP using a rectangular coordinate system. The x-axis is the meridian for the CRP, and positions due north of the CRP are indicated as positive numbers.
y distance	Essential	Number indicates distance (m) in y direction from the CRP using a rectangular coordinate system. The y-axis is perpendicular to the x-axis at the CRP, and positions due east of the CRP are indicated as positive numbers.
h distance	Essential	Number indicates distance (m) in h direction from the CRP using a rectangular coordinate system. Positions perpendicular to and above the plane formed by the x and y-axes are indicated as positive values.

2) Location information expression type 2

Location information expression type 2 is primarily used to indicate the locations of phenomena outside of intersection areas. Figure 14 shows, carriageway links connect a pair of CRPs, one for the start point and one for the end point, defined for intersection areas. The position on the carriageway link is expressed in terms of road distance, and the offset distance from the carriageway link is used to express the carriageway lateral position and lane location, with the structure shown in Table 8.

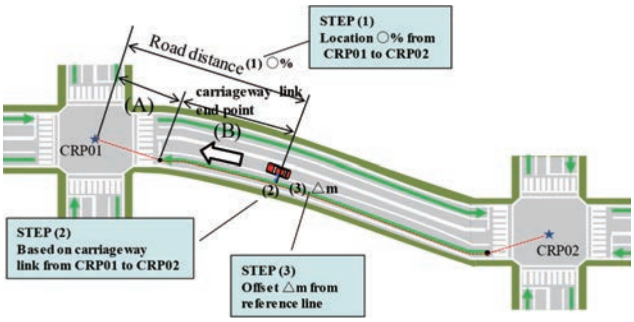


Fig. 14 Conceptual image of location information expression type 2

Table 8 Location information expression type 2 data elements

Item	Essential/optional	Format
Start point CRP identifier	Essential	CRP1 - Unique CRP ID
End point CRP identifier	Essential	CRP2 - Unique CRP ID
Distance from link start point	Essential	Number between 0 and 1 indicating ratio of distance between start point and end point
Offset direction	Essential	Number indicating angle from link (Right side with relation to direction of movement = 90, left side = -90)
Offset distance	Essential	Number indicating offset distance (m)
Position on road	Optional	Integer indicating whether vehicle is on carriageway or off carriageway (shoulder, etc.). 0 = on carriageway, 1 = off carriageway
Position direction on road	Optional	Number indicating whether lane faces start point or end point. 0 = faces start point, 1 = faces end point
Lane number	Optional	Numerical value

2.6. Linking Semi-Dynamic and Static Information

Linear semi-dynamic information such as traffic congestion information and restriction information is expressed using expression types 1 and 2 and start and endpoints (see Fig. 15).

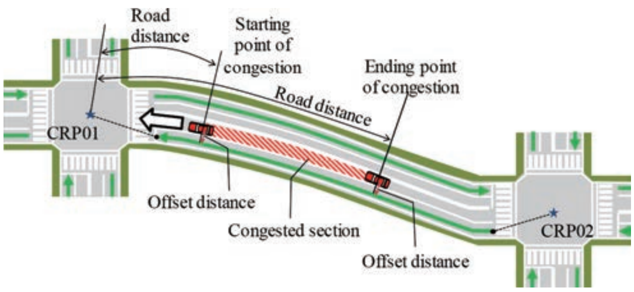


Fig. 15 Semi-dynamic information concept

Figure 16 and 17 show examples of linking semi-dynamic information and static information.

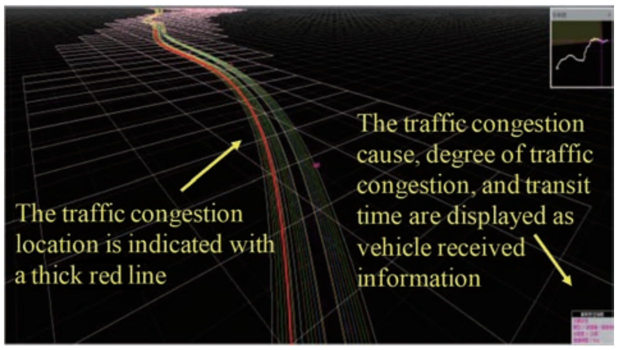


Fig. 16 Traffic congestion information

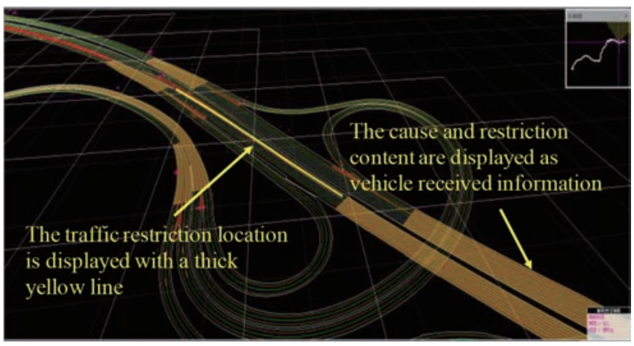


Fig. 17 Traffic restriction information

2.7. Linking Dynamic and Static Information

Point dynamic information such as traffic signal information and crosswalk pedestrian information is expressed using expression type 1 and intersection centers (see Fig. 18).

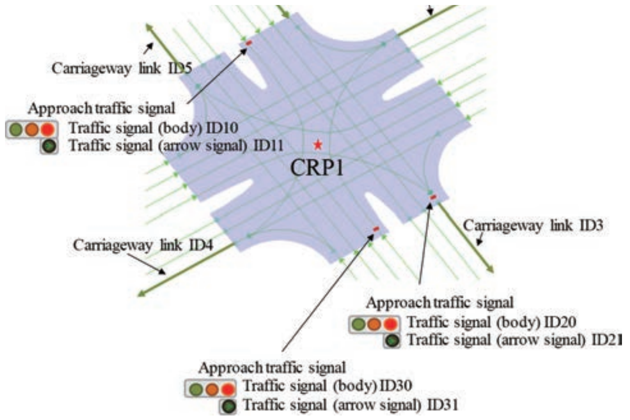


Fig. 18 Dynamic information concept

Figure 19 shows an example of linking dynamic and static information.

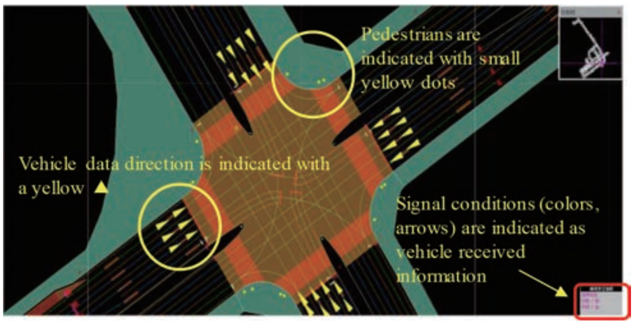
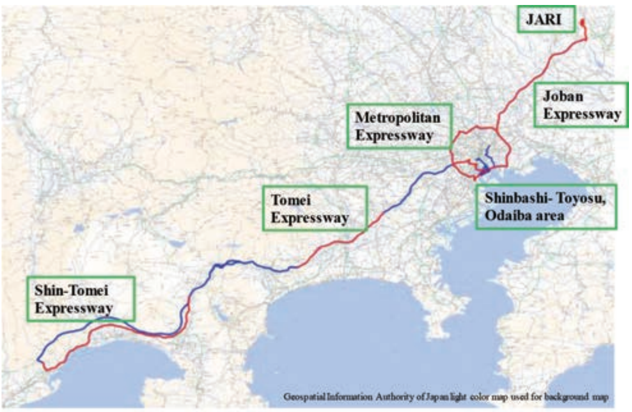


Fig. 19 Vehicle, pedestrian, and traffic signal information

3 Evaluation of Static Information

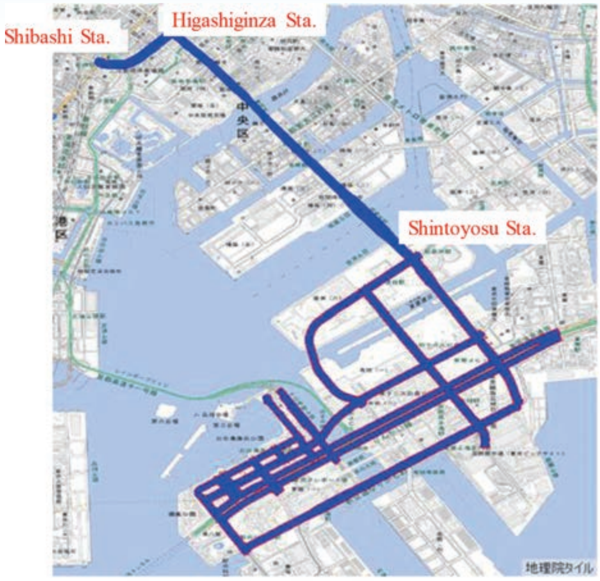
3.1. Method of Evaluating Static Information

Figure 20 and 21 show the Large-Scale Field Operational Test (Dynamic Map) test area. The blue lines in the figure are the 300 km area created in 2016, and the red lines are the test areas added in 2017 (the total length or red and blue lines is 758 km).



[Legend]:
Blue line: Section created in 2016
Red line: Test section

Fig. 20 Static information evaluation area (total length: 758 km)



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

Fig. 21 Static information evaluation area (ordinary roads: 50 km)

Table 11 List of essential/extended features

	Essential feature	Major overseas map suppliers
Actual feature	* Road shoulder	
	* Road center line	○
	* Lane line	○
	* Carriageway edge	○
	* Stop line	○
	* Pedestrian crossing	○
	* Road marking	
	* Traffic signal	
	* Road signage	○
Virtual features	* Carriageway link	
	* Lane link	
	* Intersection lane link	
	* Intersection Area	
	* CRP	

Table 11 shows the static information features distributed during the verification test.

3.3. Evaluation Results

Feature usage status information and requests for improvements to static information were collected from test participants, and evaluated.

3.3.1. Feature Usage Status

Table 12 shows the status of feature usage by test participants and the evaluation results. Some test participants requested the addition of features other than essential features. Data specifications were reviewed based on requests for additional features and the Japan Automobile Manufacturers Association's feature recommendations. Table 13 shows the results of the review.

Based on the above, the essential features in the data specifications were found to be sufficient for use by automated driving systems.

Table 12 Feature usage conditions and evaluations

FOT Paticipants	Stop Line	Pedestrian Crossing	Traffic Signal	Road Shoulder	Road Center Line	Lane Line	Carriageway Edge	Road Marking	Road Signage	Carriageway Link	Lane Link	Intersection Lane Link	Intersection Area	Other Features
A	△	△	△	○	○	△	○	△	—	△	△	△	—	—
B	—	—	△	○	—	△	△	—	△	△	○	△	○	—
C	○	○	○	○	△	△	△	○	△	○	○	△	○	○
D	○	○	○	△	○	○	○	△	△	—	○	△	△	—
E	—	—	—	—	△	○	—	△	—	○	○	—	—	—
F	○	○	○	○	○	○	○	○	○	○	○	○	○	○
G	○	○	○	○	○	○	○	○	○	○	○	○	○	○
H	△	○	△	—	—	—	—	△	△	—	△	△	△	○
I	—	—	—	—	—	△	△	—	—	△	△	△	—	○
J	—	—	—	△	—	△	△	△	△	○	△	○	○	○
K	—	—	○	△	○	○	○	○	○	○	○	○	△	○
L*	○	○	○	—	○	—	—	—	—	—	—	—	—	—
M	○	○	○	○	○	○	○	○	○	○	○	○	—	—
N	○	○	○	△	○	○	○	○	○	—	○	△	—	—
O	○	○	○	○	○	○	○	△	○	○	○	○	○	—
P	—	—	—	○	○	○	○	—	○	○	○	—	—	—
Q*	○	○	○	○	○	○	○	—	—	○	○	○	○	—
R	—	—	○	○	○	○	○	○	○	○	○	○	○	○

○:"Used this feature" and "Sufficiently usable in current state", △:"Used this feature" and "Acquisition standards should be reviewed and revised"
—:This feature was not used (no evaluation)
* For test participants L and Q, evaluation results are for the 300 km area. For all other test participants, evaluation results are for the 758 km area.

Table 13 Requests for addition of features other than essential features

Category	Sub-category	No.	Feature name	Feature requested by test participant
Essential feature	Virtual feature	1	Carriageway link	○
		2	Lane link	○
		3	Intersection lane link	○
		4	Intersection area	○
		5	Location reference platform => Marker point	
	Actual feature	6-1	Carriageway line: Carriageway center line*	○
		6-2	Carriageway line: Lane line*	○
		6-3	Carriageway line: Carriageway edge*	○
		7	Stop line*	○
		8	Pedestrian crossing*	○
		9	Road sign*	○
		10	Shoulder	○
		11	Streetcar stop area (island)	○
		12	Toll island	○
		13	Sidewalk curb	○
		14	Emergency parking zone	○
		15	Road marking	○
		16	Streetcar stop area (marking): Road marking	○
		17	Channelizing island	○
		18	Traffic signal	○
		19	Grade crossing	○
Quasi-essential feature	Virtual feature	20	Node on carriageway link	○
		21	Node on lane link	○
		22	Lane area	○
		23	Road sign regulation	○
		24	Road marking regulation	○
		25	Restriction content	○
		26	Course change prohibited carriageway position (carriageway link only)	○
		27	Course change prohibited lane position (lane link only)	○
		28	Lane link road structure attribute => Curvature radius	○
		29	Lane link road structure attribute => Longitudinal slope	○
		30	Lane link road structure attribute => Transverse slope	○
		31	Presence of covering object (tunnel, shed, etc.)	○
		32	Tunnel height limit	○
	Actual feature	33	Bus stop	○
Extended feature	Virtual feature	34	Carriageway area	
		35	Auxiliary sign	
		36	Road link road structure attribute => Horizontal direction attribute => Clothoid curve	
		37	Road link road structure attribute => Horizontal direction attribute => Circular curve section	
		38	Road link road structure attribute => Horizontal direction attribute => Straight line section	
		39	Road link road structure attribute => Longitudinal slope attribute => Monocline section	
		40	Road link road structure attribute => Longitudinal slope attribute => Curve section	

① Dynamic Maps

Dynamic Map Prototyping and Design, and Establishment of Data Linking Functions, Distribution Functions, and Updating Methods

Category	Sub-category	No.	Feature name	Feature requested by test participant
		41	Road link road structure attribute => Transverse slope attribute	
		42	Road section ID information	
		43	DRM link information	
		44	VICS link information	
		45	Connection information	
		46	Underpass height limit	
		47	Bridge width	
	Actual feature	48	Railway	
		49	Parking zone	
		50	Parking slot	
		51	Parking slot line	
		52	Guardrail	
		53	Cat's eye	
		54	Speed breaker	
		55	Delineator	
		56	Rubber pole	
		57	Road light	
		58	Utility pole	
		59	Kilometer post	
		60	Road border line	
		61	Road marking (symbol)	
		62	Drivable area within tunnel	
		63	Road drivable by special vehicle	
		64	ETC gate position	
		65	Motorcycle stop line	
		66	Two stage right turn stop line for motorized bicycles	
		67	Bus-only lane	
		68	Bus priority lane	

Essential feature: Collaborative area features envisioned as being used by many automotive manufacturers
Quasi-essential feature: Features requested by test participants
Extended feature: Other features
* Features for which consensus has been reached with two major overseas map suppliers

3.3.2. Requests for Improvements from Test Participants

Test participants pointed out some discrepancies in the positions and existence of road markings, signs, traffic signals, and the like. These were caused by construction or other activities after the data was prepared. There were 20,991 prepared features and 134 improvement requests.

Table 14 shows the types and numbers of improvement requests.

Tables 15 and 16 show typical examples of improvement requests. Table 15 shows an example in which a gantry and signs (three signs each for outbound and inbound lanes) were present when the data was generated, but had been removed by the time the field operational test was performed. Table 16 shows a road marking (bus stop) that was added after the data was generated.

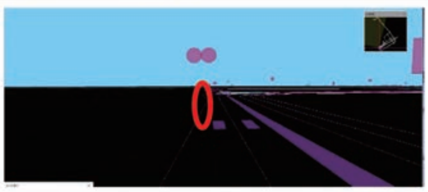
Table 14 Types and numbers of improvement requests

Type of improvement request	Quantity
1: Existed when data was generated (is currently believed to no longer exist)	47
2: Did not exist when data was generated (is currently believed to exist)	54
3: Outside design scope	11
4. As indicated in preparation specifications	5
5: Shape/location change	11
6: Due to viewer confirmation position error (no problem in data or viewer)	2
7: Unable to identify pointed out point	4
Total	134

Table 15 Improvement request example (data contains non-existent sign)

Issue pointed out	Data contains non-existent sign
Road condition during driving	
Viewer display	
Condition when data was generated	

Table 16 Improvement request example (road marking missing from data)

Issue pointed out	Road marking missing from data
Road condition during driving	
Viewer display	

Condition when data was generated	

3.3.3. Issues

As Table 14 shows, the main improvement requests were to address issues in which features existed when the data was generated but no longer exist, and issues in which features didn't exist when the data was generated, but currently do exist.

These were caused by changes to roads in the three to four months after MMS measurement. When there are changes to roads, static information must be updated. Updating static information involves a sizeable cost, so the approach used to update static map information must be given consideration, taking into account the timing of feature and road updates, update frequency, and other factors.

4 Summary

This article discussed the approach used in dynamic map static information requirements and data specifications, preparation guidelines, encoding specifications, and the like, and described the location referencing method that uses CRPs to link static information with dynamic information and semi-dynamic information.

Based on the results of evaluations by Large-Scale Field Operational Test (Dynamic Map) participants, we concluded that the essential features that make up static information (14 features) are sufficient for use by automated driving systems. Test participants also agreed that features for which there were numerous requests would be defined as quasi-essential features so that they could be developed as needed by individual companies during practical implementation.

We found that, within the category of static information, there were examples of road signs and road markings changing over the course of three to four months after MMS measurement was performed, and we identified a need to organize approaches to updating static information. We will consider these items during the 2018 field operational test.

This research and development work was carried out with the collaboration of Program Director Seigo Kuzumaki, members of SIP-adus, and Large-Scale Field Operational Test (Dynamic Map) participants, as well as Dynamic Map Platform Co., Ltd. and Mitsubishi Research Institute, Inc., which were involved in the creation of the dynamic maps.

References

(1) Strategic Innovation Promotion (SIP) Program for Automated Driving Systems, Study of advancement of map information (information assembly and structuring) for use in studies and investigations of the approaches to use in resolving issues affecting the realization of automated driving systems (2014)
(2) Strategic Innovation Promotion (SIP) Program for Automated Driving Systems, Study of measures and evaluations aimed at the creation of dynamic maps for use in studies and investigations of the approaches to use in resolving issues affecting the realization of automated driving systems (2015)
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(4) Implementation and Management of Strategic Innovation Promotion Program (SIP) for Automated Driving Systems/Large-scale Field Operational Test//Dynamic Map Prototyping and Design, Establishment of Center Functions and Updating Methods, etc.
(5) Requirement Specifications (Proposal) Ver. 1.0 (2015)
(6) Automated Driving System Map Data Specification Proposal Ver.1.1 (2016)
(7) Map Data Preparation Guidelines (Proposal) Ver. 1.0 (2015)
(8) Automated Driving System Map Data Encoding Specification Proposal (Test Data Encoding Specifications) Ver.1.0 (2016)
(9) Dynamic Map Semi-dynamic/Semi-static Information Data Specifications (Proposal) Ver.1.0 (2016)
(10) Recommended Specifications for High-accuracy Maps Used for Automated Driving (November 2016, Japan Automobile Manufacturers Association, Inc.)
(11) Materials Related to New Advanced Digital Road Surface Information for Advanced Driving Support (Japan Digital Road Map Association)

About the author
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Strategic Innovation Promotion Program (SIP) Automated Driving Systems/Large-scale Field Operational Test/Dynamic Map/Utilization of Vehicle Probe Information

Eiji Muramatsu et al. (Pioneer Corporation)

ABSTRACT: Vehicle probe information is getting more important than ever. It is useful to get data on road situations such as traffic flow, objects, as well as weather conditions, in near real-time. It is expected that this kind of information will be shared among industries to realize a more efficient and safer society especially when automated vehicles become a reality.

The purpose of this project is to evaluate the feasibility of the vehicle probe information exchange interface between cloud services through the large-scale field operational test conducted by SIP. The interface specifications are currently under development by the Dynamic Vehicle Information Sharing Working Group in Japan Automotive Software Platform and Architecture (JASPAR).

1 Background

JASPAR established the Dynamic Vehicle Information Sharing Working Group in 2017. They started to create the vehicle information exchange interface specifications referred to as the Common Vehicle Information Specification.

The purpose of this specification is to share vehicle information among industries through the dynamic map platform.

The scope of the JASPAR Common Vehicle Information Specification is depicted in Fig. 1.

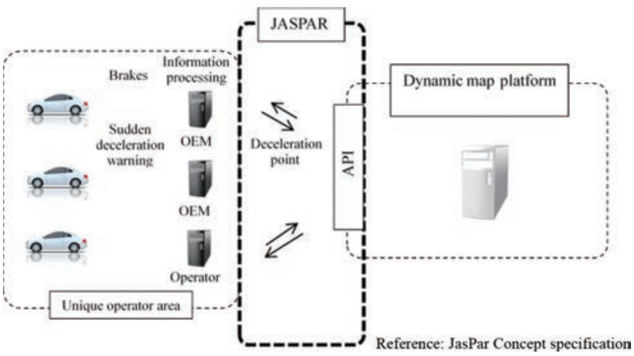


Fig. 1 Scope of Common Vehicle Information Specification

The JASPAR Common Vehicle Information Specification consists of three parts, the concept specification, the data set specification and the API specification. The concept specification defines use-cases for the vehicle information and its necessary data. The data set specification defines the exchange data format between different cloud services. The API specification defines the API to send, delete or reference data from the OEM side in the dynamic map platform presented in Fig. 1.

2 Project Overview

2.1. Purpose

The main purpose of this project is to evaluate the feasibility of the JASPAR Common Vehicle Information Specification using real vehicle information. The experiment is done by joining the SIP Large-scale Field Operational Test.

2.2. Period

This project started October 30, 2017 and will end in February 28th, 2019. This report shows the status of the project from October 30th, 2017 through September 2018.

2.3. Content to evaluate

This project makes use of traffic flow content that indicates vehicle average speed on a certain section of road.

Traffic flow is one of seven items that the JASPAR Common Vehicle Information specification defines.

We decided to evaluate both road- and lane-level traffic flow.

2.4. Evaluation scheme

Fig. 2 shows the experiment scheme of this project.

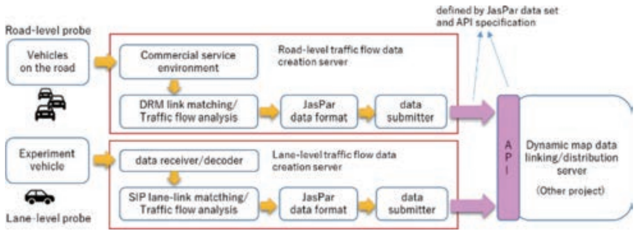


Fig. 2 Evaluation scheme

The road-level traffic flow is created by utilizing the vehicle trajectory data from a commercial service (called

"Smart loop") offered by Pioneer Corporation.

The data is derived from vehicles on the road equipped with a car navigation system. The vehicle trajectory information is matched to the road links of the Japan Digital Road Map Association (DRM). The average speed of vehicles is then calculated based on DRM road links.

In contrast, the lane-level traffic flow is created using experiment vehicles equipped with modified car navigation systems. Currently, the lane-level position cannot be determined by GNSS, so the experiment vehicle drives in a pre-defined lane and generates the traffic flow for that lane. The vehicle trajectory information is matched to lane links in the SIP dynamic map to calculate the average speed of vehicles for a section length based on SIP lane links.

The next step is to convert traffic flow data to the JASPAR message data format specified by the Common Vehicle Information Data Set Specification.

Fig. 3 shows an overview of the traffic flow message data format defined by the JASPAR specification.

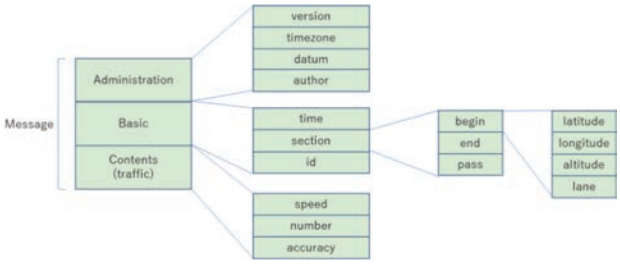


Fig. 3 Traffic flow message structure of JASPAR specification

Finally, the message is transmitted to the dynamic map platform using the REST API specified by the JASPAR API specification.

3 Confirmation of the Traffic Flow Data

To confirm the traffic data visually, we utilized the dynamic map viewer provided by SIP for the Large-scale Field Operational Test.

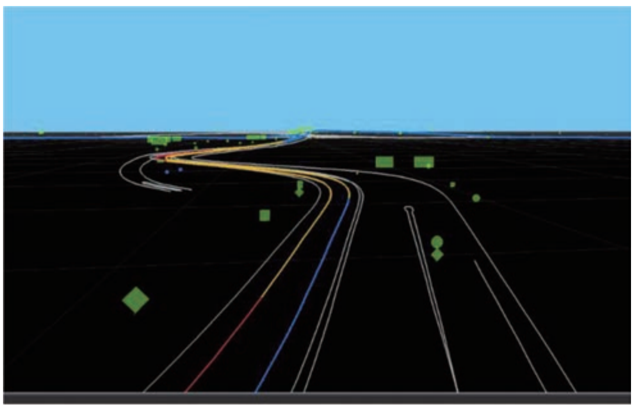


Fig. 4 Visualized image of road-level traffic flow data

Fig. 4 shows an example image of road-level traffic flow on the SIP Dynamic Map viewer. As you can see, the traffic flow data can contain altitude information to distinguish overpasses or road underneath.

4 Connecting to the Dynamic Map platform

The dynamic map platform defined in the JASPAR specification is operated by Dynamic Map FOT (Field Operational Test) Consortium, which is the management body of the SIP Dynamic Map Large-scale Field Operational Test.

The Field Operational Test starts in October 2018 and our traffic flow data will be treated as transient dynamic data for the dynamic map in their project.

We needed to confirm that the traffic flow data was transmitted to their server without problems.

4.1. Implementation specification

The JASPAR specification does not specify implementation specific matters. We created implementation specifications to connect and communicate appropriately with each server. Table 1 shows example items from the implementation specification that we defined.

Table 1 An example item of implementation spec

Item	Definition
Data transmission interval	5 min.
Maximum data size per request	1 MB
Maximum number of messages per interval	1000
Number of connectable sessions	more than 2

4.2. Logical connection test

We also created a test specification for the logical connection test between the servers of each party. The test items are classified as follows:

- Format
  Check if the data format complies with the JASPAR specification.
- Data
  Check if the system works for various data ranges.
- Performance
  Check that the system is not vulnerable to high loads.

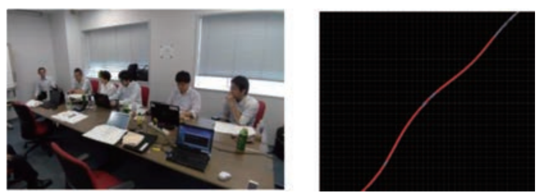


Fig. 5 Connection test with Dynamic Map FOT Consortium

4.3. System test

To confirm that all systems work as we expected, we started a systems test that utilized the final environment of the field operational test.

For lane-level traffic flow data, we prepared some experiment vehicles and gathered real-world vehicle information.

Figure 6 shows the driving course for the lane-level traffic flow data.

Fig. 6 Driving route for lane-level traffic flow

Figure 7 shows an image of the results of the lane-level traffic flow collected from experiment vehicles and transmitted to the dynamic map platform using the JASPAR Common Vehicle Information Specification.

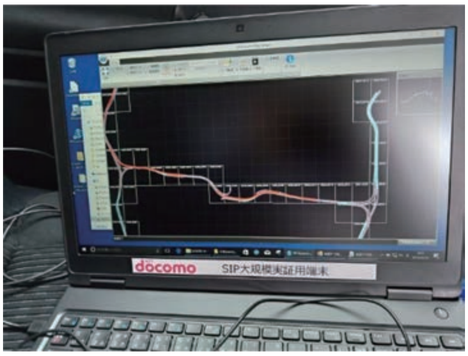


Fig. 7 Lane-level traffic flow field check using SIP Dynamic Map Viewer

5 Feedback to JASPAR Working Group

We found some problems to be pointed out in the JASPAR specifications during the implementation/evaluation.

Table 2 shows the example items that we reported to the JASPAR Working Group.

Table 2 Example feedback items for JASPAR Working Group

Item	Problem
Data type problem	unsigned int for altitude
Direction of a section	ambiguity
API request overhead	one section per request
Altitude definition	ambiguity
Lane number definition	ambiguity

6 Measurement of Calculation Delay

We measured the calculation delay of our server (between when probe data was received and when the JASPAR traffic flow message data was sent to the dynamic map platform) to understand our server performance and possible transient dynamic data latency.

In doing so, we found that the map matching function takes a relatively longer time than the other functional modules. We plan to continue investigating the overall delay in cooperation with the Dynamic Map FOT Consortium.

7 Future schedule

The Large-scale Field Operational Test will start in October 2018. The road-level traffic flow data will be delivered from October 1st to December 27th, except for the period of November 26th to November 30th. The lane-level traffic flow will be delivered from November 26th to November 30th.

Fig. 8 Deliver area of road-level traffic flow data (Green area)

8 Conclusion

The progress of this project is on schedule. We are continuing to proceed with the experiment and evaluations in cooperation with the Dynamic Map FOT Consortium. The final report is planned for submission in February 2019.

References

(1) JASPAR, *Common Vehicle Information Concept Specifications Draft ver. 1.0* (February 1, 2018)

A Study of Specifications for Providing Lane-Level Traffic Information in Dynamic Maps

Koichi Miyashita, Suguru Kawajiri and Shintaro Shimizu (Mitsubishi Research Institute, Inc.)

ABSTRACT: For automated driving to be able to use lane-level traffic information, it will be necessary to verify whether or not there are problems with regard to the following issues: 1. errors due to data conversion in the multiple conversion processes conducted when providing traffic information, 2. differences in map accuracy, updating frequency and so on between the maps used for human drivers to provide route navigation and the maps used by systems, including automated driving, and 3. time lag at each stage in the generation, transmission and utilization of traffic regulatory information by the vehicle. A proposed testing plan has been prepared to conduct tests to verify these issues as part of a different project during the next fiscal year. In this study, an equipment configuration to receive the regulatory information distributed by road operators and overlay this information onto the dynamic maps was proposed.

1 Purpose

The purpose of this study was to gather information through a survey of the traffic information currently being provided, as well as an exchange of views with the relevant entities, for using semi-static and semi-dynamic information in the dynamic maps expected to be used by automated driving systems (ADS). A proposed testing plan has been prepared for conducting tests to verify the use of lane-level traffic information for automated driving.

2 Study of Providing Lane-Level Traffic Information in Japan

2.1. Specifications for semi-static and semi-dynamic lane-level traffic information, as well as technical trends and specifications for methods of provision.

2.1.1. Process for Providing Traffic Information

Fig.1 shows the process for providing traffic information. Traffic information in Japan passes through three stages before use: information collection and consolidation, information processing and editing, and information provision.

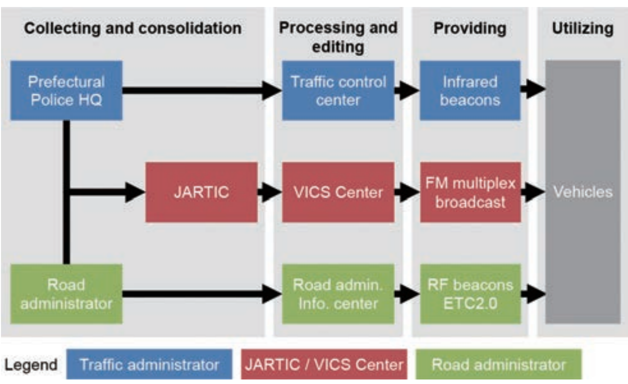


Fig. 1 Process for providing traffic information [(1)].

2.1.2. Specifications for Semi-Static and Semi-Dynamic Lane-Level Information

Common data formats and specifications have been issued to interchange road traffic information smoothly between traffic administrators, road administrators, the Japan Road Traffic Information Center (JARTIC), and the Vehicle Information and Communication (VICS) center on the process for providing traffic information (see Fig. 1). The VICS center, UTMS society of Japan, and Highway Industry Development Organization (HIDO) jointly own and manage the intellectual property concerning these specifications. In Japan, traffic information has been provided as VICS links, which are segments created by dividing up the road network into intervals between intersections or other road sections.

2.2. Domestic Projects and Mechanisms for Handling Semi-Static and Semi-Dynamic Lane-Level Traffic Information

The data format used to transmit semi-static and semi-dynamic traffic information via FM multiplex broadcasts is defined in ARIB STD-B3 *ARIB Standard for Operation of The FM Multiplex Broadcasting System*. Of the types of road traffic information, a format has been defined for regulatory information, making it possible to provide information on regulatory events at the individual lane level. This format is almost the same as that for both infrared beacons and radio wave (RF) beacons.

2.3. Points to Verify when Using Road Traffic Information for ADS

For ADS to be able to use lane-level traffic information, it will be necessary to verify whether or not there are problems with regard to the issues described below.

2.3.1. Data Conversion Errors

In providing traffic information, errors may occur during multiple data conversion processes as shown in Fig. 2, therefore verification is needed to ensure that there are no discrepancies in positional recognition.

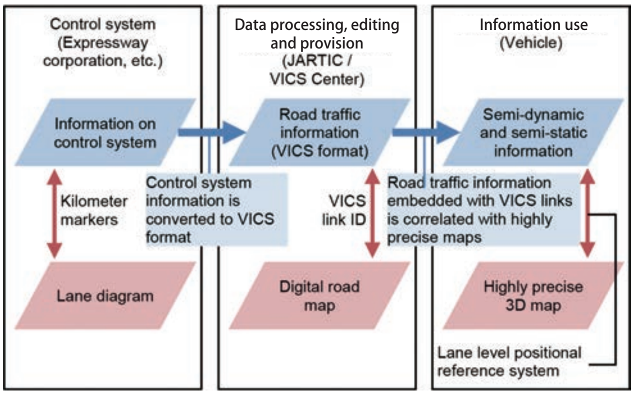


Fig. 2 Process for road traffic data format conversion.

2.3.2. Differences between Dynamic Maps and Digital Road Maps

When the map used by the ADS (dynamic map) and the map used to provide traffic information (digital road map) are different (see Table 1), it must be verified that the traffic information can be correctly correlated with the dynamic map.

Table 1 Comparison of dynamic map and digital road map.

Map	Dynamic map	Digital road map
Map accuracy	1/500 (Note: relative precision)	1/25,000
Map updating frequency	As soon as possible after updating	Once per year (March)
Map creation method	Mobile mapping system (MMS) Note: Measurement vehicle equipped with laser radar	Geographical Survey Institute 1/25,000 topographic map Road administrator references Newly published topographic map
Purpose of use	ADS	Road traffic information

2.3.3. Time Lag at Each Stage in the Generation, Transmission and Use of Information by the Vehicle

Time lags as shown in Table 2 may occur during the provision of traffic regulatory information.

Table 2 Types of time lag and examples.

Types of time lag	Examples
Information generation	Time lag between reporting a fallen object or broken down vehicle and entering traffic regulatory information in the system of the traffic control center or road administrator information center
Information transmission	FM multiplex broadcasting: time lag between transmitting information from the system of the traffic control center or road administrator information center via JARTIC and the VICS center, and broadcasting by FM multiplex every 5 minutes ETC 2.0: time lag between transmitting information from the system of the traffic control center or road administrator information center and its provision by ETC 2.0
Information utilization by vehicles	Time lag between entering traffic information in dynamic maps in vehicles and that information becoming ready for use

3 Study of Domestic Efforts Relating to the Provision of Lane-Level Traffic Information

3.1. Exchange of Information with Relevant Entities in Japan Regarding the Provision of Lane-Level Traffic Information

We held opinion exchange conferences to share information about the provision of lane-level traffic information with relevant entities in Japan. The attendees were the National Police Agency Traffic Bureau, the Ministry of Internal Affairs and Communications Telecommunications Bureau, and the Ministry of Land, Infrastructure, Transport and Tourism Road Bureau, while the observers were the VICS center, HIDO, the Japan Traffic Management Technology Association, the Japan Automobile Manufacturers Association (JAMA) , the Japan Digital Road Map Association (DRM) , JARTIC, the UTMS society of Japan, East Nippon Expressway Company (NEXCO East), Central Nippon Expressway Company (NEXCO Central) and the Dynamic Map Large-Scale Field Operational Test Consortium.

3.2. Study of the Specifications for Lane-Level Traffic Information Needed to Implement Automated Driving

We investigated formats and specifications for the lane-level traffic information needed to implement automated driving, as well as use case scenarios for connected and automated vehicles (CAVs) utilizing this information.

On the highway, lane-level traffic regulatory information defined in common data formats and specifications was provided through FM multiplex broadcasting and ETC 2.0. Lane-level traffic regulatory information also may be presumed to be used in automated driving.

JAMA has organized four use case scenarios for CAVs, as shown in Table 3. These common use cases are not only applied by JAMA, but also shared with other related organizations[2].

Table 3 Prioritized use case scenarios for CAVs [2]

Use case scenario	Description
Traffic information on road ahead	Realize smooth automated driving using safety-related traffic information on the road ahead
Merging / lane change	Realize smooth merging using information on traffic flow and mutual communication between vehicles
Emergency information on hazards	Collect information on hazards and distribute it to following and oncoming vehicles
Truck platooning	Exchange control information among trucks

3.3. Preliminary Draft Plan for Test of the Provision of Lane-Level Traffic Restriction Information

Study of test plans in anticipation of the proving tests to be conducted during the next fiscal year by the Cross-Ministerial Strategic Innovation Promotion Program (SIP), in order to confirm the following two points:

1. Technical confirmation that lane-level traffic restriction information can be used in dynamic maps.
2. Confirmation by test participants in the dynamic map proving tests that lane-level traffic restriction information can be used.

3.3.1. Proposed Configuration of Equipment to Use for Technical Verification

For the "dynamic map" proving tests in the SIP Automated driving system / Large-scale Field Operational Tests, the test functions used by dynamic maps on the vehicle side are expected to be employed for the lane-level traffic restriction information that provided by the ETC 2.0 roadside unit (see Fig. 3).

Verification of the test functions (on the vehicle side) that have been constructed in the dynamic map proving tests.

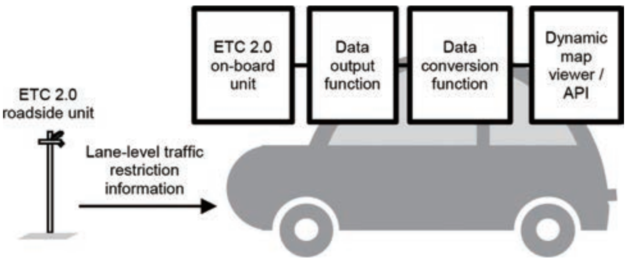


Fig. 3 Anticipated equipment configuration.

3.3.2. Proposed Test Schedule and Locations

We proposed test schedule and locations as shown in Table 4. Fig.4 shows the test locations and provision status of the lane-level traffic restriction information.

Table 4 Proposed test schedule and locations.

Development of test functions (vehicle side)	By August 2018
Evaluation by developer	September 2018
Evaluation by test participants	October - December 2018
Test location	Expressways on which lane-level traffic restriction information is provided

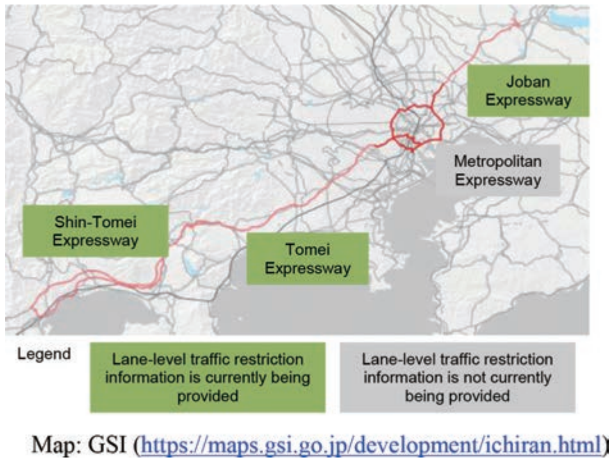


Fig. 4 Test locations and provision status of lane-level traffic restriction information.

4 Conclusion

We confirmed that lane-level traffic restriction information (restrictions on driving in driving lanes, passing lanes, etc.) is currently being provided on some expressways using FM multiplex broadcast and the ETC 2.0 system. The points of contention regarding the use of lane-level traffic restriction information on ADS were identified. During the next fiscal year, proving tests to verify that lane-level traffic restriction information can be used in dynamic maps are expected to be conducted through the SIP Program, and preliminary draft plans for the proving tests are currently being studied.

References

(1) VICS Center website (http://www.vics.or.jp/en/vics/pdf/vics_pamph.pdf).
(2) Norifumi Ogawa: "Status of Connected Vehicle Technology Development for Automated Driving in Japan", SIP-adus Workshop 2017, http://en.sip-adus.go.jp/evt/workshop2017/file/evt_ws2017_s3_NorifumiOgawa.pdf, (2017).

Change Detection and Automated Mapping for Dynamic Maps

Yasunari Goto, Takuma Kadoya (Mitsubishi Electric Corporation)

ABSTRACT: Static high-precision 3D maps, which form the basis of dynamic maps promoted and maintained for use as automatic driving maps on highways, are required to remain up to date and maintain a high level of quality. We proposed an automation technology for map generation to reduce map creation costs and realize quick updates. We confirmed the effectiveness of improving the map generation cost by comparing and verifying the automation technology and existing map generation method. As improvement measures included not only map generation but also data measurement, we implemented real-time measurements and diagrams. We will proceed with a verification of the technology for practical application.

1 Introduction

Static high-precision 3D maps, which form the basis of dynamic maps promoted and maintained for use as automatic driving maps on highways, are being developed. Static high-precision 3D maps are required to remain up to date and maintain a high level of quality. If we can alleviate the cost burden on users while satisfying the update frequency and quality requirements, their use can be expected to spread. We examined the time and cost improvement effectiveness of creating and updating maps using automation technology.

2 Practical Verification of Automation Technology

2.1. Static High-Precision 3D Map Data Generation Process

An example of the process leading up to the generation of static high precision 3D map data is shown in Fig. 1. The map generation process is classified into measurement and mapping. We considered the application of automation technology for this mapping process. For verification purposes, an intercity highway (the Tomei Expressway around the Ebina junction) and an urban expressway (the Metropolitan Expressway, C1) were taken as typical examples of highways.

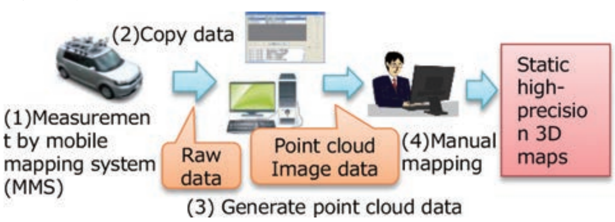


Fig. 1 An example of the flow until static high precision 3D map data is generated

2.2. Practical Verification of Automated Mapping

2.2.1. Performance Evaluation of Automated Mapping

The following indicators are used as evaluation indices for automated mapping. These definitions are shown in Fig. 2.

(1) Correct ratio: (C) / (B) in Fig. 2

Ratio of the correct features in the automated mapping results.

(2) Detection ratio: (C) / (A) in Fig. 2

The ratio of all correct features detected by automated mapping.

(3) False detection ratio: (3) in Fig. 2

Ratio of items that do not actually exist found in the automated mapping result.

(4) Undetected ratio: (4) in Fig. 2

The ratio of all correct features not detected by automatic mapping.

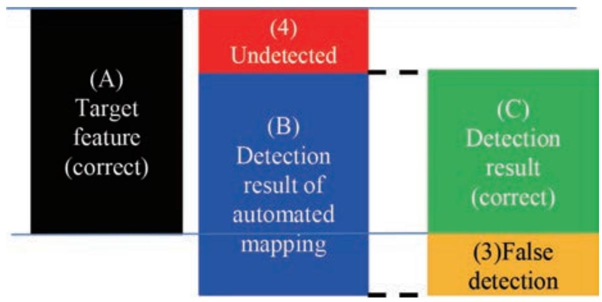


Fig. 2 Definition of evaluation index

Table 1 shows the evaluation results on the expressway.

Table 1 Evaluation results of automated mapping

	Highway : 76.5 km			
Items	(1) Correct ratio	(2) Detection ratio	(3) False detection ratio	(4) Undetected ratio
Shoulder edge	91.0%	95.8%	9.7%	4.3%
Lane division line	88.7%	92.8%	12.4%	7.1%

Figure 3 shows an example of the result of automated mapping. For the shoulder edge and road lines, the results of automated mapping were compared with the correct data.

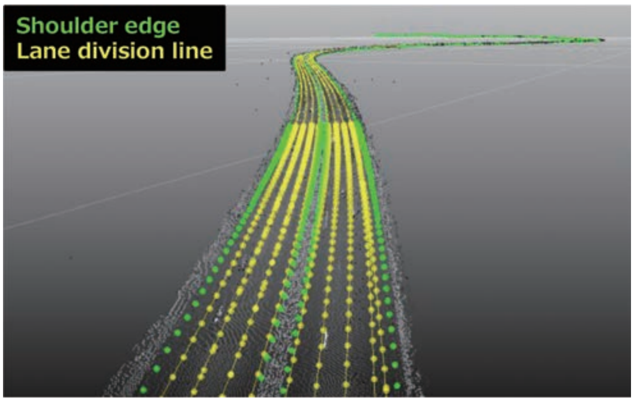


Fig. 3 A result example of the automated mapping

As shown in Fig. 4, the error factor of the shoulder edge was dominant in the case where the point cloud data of the shoulder was not acquired due to obstruction by plants or a vehicle running parallel to the measurement vehicle. Automated mapping has a function to generating the shoulder edge by interpolation if a vehicle running in parallel blocks a certain section. However, there are cases where interpolation is impossible, so there is room for improvement.

For the lane division line, there were cases where road markings such as paint blurring and arrows were erroneously detected as lane division lines. In particular, the influence of road markings is observed more frequently in curves than in straight lines, and we will continue to improve and refine the detection algorithm for automated mapping.

Fig. 4 Examples of error factors

2.2.2. Verification of the Effectiveness of Improvement Achieved with Automated Mapping

As shown in Fig. 5, the time required for automatic method and for the previous method (manual mapping) was measured to confirm the effectiveness of the improvement obtained by applying automated mapping. We confirmed the following reductions in map creation time (including automatic processing time and manual confirmation / modification time) when automated mapping is used.

Shoulder edge: About 75% reduction
Lane division line: About 30% to 40% reduction

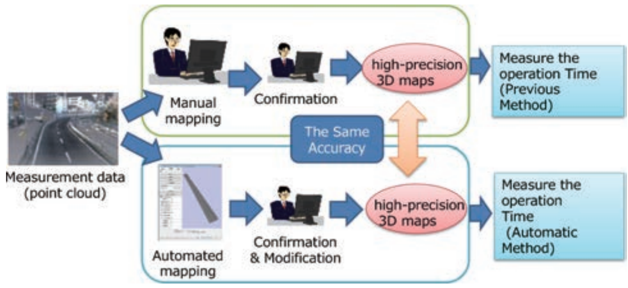


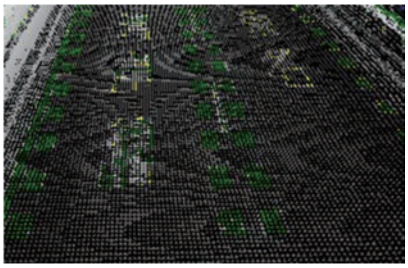
Fig. 5 Confirmation of the effectiveness of improvement by comparing map creation time

2.3. Practical Verification of Change Detection

Two kinds of technologies were examined and evaluated as change detection technology for map updates. One is point cloud change detection, which detects changes in roads and makes it possible to judge whether a modification of the map is necessary. The second is dynamic maps change detection, which extracts only the features to update in the static high-precision 3D map. Through these two techniques, it is easy to generate update data and distribute it.

2.3.1. Point Cloud Change Detection

In order to judge whether there was a change in the road, we extracted the difference between past point cloud data and newly measured point cloud data using point cloud change detection technology. The extracted difference points are shown in Fig. 6. Four items, representing differences in shape (addition and deletion) and reflected luminance (addition and deletion), in the point cloud data are detected in order to detect changes in road shape, lane markings and road signs. In Fig. 6, a change in the lane division line has been extracted. Based on this detection result, it can be judged that a correction of the lane division line is necessary, and that only the lane division line should be corrected on this route.



The difference in lane division line is shown in green.

Fig. 6 Example of the point cloud change detection

2.3.2. Dynamic Maps Change Detection

When a change in the road is detected by point cloud change detection, the static high-precision 3D map is corrected by the automated mapping technique. We extracted the difference between the result of automated mapping and the existing static high-precision 3D map through dynamic map change detection. The results are shown in Fig. 7. By comparing the data, it is possible to detect the parts with differences and extract variations on a feature basis. Although a separate discussion is required for the distribution method of the update data, it is expected that the data update and distribution cost can be reduced by minimizing the amount of data to replace.

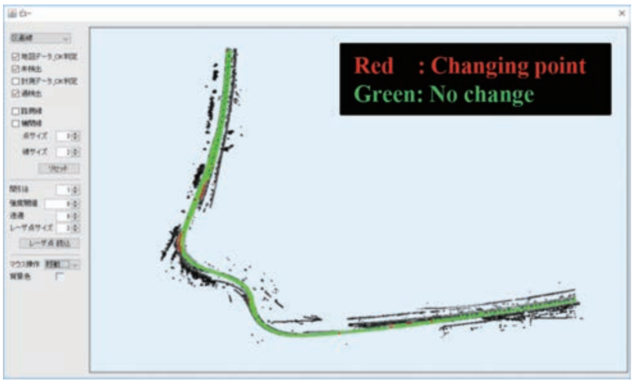


Fig. 7 Example of the dynamic maps change detection

3 Real-Time Automation Technology

In order to more efficiently generate and update static high precision 3D maps using automation technology, we combined automation technology with real-time MMS to make the automation operate in real time. Since the dynamic map data conversion is performed in the MMS vehicle, spending the time required for normal MMS measurement such as copying terabytes of data, is unnecessary, and real-time MMS also eliminates the time needed to generate the point cloud data. Figure 8 visualizes the process from measurement to mapping.

Fig. 8 Process from measurement to mapping using real-time MMS and automation technology

Figure 9 shows the overall process. For real-time centimeter grade high precision positioning with real-time MMS, we used the centimeter level augmentation service (CLAS) of the quasi-zenith satellite system (QZSS), which makes it is possible to generate highly accurate point cloud data in real time.

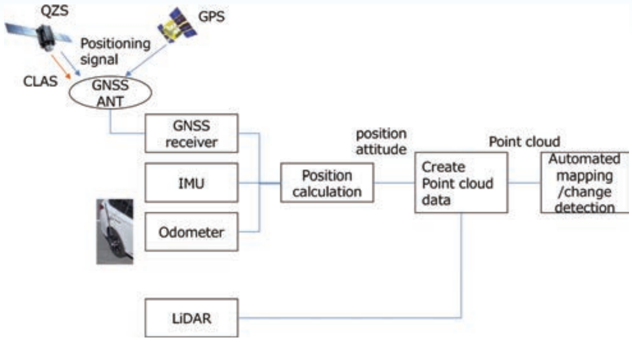


Fig. 9 Real-time MMS process with automation technology

In order to cope with the invisible satellite section, inertial navigation system (INS) combined positioning, which uses the inertial measurement unit (IMU) and the odometer, was adopted, and post-processing analysis of MMS was realized in real time. By sequentially applying the point cloud data generated in real time to the processing of automation technology, it is possible to generate the map in the vehicle.

4 Conclusion

We evaluated the practicality of the automation technology and verified the effectiveness of the improvement with the aim of improving the efficiency of generating and updating static high-precision 3D maps serving as the basis for dynamic maps. It was confirmed that false detection and non-detection by the automation technology is predominant due to disturbance such as influence of plants or other vehicles, and that point cloud data can be gathered correctly if it can be measured without disturbance. However, since actual disturbance always occurs in actual measurements, we will promote the practical application of automation technology and work on making continuous improvements to the algorithm.

We will also proceed with the verification of further efficiency improvement for future map updates using real time automation technology.

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Feasibility Study for Multipurpose Use of Dynamic Maps

Naoyuki Tsuchida (Dynamic Map Platform Co., Ltd)

ABSTRACT: This study was performed in order to identify the challenges for specifications in dynamic map preparation and clarify the necessary basic data structure requirements and the challenges to be resolved, based on on-site demonstration using specific use cases, for the ultimate purpose of employing the dynamic maps and three-dimensional map common platform data acquired during the dynamic map preparation process in public services.

1 Study Summary

The purpose of this study was to promote the utilization of dynamic maps for automated driving systems along with the three-dimensional map common platform data acquired during the platform development process (3D map common platform data) in public surveying and multipurpose applications, with the aim of creating new value and services through future realization of the goals of Japan's Society 5.0 vision. We have clarified the basic data structure requirements that are necessary in terms of application to public surveying, road ledger preparation, support for snow removal, and telecommunication infrastructure management, along with the challenges to be resolved, and we have established specific use cases and evaluated the requirements from the standpoints of preparation methods, procedures, quality, and cost. With respect to using 3D map common platform data, etc. in public surveying and multipurpose use, the idea is that 3D map common platform data will be supplied according to the needs of users, as shown in Fig. 1. In addition, it is expected that the existing content will be expanded, depending on the requirements for use in public surveying and multipurpose use.

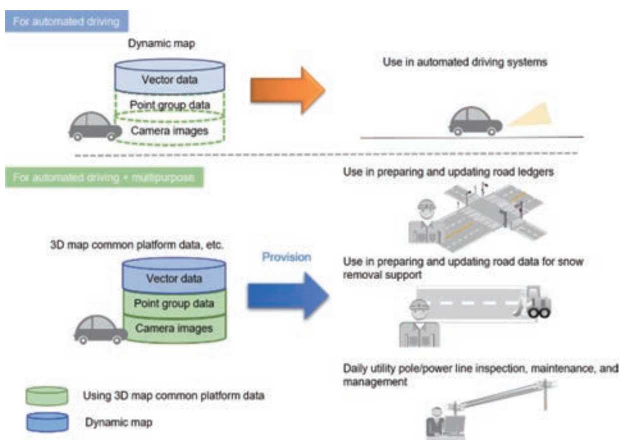

Fig. 1. Diagram of 3D map common platform data when expanding automated driving dynamic maps for multipurpose use

2 Study on Use in Map Applications for Public Use (Study for Application in Public Surveying)

2.1. Identification of 3D map Common Platform Data Requirements (Accuracy- and System-Related Challenges)

In the development of 3D map common platform data, which is prepared by private entities for use in public surveying results, the data must have adequate accuracy for use in public surveying, and must meet the system-related requirements of public surveying. Therefore, we have prepared a 3D Map Common Platform Data and Dynamic Map Work Manual (Preliminary Draft) by verifying whether the level of accuracy is adequate for use in public surveying and whether the necessary requirements of public surveying are met, while referring to results from past years. With regard to accuracy requirements, we have concluded that the only solution is for the 3D map common platform data to satisfy accuracy requirements equivalent to those of the public surveying work regulation standards (revised March 31, 2016). With regard to accuracy-related challenges, we have clarified differences between the work regulation standards and the preparation of 3D map common platform data and studied techniques and operation methods that are both rational and efficient. We have placed the greatest emphasis on how to lower the cost of

Table 1 Measures for use of automated driving dynamic maps in public surveying

	Issues which would present challenges to applying 3D map common platform data, etc. to public surveying	Handling measures (requirements)
System-related	The following two issues exist with relation to the application of measurement results by private companies to public surveying ✓ Approach of using dynamic maps to correct existing public survey results through the "use of measurement results by private companies (notification pursuant to Survey Act Article 46 Paragraph 1)" ✓ Approach of having dynamic map preparation agent perform measurements as a surveying planning organization (falling under Survey Act Article 5 Item 1)	Consider taking approach of having dynamic map preparation agent perform measurements as a surveying planning organization so that measurement results by private companies can be used even if new. (Survey Act Article 5 Item 2) * The recognition of 3D map common platform data, etc., as public surveying results will objectively demonstrate that it possesses a level of accuracy equivalent to the work regulation standards as well as promoting its use in public fields.
Accuracy-related	Data preparation specifications, etc., for dynamic maps for automated driving do not specify the creation of Ground Control Points (GCPs) stipulated in the work regulation standards, nor do they specify the accuracy, etc., of GCPs.	Stipulate GCP installation locations and GCP accuracy, etc., in the "Work Manual (draft)" for application to public surveying.
	Data preparation specifications, etc., for dynamic maps for automated driving do not specify the evaluation and inspection of absolute positions of data for numerical plotting (3D map common platform data) or numerical plotting data (dynamic maps) stipulated in the work regulation standards.	Stipulate 3D map common platform data, etc., absolute position evaluation and inspection in the "Work Manual (draft)" for application to public surveying.
Plotting method	Data preparation specifications, etc., for dynamic maps for automated driving do not specify the features stipulated in the work regulation standards. The plotting method of the data preparation specifications, etc., for dynamic maps differs from that of the work regulation standards.	Stipulate the features and plotting method indicated in the work regulation standards in the "Work Manual (draft)" for application to public surveying. When the agent responsible for the preparation of dynamic maps conducts public surveying, add the features and plotting method needed for automated driving to the manual.

installation of correct-answer values (ground control point, abbreviated GCP) obtained on-site using evaluation methods of absolute accuracy. Meanwhile, with regard to system-related challenges, it was necessary to study means of implementing the project of preparing 3D map common platform data in the context of public surveying. Table 1 below summarizes the (proposed) accuracy-related and system-related measures, with reference to advice and guidance from the Geospatial Information Authority of the Ministry of Land, Infrastructure, Transport and Tourism.

2.2. Study of Methods to Assure Accuracy and Quality

Under the existing approach, when differences from GCP fail to meet the standard, accuracy is improved either by repeat measurement or by means of adjustment based on a control point. However, GCP installation has a considerable impact on cost because of the on-site work that it involves. Therefore, we have devised ways to make effective use of existing resources of the public and private sectors, such as a method of GCP limitation by combined evaluation and analysis of good measurement data as an effective replacement for GCP installation, and enabling the use of aerial photography results in verification. We have also given consideration to new technologies expected to be effective in 3D map common platform data preparation, accuracy improvement using quasi-zenith satellites, and the feasibility of automated plotting based on high-density point group data.

3 Study for Utilization in Various Fields

Confirming the Usefulness of 3D Map Common Platform Data Based on the Specifications of Systems for Automated Driving Mobile mapping systems (MMS) are promising for future multipurpose use, because they use high-resolution lasers and images to supply the information needed by automated vehicles when detecting their surroundings, and offer a high level of visibility and affinity. However, the specifications of MMS equipment are varied, and it is necessary to study the requirements needed to improve their multipurpose and practical expandability. These systems are expected to be used in many ways by relevant government agencies and key infrastructure management companies because of their public nature. In the study, we have examined use cases and identified the requirements and challenges in order to clarify the differences between conventional maintenance methods in each of the use cases and the maintenance specifications for dynamic maps for use in automated driving systems. We also held periodic study sessions with persons involved in other SIP research topics as necessary. This will lead us to study the requirements needed for revision of the specifications for the preparation of dynamic maps for use in automated driving systems, based on a model of utilization in the following areas: road ledger preparation and updating, support for snow removal, and everyday utility pole/power line inspection, maintenance, and management.

4 On-Site Demonstration Based on Specific Use Cases

4.1. Positing and Demonstration of Use Cases

Actual field data was obtained and used to evaluate the validity of the results of the theoretical study. For application to public surveying, based on the Work Manual (Preliminary Draft), we demonstrated the effects of feasibility and practicality in the field, and estimated the cost of preparation of 3D map common platform data. The estimate confirmed that an increase of approximately 16% could be anticipated with preparation according to the existing standards for public surveying, while the expected increase would be only about 6% for preparation according to the Work Manual (Preliminary Draft). Based on the study results, the Work Manual (Preliminary Draft) was compiled with the Work Manual (Draft) of 3D map common platform data and dynamic maps. In road ledger preparation and updating, when the accuracy and imaging range of the 3D map common platform data meet the requirements of the specifications for the preparation of road ledger drawings, this can substitute for basic data collection, or a portion of the work. In addition, road edges, which are handled as features of dynamic maps, can be directly used as sidewalk-road boundary data. (Some processing may be needed depending on the place of preparation.) Shapes such as signals and road signs are usable, because they are similar to the acquisition standards of dynamic maps. With regard to support for snow removal, location information on individual features can be extracted, and this can be used as basic data for data preparation. With regard to everyday utility pole/power line inspection, maintenance, and management, the data acquired through such operations was shown and explained to workers, assuming uses such as on-site confirmation prior to construction for the purpose of verifying the increase in efficiency and practicality of using 3D map common platform data. Meanwhile, it has become clear that 3D map common platform data would have a limited scope of applicability as input data for the automatic identification of utility pole inclination and electric line sagging during inspection of equipment. Since the identification technologies for cable inspection purposes are highly dependent on point group density, the results of automated identification by the conventional type (27,000 points/second) show low accuracy of detection. In high-density measurement (250,000 to 1,000,000 points/second), the rate of accurate identification increased to over 90%.

4.2. Results of Verification of Effectiveness for Multipurpose Use (Changes in 3D Map Common Platform Data)

Figure 2 below shows the points of change in the equipment requirements, acquisition scope requirements, plotting requirements, and freshness requirements as preparation specifications to increase affinity when the specifications for the preparation of 3D map common platform data for use in automated driving systems are applied to the three use cases that were used in this study.

Changes will need to be studied to meet the necessary requirements for multipurpose use in the future, mainly with regard to the portions outlined in red in Fig. 2. Also, since it has become clear that dynamic maps and 3D map common platform data can be given a high degree of expandability in multipurpose use, we have learned that it will be necessary to change the work processes in the standards and dynamic map preparation specifications, and to change the 3D map common platform data through additional file provisions to supplement features that were lacking in terms of multipurpose use. The changes and benefits are summarized in Tables 2 and 3 below.

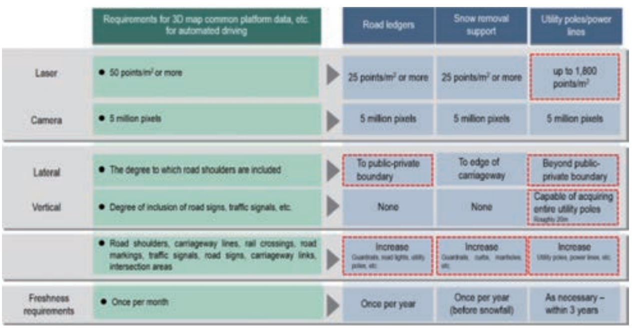

Fig. 2 Equipment requirements, acquisition requirements, etc. when applying the specifications for preparation of 3D map common platform data, etc. for automated driving systems

Table 2 Changes from the 3D map common platform data for automated driving

		Changes from data preparation specifications, etc., for dynamic maps aimed at automated driving		Impact on data quality and cost
		Contents	Reason for change	
Data preparation	Road measuring	Work process changes: 1. Addition of accuracy management (absolute position evaluation) indicated in work regulation standards 2. Improvement of GCP placement efficiency, use of existing resources, and use of new technologies	1. For public uses such as road ledger attached diagrams, etc., data must be applied to public surveying 2. Reduces costs compared to work performed as indicated in work regulation standards	☐ Accuracy of data is objectively guaranteed for public surveying ✓ Performing work as indicated in work regulation standards would increase preparation costs for general roads for automated driving by 16% (the increase could be reduced to 6% if cost reduction measures being considered separately are used)
		Changes to survey devices and survey methods, etc. 1. Use of high-density (500,000 to 1,000,000 points/second) long-range laser equipment 2. Changes to imaging intervals, direction, and scope (complete perimeter imaging)	1. Data acquired by high-density, long-range laser equipment is necessary when using point group data in management of utility poles and power lines to extract power lines 2. Accurate assessment of entire work sites	☐ High-density point group data has the potential for increasing the accuracy of dynamic map automatic plotting (technical verification has not yet been performed) ✓ Laser device changes and measurement method changes will increase cost of measurement equipment ✓ Point group data volume will increase, raising management costs
	Plotting	None	-	-
Data provision		Addition of provided files: Add 3D map common platform data (point group data, image data) in addition to dynamic map	3D map common platform data will supplement features, etc., lacking in dynamic maps when using data for various purposes	✓ Need to create a system for providing large volumes of 3D map common platform data in addition to dynamic maps

Legend ■ : Items required for multipurpose use ■ : Items required to promote multipurpose use

5 Summary

In this study, we have examined 3D map common platform data for use in automated driving systems with regard to its application to public surveying, and organized the requirements and issues related to multipurpose use. We have drafted a Work Manual for more efficient and economical preparation for application to public surveying. To prepare 3D map common platform data that is highly public in nature and more flexibly allows multipurpose use, it is important to unify the location standards. It is also necessary to study ways to achieve uniform accuracy, while giving consideration to the implementation techniques and quality evaluation methods indicated in the work regulation standards. Meanwhile, it is also necessary to study ways to ensure that the dynamic map preparation project will be of a public nature in the future. In multipurpose use, we have conducted evaluation in terms of data quality and the cost of preparation. We have determined that utilization will become feasible in the three use cases studied by making changes in work processes at the time of data preparation and providing additional files at the time of data provision, and we have learned that the cost of preparation will increase by about 6% compared to existing costs. Meanwhile, expanding the scope of application to include everyday utility pole/power line inspection, maintenance, and management, and making changes to satisfy all of the studied use cases, including use as input data in maintenance and inspection, would require changes in measurement equipment and incur additional data management costs due to increased data capacity, in addition to the above cost increase of around 6%. The reduction in total work hours due to changes in work methods and improved accuracy compared to data preparation using existing methods can be expected in both cases. In addition, we have determined that it is possible to achieve sharing and reduction of preparation costs through data sharing, as well as ensure the safety of workers. Further benefits are also anticipated, including more efficient measurement work due to changes in measurement equipment, and more accurate automatic plotting and improved detection rates due to higher density 3D map common platform data (point group data). Data utilization based on multipurpose use is also expected to have both direct effects and secondary benefits.

As a final note, this study was implemented with cooperation from NTT Data Corporation, MRI Research Associates, Inc., Mitsubishi Electric Corporation, and PASCO Corporation.

Table 3 Summary of verification of multipurpose use benefits

I	**Use of 3D map common platform data, etc. for automated driving without major changes for various purposes**
Data preparation	● For data preparation, make work process changes in order to comply with work regulation standards and, for data provision, add provided files.
Multipurpose use	● Data could be used in the preparation or updating of road ledgers, and in the preparation and updating of road data for snow removal support. ● Data could be used in utility pole/power line daily inspection, maintenance, and management for site confirmation before starting work.
Impact on automated driving	□ Road ledger preparation costs would be reduced (by approximately 20%), data could be used to provide snow removal support and for work site confirmation for utility poles/power lines, and preparation costs would be shared. ✓ Preparation costs would cost roughly 6% compared to the preparation of data for automated driving.
II	**Changes to 3D map common platform data, etc., for automated driving to meet all multipurpose use requirements**
Data preparation	● (In addition to I) Change preparation method to perform measurement using high-density (500,000 to 1,000,000 points/second) long-range laser equipment.
Multipurpose use	● (In addition to I) Envisioned expansion of application scope to utility pole/power line daily inspection, maintenance, and management operations, and of use as input data for new technologies applied to operations such as facility inspection.
Impact on automated driving	□ (In addition to I) Use data in utility pole/power line daily inspection, maintenance, and management operations, sharing preparation costs. Point group data acquired by telecommunications companies, etc., would also be sharable. ✓ (In addition to I) Preparation costs would be expected to decrease due to data sharing, but data management costs would rise due to changes to measuring equipment and increases in data volume.

Study on Considerations for the Making of a Business Model for the Dynamic Map Service Platform

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Akio Kani(Hitachi, Ltd.)
Yukikazu Kanoya(Mitsubishi Electric Corporation)
Akinori Sato(NEC Corporation)
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ABSTRACT: The concept of Society 5.0, a super smart society aiming to balance economic development and the resolution of social issues, states that intelligent transport systems, one of the 11 types of system identified in the 2015 Comprehensive Strategy, will be developed as core systems. The construction of a platform enabling various systems to utilize dynamic maps is needed to create new values and services. For that reason, it is important to realize the Dynamic Map Service Platform, a base system for the use of dynamic maps that is planned to be constructed in the context of the SIP-adus project and encompass various fields. The object of this project is to develop the concept of the Dynamic Map Service Platform, which will be utilized in various fields in the future, as a part of government measures involving cutting-edge ICT technologies and extensive collaboration between wide-range of parties.

1 Concept of the Dynamic Map Service Platform

1.1. Definition of the Dynamic Map

In this project, we defined the components of the Dynamic Map as shown in Fig. 1.

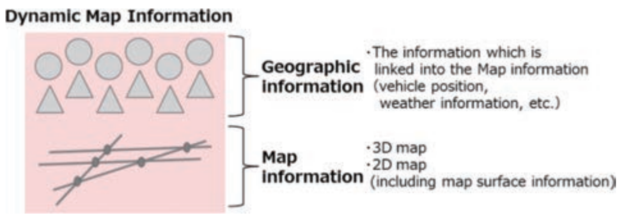


Fig. 1 Definition of the Dynamic Map

The dynamic map consists of both map and geographic information. Map information includes the 3D maps made by SIP, and the 2D maps provided by map vendors. Geographic information is the generic name for information linked with map information, such as longitude, latitude, or load ID.

1.2. Outline of the Dynamic Map Service Platform

The Dynamic Map Service Platform (SPF) has a mechanism which enables the geographic information, stored at various fields, to be utilized in various fields (see Fig. 2).

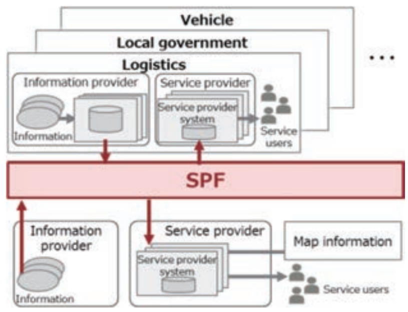


Fig. 2. Outline of the SPF

It is assumed that the types of geographic information handled by the SPF will gradually expand. For that reason, scalability should be considered for the SPF. Accessibility, including the preparation of interfaces for various systems, should also be considered because the SPF sends and receives a variety of information through connections with many systems. In addition, it is necessary to consider security measures to use the information in a safe and secure manner.

2 Considerations for the SPF

2.1. Study of Use Cases for the SPF

We considered SPF service models in various fields, and studied the needs and feasibility of those models. We also considered the information processing required in those models, and sorted out the requirements needed to create the SPF architecture.

2.2. Architecture of the SPF

Based on the results of the above study, we considered system functions that enable the SPF to distribute geographic and map information to various fields (see Fig. 3).

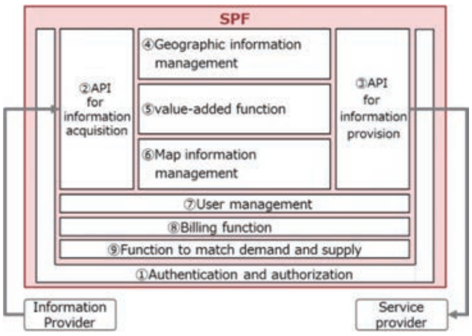


Fig. 3 Architecture of the SPF

3 Demonstration of the SPF

Based on the results of considering the use cases and architecture of the SPF described in Section 2, Considerations for the SPF, we made a prototype to demonstrate its value.

3.1. Dynamic Map Information

Based on the results of considering the use cases of the SPF, we chose the dynamic map information that should be handled by the SPF as listed in Table 1.

Table 1 Selection list of information that should be linked to dynamic map

No.	Information
1	Vehicle probe information (trucks)
2	Vehicle probe information (taxis)
3	Vehicle probe information (buses)
4	Vehicle probe information (construction vehicles)
5	Tweets
6	Advanced traffic information (including road lane information)
7	Weather information
8	Mobile spatial statistics (population distribution)
9	Information on spots with frequent occurrences of rapid deceleration
10	Facility information (public facilities, doorways, designated evacuation shelters, etc.)
11	Digital national land information (waterlogged areas, etc.)
12	Road information where there is a risk of flooding
13	2D maps
14	2D maps (including information on points where accidents occur frequently)
15	Road width information in 3D maps
16	Pedestrians crossing information in 3D maps
17	Road lane information in 3D maps
18	3D maps

3.2. Service Model

Through the study of the use cases for the SPF, we clarified the issues in actual businesses in each field. We selected issues that match the following conditions.

- Issues that can demonstrate solutions in collecting the dynamic map information during the project activity period.
- Issues that can be resolved by capitalizing on the strong points of the SPF, such as gathering and collating the various types of dynamic map information.

We prepared service models for each field that resolve the above issues, and created prototypes.

3.2.1. Logistics Field

(1) Outline of the Service Model

This service model provides a safe route for truck drivers by analyzing the latest traffic information based on the dynamic map information such as vehicle probe information, road width, and the weather.

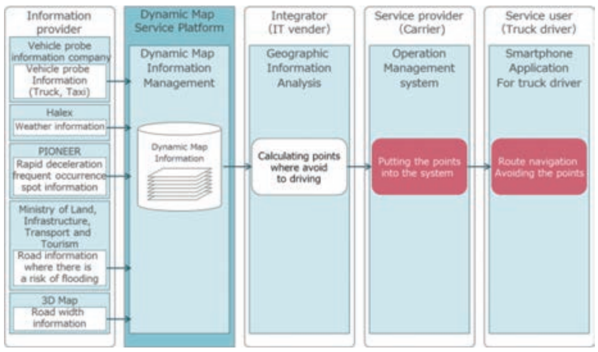


Fig. 4 Service Model for Logistics

(2) Effectiveness of the Service Model

It was clarified that this service model is effective for commercial vehicle drivers and truck operation managers.

If commercial vehicle drivers lack the knowledge necessary to drive safely in a certain area (e.g., traffic information, or information near-miss spots), this service model is useful for them. Truck operation managers can utilize this service model when they plan the delivery route, and send alerts to truck drivers. At the same time, providing value-added information, such as traffic jam prediction, traffic regulation and the travel history of different vehicle types, is required to ensure this service model is actively utilized.

This service model is useful not only for safe driving, but also for increasing the revenue of transport companies. If the driving time for commercial vehicle can be calculated with high accuracy, the number of pick-up and shipping destinations in a day can be predicted correctly. This then makes it possible to deliver a lot of goods with fewer trucks.

3.2.2. Local Government Field

(1) Outline of the Service Model

This service model is utilized to shorten the time of arrival of emergency vehicles and to support appropriate instructions such as the order of emergency vehicle dispatch and decision-making by superimposing a variety of information such as vehicle probe data, or weather information on a 2D map using commercial GIS software, and displaying information and relevant directives on the screen of the vehicle device.

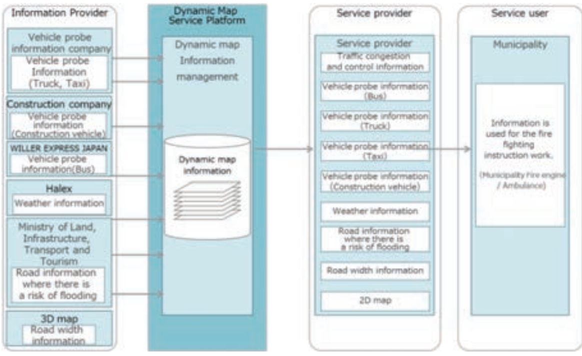


Fig. 5 Service Model for Local Government

(2) Effectiveness of the Service Model

This service model supports the firefighting and disaster prevention management tasks by local governments by, for example, shortening the arrival time of emergency vehicles to certain sites, or determining the order of the dispatch of emergency vehicles. Traffic jam information is not currently fully utilized in firefighting and disaster prevention management, and there are cases where it takes time for the emergency vehicles to reach its destination. Details of traffic conditions can be ascertained using this service model, and arrival time to the site can be shortened. As a result, this service model contributes to minimizing damage in the event of a disaster, as described below.

For humans: minimizing critical injuries, increasing the survival rate, and so on.

For the economy: minimizing the spread of fire, flooding damage, and so on.

3.2.3. Construction Field

(1) Outline of the Service Model

This service model provides various information, such as road regulations, spots with frequent occurrences of rapid deceleration, operation routes that take prohibited roads into account, or entrances to construction sites, on the map screen. The information is shared between construction sites and construction vehicle drivers, allowing the use of the wrong entrance to be avoided, thereby reducing vehicle accidents. Furthermore it make it possible to ascertain the driving conditions of construction vehicles and share them among the people involved at the construction site based on real-time vehicle probe data.

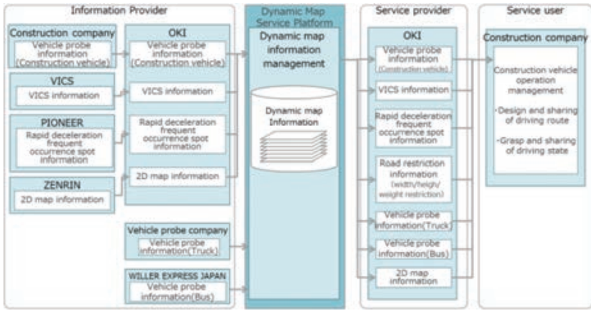


Fig. 6 Service Model for Construction

(2) Effectiveness of the Service Model

It is effective to confirm road regulations and spots with frequent occurrences of rapid deceleration on a map in advance when designing construction vehicle routes. This information, as well as information on prohibited roads, which are decided by neighborhood agreement, are displayed on the map and can be shared between drivers and sites using this service model. This is effective at preventing drivers from using the wrong route. In this demonstration, we confirmed that no driver entered the prohibited roads while using construction vehicle position data in real time. This service model can reduce the management tasks of the construction site supervisor. If the position and status of construction vehicles can be ascertained with a terminal device in real time, it is possible for the site supervisor to make work plans based on the construction vehicle arrival time. Also, it is expected to reduce the task of making contact for supervisors and construction vehicle drivers.

3.2.4. Personal Navigation Field

(1) Outline of the Service Model

This service model supports travel using personal navigation by displaying destinations such as communal facilities around the station in a list, allowing users to easily search for their destination while providing guidance and support for user travel by highlighting feature information such as public restrooms and crosswalks.

① Dynamic Maps

Study on Considerations for the Making of a Business Model for the Dynamic Map Service Platform

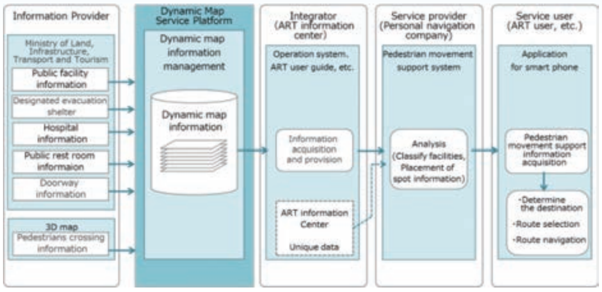


Fig. 7 Service Model for Personal Navigation

(2) Effectiveness of the Service Model

In this project, we confirmed that providing information, such as the location of the doorways of facilities and the details on public restrooms, is effective at expanding services for a wide range of users including the elderly and persons with disabilities. In light of the aging of society, it is mandatory to improve services by taking user characteristics into account to maintain the number of personal navigation system users.

3.2.5. Vehicle Service Field

(1) Outline of the Service Model

This service model makes it possible to provide detailed route guidance for individual road lanes by transmitting information to the vehicle navigation system (road lane information and per-lane traffic information), allowing drivers to reach their destination faster and more safely.

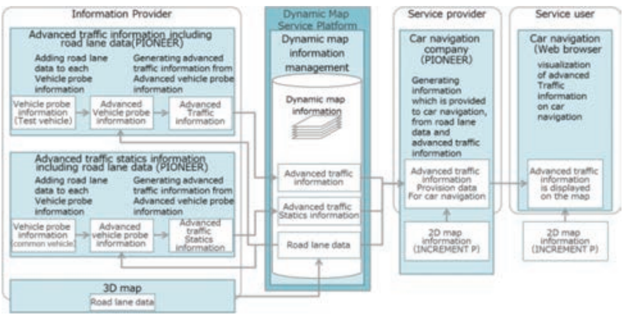


Fig. 8 Service Model for Vehicles

(2) Effectiveness of the Service Model

For general drivers, the service is expected to effectively enable smooth driving through higher route guidance accuracy than current vehicle navigation, and the visualization of traffic conditions in individual road lanes. For the society overall, the effectiveness transport efficiency can be expected to improve. Also, this service model also has the potential to be utilized not only to acquire traffic jam information, but also for automated cruising such as maintaining road lanes and signal control, to estimate the number of participants at an event, and to detect vehicle accidents.

3.2.6. Infrastructure and Area Management Field

(1) Outline of the Service Model

Based on predictions of human movement flow and behavior, information concerning congestion, such as the resident population, precipitation, and messages on social media, is displayed on a map and visualized. This service model provides services which contribute to enhancing the efficient management, attractiveness, and area safety for transportation companies, public agencies, area management companies, and town planning councils.

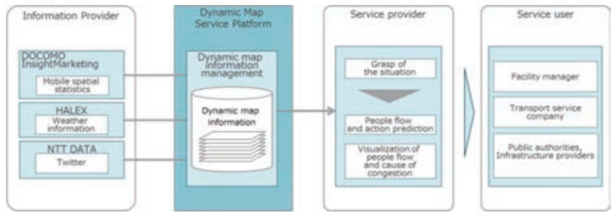


Fig. 9 Service Model for Infrastructure and Area Management

(2) Effectiveness of the Service Model

For the general users (residents, commuters, students, visitors) in the area, the service is effective at resolving issues related to travel support/congestion avoidance to enhance the attractiveness of the area. For transportation or security companies, this service model is effective at resolving issues involving crime prevention/security (such as understanding congestion situation in areas supervised by the company as well as surrounding areas, improving arrangements for security guards and attendants, or suitably increasing the number of temporary buses or trains) when unexpected congestion or a disaster occurs. For transportation companies, public agencies and infrastructure companies, this service model is effective at achieving efficient management when planning a special schedule, vehicle guidance to parking lots, park maintenance, or other activities by providing useful data, such as congestion information in the surrounding areas, ahead of time.

3.2.7. SPF

(1) Functions of the SPF

The SPF has functions to retrieve, provide, and catalog the information it offers. Meta-information is displayed on the web portal by the cataloging function. The SPF also has a function to visualize a variety of information (it can change the order of overlapping information), and changes in that information due to the passage of time.

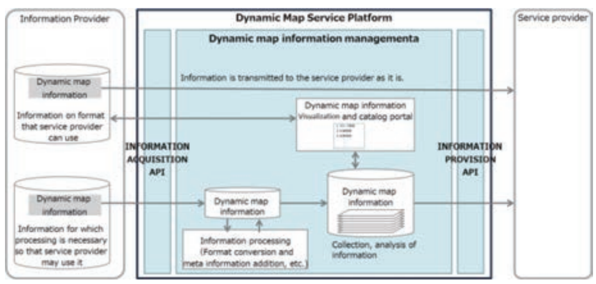


Fig. 10 Function image of the SPF

(2) Effectiveness of the SPF

We could confirm the effectiveness of the SPF in the demonstration, as outlined below.

(a) Effectiveness of dynamic map information

It was confirmed that it is possible to use dynamic map information collected in various fields and combined across various fields. In particular, it was confirmed that vehicle probe information was effective as follows.

- If the amount of vehicle probe information increases, the accuracy of traffic density estimation improves.
- Multiple combinations of large vehicle probe information make it possible to judge whether it is possible to travel on a road.

(b) Effectiveness of common interface

It was confirmed that developing a common interface makes it possible to reduce development work hours to a greater extent than if interfaces were developed separately. (For the service models studied in this project, three models utilizing the same information would have required the development of nine interfaces. However, using the SPF reduced the number of interfaces from nine to three.)

(c) Effectiveness of 3D maps

The effectiveness of the road lane, road width and pedestrian crossing information extracted from the 3D map was confirmed. Road width information is needed in multiple fields. Advances in the maintenance of maps for general roads make those maps more effective. It was confirmed that geographic information, such as road lanes, pedestrian crossings, signals for pedestrians, and sidewalks and steps, can be used effectively after they are extracted from a 3D map.

(d) Effectiveness of prototype functions

It was confirmed that the meta-information listed in the catalog portal can combine the seeds and needs of dynamic map information. Visualizing the function of dynamic map information is useful to obtain an intuitive understanding of granularity, of the provided areas, and the update frequency of dynamic map information. It was confirmed that dynamic map information could be used on multiple 2D maps.

4 Future Tasks

The study conducted and considerations examined in this project identified the following issues in terms of finalizing the SPF.

4.1. Establishing an Environment to Promote the Use of SPF

With support from governments and private industry groups from each field, it is necessary to create an environment that promotes the provision of geographic and map information from their owners to the SPF and fosters an increase in the number of companies and corporations accessing the SPF.

4.2. Formulation of Interfaces to Connect with Various Systems

It is necessary to define the interfaces (e.g., API, authentication methods) by checking the specifications of other relevant system to enable the exchange of information with those systems.

4.3. Provision of Valuable and Unique SPF Information

To expand the business scale of the Dynamic Map Service Platform, it is very important to gather and analyze a variety of information to produce valuable data that can be used cooperatively in specific business fields.

4.4. Providing Information in Real Time

It is necessary to consider an architecture that allows a shorter lead time (from getting the dynamic map information to analyzing and providing it). For example, it is expected that the lead time between acquiring vehicle probe information, analyzing it, and generating the traffic information would be 5 to 10 minutes.

4.5. Utilization of Social Information

Public information, such as the regulation of traffic and accident information, which is stored in local government databases, is expected to be provided in real time in the future. It is necessary to consider how the system will obtain this information.

5 Conclusion

We made prototypes of six service models and the SPF, and interviewed companies representing potential users of those service models. We confirmed the effectiveness of the six service models and the effectiveness of the service platform through the above approaches.

5.1. For Dynamic Map Information

It was confirmed that it is possible to use dynamic map information collected in various fields and combined across various fields. It was also confirmed that utilizing the vehicle probe information, which combines multiple kinds of data from vehicles and real time traffic flow information based on that data is essential for many services.

Also it was confirmed that 3D maps would be easy to use and that it is possible to expand their field of application by providing features extracted in advance to service providers.

5.2. Service Models utilizing the SPF

In this program, after studying the use cases for the SPF and its architecture, we made prototypes of six services and verified whether they could offer the expected value to their users. The results confirmed that each service model was marketable. At the same time, we deepened our knowledge of how to use dynamic map information and of the needs related to dynamic map information through interviewing various companies.

5.3. Effectiveness of the SPF

It was proven that it is possible to support the understanding of the content of individual dynamic map information items and the value generated by combining dynamic map information to provide cataloging and visualization functions. It was also proven that it is possible to connect to each service model by making prototypes of the information acquisition and provision functions, as well as the geographic information management function, which were needed to distribute dynamic map information. The benefit of dealing with different types of dynamic information in a common interface was also confirmed. It was possible to obtain the requirements of additional functions to the interface from service providers, and to consider the interface more concretely.

Investigation about Availability of Satellite Positioning to Realize Automated Driving Systems

Mikihiro Hosoi (Aisan Technology Co., Ltd.)

ABSTRACT: Recently, new satellite positioning methods with multi-GNSS or Quasi-Zenith Satellite System (QZSS) are becoming available. In this survey, we installed several GNSS devices in a measurement vehicle, conducted experiments and evaluated the performance of each satellite positioning method. In addition, the tasks for using satellite positioning in automated driving systems were summarized. From this survey, it was confirmed that the new satellite positioning method makes driving lane recognition possible with no other positioning sensors. However, it has also been shown that there are some restrictions, such as satellite signals shielded by buildings or slopes. To utilize the map information, it is necessary to acquire the position obtained by satellite positioning, and the next step will be to effectively tackle improving the availability and reliability of satellite positioning to achieve practical application.

1 Background

In automated driving systems, advanced sensors for dead reckoning and precise dynamic map information are the main methods used to determine vehicle position. Studies to complement these local positioning methods utilizing satellite positioning, which can obtain global positions without being affected by weather or time, have been conducted. International discussion about automated driving systems, such as the standardization of inter-vehicle communication, is expected to intensify in the future. Meanwhile, the various satellite positioning system providers are actively updating and deploying their systems. In that respect, QZSS is aiming to start full practical operation in 2018, and the shift from experimental to practical service has begun. It is necessary to verify the availability of satellite positioning in automated driving systems to contribute to the discussion of international standardization.

2 Contents of Investigation and Review

We gathered satellite positioning information in urban areas and an expressway between cities using a measurement vehicle equipped with various GNSS devices. We used the mobile mapping system (MMS), which can obtain the correct position where a vehicle has driven, in the measurement vehicle. We evaluated performance of each satellite positioning method in reference to the correct position obtained from MMS. The target satellite positioning systems in this experiment were GPS, QZSS, GLONASS, Galileo, and BeiDou. The positioning methods examined are single-frequency, multiple-frequencies, the sub-meter level augmentation service (SLAS) and centimeter level augmentation service (CLAS) in QZSS, RTK, and Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis (MADOCA) precise point positioning (PPP).

Fig. 1 Measuring vehicle (MMS)

2.1. Evaluation of Satellite Positioning Accuracy

The positioning ratio of single-frequency positioning was 100%, and the RMS of lateral error was within 1.5 m. Even with single-frequency positioning, it can recognize the driving lane if the sky visibility is good.

Table 1 Positioning accuracy on expressway

Method	Positioning ratio	Fix ratio	Lateral error	
			RMS[m]	95.45%
Single-frequency	100.00%	—	1.184	2.391
SLAS (QZSS)	90.80%	—	0.554	—
CLAS (QZSS)	94.16%	63.59%	0.084	0.120
MADOCA-PPP AR	92.44%	70.71%	0.074	0.156
RTK	99.99%	85.83%	0.023	0.036

In positioning using QZSS CLAS, the fix ratio was as low as 63.59%. This is mainly because L6 at the time of our experiment was only available for GPS and QZSS. We expect this to improve as it is adapted to Galileo and GLONASS in the future. The value of RMS is within 10 cm, which can be said to represent sufficient performance. The CLAS method, which does not depend on a base station, is a positioning method suitable for moving platforms. QZSS L1S, which is an augmentation signal for single-frequency positioning, was evaluated by post-processing. The value of RMS was 0.55 m, and the lateral error within 1.5 m was 90%.

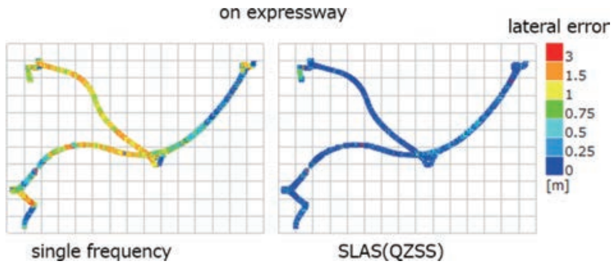


Fig. 2 Heat map of positioning accuracy

Figure 2 shows a heat map of lateral error during expressway driving. The left is the result for single-frequency and the right is the result of augmentation using the QZSS SLAS method. This positioning result is calculated from observation data of the same receiver by post processing. It was confirmed that the positioning performance is improved by the augmentation signal of QZSS.

2.2. Multipath Mitigation

Multipath is a major factor that degrades the performance of satellite positioning. We studied the correlation with multipath using data around the Ginza area where multipath occurs frequently due to the presence of many tall buildings.

2.2.1. Measures Using Signals from Satellites

The possibility of improving positioning accuracy by checking and removing the signal from the satellite when signal strength is low or no carrier phase is observed was confirmed as a viable method of removing a signal including multipath in single frequency measurement. However, the positioning ratio falls as the number of satellites decreases. It was confirmed that using RTK with Doppler frequency coupling improved the positioning ratio from 51.54% to 92.41%.

2.2.2. Simulation of Radio Wave Propagation

We confirmed that positioning performance can be improved by removing satellite signals that generate multipath from the results of radio wave propagation simulation using a 3D map. However, we judged that utilization in real time is difficult because calculating the simulation takes a long time. Instead, we showed that by creating a sight mask of satellite signals by simulation, it is possible to eliminate satellites in which multipath occurs.

2.3. Dynamic Map and Satellite Positioning

We examined methods of arranging the difference between the dynamic map and the position information of the satellite positioning and achieving consistency. We examined methods to consistently determine the difference in position information between dynamic maps and satellite positioning. The differences in the coordinate systems between dynamic maps and satellite positioning were clarified, and a conversion method was demonstrated.

Figure 3 visualizes the crustal movement of Japan from JGD2011 based on the semi-dynamic correction parameter provided by the Geospatial Information Authority of Japan (GSI). It shows that a horizontal movement of about 1 m has occurred in the Tohoku region or remote islands. Moreover, it became clear that complicated distortion (deviation of direction) has occurred.

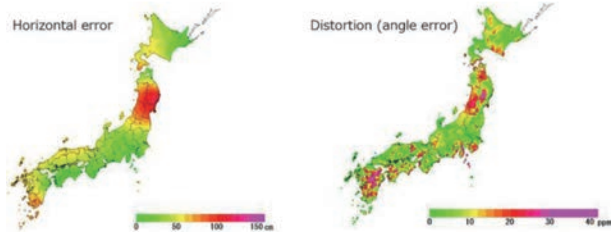


Fig. 3 Variation from 2011 to 2016

We showed that it is possible to reduce the error of the coordinate value in the Tohoku region down to several centimeters by applying grid parameters calculated from the movement amount estimated from the GNSS Earth Observation Network System (GEONET) coordinate values.

2.4. Consideration of Integrity

Integrity is important to use the results of satellite positioning with confidence.

2.4.1. Integrity Evaluation of Satellite Positioning

We carried out static observation to verify the reliability of satellite positioning. We defined the error variance of satellite positioning solutions as the reliability of the satellite positioning and used error ellipse as an indicator to evaluate that reliability. As the non-line-of-sight (NLOS) multipath does not follow a normal distribution, the rate at which the positioning solution occurs outside the error ellipse increases, which allows the positioning reliability can be evaluated.

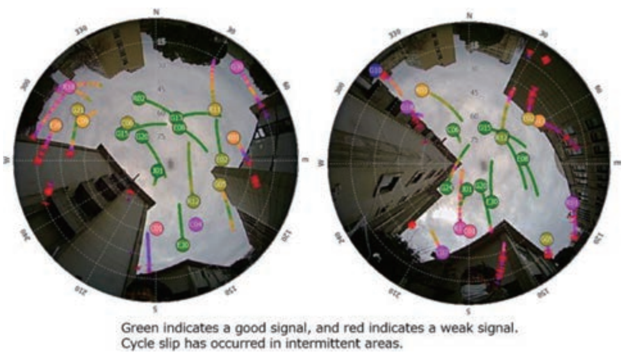


Fig. 4 Sky plot and satellite signal status

Figure 4 shows the influence of shielding objects on the satellite signal. It can be confirmed that signal deterioration and cycle slip occur due to the influence of the shield. We showed that positioning precision and reliability are improved by rejecting NLOS through the use of multi GNSS and an SNR mask. We propose a method to compare the error covariance of the observed value with the estimated prior error covariance from inertial navigation sensors (INS) or other sensors as a method of detecting missed fixes in a moving platform.

2.4.2. Investigating the Security of the Positioning Signal

Attack methods on positioning signals include jamming and spoofing. We clarified the attack method and investigated what kind of influence it has on the actual attack. We investigated the methods of detecting and suppressing attacks on the current positioning signal and evaluated each method. If the attack direction is known, it was found that suppression in the spatial domain using an array antenna is the most suitable method. In addition, we evaluated the robustness against attack of specific receivers by simultaneously sending the correct signal and a spoofed signal at the same time to simulate a spoofing state. Figure 5 shows the experimental results of the strength of the synchronized spoofing signal. This result indicates it is possible to spoof when the spoofing signal becomes stronger than the true GNSS signal.

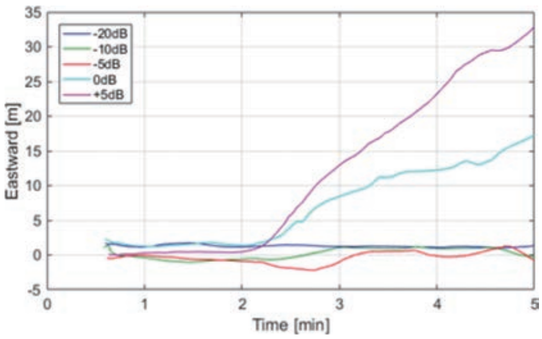


Fig. 5 Synchronized simplistic spoofing attack

Furthermore, we showed that attacks can be detected by mobile combinations such as INS. Since the influence on the positioning result when receiving an attack differs according to the suppression technique used by the receiver, filtering settings, and other factors, an evaluation system using a simulator is indispensable in evaluating the behavior of a specific receiver.

3 Conclusion

We have evaluated the accuracy and availability of satellite positioning in various cases using a measurement vehicle equipped with many GNSS devices. We also showed a method of evaluating satellite positioning in a moving platform. It was confirmed that using the augmentation signal, allows position information by satellite positioning to be obtained at a higher level than before, and is fully usable for precision around the level of lane recognition. Using a high-accuracy augmentation service, we can obtain positioning results with an accuracy of about 10 cm. Meanwhile, multipath and attacks on signals have become serious issues. To use satellite positioning with confidence, its results must have high integrity. Utilizing the position information on the map with high accuracy, it is necessary to deal with the difference between the satellite positioning and the position of the map. Integrity and availability are critical issues for satellite positioning. It is necessary to solve these problems by combining satellite positioning with other sensors. In the future, as satellite systems are upgraded, the convenience of satellite positioning is expected to further improve. The utilization of satellite positioning in a moving platform requires ongoing information gathering.

Report on model Verification for the Enhancement of Driving Support Utilizing Traffic Signal Information (SIP NPA 1)

Yuichi Takayanagi (UTMS Society of Japan)

ABSTRACT: The effectiveness of introducing ITS wireless roadside units (the complement rate with infrared beacons and improvement in the percentage of drivers who decelerate in reaction to information from the beacons) was evaluated using a model route (a route equipped with ITS wireless roadside units and infrared beacons) installed in Aichi Prefecture.

The results of the evaluation concluded that an optimal combination of introducing infrared beacons and ITS wireless roadside units will have a positive effect on intersections, particularly important intersections whose traffic signal cycle lengths and other parameters change in real time.

In the future, the accuracy of signal information required for controlling automated vehicles will be examined. Cost reductions for roadside units must also be considered.

1 Purpose

In the field of ITS, vehicle-infrastructure cooperative systems that help to prevent traffic accidents are an essential technology for connected and automated vehicles, the development of which is progressing rapidly around the world.

In particular, to realize automated driving, a mechanism that allows a vehicle to recognize traffic signal information in real time and perform control is indispensable.

Therefore, surveys and research were carried out with the aim of enhancing driving support through cooperation between signal information provided from roadside systems to vehicles and the automated systems installed in these vehicles. In addition, existing systems were also studied, and methods of improving the accuracy of information provision, and operational management were examined.

2 Details of Implementation over Three-year Period from Fiscal 2015 to 2017

2.1 Fiscal 2015

The Japanese Police have developed and introduced Traffic Signal Prediction Systems (TSPS) as vehicle-infrastructure cooperative systems that provide traffic signal information. However, because TSPS is inadequate to provide signal information at important intersections where the traffic signal cycle length varies according to traffic volume, various types of communication media including Wi-Fi were evaluated and examined in a comparative verification of communication media to complement advanced infrared beacons. The results concluded that ITS radio communication on the 700 MHz band is effective in consideration of security and actual performance.

2.2 Fiscal 2016

Selection of model points (Aichi Prefecture - Refer to Fig. 1)

An on-road driving survey was conducted at points in key prefectures where advanced infrared beacon services are not functioning effectively for distance-related reasons. It was decided to install 700 MHz band wireless roadside units at five important intersections on the Seto Obu Tokai Route in Aichi Prefecture where eight advanced infrared beacons are installed.

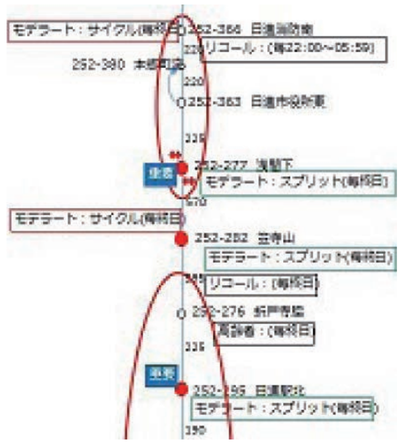


Fig. 1 Model points in Aichi Prefecture

2.3 Fiscal 2017

Utilizing the multi-adapter (including a hybrid receiving function for receiving information via 700 MHz and information via advanced infrared beacons), which was used in SIP projects led by the Ministry of Internal Affairs and Communication, a function to sort the data described above when receiving and storing data from the adapter was developed, and an application was built for displaying TSPS information on a PC monitor.

Data was obtained in 514 road tests using a demonstration system that displays traffic signal colors and the remaining seconds until the signal color changes.

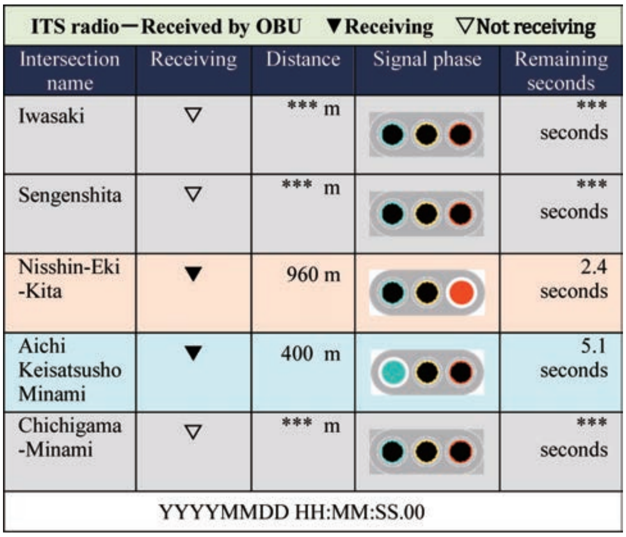
From the data obtained, the number of times that effective support was provided by infrared beacons, and the complement rate of the ITS wireless roadside units to the infrared beacons were derived.

Further, the number of sudden decelerations and energy consumption were tallied and examined based on the acceleration data of the test vehicles.

In addition, the difference between the signal colors at the five important intersections and the remaining seconds shown by the system was measured using a high-precision video camera (to an accuracy of 10 ms).

3 Evaluation Details

An example of the evaluation system screen is shown in Fig. 2.



ITS radio—Received by OBU ▼Receiving ▽Not receiving				
Intersection name	Receiving	Distance	Signal phase	Remaining seconds
Iwasaki	▽	*** m		*** seconds
Sengenshita	▽	*** m		*** seconds
Nisshin-Eki -Kita	▼	960 m		2.4 seconds
Aichi Keisatsusho Minami	▼	400 m		5.1 seconds
Chichigama -Minami	▽	*** m		*** seconds
YYYYMMDD HH:MM:SS.00				

Fig. 2 Evaluation system screen (example)

In fiscal 2017, statistical data about the following eight items were collected and evaluated.

(1) Verification of complement rate (effective support rate) for information at important intersections [effectiveness verification]
(2) Confirmation of Received Signal Strength Indicator (RSSI) information relating to ITS radio communication [verification of basic function]
(3) Comparison of fuel consumption [effectiveness verification]
(4) Comparison of stop time ratios and stop time lengths [effectiveness verification]
(5) Evaluation of longitudinal acceleration [effectiveness verification]
(6) Verification of origin-destination travel times (southbound and northbound travel times) [effectiveness verification]
(7) Confirmation of the accuracy of signal information provision [verification of basic function]
(8) Compilation of the results of questionnaire surveys from participants (drivers) about the acceptable range of difference in the remaining signal time, and at how many meters from the intersection it was helpful to receive the information.

4 Evaluation Results

Among the items described in Section 3, the results of main items (1), (5), (7), and (8) are shown from Table 1 to Table 3.

Table 1 Complement rate of service

Intersection name	Effective support rate		Complement rate of ITS radio communication
	Combined use with ITS radio communication	Infrared beacon	
Chichigama-Minami	100%	33%	67%
Aichi Keisatsusho-Minami	100%	33%	67%
Nisshin-Eki-Kita	100%	35%	65%
Sengenshita	100%	30%	70%
Iwasaki	100%	34%	66%

After confirming the status of information complementation with ITS wireless roadside units at important intersections where the service cannot be provided by infrared beacons alone (due to reasons such as the range of traffic signal cycle length variations and expiration of the validity period), it was found that the complement rate at all five important intersections reached 50% or higher.

Table 2 Percentage of sudden deceleration

Overall	Average number of sudden decelerations	Probability of sudden decelerations	Signal information support	Travel direction	Reduction rate
	0.275	1.06%	Infrared beacon +700M	South-bound	21.4%
	0.350	1.35%	Infrared beacon	South-bound	
	0.287	1.11%	Infrared beacon +700M	North-bound	14.8%
	0.337	1.30%	Infrared beacon	North-bound	

Improvement in the smoothness of driving was confirmed by comparing and evaluating longitudinal acceleration. It was also confirmed that the frequency of sudden decelerations decreased when the remaining seconds of a green signal were provided.

Table 3 Accuracy of signal color information

Intersection name	Traffic signal color change	Time difference (Unit: ms)
Iwasaki	Green → Yellow	-66.6ms
	Yellow → Red	0ms
	Red → Green	-99.9ms
Sengenshita	Green → Yellow	-66.6ms
	Yellow → Red	-66.6ms
	Red → Green	-66.6ms
Nisshin-Eki-Kita	Green → Yellow	-33.3ms
	Yellow → Red	-33.3ms
	Red → Green	-33.3ms
Aichi Keisatsu- Minami	Green → Yellow	-33.3ms
	Yellow → Red	-33.3ms
	Red → Green	-33.3ms
Chichigama-Minami	Green → Yellow	-49.8ms
	Yellow → Red	-49.8ms
	Red → Green	-83.5ms

Accuracy of within 100 ms was obtained at the important intersections after verifying the difference in accuracy by measuring the variation between the information provided via the ITS radio communication and the actual traffic signal phases.

The variation in the results is probably due to fluctuations in the output time required to switch from the signal controller to the signal lamp device.

The questionnaire survey of drivers examined the effects of introducing the system. Responses stated that the system is significant because, if it allows drivers to receive information about the intersection through which the vehicle is going to pass at a point 300 to 500 m from the intersection, as well as information about the next intersection, then drivers can adjust their speed, which is an effective way of helping to alleviate congestion.

5 Conclusion and Discussion

The research project found that the introduction of 700 MHz ITS wireless roadside units helps to complement the function of advanced infrared beacons.

However, research needs to be continued to investigate the following five issues.

(1) The reliability of the system in cases where differences occur in the timing of signal phase changes obtained from multiple information sources (infrared beacons and ITS radio communication)
(2) Statistical study on driver behavior when informed about a situation in which traffic signal phase changes are predictable.
(3) Optimization of HMI, such as the timing of information provision to drivers
(4) Correlation of the situation observed in this research project in which the influence on the driver's psychology cannot be eliminated to match the current status of automated driving.
(5) The effects of traffic signal information provision on automated driving algorithms.

(*) Reference

1. The 15th Symposium on ITS 2017 (in Japanese)
[Analysis of the impact of the percentage of drivers on arterial roads who responded to signal information on the passage through traffic lights] (in Japanese)
K. Nishio*1, Y. Matsumoto*2, M. Sugita*3
Meijo University, Graduate School of Science and Technology, Civil Engineering Major*1
Meijo University, Graduate School of Science and Technology, Department of Civil Engineering*2
Japan Road Traffic Information Center*3

2. 24th World Congress on ITS presentation materials
Yuichi Takayanagi (2017). Strategy of Practical Implement V-I Cooperative Systems for Traffic Accident Avoidance (24th World Congress on ITS, Montreal)

3. 25th World Congress on ITS presentation materials
Yuichi Takayanagi, Shunichi Kawabe (2018). Advanced Traffic Signal Prediction Systems(TSPS)

METI 3: Development and Demonstration of Technology for Real-time Utilization of Traffic Signal Information

Masao Fukushima (UTMS Society of Japan)

ABSTRACT: This project is aiming to develop driving support systems that are effective at preventing traffic accidents at intersections, as well as reducing traffic congestion and environmental burden, while assessing and examining the cost effectiveness and driver acceptance of such systems. The systems covered by this project utilize traffic signal information (a collection of traffic signal phase and timing information from up to 16 downstream intersections) provided by advanced infrared beacons, which are scheduled to be installed in the future. The project will be implemented under the auspices of the Ministry of Economy, Trade and Industry in consideration of commercialization, and involves the participation of the National Police Agency from the standpoint of traffic safety.

1 Commissioning Framework

UTMS Japan will receive the order for the project, and Subaru Corporation, Nissan Motor Co., Ltd., and Mitsubishi Motors Corporation will be re-commissioned to develop an on-board system that allows vehicles smooth passage through signalized intersections, safe deceleration, and smart idling stop using traffic signal information from advanced infrared beacons, for which installation or replacement has already started. The project will also verify the effectiveness and acceptance of the traffic signal information, as well as its impact on traffic flow.

2 Route Traffic Signal Information

As shown in Fig. 1, the traffic control center determines the optimal traffic signal parameters (cycle, split, and offset) based on traffic volume data obtained from traffic detectors, and provides traffic signal information to vehicles via advanced infrared beacons. However, as the traffic control center periodically updates these traffic signal parameters, traffic signal information may lose its freshness while vehicles are driving along a set route. This may cause a time gap between actual signal indications and predicted indications on vehicle displays.

Furthermore, if there is an actuated traffic signal along a route whose indication is affected by nearby traffic, a time gap similar to the above will also occur.

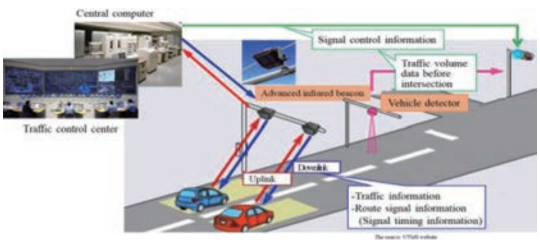


Fig. 1 Traffic Control Center signal control system

3 Services that Utilize Signal Information

The following five services that utilize route traffic signal information were tested.

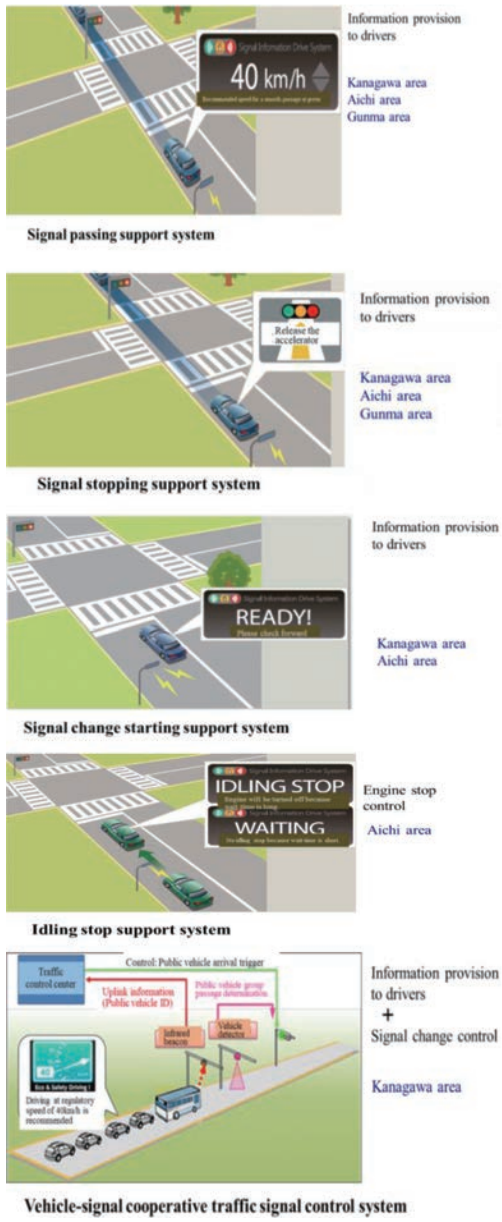


Fig. 2 Five services that utilize signal information

4 Development of On-board unit

An on-board unit for realizing and testing the services described above was developed by the car manufacturers participating in the project. The on-board unit is equipped with an antenna for advanced infrared beacons, a processing unit, forward and backward cameras, vehicle CAN data, a display for providing information to drivers, and an audio and voice function. The on-board unit can record how the test vehicle was driven using signal information.

Due to differences in the configuration of the driving support systems used by the car manufacturers, an on-board system was provided by each of the three manufacturers.

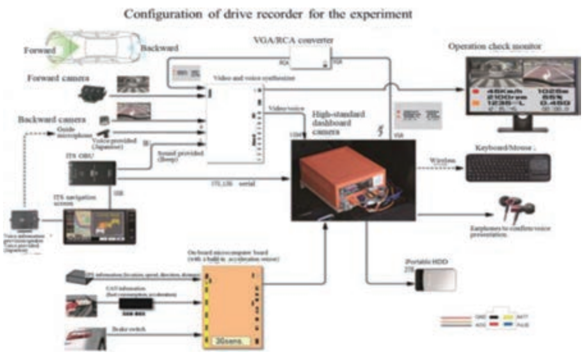


Fig. 3 On-board system configuration example 1

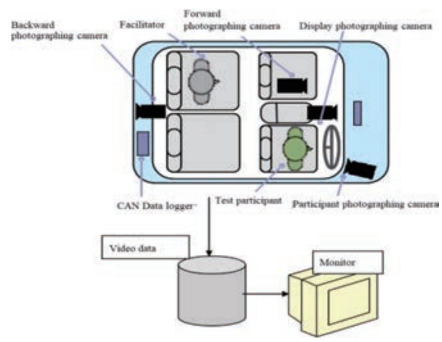


Fig. 4 On-board system configuration example 2

5 Demonstration Experiments

Based on a policy of conducting demonstrations in different traffic environments, demonstration experiments were carried out in three areas where (1) the traffic volume is high and chronic traffic congestion occurs (Kanagawa area), (2) the traffic volume varies greatly throughout the day (Gunma area), and (3) driving speeds tend to increase (Aichi area). The routes for the demonstration experiments were selected after a survey of the installation status of advanced infrared beacons, traffic light control systems, and the like in each area.

Around 50 experiment participants were recruited for each experiment area in such a way to eliminate gender and age bias. In addition, the signal passing support system, signal stopping support system, signal change starting support system, and idling stop support system described above were evaluated using passenger vehicles from each manufacturer. In the vehicle-signal cooperative traffic signal control system experiment, the on-board unit was installed in shuttle buses operating between a company office and railway station to statistically identify the effects and impacts of the system on travel times and traffic flow.

Fig. 5 Experiment route example (Gunma area)

6 Experiment Results and Conclusion

6.1. Effects on travel times and fuel consumption

For the signal passing support system, signal stopping support system, and idling stop support system, the results of the experiments carried out in each area found no statistically significant difference in travel times and fuel consumption with or without the systems. Therefore, no noticeable effects were observed. Although various factors may have contributed to these results, the following can be considered as the main causes:

(1) The experiments were conducted on public roads used by ordinary vehicles, which resulted in less frequent occurrence of the situations expected by the systems in which effective support can be provided. Even in situations in which effective support was provided, there were cases in which the vehicles were not able to utilize the system support because of the preceding and following vehicles. For example, in the case of the signal stopping support system, some participants did not follow the deceleration advice as they were concerned about the possible negative impact of deceleration on following vehicles.

(2) Some time ranges in route traffic signal information provided by infrared beacons contained differences between the signal information and the actual signal phase timing, and cases occurred in which the validity of route traffic signal information expired due to its short validity period.

In contrast, in the signal change starting support experiment, the time until the brake is released after the traffic signal turned green was compared with and without support. The mean value of the time with support decreased in both the Kanagawa and Aichi areas. However, although there were no significant statistical differences in Kanagawa, significant differences were apparent in Aichi. This result is probably due to differences in the traffic environment between the two areas.

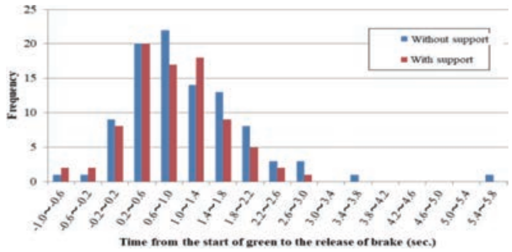


Fig. 6 Example of effect of signal change starting support system (Aichi area)

In the vehicle-signal cooperative traffic signal control experiment, the travel time of the experimental route was compared with and without route traffic signal information. The results found an average decrease of 15 to 16%, i.e., about 30 seconds, in travel times, which confirmed the effectiveness of the system in this experimental environment.

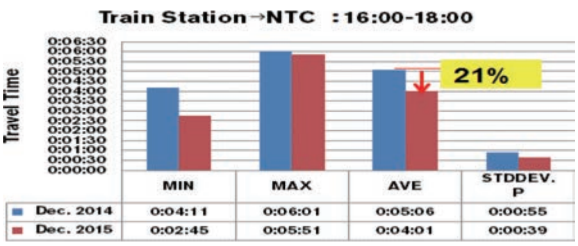


Fig. 7 Example of vehicle-signal cooperative traffic signal control (Kanagawa area)

6.2. Acceptance evaluation results

There were no quantitative differences in the results with and without the systems in the signal passing support system, signal stopping support system, and signal change starting support system experiments. However, the questionnaire survey found that about 60 to 80% of respondents evaluated the systems positively, although the responses varied slightly in each area. Feedback about the vehicle-signal cooperative traffic signal control system also found that many bus drivers who participated in the experiment felt that travel times were reduced by one to two minutes. Thus, the evaluation results demonstrated user expectations for these systems.

In contrast, some respondents expressed that they could not feel the benefits of the support service provided by the idling stop support system.

6.3. Future issues (accuracy of route traffic signal information)

Route traffic signal information provided at critical intersections indicates the start time of a green signal and the cycle length in the form of maximum and minimum values. However, this generates relatively large time ranges, leading to gaps in timings between the signal color predicted by the route traffic signal information and actual signal color. Also, the validity of data may expire while the system's service is being provided because of its short validity period, as seen in the data from the critical intersections, where the validity period is equal to only one cycle length.

In the experiment, when the route traffic signal information was provided within a certain time range, the median was used to obtain an estimate. However, last year's preliminary survey confirmed that the data was effective even if its validity had expired. Therefore, expired data was also included in statistical processing to ensure a sufficient number of samples.

To address these issues, it is desirable to examine ways to provide information in the most manageable way for the on-board unit, such as narrowing the range of fluctuations in the information on the timing of traffic signal colors and adding information on the timing of red and yellow signals, with consideration also given to traffic control systems that performs dynamic control while detecting the degree of traffic flow congestion. If the range of time fluctuation in traffic signal information is relatively small, the median between the maximum and minimum values may be used for the time being as timing information, as was the case in this experiment.

It should also be effective to provide information by refreshing traffic signal information at regular distances on the route using infrared beacons or other communication media to reduce the occurrence of information validity expiration.

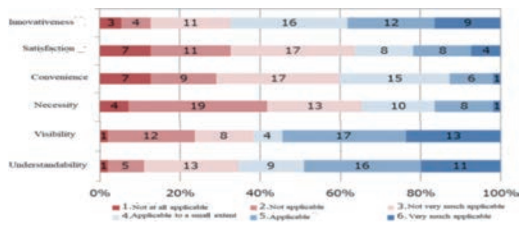


Fig. 8 Example of questionnaire results for signal passing support system (Aichi area)

Construction of Traffic Regulation Information Management System for Realization of Automated Driving

Masayuki Jinno (Sumitomo Electric System Solutions Co., Ltd.)

ABSTRACT: To realize automated driving, use of the latest traffic regulation information is an important aspect of vehicle control. This traffic regulation information is managed by the police in each Japanese prefecture. It is necessary to build a structure capable of gathering and providing traffic regulation information from the whole country. To develop this structure, we carried out the following steps: (1) standardization of the traffic regulation information data format, (2) construction of a traffic regulation information management model system.

1 Standardization of Traffic Regulation Information Data Format

1.1. Investigation of traffic regulation information data items

First, in the 2014 fiscal year, we investigated the traffic regulation information data items used by each prefectural police.

1.2. Design of standard data format

As shown in Fig. 1, in the 2015 fiscal year, we designed a standard data format by selecting the necessary data items for realizing automated driving from all the data items.

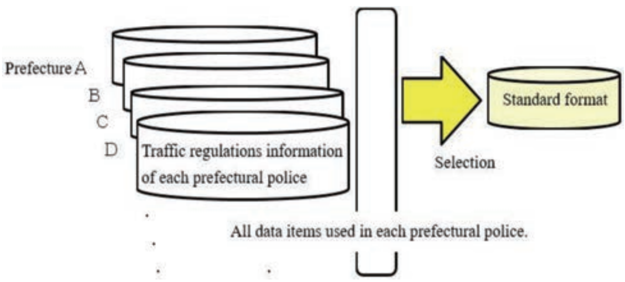


Fig. 1 Design of the standard format

Specifically, first, as shown in Fig. 2, we counted the number of prefectures using each data item and selected the frequently used items for the standard format. Data items used only by specific prefectural police were excluded.

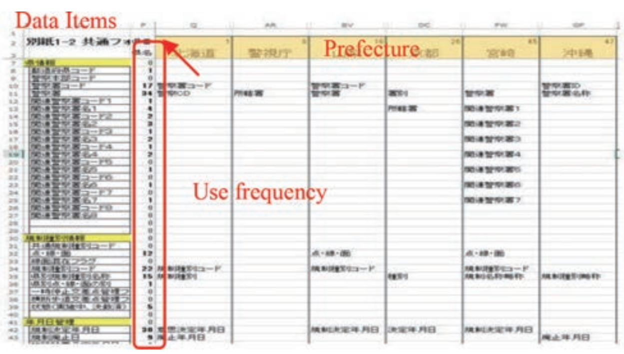


Fig. 2 Number of prefectures using each data item

In addition, we added some items to the standard format data from the standpoint of using for automated driving, even though the required traffic regulation information data for automated driving are not yet clear.

2 Construction of Model System

2.1. Design policy of model system

When designing the functions of the model system, adopting only traffic regulation information database editing functions through input, correction, and deletion is not enough. As shown in Fig. 3, the model system functions must support the whole workflow of traffic regulation information and facility management. For example, the data application function shown in Fig. 4 and a road sign construction management function are needed to maintain the traffic regulation information database in the latest state.

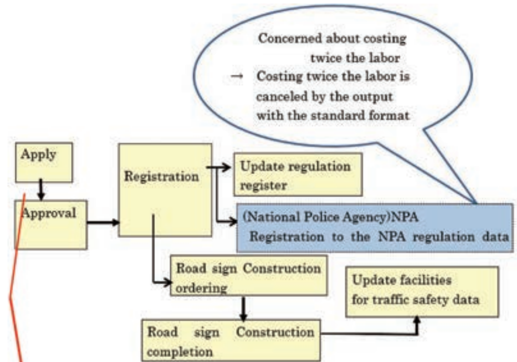


Fig. 3 Work flow of traffic regulation information and facility management

Fig. 4 List and sheet of regulation data application function

Some prefectural police manage traffic regulation information using a paper account book and some prefectural police use electronic data via an original prefectural computer system. The model system is not a substitute for these original prefectural computer systems. Instead, the model system is introduced when a prefectural police office wishes to introduce a new computer system. However, it is necessary to unify the data to the designed standard format. Therefore, the model system must have a function that can output data in a standard format. If a prefectural police office wishes to continue managing traffic regulation information using an original prefectural computer system, a conversion tool to generate standard format data will be necessary. By the 2017 fiscal year, the standard format data was adopted by four prefectures. It is planned to provide a conversion tool to generate standard format data to other prefectures in the future.

2.2. Connection function of traffic regulation and road sign information

From the standpoint of automated driving, the model system requires a function to display the traffic regulation and road sign information on maps, as shown in Fig. 5. The model system should also have a function of mutually connecting this information.

Fig. 5 Connection function of traffic regulation and road sign information

2.3. Creation of draft specifications for traffic regulation information management system

To examine the model system, a questionnaire survey about the problems of each original prefectural system was carried out.

A summary of the results of that questionnaire survey is as follows.

1) Management of road sign information is not possible.
2) Data management with maps is not possible. (The system has no geographic information system (GIS)).
3) Map searches are not possible. Traffic regulation and road sign information cannot be searched using maps. Screen captures and print outs are not possible.
4) It is hard to identify the relationship between traffic regulation and road sign information.
5) Correct positional information is necessary.
6) Operability (the speed of operation response) is not good. Work efficiency is not good.
7) It requires twice the labor costs to register information on both the original prefectural system and the National Police Agency system.

It was necessary to consider measures for these problems when designing the specifications of the model system. Table 1 on the next page shows the results of the questionnaire survey and the measures for the identified problems. We designed draft model system specifications that include these measures in the 2015 fiscal year.

2.4. Construction of model system

In the 2016 fiscal year, we introduced a model system based on these draft specifications to the Kyoto police headquarters, which had conventionally managed traffic regulation information using a paper account book. As a result, the traffic regulation information was computerized. We investigated road signs at the same time, and joined all the road sign information with the traffic regulation information using a connection function.

3 Conclusion

We designed a standard traffic regulation information format and made a conversion tool to generate standard format traffic regulation information data. We also designed specifications for a model system and constructed a system based on these specifications. This initiative has created a roadmap for implementing national uniform management of traffic regulation information (103 kinds). It is believed that the national uniform management of traffic regulation information should help to realize automated driving.

① Dynamic Maps

Construction of Traffic Regulation Information Management System for Realization of Automated Driving

Table 1 Problems of each prefectural system and measures adopted in model system

Prefecture	Problems	Measures
A	・Road sign information is not sufficient for management. ・An automatic numbering function is needed for new road signs. ・A selectable map printout function should be available for traffic regulations and road signs. ・When traffic regulation data is displayed, the connection with road signs should also be displayed at the same time.	・Improvement of the road sign information items. ・Implementation of an automatic numbering function for traffic regulation and road sign information. ・Implementation of a printout function with high flexibility about what to print. ・Implementation of functions to connect and display the traffic regulation and road sign information.
B	・The management of facilities such as road signs and road markings is carried out by individual systems. These systems should be unified.	・Realization of unified system following the work flow of traffic regulation information and facility management.
C	・Because the traffic regulation information management system is not separate from other police systems, it is not easy to revise it freely. ・The system manages traffic regulation information only as text data and does not have a GIS.	・Realization of unified system following the work flow of traffic regulation information and facility management. ・Implementation of function to manage traffic regulation information with maps.
D	・Because the road sign and road marking management system is separate from the traffic regulation information management system, a time lag occurs when updating this information.	・Realization of unified system following the work flow of traffic regulation information and facility management.
E	・Much time and many staff are necessary to take all steps because the data volume is too high.	・Realization of easy operation and high speed response.
F	・The system does not have a function to register the direction and section of traffic regulation information. ・In the system, positional information such as road signs is managed as latitude/longitude data. However, it does not match the real setting position because icons are located on rough electronic maps.	・Implementation of function to register detailed traffic regulation information. ・Implementation of positional information management function on detailed house-level map.
G	・It is necessary to input traffic regulation information into both the National Police Agency system and the prefectural police system. It requires twice the labor.	・Implementation of function or tool to generate a standard format from the prefectural system format.
H	・The current system cannot manage traffic regulation information on maps.	・Implementation of function to manage traffic regulation information on maps.
I	・Sufficient map search functions are necessary. ・Correct positional information is necessary.	・Implementation of search function that uses both place names, as well as traffic regulation and road sign information. ・Implementation of positional information management function on detailed house-level maps.

Development of V2V and V2I Communication Technology for Automated Driving Systems

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Yoshinori Hatayama (Panasonic Corporation)
Tetsuya Takahashi (Pioneer Corporation)
Yasushi Yamao (The University of Electro-Communications)

ABSTRACT: The development of automated driving systems is mainly based on the use of in-vehicle sensors, but adding vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication has the potential to realize advanced automated driving systems capable of cooperating with other vehicles and the surrounding infrastructure. The purpose of this project is to develop the necessary technologies for realizing such cooperative automated driving systems. We are confirming the feasibility of communication to support automated driving systems, and developing technologies to improve the characteristics and processing efficiency of this communication.

1 Summary

The purpose of this research and development is to develop the necessary technologies for realizing cooperative automated driving systems that utilize vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. We evaluated the feasibility of two V2X use cases: merging support on the freeway and emergency vehicle recognition support on ordinary roads. To research these cases, we developed communication technologies to improve communication quality, as well as nd methods to improve the efficiency of data processing. This study is based on the 700 MHz band ITS communication (ARIB STD-T109) deployed for safe driving support in Japan.

2 V2X communication Use Cases for Automated Driving Systems

V2V and V2I communication enables the acquisition of information from areas beyond the sensing range of in-vehicle sensors, which can provide safety margins to the operation of automated driving systems. Two cases were examined. One is merging support on a freeway, which has the potential for early deployment. Merging vehicles on the slip road build a consensus with vehicles on the freeway using V2V or V2I communication, enabling the vehicles on the freeway to decelerate to maintain their following distance and realizing smooth merging. The other case is recognition support, in which an automated vehicle encounters emergency or public vehicles on an ordinary road. Smooth automated driving can be realized by using V2V communication to recognize the presence and behavior of ambulances, buses, and trams at longer distances than in-vehicle sensors.

2.1. Feasibility evaluation of merging support on freeway

First, we conducted V2V communication experiments on several freeways to evaluate. As a result, although the requirements were satisfied in many places, we found that the requirements could not be satisfied at the junctions of tunnel roads seen on urban freeways. In response, we also considered a support model (message formats and exchange sequence) using V2I communication (Fig. 1). To verify the validity of the support model, we conducted experiments on a test course (Fig. 2). As a result, it was demonstrated that V2V communication built a consensus between the merging vehicles on the slip road and the vehicles on the freeway, enabling the vehicles on the freeway to decelerate to maintain their following distance for merging. We confirmed that V2I communication can be used to maintain following distances or adjust acceleration timings by providing information about detected vehicles merging on a slip road and vehicles on the freeway from roadside infrastructure.

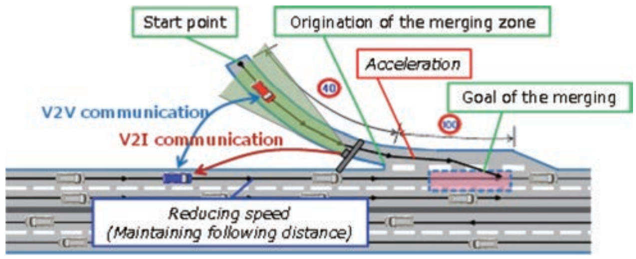


Fig. 1 Merging support model using V2V and V2I communication

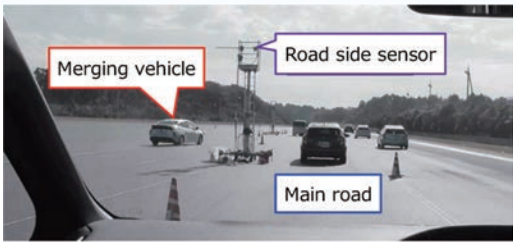


Fig. 2 Verification experiment on test course

2.2. Evaluation the usefulness of emergency vehicle recognition support

We conducted experiments to compare methods of recognizing ambulances by installing V2V equipment in actual ambulances. We confirmed that V2V communication can recognize the existence of ambulances from further away than camera images or siren sounds. We created a deceleration model for yielding automated vehicles when encountering an ambulance entering an intersection on a red traffic signal. Using the model, we confirmed that the difference in the success rate of yielding in an intersection depended on whether V2V communication was used (Fig. 3). It was found that the success rate of yielding was increased by V2V communication, and that cases of maximum deceleration can be reduced. In addition, we conducted V2V experiments on route buses and taxis, and found that the behavior of these vehicles can be recognized from further away in low visibility situations.

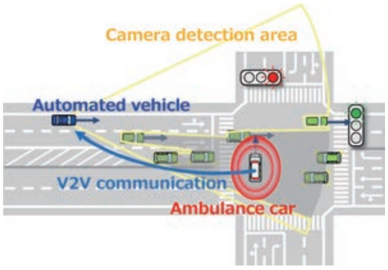


Fig. 3 Emergency vehicle recognition support model using V2V communication

3 Technology Development for Use Cases

One of the important issues for practical application of these use cases is maintaining performance and functions even the spread of V2X systems. We developed technology to maintain and improve communication performance (Section 3.1.) and to improve data processing efficiency (3.2.) without making major changes to current specifications. We also developed new communication technology (3.3.) under the consideration that higher communication performance will be required in the future.

3.1. Development of V2V communication technology for merging support

As V2X communication systems become widespread and communication traffic increases, packet collisions will become more likely and communication quality may decrease. It is important to maintain communication quality for merging support, because it is necessary to establish communication in a short period of time. In addition, it is necessary to add messages for merging support while maintaining compatibility with current specifications. To resolve these issues, we examined a variable transmission period function, a reservation transmission timing function, and a hierarchical modulation technique. Simulation results confirmed that the amount of transmission data can be expanded and that high communication quality can be maintained compared to a case without the developed technology (Fig. 4).

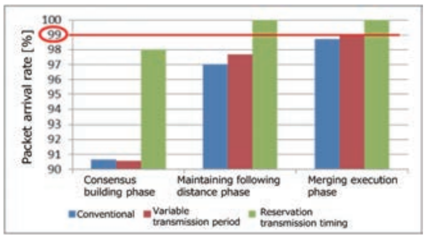
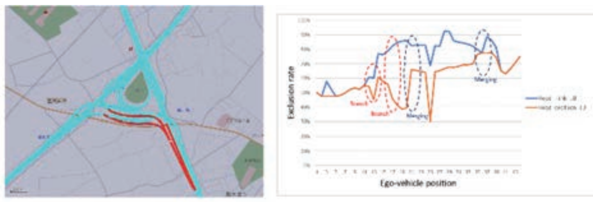


Fig. 4 Communication quality of V2V communication for merging support

3.2. Development of method to improve V2V data processing efficiency

When performing V2V communication with many surrounding vehicles, it is necessary to filter the data of the target vehicles to be monitored by the driver's vehicle from the high volume of received data. Especially in complicated road shape environments (like freeway junctions), filtering is difficult with the current message format. We examined including "road-specifying information," which specifies the road on which the driver's vehicle is traveling, in transmitted messages. We then clarified that this allows efficient and appropriate filtering even with complicated road shapes (Fig. 5). We also showed that this road-specifying information can be added without changing the current V2V communication message format (ITS FORUM RC-013).



(a) Selected road link at position #16 (b) Comparison of exclusion rates

Fig. 5 Simulation example of target selection

3.3. Development of V2V and V2I communication technology for future use cases

3.3.1. Study of high-reliability V2V communication with multi-dimensional distributed cooperative technology

To realize highly reliable V2V communication, a transmission method applying multi-vehicle cooperative multi-hop communication using space-time block codes was studied. By adaptively selecting relay vehicles with a high contribution to packet transmission based on radio wave propagation characteristics and vehicle position, unnecessary relay transmission can be reduced while enhancing communication reliability through the cooperative diversity effect. We conducted a computer simulation assuming use on a freeway, and confirmed that the proposed method can reduce the average number of relay transmission vehicles while attaining the same communication success rate as the conventional method. We also constructed a communication reliability database based on the experimental V2V communication data, and confirmed that the packet error rate improves when the relay vehicles are selected using this database (Fig. 6).

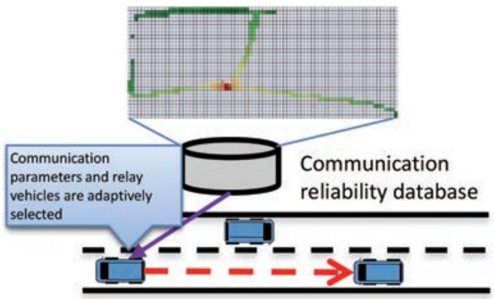


Fig. 6 Multi-vehicle cooperative relay transmission with communication reliability database

3.3.2. Study of high-reliability V2V communication with sectorized relay stations

We investigated a system using roadside relay stations with a sectorized antenna system as a measure against the shadowing loss and hidden node issues of intersections, which severely deteriorate the quality of V2V communication. By using sectorized receiving antennas and individual receivers for each direction, the relay station can maximize the relay performance and compensate for both the hidden terminal issue and shadowing loss caused by corner buildings. We clarified that the area averaged packet delivery success rate can be greatly improved by assuming a case in which multiple roadside relay stations are installed on an urban road consisting of multiple intersections, and then assigning the relay area between adjacent relay stations (Fig. 7).

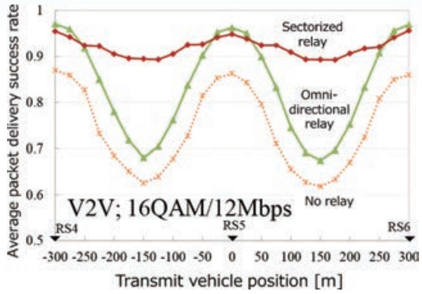


Fig. 7 Improvement effect of V2V communication quality using sectorized relay stations

3.3.3. Study of high-reliability V2V and V2I communication with error correction code technology

We focused on repeat-accumulate (RA) code, which has small coding computation volumes and strong error correction capabilities, as an error correction coding technique for improving the quality of V2V communication. We designed a lattice code that exploits the properties of RA code. Computer simulations clarified that the RA signal code exhibits the best characteristics at mid-range code lengths, including the convolutional code adopted in current V2V communication standards. In addition, we studied multi-dimensional spatially-coupled RA coding coordination as a technique to realize highly reliable communication from a group of vehicles to a base station. By optimizing the encoding method, it was clarified that developed codes can obtain high-reliability in various communication channels (Fig. 8).

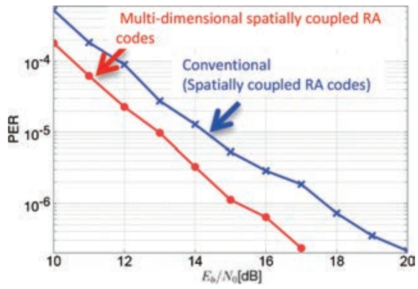


Fig. 8 Improvement effect of V2I communication quality using multi-dimensional spatially coupled RA codes

4 Conclusion

This research and development verified use cases and developed technologies to help realize cooperative automated driving systems. Since these research results cover wide technical fields and a wide range of assumed application timings, they have the potential to contribute to the realization of cooperative automated driving systems.

Research into Practical Application of Safe Driving Assistance System Utilizing Vehicle to Vehicle (V2V) Communication and Research into Required Conditions of Vehicle to Pedestrian (V2P) Communication

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ABSTRACT: These two research cases were carried out as a three-year project. In the first year, the accuracy of vehicle and pedestrian positions of V2V and V2P communication systems, communication delay, and the like were investigated in tests on public roads. In the second year, driver acceptance of these kinds of safe driving assistance systems that utilize V2V and V2P communication was investigated in tests on a test track. In the final year, driver acceptance of automated driving systems that utilize V2V and V2P communication was investigated in tests using a driving simulator.

1 Purpose of the Research

The following main items were carried out in these two research cases to help make a draft of technical guidelines for automated and safe driving assistance systems that utilize V2V and V2P communication.

(1) Investigations of the positional accuracy, communication delay, and the like of V2V and V2P communication in tests on a test track and public roads

(2) Investigations of driver and pedestrian acceptance of safe driving assistance systems that utilize V2V and V2P communication in tests on a test track

(3) Investigations of driver acceptance of automated driving systems that utilize V2V and V2P communication in tests using a driving simulator

2 Validation of V2V and V2P Communication

2.1. Locations of validation tests

V2V and V2P communication were validated in three cities, Yokosuka, Kobe, and Nagoya. Figure 1 shows photographs of the validation tests in Nagoya.

2.2. Examples of data from validation tests

Figure 2 shows measured data of the differences in the distance between high-accuracy and normal GPS installed in the test vehicles. The data was measured in Nagoya. The average error was 6.1m, with a minimum error of 2.1m and a maximum error of 11.5m.

Figure 3 shows measured data of the communication delay of mobile terminals. Fifty vehicles and pedestrians were respectively provided with mobile terminals. The communication delay was within 200ms.

Fig. 1 Validation tests in Nagoya

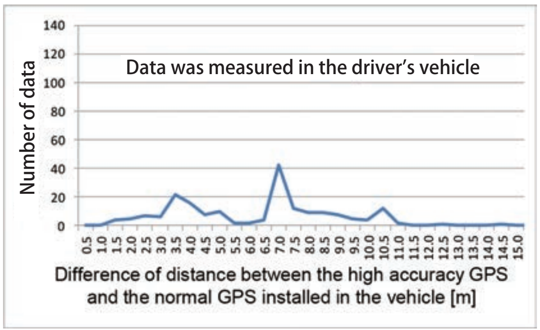


Fig. 2 Difference of distance between high-accuracy and normal GPS installed in vehicles

The V2V and V2P communication system validation tests confirmed that current positioning accuracy technology can only be utilized for V2V and V2P communication systems that supply information to drivers or pedestrians. Further improvement of positioning accuracy is necessary to utilize V2V and V2P communication systems that supply cautions or warnings to drivers or pedestrians.

3 Tests to Investigate Driver and Pedestrian Acceptance of Safety Assistance Systems

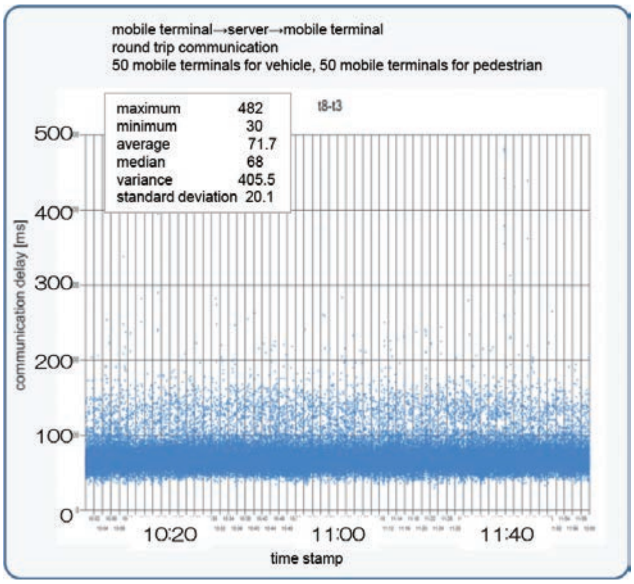


Fig. 3 Example of data of communication delay

3.1. Test preconditions

Tests were carried out under ideal conditions enabling a positioning accuracy of within 10cm by utilizing high-accuracy GPS at a test track. Driver and pedestrian acceptance of a safe driving assistance system that supplies information, cautions, and warnings utilizing V2V and V2P communication was evaluated.

3.2. Scenarios and test conditions

The test scenarios were chosen based on accident data in Japan. We carried out tests involving two scenarios of V2P communication and two scenarios of V2V communication. Figure 4 shows the V2P scenarios, and Fig. 5 shows the V2V scenarios.

To decide the test parameters (for example, the timing of information supply) before the test using actual V2P and V2V communication systems on a test track, a pre-test was carried out using twenty people (ages: from 20s to 60s) in a driving simulator.

The test using the actual V2P and V2V communication systems was carried out on a test track at the Japan Automobile Research Institute that simulates city roads. The prototype V2P and V2V communication systems realized positioning accuracy within 4 cm. Ten people (ages: from 20s to 50s) who are frequent drivers participated in the test. Figure 6 shows photographs from the test.

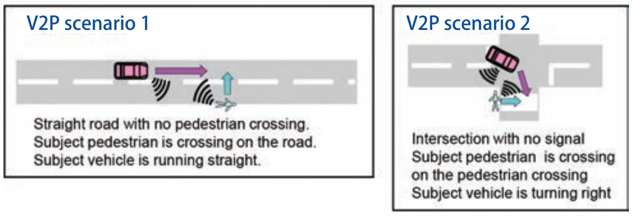


Fig. 4 Experimental test scenario for V2P communication

3.3. Test results

Figure 7 shows an example of the test results regarding driver acceptance of the V2P communication system. In this case, "before 4.0s" is considered to be an appropriate timing for drivers.

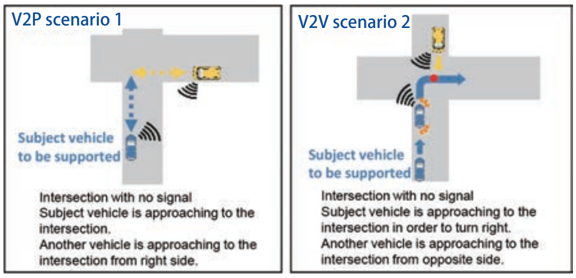


Fig. 5 Test scenario for V2V communication

Fig. 6 Test on test track

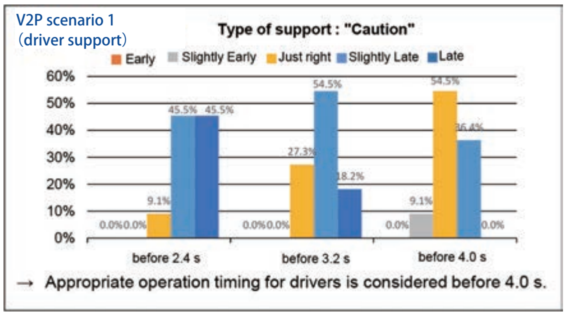


Fig. 7 Example of data of driver acceptance

According to the test results, effective operation timings for drivers and pedestrians were confirmed as follows.

- V2P communication system (drive support)
  - Information supply: from 5.1s to 6.5s in advance
  - Caution: from 3.2s to 4.0s in advance
  - Warning: more than 2.0s in advance
- V2P communication system (pedestrian support)
  - Information supply: from 5.1s to 6.5s in advance,
  - Caution: from 3.2s in advance

① Dynamic Maps

Research into Practical Application of Safe Driving Assistance System Utilizing Vehicle to Vehicle (V2V) Communication and Research into Required Conditions of Vehicle to Pedestrian (V2P) Communication

Warning: more than 2.0s in advance

・ V2V communication system

Information supply: from 5.1s to 6.5s in advance

Caution: from 3.2s to 4.0s in advance

Warning: more than 2.0s in advance

4 Driving Simulator Tests to Investigate Driver Acceptance of Automated Driving Systems

4.1. Test preconditions

The automated driving system utilizing V2V and V2P communication in this test was provided with functions to both supply information and warnings to the driver and control the speed of the vehicle to avoid a collision. When the system receives information of an object around the vehicle, it can reduce the vehicle speed before the driver sees the object if it judges that the risk of collision is high. It was necessary to investigate whether normal drivers would accept such a system.

4.2. Scenarios and test conditions

In this research, the following two traffic scenarios were used.

Scenario A: When a normal driver would not usually be aware of a potential collision with an object that cannot be seen directly

Scenario B: When a normal driver would usually be aware of a potential collision with an object that cannot be seen directly

Table 1 shows the combination of the test cases for the V2P system, and Fig. 8 shows the traffic scenarios. Table 2 shows the combination of the test cases for the V2V system, and Fig. 9 shows the traffic scenarios.

Table 1 Combination of test cases (V2P)

Test number	Traffic scenario	Judgment of the system for the collision risk	Smaller deceleration braking (for reducing collision risk)	Occurrence of the dangerous situation	Automatic emergency braking (for avoiding a collision)
①	A	Collision risk is existing.	Execute	A pedestrian crossing a road	Execute
②	A	Collision risk is existing.	Execute	Not occurring	Not execute
③	A	Collision risk is **not** existing.	Not execute	A pedestrian crossing a road	Not execute
④	B	Collision risk is existing.	Execute	A pedestrian crossing a road	Execute
⑤	B	Collision risk is existing.	Execute	Not occurring	Not execute
⑥	B	Collision risk is **not** existing.	Not execute	A pedestrian crossing a road	Not execute

・As the experiment condition of test number ①,②,④ and ⑤, the driver could not see the object pedestrian at the timing of start of smaller deceleration braking.

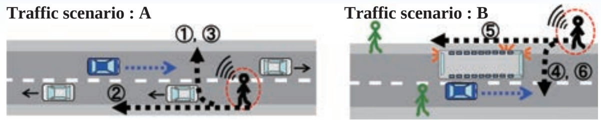


Fig. 8 Traffic scenario for test cases (V2P)

Table 2 Combination of test cases (V2V)

Test number	Traffic scenario	Judgment of the system for the collision risk	Smaller deceleration braking (for reducing collision risk)	Occurrence of the dangerous situation	Automatic emergency braking (for avoiding a collision)
⑦	A	Collision risk is existing.	Execute	A vehicle entering a road	Execute
⑧	A	Collision risk is existing.	Execute	Not occurring	Not execute
⑨	A	Collision risk is **not** existing.	Not execute	A vehicle entering a road	Not execute
⑩	B	Collision risk is existing.	Execute	A vehicle turning right	Execute
⑪	B	Collision risk is existing.	Execute	Not occurring	Not execute
⑫	B	Collision risk is **not** existing.	Not execute	A vehicle turning right	Not execute

・As the experiment condition of test number ⑦, ⑧, ⑩ and ⑪, the driver could not see the object vehicle at the timing of start of smaller deceleration braking.

Seven non-elderly people (ages: 30s to 50s) and seven elderly people (ages: from 65s to 80s) who are frequent drivers participated in the test. The participants were directed to operate the OFF button of the automated driving system if they felt that they could not accept the behavior of system.

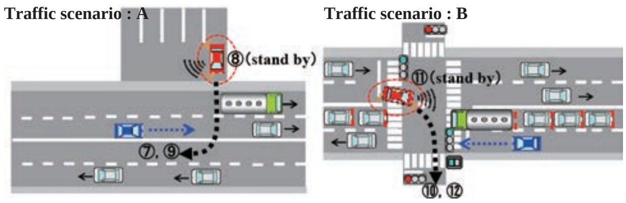


Fig. 9 Traffic scenario for test cases (V2V)

4.3. Test results (example)

Figures 10 and 11 show the rate of OFF button operation by the drivers after the system reduced the vehicle speed in scenarios A and B, respectively. The rate of OFF button operation in scenario B by the non-elderly drivers was lower than that in scenario A. This suggests that driver acceptance of reductions in vehicle speed by the system in scenario B was higher than that in scenario A. In contrast, the rates for both scenarios A and B were lower for elderly drivers than for non-elderly drivers.

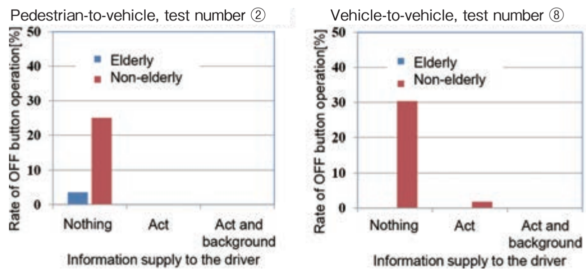


Fig. 10 Rate of OFF button operation (traffic scenario A)

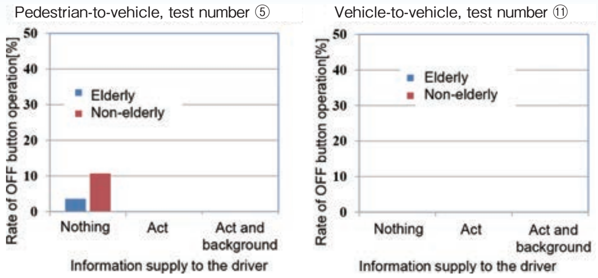


Fig. 11 Rate of OFF button operation (traffic scenario B)

5 Conclusion

Draft technical guidelines for automated driving and safe driving assistance systems that utilize V2V and V2P communication systems were formulated based on the results of the research described above.

References

(1) Ministry of Land, Infrastructure, Transport and Tourism:
Guidelines for Communication-based driver assistance systems, pp.12-13 (2011).

② Human Machine Interface (HMI)

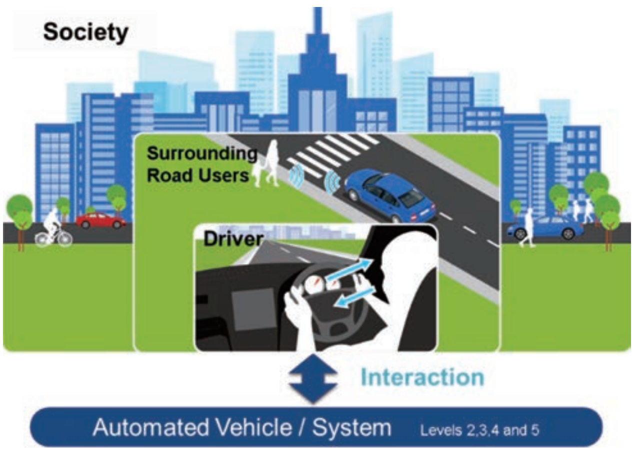
Outline of Human Machine Interface (HMI)

Kiyozumi Unoura (Honda R&D Co., Ltd.)

With regard to the human machine interface (HMI) used by automated driving systems, SIP is formulating guidelines and aiming to achieve international standardization. Although HMI technology is in the competitive domain of each company, minimal arrangements must be agreed to prevent user confusion, facilitate understanding of the functions, states, and actions of the automated driving system, establish the driver's condition and appropriate handover time, and the like. Guidelines have been formulated for these items. Each company is considering how to realize these guidelines, and to develop competitive and high-quality products.

We describe three issues to be resolved to help realize a level 3 automatic driving system in "Considerations on automated driving HMI" (JAMA) and proposed guidelines for the readiness index and measurement method (international standard ISO/TC22/SC39).

For a level 3 automated driving system, it is desirable that the results of prior knowledge be understood and utilized by vehicle sales companies, driving education sites, and the like so that drivers and all traffic participants can be made aware of this information. However, to accept and utilize automated cars as safe vehicles, we believe that it is important for each stakeholder to obtain common awareness through, for example, the development of specific teaching materials, and to enhance the quality of understanding.



1 Task A (issues related to driver understanding of the system)

For level 2 and 3 automated driving systems, it was possible to clarify the influence of the HMI on driver behavior and the influence of driver behavior on the system functions through driving simulator and test course experiments that examined the handover from automated to manual operation. Based on these results, we derived basic knowledge about HMI and knowledge about what information to provide in advance.

2 Task B (issues related to identifying driver readiness)

As an index to evaluate the state of the driver during automatic driving, the conventional techniques of observing driver inattention and drowsiness were supplemented by technology to observe driver consciousness and the state of the driver based on these indices. We developed a prototype monitoring system, demonstrated its effectiveness and feasibility, and derived the relationship between the time required for an appropriate transition when returning from automated to manual operation and the driver condition. Using these results, we proposed a readiness level to the International Standards Conference, which represents the degree of driver preparation when switching from automated to manual operation.

At the same time, we developed an HMI concept and device that helps to restore and maintain driver preparedness, and obtained results suggesting that this HMI is effective.

3 Task C (issues related to interaction with pedestrians and cars other than automated vehicles)

The intention of an automated vehicle to alter its path can be communicated through inter-driver communication, vehicle behavior, and external HMI (mainly related to deceleration behavior). In situations where deceleration behavior or the like cannot be sufficiently understood by drivers and pedestrians at an early timing, the potential effectiveness of external HMI to indicate behavior was demonstrated.

In contrast, if the intention of an automated vehicle cannot be clearly predicted, thereby affecting other drivers and pedestrians, it was suggested that standardization and educational learning for drivers and pedestrians will be necessary to enable utilization of external HMI. However, since it was not possible to identify the specific effects of external HMI on the current traffic environment, efforts were limited to consolidating basic knowledge and concrete device development has yet to take place.

Human Factors and HMI

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Toshihisa Sato (National Institute of Advanced Industrial Science and Technology)
Tatsuru Daimon (Keio University)

ABSTRACT: The Human Factors and HMI research project consisted of three tasks: A, B, and C, and started in FY2016 as a three-year project. Task A investigated the effects of system information on driver takeover performance. The provision of well-defined knowledge about the system before driving and experience of using the system were found to have a positive effect. The provision of some dynamic information about the system state was also shown to be effective. Task B investigated the effects of the driver state (readiness) on takeover performance and metrics of readiness. It was found that different driver states influenced takeover performance in different ways. Some metrics for states (readiness) influencing takeover performance were found. Task C investigated effective ways of functionalizing automated vehicles to communicate with nearby road users. An external HMI was found to be an effective additional cue for pedestrians to make a decision to cross a road when an approaching automated vehicle intended to yield but did not decelerate largely enough to clearly signal this intention. It was observed that the external HMI also induced unsafe behavior in some pedestrians. This report was produced in the middle of the third year of the project and does not include all the studies conducted in the project.

1 Defining Tasks for Research

The SIP-adus HMI Taskforce was established in 2015 to define the research tasks related to human factors for safe and socially acceptable automated driving. The taskforce used a framework to extract potential problems related to human factors. The framework consisted of three interactions: interactions between the driver and the system, between the system and nearby road users, and between the system and society (Fig. 1).

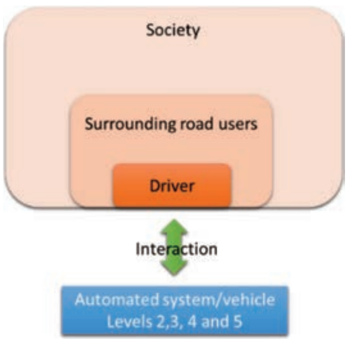

Fig. 1 The framework used to extract potential problems related to human factors in automated driving.

Extracted potential problems were classified between those in cooperative fields and those in competitive fields from the standpoint of developers in the industry. Issues in cooperative fields were prioritized. Three issues with the highest priority in the cooperative fields were set as the three tasks A, B, and C for the SIP-adus human factors and HMI research project.

- Task A investigated the effects of system information (knowledge and dynamic state) on drivers' takeover performance for level 2 and 3 automated driving systems.
- Task B investigated the effects of the driver state (readiness) on takeover performance for level 2 and 3 automated driving systems, and extracted metrics of readiness for driver monitoring.
- Task C investigated effective ways to functionalize automated vehicles to communicate to nearby road users for level 2 and higher automated driving systems.

2 Task A

2.1. Overview of the task

In the case of a level 2 automated driving system, the driver must constantly acquire information about the traffic and the environment outside the vehicle (object and event detection and response: OEDR), and must acquire that information within the designed transition time for a level 3 system. The driver must also have or acquire information about the system at the same time to enable potential safe transitions in the near future. Such system information is classified as knowledge (i.e., static information) and dynamic information (Fig. 2). Knowledge includes information about the system functions, limitations, and the driver's role. Dynamic information includes the system state (i.e., its operating mode, level, occurrence of malfunctions, and the like) and actions that the system is planning and executing.

Aim 1 of this task was to investigate the effects of system knowledge given to the driver before driving and experience of using the system on takeover performance. The effects of age were included. By achieving aim 1, we expected to learn requirements for pre-driving education and training for safe use of these systems. Aim 2 was to identify effective dynamic information for enabling successful takeovers. This aim also included fundamental studies for HMI that effectively display dynamic information in the cockpit.

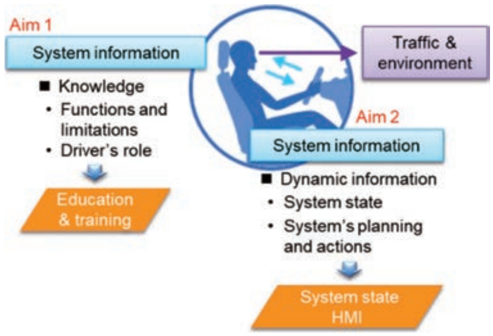

Fig. 2 Information the driver needs to have or acquire for level 2 and 3 automated driving systems.

2.2. Aim 1

2.2.1. Methods

The experiment used the fixed-base driving simulator located at the University of Tsukuba (Fig. 3). Subjects in two groups, a younger subject group (below 60 years old) and an older subject group (60 years and above) participated in the experiments. The subjects were given knowledge about the functions and limitations of the level 3 system before driving with the system using the driving simulator. The knowledge information was categorized into five levels of quantity raging from condition 1 for no information to condition 5 for full information (Table 1). The subject was instructed to perform a surrogate reference task (SuRT, ISO/TS14198) with both hands off the steering wheel until the onset of the takeover request (TOR).

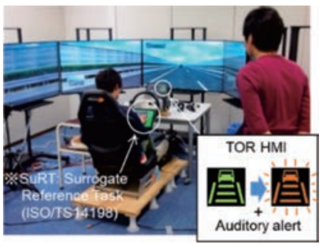

Fig. 3 The driving simulator at the University of Tsukuba used for the Task A experiments.

Table 1 Experimental conditions

Experimental conditions	Information contents
Condition 1	No information
Condition 2	Possibility of takeover requested by the system
Condition 3	Condition 2 + how TOR is displayed in the HMI
Condition 4	Condition 3 + some takeover situations included in the scenario
Condition 5	Condition 3 + all takeover situations included in the scenario

The experiment scenario included several objects/events for which the system issued a TOR using a HMI with a flashing visual icon and an auditory alert. When the TOR was issued, the subject was expected to take over control of the vehicle and continue driving. The subject's response time before initiating a steering operation was measured as the takeover performance metric. The first event of the scenario was exiting a motorway, which was used to analyze the effects of knowledge information on takeover performance. The subsequent objects and events were used to investigate the effect of experiencing takeover situations.

2.2.2. Some results

The response time from the onset of the TOR to initiation of the steering operation of each subject group was classified into three (Fig. 4) for each condition: within 10 seconds (green), between 10 and 15 seconds (orange), and longer than 15 seconds or failure to implement takeover (red). It was found that information about takeover situations was important for implementing successful takeovers (conditions 1 to 3 vs. conditions 4 and 5). However, too much information about takeover situations degraded the subjects' performance, especially in the case of the older subjects (condition 4 vs. condition 5).

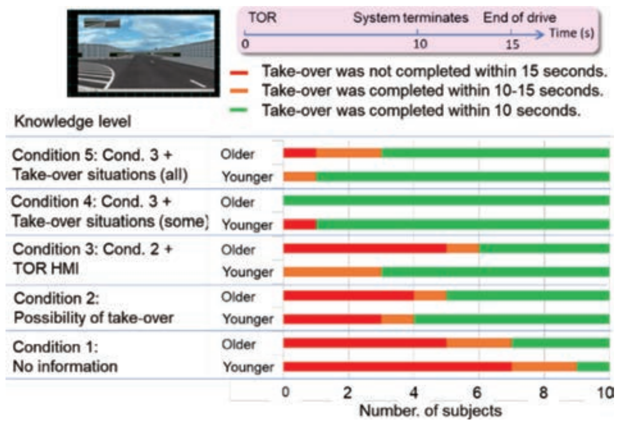

Fig. 4 Response time from TOR to initiation of steering operation.

Changes in the takeover success rate (success was defined as a response time within 10 seconds) over a number of takeover situations were calculated. The success rates were mean values across all the conditions from 1 to 5 for each

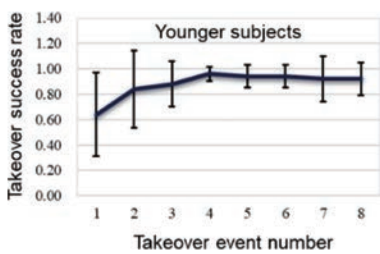

Fig. 5.1 Change in success rate of takeover of younger subjects over number of takeover situations.

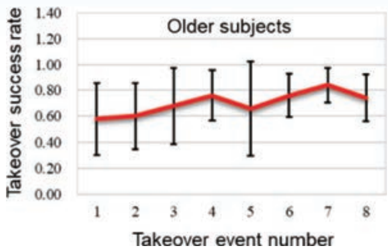

Fig. 5.2 Change in success rate of takeover of older subjects over number of takeover situations.

subject group. Experiencing takeover situations improved the success rate of the younger subjects (Fig. 5.1), while the effect was limited for the older subjects (Fig. 5.2).

2.3. Aim 2

2.3.1. Methods

A level 2 system may stop functioning due to a failure without notifying the driver (i.e. a silent failure). The system may also fail to alert the driver when an object or event that is not detected by the system is encountered due to a functional limit of the system. The driver is expected to monitor the environment (OEDR) and the system all the time so that the takeover action can be initiated when necessary. The study investigated what dynamic system information can help the driver to initiate a takeover action when an object or event that is not detected by the system is encountered.

The experiment compared driver-initiated takeover performance when information about objects detected by the system was provided, when information about planned system actions was provided, when a combination of these two information types was provided, and when no information was provided (i.e. the baseline). The information was visually displayed with icons (Fig. 6) on a monitor placed in the center stack of the cockpit mounted in the fixed-base driving simulator. A total of 60 subjects aged 60 years and older participated in the experiment. The subjects were given knowledge prior to driving that the system may fail to detect objects or events due to a functional limitation. The subjects were instructed to perform the OEDR task with both hands off the steering wheel.

The scenario included several objects and events for which the system issued a TOR, avoided automatically, or failed to detect. The object detection failures (4 times) were designed to cause crashes unless the subject initiated a takeover. The number of crashes was counted as the measure to compare the four conditions.

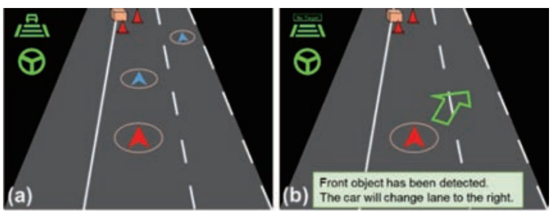

Fig. 6 (a) Information of detected objects (b) Combination of detected objects and planned action.

2.3.2. Some results

The number of crashes with undetected objects is shown in Fig. 7. The crashes were caused when the subject failed to initiate or delayed initiation of a takeover. Subjects who did not use the HMI throughout the scenario were excluded. The combination of information about detected objects and planned actions largely lowered the number of crashes from the baseline condition (no information) while the number of crashes did not decrease when only information about detected objects or planned actions was provided.

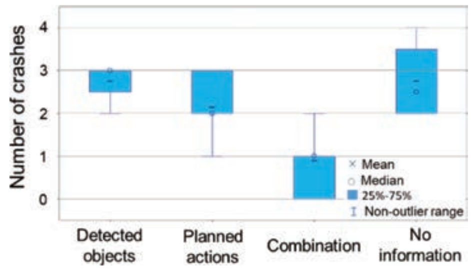

Fig. 7 Number of crashes with objects undetected by the system with provision of various system information.

2.4. Some conclusions

- Knowledge required for successful takeover was clarified.
- Experiencing takeover situations improved the takeover performance of younger subjects, but had a limited effect for older subjects.
- The results will be verified in test track experiments.
- The provision of a combination of visual information about detected objects and planned system actions improved driver-initiated takeover performance in the case of objects undetected by the system.
- Other types of dynamic information are also being studied.

3 Task B

3.1. Overview of the task and aims

With a level 2 system, the driver is expected to perform the OEDR task at all times and take over control immediately after a system request. With a level 3 system, the driver is allowed to perform non-driving related activities but is expected to take over control within a designed transition time after a system request. When the driver state is not ideal, the takeover action may be delayed or its quality may decline when a system request occurs.

A driver monitoring system (DMS) constantly monitors the readiness of the driver to take over control, detects decreases in readiness, and informs the system of this state. The main system then executes an intervention through an alert and/or termination of the automated mode with the aim of improving the reduced driver readiness, or stops the vehicle when continuing driving is determined to have a high risk (Fig. 8).

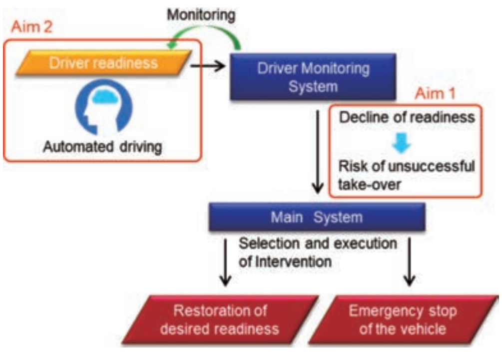

Fig. 8 Research aims of driver monitoring system and interventions.

This task had two aims. Aim 1 was to investigate the effects of various driver states on takeover performance and to define readiness as a state that affects takeover performance. Aim 2 was to extract readiness metrics for a DMS. Readiness was considered to include both the physical and visual-cognitive state of the driver. Although physical states include the position of hands, posture, seating position, and the like, these were not included in this task because their effects and metrics are both relatively apparent. The visual-cognitive state was classified as cognitively loaded, visually loaded, and low alertness, and their effects on takeover performance and the metrics were investigated. Takeover performance included both the speed and the quality of the action to manually cope with an object or event, and to stabilize the vehicle after the takeover to normal manual driving.

3.2. Methods

Experiments 1 and 2 below were carried out to accomplish aims 1 and 2. A total of 80 subjects participated in the experiments. The experiment used the motion-base driving simulator located at National Institute of Advanced Industrial Science and Technology (Fig. 9).

3.2.1. Experiment 1

The subjects drove a simulated level 2 automated driving system while both performing and not performing non-driving related tasks (NDRTs). The NDRTs were cognitive N-back tasks (low and high loads) and visual SuRTs (low and high loads). The subjects were instructed to place their hands off the steering wheel, and monitor the environment as well as the system while performing the NDRT. Various physiological indices of the subjects were measured while driving (Table 2).

The driving scenarios included several events with low criticality for which the system requested takeover to the subject. The following event was used for measuring takeover performance: The subject vehicle was following a leading vehicle with the system activated, a TOR was issued due to a system malfunction causing the system to shut down. The leading vehicle then changed lanes 1 second after the TOR and exposed a stationary broken-down vehicle in the same lane. The TOR was issued when the TTC to the broken-down vehicle was 6 seconds. The subject was expected to takeover in response to the TOR, detect the stationary vehicle, change the lane manually, and finally stabilize the vehicle in the next lane. Various performance measures were collected in terms of response to the TOR, maneuvering to change lanes and avoid a crash, and stabilization of the vehicle after changing lanes.

3.2.2. Experiment 2

To investigate the effects of arousal, the subjects drove a level 3 system through another scenario. The subjects were not given any tasks, including monitoring the environment or the system, with the expectation that monotony would induce drowsiness with enough inter-subject variability. The physiological indices shown in Table 2 were also measured in experiment 2. The scenario was a monotonous 20 minutes motorway drive and included a motorway exit event after issuing a TOR at the end of the scenario. The time to initiate a steering maneuver in response to the TOR was used as the performance measure.


Fig. 9 The driving simulator at AIST used for the Task B experiments.

3.3. Some results

The level of cognitive load applied to the subjects while the system was operational correlated with the minimum distance to the stationary vehicle while changing lanes after the TOR (Fig. 10.1). The results implied that the effect of the cognitive load remained after the TOR and that the cognitive process remained slow, resulting in degradation of the driver's ability to avoid a collision with the object. In contrast, the level of visual load correlated with the variability in the steering angle in the 5 seconds after changing lanes (Fig. 10.2). The results implied that the visual load degraded situational awareness, resulting in abrupt steering and unstable steering operations to stabilize the vehicle after changing lanes. There was no difference found in the response times for steering initiation between the two loading conditions. A schematic expression of the vehicle trajectories under the two loading conditions is shown in Fig. 11.

Table 2 Physiological measurements

Physiological measurements
EEG (Event-Related Potentials)
Visual behavior
Saccadic movements of the eyes
Pupil diameter
Blinking frequency
Perclos
Heart rate
Blood pressure

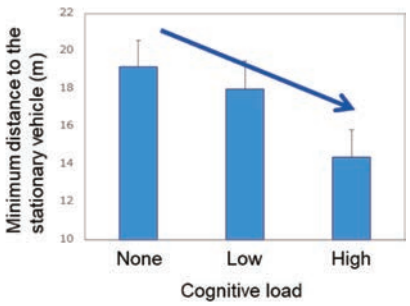

Fig. 10.1 Cognitive load applied to the driver before the TOR and takeover performance after the TOR.

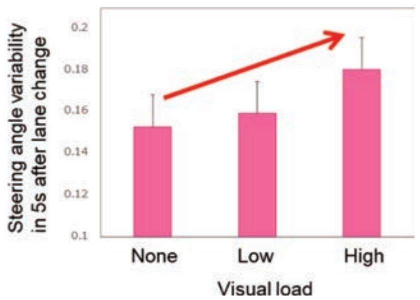

Fig. 10.2 Visual load applied to the driver before the TOR and takeover performance after the TOR.

Multiple biometrics of the cognitive and visual state of the driver (readiness) were extracted. Considering in-vehicle real-time monitoring of readiness by the DMS, the blinking frequency and the frequency of saccadic eye movement were candidate metrics for the cognitively loaded state (Fig. 12.1), while the percentage of time looking forward and the frequency of saccadic eye movement were candidate metrics for the visually loaded state (Fig. 12.2). For the arousal level, "Perclos" (percent eye closure, Dingus and Grace, 1998) was found to correlate with the time to initiate a steering operation to exit the motorway after the TOR (Fig. 13).

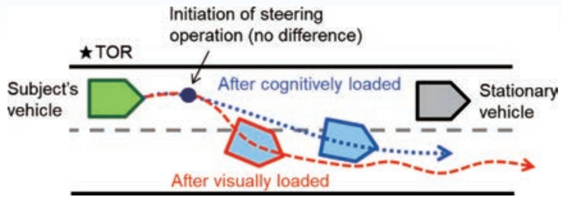

Fig. 11 Schematic expression of trajectories of the subject's vehicle after the TOR.

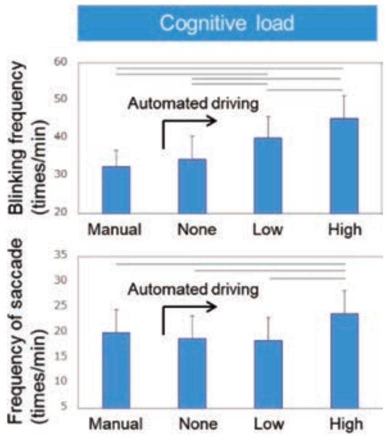

Fig. 12.1 Cognitively loaded driver state and biometrics.

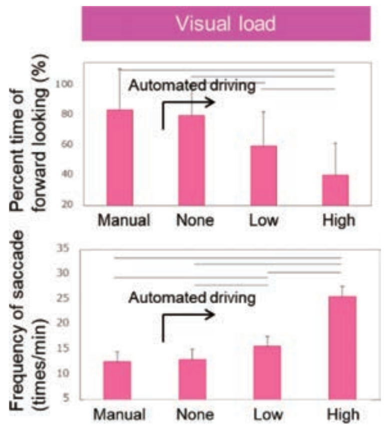

Fig. 12.2 Visually loaded driver state and biometrics.

3.4. Some conclusions

- Low arousal, cognitive load, and visual load degraded the driver's take-over performance in different ways. They were found to be components of readiness.
- The frequency of saccadic eye movement, blinking frequency, percentage of time looking forward, and Perclos were extracted as metrics of readiness for driver monitoring.
- The results were tested in test track experiments and similar results were obtained. The results will be tested in a FOT.
- A prototype DMS is being prepared based on these findings to examine applicability with an on-board system.
- An HMI to maintain an appropriate level of driver alertness is being investigated.

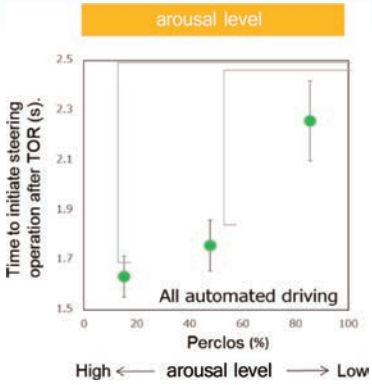

Fig. 13 "Perclos" measured before the TOR and takeover performance after the TOR.

4 Task C

4.1. Overview of the task

Drivers exchange their intentions with other drivers or vulnerable road users (e.g. pedestrians and cyclists) using various non-verbal communication cues in situations where traffic regulations are uncertain. These cues include signaling devices, vehicle behavior, and driver behavior such as eye contact and hand gestures. A large part of on-road communication is informal and likely to be influenced by individual attributes and social norms.

When considering mixed traffic flows of automated (level 2 or above) and non-automated vehicles, automated vehicles are also expected to non-verbally communicate with other road users for safety, security, and traffic efficiency, all of which are considered to be components of social acceptance. Task C firstly investigated current on-road communication between drivers and between drivers and pedestrians (Aim 1). Secondly, measures to functionalize automated vehicles to enable communication were investigated to identify design requirements and recommendations (Aim 2). The effects of the attributes of road users and social norms were also considered (Fig. 14).

4.2. Aim 1

To understand the current situation, on-road communication between drivers and between drivers and pedestrians was observed and measured using multiple methods, including fixed point observation, in-vehicle observation (using an instrumented vehicle), test track experiments, and web-surveys. It was found that vehicle behavior was the primary communication cue when yielding to other road users. Rather than deceleration alone, flashing the headlights was sometimes used as an additional cue to express that the vehicle planned to yield and let another road user go first. It was also found that the driving experience of pedestrians influenced the type of cues they used in communication.

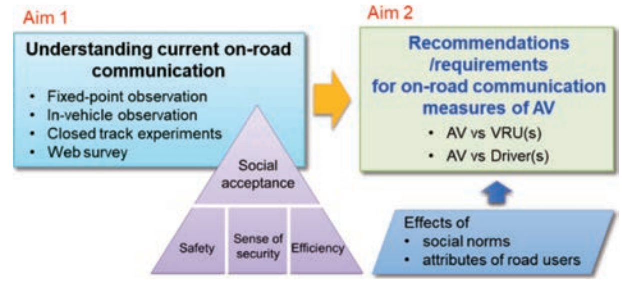

Fig. 14 Approaches to Task C

4.3. Aim 2

4.3.1. Method

Test track experiments were conducted using a simulated automated vehicle with a simulated external HMI. The simulated external HMI was a board with a written message, which was displayed in the car facing towards other road users in front of the vehicle (Fig. 15). Several different written messages were used to investigate the effects of the type of message separated from the effects of the external HMI design. The written messages were large enough for other road users to read.

Fig. 15 Simulated external HMI.

One of the experiments investigated communication between the automated vehicle and a pedestrian. The subject stood by an unsignalized crosswalk waiting to cross the road while the simulated automated vehicle was approaching. The simulated automated vehicle sent communication cues that it planned to yield. These cues were combinations of different written messages (no message, "After you" and "Automated driving") and different deceleration profiles (large deceleration: 25→10 km/h and small deceleration: 25→15 km/h). A total of 14 adults with driving experience (licensed subjects) and 13 adults without driving experience (non-licensed subjects) participated in the experiment. The subject was instructed to press a handheld button when the subject believed the vehicle planned to yield and when the decision was made to start crossing. The subject rated the level of confidence about the decision after pressing the button. In one of the conditions, an additional ordinary (manual) vehicle approached the same crosswalk from the other side of the crosswalk (Fig. 16). The subject's head turning behavior to check the approaching vehicles on both sides was observed (after reading the message and before crossing).

Fig. 16 Experiment with an additional ordinary vehicle.

4.3.2. Some results

(1) Traffic efficiency

The ratio of the subjects who believed that the vehicle planned to yield is shown for each written message in Fig. 17.1 for the large deceleration condition and in Fig. 17.2 for the small deceleration condition. It was found that large deceleration was a clear sign that the vehicle planned to yield. However, whereas small deceleration was not a clear sign that the vehicle planned to yield, the "After you" message compensated for this situation. The "Automated driving" message resulted in lower or no increase in the rate that the subjects believed the vehicle planned to yield. The responses were similar for both subject groups.

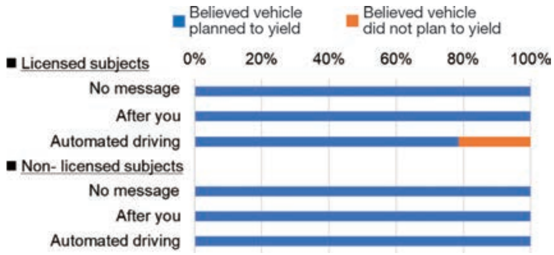

Fig. 17.1 Ratio of the subjects who believed the vehicle planned to yield for each of the written messages under the large deceleration condition.

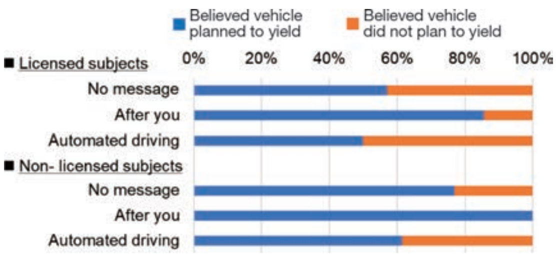

Fig. 17.2 Ratio of the subjects who believed the vehicle planned to yield for each of the written messages under the small deceleration condition.

(2) Sense of security

The subjects' confidence scores are shown in Fig. 18 for each message and small deceleration. It was found that both the "After you" and "Automated driving" messages increased the confidence of the licensed subjects compared to a condition with deceleration only. For the non-licensed subjects, deceleration alone gave more confidence than for the licensed subjects, and the effect of the "After you" message was small. The "Automated driving" message largely decreased confidence.

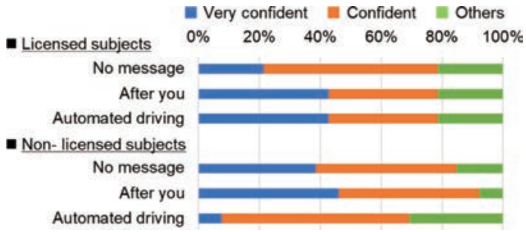

Fig. 18 Scores for the subjects' confidence in their decisions under the small deceleration condition.

(3) Safety

Observation of the subjects' head motions for checking approaching vehicles after reading the message indicated that two of the 27 subjects did not check the other side at all, and that three subjects checked both sides but fewer times than the baseline situation without the automated vehicle. The results implied that the messages might have drawn too much attention from some subjects and degraded their alertness, resulting in unsafe behavior. The behavioral changes did not show any correlation to the subjects' driving experience or the message type. More data were needed to find criteria to minimize negative effects.

4.3.3. Some conclusions

- Vehicle behavior is the primary communication cue to surrounding pedestrians.
- An external HMI can be an additional cue for pedestrians to clarify the intention of an automated vehicle to yield when the vehicle behavior is not clear enough.
- The meaning of an external HMI signal needs to be selected carefully to magnify the positive effects.
- Some external HMI might cause negative safety effects for some pedestrians.
- The driving experience of pedestrians may be a contributor to different responses to the external HMI. The design of an external HMI must be universal.
- Communication between automated vehicles and nearby driver is being investigated in parallel.

5 General Conclusions

The three tasks A, B, and C have been tackled. The results indicated that human factors are major issues, but also suggested some possible solutions to these issues for the development of safe and socially acceptable automotive vehicles. This document only shows a part of the experiments and results that were carried out and omits some studies for all of the three tasks.

Basic Research into Requirements of HMI to Ensure Safety for Automated Driving Systems

Toru Kojima (National Agency for Automobile and Land Transport Technology, National Traffic Safety and Environment Laboratory)

ABSTRACT: While a driver is driving on the highway using a level 2 automated driving system and a system malfunction occurs, control of driving operations are handed over from the system to the driver. This research examines the necessary time margin for the driver to take over manual operation based on experiments conducted with normal drivers using a driving simulator.

1 Purpose of the Research

If a malfunction occurs while a driver is using an SAE level 2 automated driving system on a highway, and it becomes difficult to continue automated driving, the driver has to take over manual driving safely and smoothly. In this case, if communication via the human machine interface (HMI) between the system and driver is not executed rapidly and appropriately, the driver may become confused and unable to drive safely. This research investigated the technical requirements for HMI and the like to ensure the safety of automated driving systems (level 2) based on experiments using a driving simulator (DS) capable of simulating typical driving transitions from the system to the driver.

2 Experimental Method

2.1. Functions of the automated driving system

This research defined a combination of an automatically commanded steering function (ACSF) and adaptive cruise control (ACC) as a level 2 automated driving system for use on a highway under the premise of driver monitoring of the surrounding traffic situation. ACSF is capable of keeping the vehicle in its lane and changing lanes automatically, and ACC is capable of keeping a constant distance between cars. While the system was operating normally, it was not necessary for the driver to operate the steering wheel, accelerator pedal, or brake pedal manually.

2.2. Experimental scenarios

In this research, the following two experimental scenarios were carried out.

2.2.1. Occurrence of malfunction on curve

Figure 1 shows the outline of the experimental scenario. An ACSF malfunction occurs while the car is driving on a curve, requiring the driver to take over steering operation. Figure 2 shows the methods for reducing steering torque when a malfunction occurs. In case 1, steering torque is reduced to 0 Nm suddenly, and in case 2, steering torque is reduced to 0 Nm gradually. Table 1 shows the time from the start of the malfunction warning until the system stops. Table 1 also shows the condition of button operation at certain time intervals. Button operation was carried out as a task to investigate how effectively drivers can maintain concentration while using the level 2 automated driving system.

Fig. 1 Outline of experimental scenario (driving on curve)

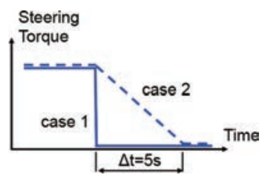

Fig. 2 Methods of reducing steering torque

Table 1 Combinations of experimental conditions

Method of reducing steering torque	Time from start of malfunction warning until system stop			Operation of the button for every certain time interval
	0[s]	2[s]	4[s]	
case 1	Conducted	Conducted	Conducted	Non operation
	Conducted	-	-	1 min. interval
	Conducted	-	-	5 min. interval
case 2	Conducted*	-	-	Non operation

*Steering torque was reduced gradually just after occurrence of a malfunction.

2.2.2. Occurrence of malfunction while changing lanes

Figure 3 shows the outline of the experimental scenario. An ACSF malfunction occurs while the car is changing lanes, requiring the driver to take over steering operation. Figure 4 shows the definition of "lane change time and Table 2 shows the combinations of the lane change time and the time from the start of the malfunction warning until the system stops.

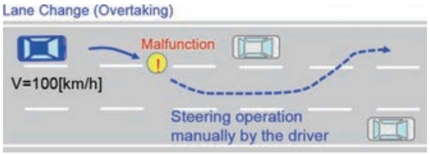

Fig. 3 Outline of experimental scenario (changing lanes)

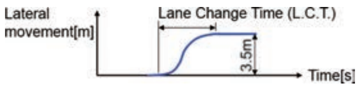

Fig.4 Definition of lane change time

Table 2 Combinations of experimental conditions

Lane Change Time (L.C.T.)	Time from start of malfunction warning until system stop	
	0[s]	2[s]
3[s]	Conducted	-
6[s]	Conducted	Conducted

・Method of reducing steering torque was conducted by "case 1" shown in fig.2.
・Task of button operation for every certain time interval was not conducted.

2.3. Other experimental conditions

Tables 3 and 4 show the running times of the scenarios in the DS, as well as the number of times of driving on the curve and the number of overtaking maneuvers that were performed before a malfunction occurs. In this experiment, several different running times were applied to avoid creating expectation of the event by the experimental participants.

Table 3 Scenario running times and number of operations (2.2.1.)

		short	long		
Approximate time of experimental scenario		4[min.]	25[min.]	30[min.]	35[min.]
The number of running on the curve*	R300(left)	0[time]	5[times]	6[times]	7[times]
	R500(left)	1[time]	5[times]	6[times]	7[times]
	R800(right)	1[time]	10[times]	12[times]	14[times]
The number of overtaking*		3[times]	15[times]	18[times]	21[times]

*While the system operates normally.

Table 4 Scenario running times and number of operations (2.2.2.)

		short	long		
Approximate time of experimental scenario		4[min.]	26[min.]	32[mjn.]	39[min.]
The number of running on the curve*	R300(left)	0[time]	0[time]	0[time]	0[time]
	R500(left)	1[time]	8[times]	10[times]	12[times]
	R800(right)	1[time]	8[times]	10[times]	12[times]
The number of overtaking*		3[times]	24[times]	30[times]	36[times]

*While the system operates normally.

In this experiment, visual information on a display and an acoustic signal from a speaker were used as the HMI.

Twenty-five non-elderly persons (ages: from 20s to 50s) and five elderly persons (ages: from 65s to 70s) who frequently drive participated in the experiments. When using the automated driving system, they kept their hands off the steering wheel until they recognized a warning about a system malfunction. The participants were also asked to look forward and confirm the behavior of the car.

Each person participated in all the experimental conditions shown in Tables 1 and 2.

Figure 5 shows photographs of the DS that was used in the experiment. This DS uses an actual passenger car body, and has several motion devices that simulate the motions of the car. The steering wheel of the DS turns automatically following the vehicle course.

Fig. 5 External view and driver's seat of DS

3 Experiment Results

3.1. Occurrence of malfunction while driving on curve

3.1.1. Condition: no button operation at certain intervals

Figure 6 shows the response time in each experimental condition until the driver held the steering wheel after a malfunction warning was shown. The average reaction time including the standard deviation was from 1.0 to 1.3 seconds, and no statistical difference was found. Figure 7 shows the maximum deviation of the right front wheel in each experimental condition (a positive value indicates departure from the lane). For case 1 (0[s] later stop), a maximum deviation of 3.2 meters, including the standard deviation, was observed, and a statistical difference was found compared to the other three experimental conditions. No statistical difference was found in the other three conditions.

These experimental results suggest that the system should maintain the steering torque for driving around the curve for at least 2 seconds after the system shows a malfunction warning to the driver. In contrast, the experimental results of case 2 (0[s] later stop) suggest that reducing steering torque gradually is an effective, way of maintaining the time margin.

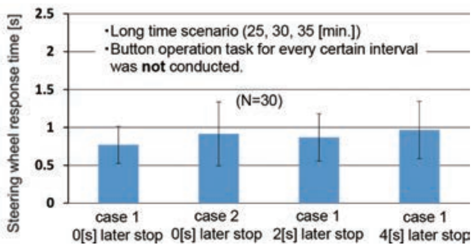

Fig. 6 Comparison of steering wheel response time

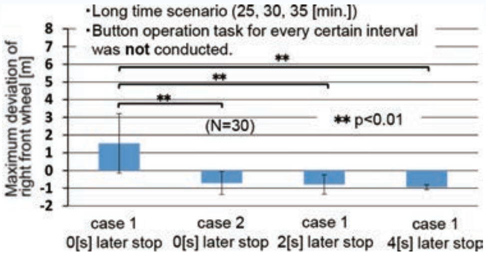

Fig. 7 Comparison of maximum deviation of right front wheel

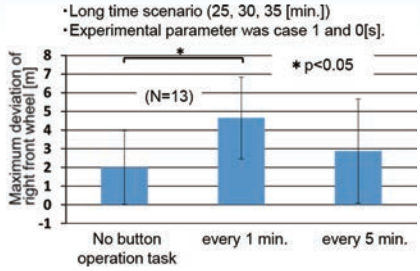

Fig. 10 Comparison of maximum deviation of right front wheel

3.1.2. Condition of button operation at certain intervals

Figure 8 shows the rates of button misoperation after showing a malfunction warning. When the interval condition was set to every 1 minute, 13 drivers recognized the warning as a button operation signal by mistake. Under the 5-minute interval condition, 3 drivers recognized the warning as a button operation signal by mistake. Figure 9 compares the response time until the driver held the steering wheel after the malfunction warning was shown in the case of 13 drivers. Under the 1-minute interval condition, the average reaction time, including the standard deviation increased by around 1 second compared to when there was no button operation task. This is a statistically significant difference. Figure 10 compares the maximum deviation of the right front wheel for the same 13 drivers. Under the 1-minute interval, the maximum deviation, including the standard deviation, increased by around 3 meters compared to when there was no button operation task, which is also a statistically significant difference.

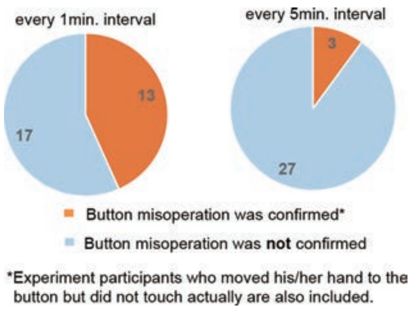

Fig. 8 Comparison of number of button misoperations

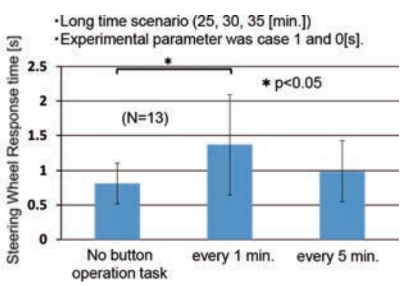

Fig. 9 Comparison of steering wheel response time

3.2. Occurrence of malfunction while changing lanes

Figure 11 shows the response time under each experimental condition until the driver held the steering wheel after the malfunction warning was shown. When the lane change time was 6[s] (2[s] later stop), the reaction time was longer than in the other two cases, which is a statistically significant difference. Figure 12 shows the maximum deviation of the right front wheel in each experimental condition. When the lane change time was 3[s] (0[s] later stop), a maximum deviation of around 1 meter, including the standard deviation, was observed. This is a statistically significant difference compared to the other three experimental conditions. In contrast, no departure from the lane was observed under the other experimental conditions (lane change time: 6s).

These experimental results suggest that the system should continue steering control for at least 2 seconds after the system shows a malfunction warning to the driver, the same as the result described in Section of 3.1. above. However, the experimental results with a lane change time of 6[s] (0[s] later stop) suggest that taking a slightly longer time to change lanes under normal conditions is an effective way of maintaining the time margin.

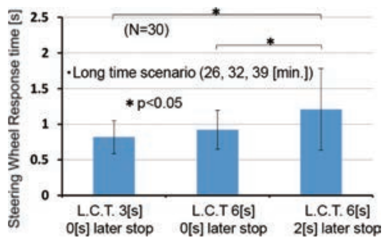

Fig. 11 Comparison of steering wheel response time

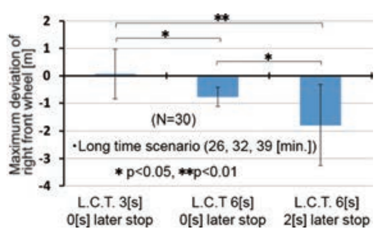

Fig. 12 Comparison of maximum deviation of right front wheel

4 Conclusion

According to the results of the experiments described above, when a system malfunction occurs and the driver takes over manual driving, around 2 seconds may be regarded as the necessary time margin for a safe takeover operation in the case of a level 2 automated driving system. In addition, gradually stopping the steering control after the start of the warning, and carrying out lane changes over around 6 seconds under normal conditions were found to be effective ways of maintaining the time margin.

References

(1) SAE: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems, J3016-201401(2014)
(2) Cabinet Office, Government of Japan: SIP Automated Driving System's Research & Development plan(2016)

Outline of Cybersecurity

Takashi Imai (President, Toyota InfoTechnology Center Co., Ltd.)

1 Trends in Vehicle Cybersecurity

1.1. Advances in vehicles

As vehicles become increasingly equipped with multiple electronic control units (ECUs), these ECUs—which have specific features and purposes—are connected via a controller area network (CAN). It is necessary for advances in vehicles to provide safe and comfortable mobility, as well as support for basic car functions (e.g. accelerating, steering and braking), and this is realized by having communication links with each ECU. Recently, it is common for vehicles to communicate with the outside world through wireless communications; mobile networks, dedicated short range communications (DSRC), Wi-Fi, Bluetooth or other meas. As a result, vehicle cooperative functions using external communications have dramatically improved.

1.2. Trends in Vehicle Cybersecurity

As wireless communications are coming to play a more important role in vehicles with advances in automated driving technologies, the risks presented by cracking and black-hat hacking have to be considered more carefully from the perspective of vehicle cybersecurity. In fact, hacking has become increasingly sophisticated year by year. In 2013, there was a report that certain vehicles were controlled by connecting a wire to the vehicle network to inject vehicle control commands. In 2015, the first remote hacking via cellular communications was reported in America. Exploiting vulnerabilities in the internal vehicle network and devices, the hackers sent unauthorized commands and thus remotely controlled its steering, brakes, and transmission, all from a laptop. Thereafter, hacking cases have been reported every year in both wired and wireless networks. Hacking over wireless networks, especially, leaves a lot of cars widely vulnerable to the threat of a remote attack. With the spread of connected vehicles and tools that access vehicle networks, it is becoming easier to make attacks. Therefore, it is necessary to ensure that vehicles are protected from cracking and black-hat hacking, and clear cybersecurity is required. In addition, significant concern and cost is required in developing the safety and security of vehicles with automated driving technologies. Furthermore, there is high demand for a cybersecurity evaluation and secure design process.

2 Trends in the Automotive Industry

2.1. Strategies of the Automotive Industry

The difficulties of developing cybersecurity for vehicles are: 1) to address security challenges for customers and passengers, a concern that is different from those of the IT industry, 2) to deal with malicious intent (i.e. cybersecurity), which is a change for automakers that used to focus on accidental failure from the viewpoint of function safety, 3) the long lifecycle of vehicles. These tasks cannot be achieved through competition. The automotive industry as whole has to closely collaborate on these issues as much as possible. Currently, the following organizations have a specific role:

- JAMA – Industry Principles (Planning and Operation)
- JSAE – Standardization (Requirements)
- JasPar – Standard Technologies (Design)

Moreover, in terms of international relationships:

- JAMA cooperates with United Nations WP.29
- JSAE cooperates with the ISO and SAE
- Jaspar cooperates with Autosar

2.2. Trend in Legislation

The United Nations WP.29 has decided that the guidelines on cybersecurity and data protection for vehicles with automatic driving technologies will come into effect in 2020. They require warning drivers and a safety controller for the vehicle when the vehicle detects a cyberattack. The ISO and SAE have been working together to define a structured process to ensure cybersecurity and ISO/SAE 21434, a world-first joint standard by the ISO and SAE, will be released in 2020.

2.3. Auto-ISAC

Meanwhile, in America, Alliance of Automobile Manufactures (AAM) established Auto-ISAC (Automotive Information Sharing and Analysis Center) in 2016, in response to the above mentioned cases (cf. Section 1.2). Auto-ISAC is to share the most up-to-date information on vehicle cyberthreats for vehicle devices and networks among the automotive industry. One year later, Auto-ISAC was also established in Japan under JAMA.

3 Study of Cybersecurity by SIP-adus

3.1. Scope of Study for Research and Development Scenarios by Sub-Working Group

Prior to the start of the study, we, all entities involved in vehicle cybersecurity in Japan, reached an agreement with respect to the basic on-board system architecture for vehicles as part of a consensus with the automotive industry in order to clarify the scope of the study. Thereafter, our objective was determined as the study of cybersecurity inside vehicles to achieve industry and international standards. Meanwhile, data center security is being assessed by SIP- Cybersecurity for Critical Infrastructure.

3.2. Overview of 4-Year Plan for Sub-Working Group

- Construct a common type of system modeling for automotive driving technologies
- Develop security requirements via threat analysis
- Develop evaluation environments and standardize evaluation methods
- Study the simplification of signatures for V2X communications and standardize the relevant methods

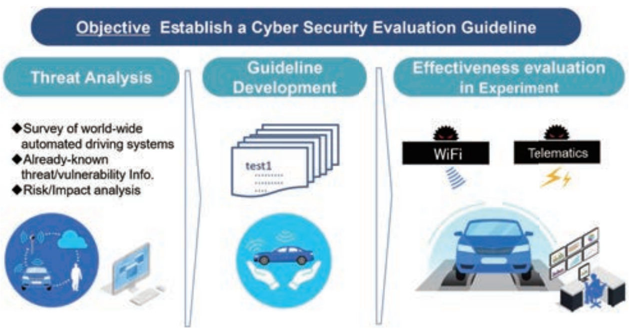

Fig. 1 Objective Establish a Cyber Security Evaluation Guideline

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Formulation of a Comprehensive Threat Model for Automated Driving Systems Including External Vehicular Attacks such as V2X and the Establishment of an Attack Evaluation Method through Telecommunication

Ken Okuyama (PwC Consulting LLC)

ABSTRACT: Information used as the foundation for automated driving systems is expected to be obtained from external networks, which could cause cybersecurity issues that did not exist in conventional cars. In this project, the activities related to automated driving/connected cars were researched, categorized and organized on a factual basis to derive a common model for automated driving systems and formulate a comprehensive threat model for automated driving systems. In addition, an information security evaluation method was defined and issued as a draft to serve as a guideline for the overall assessment of V shape vehicle development models.

1 Project Overview

The basis of automated driving systems, information such as high definition map data and data on vehicles, pedestrians, road infrastructure and so on, is expected to be obtained primarily from external networks. Such information will be transferred to vehicle control/information devices used for vehicle control in the automated driving system. This could lead to cybersecurity issues that did not exist in conventional cars. In order to resolve these issues, the Cross-ministerial Strategic Innovation Promotion Program (SIP), Automated Driving System/Large Scale Field Operational Test, Information Security Field Operational Test conducted threat research/analysis on cybersecurity threats related to automated driving, established cybersecurity evaluation methods/protocols at the vehicular level aimed towards international standardization, and planned to conduct technical research through black box testing of the vehicle systems provided from participants in the field operational test.

2 Formulation of Comprehensive Threat Model

2.1. Objectives and Scope

The objective of the project is to formulate a comprehensive threat model of attacks that could come from sources external to the vehicle, such as V2X, and to establish public consensus on the cybersecurity of automated driving vehicles.

The formulation of the comprehensive threat model was conducted in two phases. The first phase consisted of research on a common model of automated driving systems. The activities by automotive manufacturers, suppliers, and IT companies related to automated driving/connected cars were researched, categorized and organized on a factual basis. The second phase listed threats from sources outside the vehicle, such as V2X, against the common model, evaluated the impact of each threat item, and conducted research on countermeasures for highly critical threats, reflecting any changes to the evaluation guidelines developed as necessary.

2.2. Research Approach

Threat analysis research was conducted in two phases: Research on a common model for automated driving systems, and Research on a comprehensive thread model.

2.3. Research on Common Model for Automated Driving Systems

In this phase, services and features related to automated driving systems were listed and, for each feature, an assumed system architecture was developed and taken into consideration to identify a common model for automated driving systems.

2.3.1. Listing Services and Features Related to Automated Driving

As a first step, all services and features related to automated driving systems were listed. Research targeting 16 automotive manufacturers, 4 automotive component manufacturers and 24 IT companies that develop automated vehicles was conducted on services related to automated driving as well as the features required to enable such services.

The list of services and features identified through the research is as follows:

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Driving/parking assistance: distant control, lane control, lane control (ITS cooperative), platooning, automated driving, automated driving (ITS cooperative), parking environment display, automated parking, automated parking (smartphone cooperative)

Safe driving assistance: emergency braking, pedestrian detection (V2P), danger alert (ITC cooperative)

Fuel saving driving assistance

Remote vehicle control: door locking/unlocking, charging control, charging control (AI voice recognition), air conditioner control, air conditioner control (AI voice recognition), restart engine/unable steering lock release

Failure detection: failure detection

Navigation: route search, operator service

Entertainment: calendar/email syncing, social media, Wi-Fi spots, other applications

2.3.2. Assumed System architecture for Each Feature

Along with the list of services and features related to automated driving presented in Subsection 2.3.1, assumed system architectures for each features were developed. In this process, leading companies in development of various automated driving vehicle models were selected, and a desk study was conducted based on information made public by each companies. A series of expert interviews was then conducted to review the developed assumed system architecture.

2.3.3. Definition of a Common Model for Automated Driving Systems

In this project, all assumed system architectures for each feature were considered and integrated to identify a common model for automated driving system for threat analysis/research. Expert interviews were conducted for this step as well to review the common model.

The following Figure 1 depicts the common model for automated driving system identified through the threat analysis research.

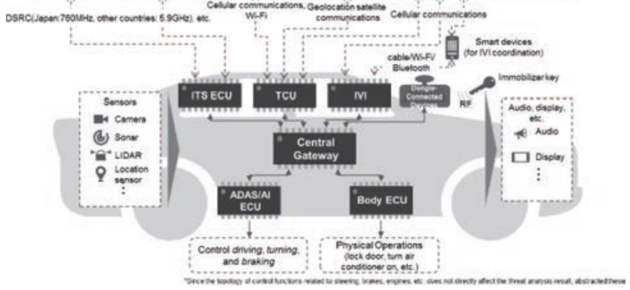

Fig. 1

2.4. Research on Complete Picture of Threats

In this research, threat was defined as "a potential element that causes harm (damage) to the common model of automated driving system". This definition was refined from the definition of Threat in ISO/IEC 27000:2009 to match the purpose of the research.

2.4.1. Listing of Threats against Common Model of Automated Driving Systems

Based on the above definition, the common model and the threat matrix by the World Forum for Harmonization of Vehicle Regulations (WP.29) were compared to extract the target of attack and threat against the common model, which were then categorized based on the CAPEC attack type, and common weakness enumeration (CWE) was used to compare and verify the result of categorization from the viewpoint of defects to create a list of threats against the common model of automated driving systems.

The list created is as follows:

(1) Threats related to vehicle system

Leakage of OEM assets (information), leakage of vehicle owner's personal data, leakage of encryption keys, falsified vehicle control software, unauthorized vehicle ID change, ID spoofing, falsification of driving data, unauthorized vehicle diagnostic data falsification, deletion of log data, falsification of control feature parameters, falsification of charging feature parameters, service disruption due to data flooding, introduction of malware, circumvention of monitoring systems.

(2) Threats related to vehicle physical external interfaces

Sensor spoofing, communication data route falsification, virus infection from external media, intrusion from physical external interfaces (USB etc.) sending unauthorized diagnostic message (OBD II etc.)

(3) Threats related to vehicle internal communication channels

Communication interception, unauthorized data access from communication channel, falsification of communication data, falsification of communication feature (e.g. remote keys), data falsification of short range communication/sensors, unintended feature execution due to command injection, falsification/overwriting/deletion/addition of data/code, virus infection from communication channels, sending unauthorized CAN messages, sending unauthorized special messages (e.g. messages only allowed to be sent from OEMs), data input from unreliable source, service disruption due to data flooding, sender spoofing, civil attacks, replay attacks.

(4) Threats related to vehicle external communication channels

Communication channel interception, unauthorized access to data through communication channels, MITM attacks, data/code falsification/overwrite/deletion/addition, data input from unreliable source, sending unauthorized V2X messages, virus infection from communication channel, falsified third party application, disruption of service due to data flooding, black hole attack in V2V communication, civil attack, command injection, replay attack, root compromise.

(5) Threats related to external server

Information leakage due to server intrusion, information leakage due to inappropriate data sharing, server takeover due to server intrusion, DoS attack on server, server destruction due to server intrusion, unauthorized usage of facility

(6)Threats related to update service

Leakage of encryption key for updates, disruption of update/falsification of update program (server/local), injection of unauthorized update data, disruption of authorized update

(7) Threats related to attacks from vehicle (secondary damage)

Transmission of unreliable V2V data, timing attack, sending false emergency information, DoS, attacks from vehicle to other system, transferring unreliable data to infrastructure, DoS against infrastructure, botnet vehicle, DoS against network

(8) Threats related to physical factors

Data loss due to crash or other accident, data loss due to failure in DRM management, data loss due to malfunction of IT component, data leakage due to resale/purchase of vehicle by the owner, OEM data falsification

2.4.2. Identification of a Comprehensive Threat Model for the Automated Driving System Common Model

A framework was developed to evaluate the criticality of the threats extracted. The framework combines the evaluation criteria developed by WP.29 and JSAE to semi-quantify the Threat Impact and the Attack Difficulty to estimate the Threat Criticality.

*Threat Criticality calculation formula:

Threat Impact × Attack Difficulty × Impact of Incident × Information Asset Criticality = Threat Criticality

Table 1

Threat Impact

	Details	Score
Lv 7	Can affect vehicle safety	7
Lv 6	Disrupt Vehicle function	6
Lv 5	SW tampering, change performance	5
Lv 4	SW change (no impact to operation)	4
Lv 3	Compromise Data Integrity	3
Lv 2	Compromise Data Confidentiality	2
Lv 1	Others	1

Attack Difficulty

	Details	Score
H	Require multiple conditions such as escalation of privilege, information collection for successful attack	1
M	Difficulty dependent on system inherent vulnerability	2
L	Easily attackable (No conditions mentioned in "H" are required)	3

Impact of Incident

	Details	Score
H	Impact unspecified number of target	3
M	Impact multiple target but in limited proximity	2
L	Impact limited to single target	1

Information Asset Criticality

	Details	Score
VH	Control Information	4
H	Financial Asset Information	3
M	Privacy Information	2
L	Other Information	1

Threat Criticality

Threat Level	Score
Level III (Critical)	10.0 ~ 7.0
Level II (Warning)	6.9 ~ 4.0
Level I (Alert)	3.9 ~ 0

Using the framework, threat criticality was calculated for each feature that enables automated driving systems.

Of the inherent threats, threats with a criticality score of Level II or higher were extracted and shown in the following table. Countermeasures and responsible parties for each countermeasure were also determined, taking into consideration the countermeasures recommended in WP.29 etc.

Table 2

Level of threat	Level I (Caution)	Level II (Warning)	Level III (Critical)
Score	0 ~ 3.9	4.0 ~ 6.9	7.0 ~ 10.0

Feature		Threat	Threat Severity
1-3	Vehicle Distance Control (V2V)	Accepting information from an unreliable or untrusted source	4.4
		Sending a large number of garbage data to vehicle information system, so that it is unable to provide services in the normal manner	6.7
1-4	Veihicle Platooning (V2V)	Accepting information from an unreliable or untrusted source	4.4
		Sending a large number of garbage data to vehicle information system, so that it is unable to provide services in the normal manner	6.7
1-5	Automated driving(C-ITS)	Accepting information from an unreliable or untrusted source	6.7
		Sending a large number of garbage data to vehicle information system, so that it is unable to provide services in the normal manner	10.0
1-9	Automated parking(Cooperative Smart device)	Attack on back-end server stops it functioning	4.3
		Accepting information from an unreliable or untrusted source	6.7
2-2	Pedestrian detection(V2P)	Accepting information from an unreliable or untrusted source	4.4
		Accepting information from an unreliable or untrusted source	6.7
4-1	OTA	Compromise of over the air software update procedures	10.0
		The software is manipulated before the update process	4.3
5-1	Failure detection	Attack on back-end server stops it functioning	4.3
8-1	Lock/unlock doors remotely	Attack on back-end server stops it functioning	4.3
8-3	Power charge control	Attack on back-end server stops it functioning	4.3
8-4	Power charge control (collaborating with cloud-based AI service)	Attack on back-end server stops it functioning	4.3
8-5	Air conditioner control	Attack on back-end server stops it functioning	4.3
8-6	Air conditioner control (collaborating with cloud-based AI service)	Attack on back-end server stops it functioning	4.3
8-7	Engine restart/steering lock release prohibition	Attack on back-end server stops it functioning	4.3

For threats classified as Level II or above, the necessary vehicle-side countermeasures were included in the Information Security Evaluation Guidelines developed during this project. However, threats described in red text cannot be adequately countered with vehicle-side measures alone and therefore require separate consideration for countermeasures by the responsible party identified in the table.

Refer to Cybersecurity for Critical Infrastructure, separately studied in SIP, for countermeasures by IT service providers.

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The following Figure 2 depicts the threats with a score of 6.0 or above along with a visualization of the common model of automated driving system.

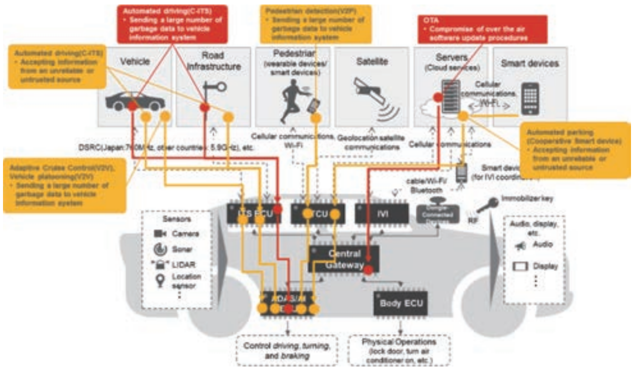

Fig. 2

2.5. Summary of the Approach towards Research on Complete Picture of Threats

In the research, all possible threats were derived by taking into consideration the system architectures related to automated driving system. Threats to be responded with priority were identified using the Criticality Evaluation Framework. Then, responsible actors for the countermeasures were identified and the necessary vehicle-side countermeasures were reflected in the Information Security Evaluation Guidelines.

In the analytic approach in the research, 40 assumed system architectures were identified from 35 features that comprise 12 services. For each system architecture, 72 threats were listed, and the WP.29, CWE and CAPEC categories were combined to identify 3,040 threats in total.

Of the 579 threats with a possibility of occurrence that were derived, considering the system architecture and applying the Criticality Evaluation Framework identified 560 threats classified as Caution, 17 as Warning and 2 as Urgent. The responsible actors were identified and included in the guidelines for the 17 threats classified as Warning and the 2 threats classified as Urgent.

3 Establishment of Information Security Evaluation Method

3.1. Scope of the Evaluation Guideline

The following diagram depicts the function and positioning of the evaluation method established in the guidelines in the V-model vehicle development process.

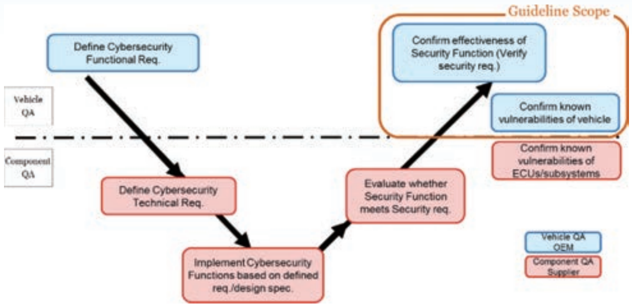

Fig. 3

3.2. Principles of Evaluation Guideline Development

The evaluation items in the guidelines were developed using the following three principles.

The first principle was to identify threats that could potentially materialize with clear evidence in real-world conditions.

Issues identified through attacks (evaluation) from actual attack cases, which are issues that could arise, were used as final evidence for judging whether remediation is necessary.

The second principle was to construct a practical work procedure by focusing on discovering the critical path that can lead to serious issues.

The work procedure for discovering issues was optimized to enable adoption in the vehicle development process by setting the evaluation goal at taking over the feature of privilege over vehicle control, which could inflict the most serious vehicle security issues.

The third principle was to identify items to be added to the evaluation method from the viewpoint of developers, as well as included in the guidelines.

Discovering actual issues from the viewpoint of developers clarified the security measures missing in the evaluation method from that viewpoint, which was also applied to a review of the evaluation guidelines. This will in turn improve the quality of future development activities

3.2.1. Previous Incidents Covered by the Evaluation Items in the Guidelines

The guideline aims to evaluate cybersecurity robustness against cyberattacks performed by actual attackers (hackers). Therefore, the evaluation methods described in the guidelines were used to confirm that past cybersecurity incidents can be prevented.

The list of cybersecurity attack cases targeting automotive manufacturers included in the guidelines is presented below. In actual attacks on the vehicle, techniques such as hardware analysis, firmware extraction, and reverse engineering were used to steal information, and those techniques are included in the evaluation items in the guidelines.

(1) Vulnerability in vehicle infotainment system, Automaker A

A vulnerability that can be exploited by a third party to remotely identify vehicle location or control the vehicle. The vehicle can be remotely controlled by intruding into the vehicle embedded system from an exploited port on cellular network and falsifying the CAN controller firmware.

(2) Vulnerability in vehicle infotainment system, Automaker B

A vulnerability that can be exploited to enable a third party to remotely control the vehicle. The vehicle doors can be unlocked by sending a command from a telematics server set up by the researcher.

(3) Vulnerability in wireless LAN, Automaker C

A vulnerability that can be exploited to enable a third party to remotely control the vehicle. The researcher presented a method to direct the user to the attacking site using a fake Wi-Fi spot. The attack can also be made through the cellular network. In this case, a fake email will be used to direct the user to the attacking site.

(4) Vulnerability in mobile application, Automaker DA vulnerability that can be exploited to enable a third
party to remotely control the settings of the air conditioner and other devices in the vehicle. The air conditioner or security alarm can be remotely controlled by accessing the Wi-Fi spot in the vehicle.

(5) Vulnerability in vehicle infotainment system, Automaker E

Confidential information such as user ID, or password may be leaked due to a leftover development setting that general users do not use.

(6) Vulnerability in connected service authentication, Automaker E

Authentication between smartphones and the server API was not implemented, allowing attackers to control other vehicles if the last five digits of the VIN were identified.

*While this was a vulnerability in the smartphone application, it was used to confirm that the same issue does not exist between the server and vehicles or between smartphones and vehicles.

(7) Vulnerability in connected service, Automaker F

No expiration period was set for the security token used to authenticate the smartphone devices, so in case the token was stolen, the door can be unlocked by an attacker.

*While this was a vulnerability in the smartphone application, confirm that the same issue does not exist between server and vehicle as well as between smartphone and vehicle.

(8) Vulnerability in Telematics Control Unit, Automaker G

A vulnerability that can be exploited to enable a third party to remotely control the vehicle TCU.

(9) Vulnerability in connected service, Automaker H

A vulnerability that can be exploited to enable the execution of unintended code from a USB port inside the vehicle. The vulnerability was used for AVN customization.

*While this was a local attack, it was taken into consideration as an evaluation criterion for anti-reverse engineering performance.

(10) Vulnerability in connected service, Automaker I

A vulnerability that may enable the execution of unintended code from a USB port inside the vehicle. The vulnerability was used for AVN customization.

*While this was a local attack, it was taken into consideration as an evaluation criterion for anti-reverse engineering performance.

3.2.2. Assumed Level of Evaluation Method

Based on the principles in Subsection 3.2, attacker profiles were analyzed in order to ensure the effectiveness and practicality of the evaluation, and to set its scope to cover up to the level of attacker capable of combining existing attack methods to attack new targets and of acquiring and utilizing all commercially available hacking devices.

In terms of attack probability, attacks that require extremely high level of technical expertise, such as inventing new attacks methods by spending multiple years on research and development or utilizing analytics devices that only have a few of their kind in existence, are excluded from the scope.

3.3. Evaluation Method Established

3.3.1. Evaluation Method Overview

The vehicle evaluation was conducted in four phases: Reconnaissance, Intrusion, Escalation of privilege, Actions on Objectives.

3.3.2. Evaluation Method in Reconnaissance Phase

In the Reconnaissance phase, in order to avoid inefficiency of random attacks, prior analysis on system architecture, functional conditions of the target vehicle is conducted to identify the conditions necessary for a successful attack. The analysis involves physical contact with the target vehicle.

This phase has the two following aspects:

(1) Hardware investigation

In the hardware investigation, data extraction is tested against all available interfaces of the target embedded hardware (vehicle, devices, chips) used for data input/output. Once an attempt was successful, the binary file is reverse engineered and the system is analyzed.

(2) Software investigation

In the software investigation, communication interception is attempted against wireless communications (TCU (3G/4G), Wi-Fi, Bluetooth) and related components with the aim of obtaining information necessary for intrusion and/or spoofing.

3.3.3. Evaluation Method in Intrusion Phase

In the Intrusion phase, the information obtained in the previous phase was used to attempt an intrusion through the target wireless interface. From this phase onwards, all attacks are attempted through wireless interfaces.

The attack through a wireless interface is attempted until control of the system console is achieved. Also, the attack patterns are categorized based on the conditions affecting the attack method, such as vehicle network access conditions and driver involvement.

This phase has the four following aspects:
(1) Passive attack with user intervention
(2) Passive attack without user intervention
(3) Active attack exploiting a vulnerability
(4) Active attack using information obtained through communication interception

3.3.4. Evaluation Method in Escalation of Privilege Phase

After a successful intrusion, the necessary privilege is obtained through root compromise, jailbreaking or similar hacks. If the necessary privilege is obtained immediately after intrusion, this process becomes unnecessary. Depending on the error conditions at the time of the arbitrary code execution, a workaround for the cause may be attempted.

This phase has two aspects:
(1) Removal of protection
(2) Escalation of privilege

3.3.5. Evaluation Method in Actions on Objectives Phase

After being successful in the previous phases, simulated attacks are performed to specifically damage the system/user by compromising security characteristics (confidentiality, integrity, availability) and confirm the impact caused by the discovered intrusion path (vulnerability). DoS (Denial of Service) attacks from the external network are also tested even if the intrusion fails.

This phase has four aspects:
(1) Information leakage
(2) Denial of service
(3) Unauthorized operation (related to control)
(4) Unauthorized operation (not related to control)

3.4. Finalizing the Evaluation Method

The evaluation method will be updated to reflect the outcome of the 2018 field operational test. Specifically, the conducting of threat analysis before the initiation of analytics work and the clarifying of criteria for the evaluations as well as the evaluators will be added to the evaluation guidelines.

4 Conclusion

Lastly, based on the outcome of the research, we will summarize our suggestions for stakeholders in relation to the threats and countermeasures each of them should consider.

Automotive manufacturers should implement countermeasures to protect from Service disruption due to data flooding against ITS cooperative automated driving features.

Critical threats that the automotive manufacturers should respond to are included as items in the evaluation guidelines, in the hope that countermeasures will implemented based on the guidelines.

IT service providers should implement countermeasures for Disturbing Update against over-the-air (OTA) features.

The countermeasures are required mainly for information systems, such as servers, which are outside of scope of consideration for this project.

However, the topic is separately studied in Cybersecurity for Critical Infrastructure within SIP, and cooperative action will be important in the future.

The government and related organizations should implement countermeasures for Service disruption due to data flooding against road infrastructure that cooperates with the vehicles.

Currently there is no consideration on cybersecurity measures in coordination with automated driving system and the acceleration of such consideration is required to prepare for the spread automated driving system.

Wearable device and smart device manufacturers should implement countermeasures for Data input from unreliable sources against V2P devices.

Currently there is no consideration on cybersecurity measures in coordination with automated driving system and the acceleration of such consideration is required to prepare for the spread of automated driving systems.

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③ Information Security

Research and Development Project for Automobile Security for Utilization of Information Obtained by Communication such as V2X

Atsushi Ohba, Hiroshi Ito (Japan Automobile Research Institute)

ABSTRACT: Communication technologies such as V2X are expected to be used in cars to acquire dynamic maps and the surrounding environment information necessary for automated driving. Meanwhile, external connectivity through communications makes cybersecurity as an important issue. To derive the requirements for vehicle cybersecurity, a common model of automated driving systems was constructed and used to carry out threat analysis. Furthermore, evaluations and verifications ranging from the component to the vehicle levels were carried out. Based on this, the testbed requirements for vehicle security studies were developed. In addition, methods of simplifying certificate verification were studied.

1 Background

The theft of cars is a major topic in automotive security. In 2010, there was a report[(1)] that the electronic systems in automobiles could be hacked. Since then, cybersecurity in automobiles has been the object of attention. In 2015, it was demonstrated[(2)] that controlling a car remotely via a mobile phone network was possible.

In recent years, various connected services, such as telematics, have become widely available. In addition, connecting smartphones to car infotainment systems is gaining in popularity. Under these circumstances, it is expected that security measures will be treated accordingly as an important issue.

2 Abstract of Research and Developments

In FY 2014, we conducted the "Survey on overseas trends in security technology related to the V2X (Vehicle to X) system in the Cross-ministerial Strategic Innovation Promotion Program (SIP): Automated Driving for Universal Services (adus). In FY 2015 and FY 2016, we conducted Research and development of automobile security for utilization of information obtained by communication such as V2X.

From FY 2017, we conducted the security part of the Research and Demonstration Project for Social Deployment of Highly Automated Driving : Automated Valet Parking Demonstration Experiment toward the Implementation in General Society Project (Development of Evaluation Environment for Safety and Security) , which was supported by the Ministry of Economy, Trade, and Industry (METI).

2.1. Basic Concept Underlying Automotive Security Measures

In an automobile, communication with the outside of the car is the most likely target entry point for a security attack. Automobile wireless communication such as 4G / LTE or V2X, or wired communication such as OBD-II (OBD: on-board diagnostics) are used to communicate with the outside world and can become such an attack vector, as shown in Fig. 1.

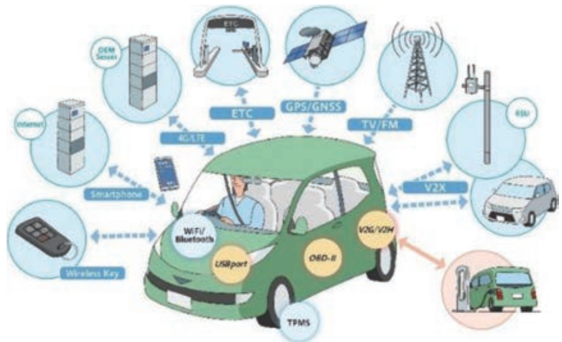

Fig. 1 Example of the External Communications in Vehicles

As in the IT industry, multi-level defense, or defense in depth, is commonly used to protect in-vehicle systems. In this project, a four-layer model was used, as shown in Fig. 2.

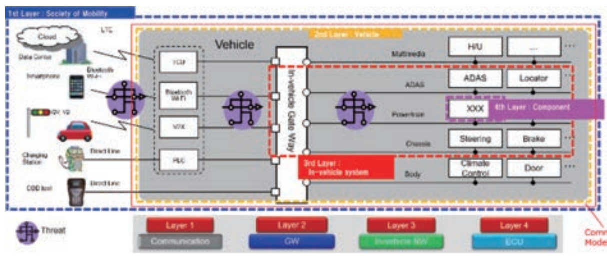

Fig. 2 Layered Structure for Automotive Cybersecurity

The first layer is composed of the entire mobility society including the cloud and other services, the second layer is the whole vehicle, the third layer is composed of the components such as the in-vehicle network below the central gateway, and the fourth layer is the components such as ECUs.

2.2. Research Themes

In this research, the following three themes were set for security at the second layer and below, as shown in Fig. 2:

Threat Analysis, Evaluation Methods and Criteria for Cybersecurity Countermeasures, and Omitting Message Verification in V2X Communication.

3 Threat Analysis

A threat analysis was conducted to clarify what kinds of threats exist, determine what countermeasures (security requirements) are appropriate against the threat, and assess whether the expected risk was sufficiently reduced.

Threat analyses are generally performed based on the following factors: system architecture, use cases (assumed usage examples), threat analysis methods, criteria for risk assessment, and creation of countermeasures (security requirements).

In this section, we surveyed and organized case studies of threat analysis in domestic and overseas projects and set up the in-vehicle system architecture of automobiles used in this research, as shown in Fig. 3.

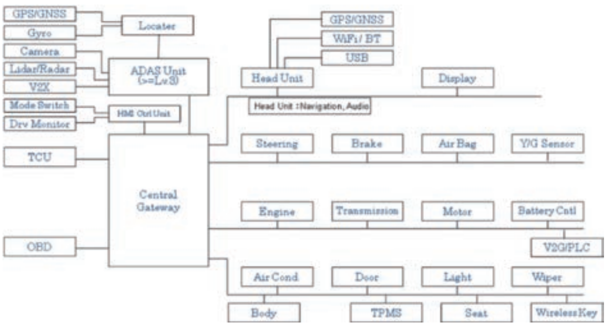

Fig. 3 Assumed In-Vehicle System Architecture

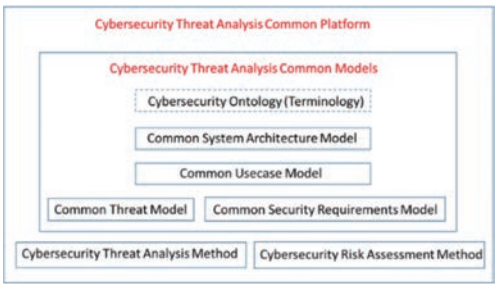

Fig. 4 Threat Analysis Platform

In addition, to conduct the threat analysis, we first built the common platform for threat analysis shown in Fig. 4, as a tool environment that can integrate the various techniques and methodologies necessary to perform threat analysis.

4 Study on Evaluation Methods and Criteria for Cybersecurity Countermeasures

Attack methods using the evaluation systems for the whole vehicle, in-vehicle systems, and components were developed to examine the evaluation technology and criteria concerning vehicle cybersecurity, and the evaluation method was examined.

4.1. Evaluation at the Component and In-Vehicle System Levels

Investigating the evaluation criteria for cybersecurity measures against automotive components (ECUs), requires quantifying the possibility of attack. Focusing on the software update function (reprogramming), which is an important function in the component, a cybersecurity evaluation system was developed. In this research, in order to evaluate the effect of the level of cybersecurity countermeasures, multiple levels of entropy for the random number used for security authentication were set in the evaluation board.

In the METI project, CAN message authentication in the in-vehicle system was also evaluated for vulnerability by setting freshness values (FVs).

Figure 5 shows an example of the system used for these evaluations. The signal coming out of the ECU is acquired and processed with the PC.

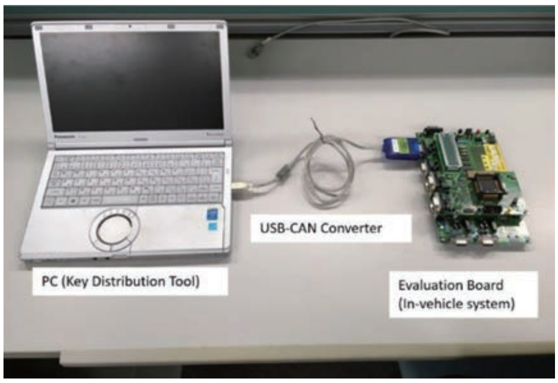

Fig. 5 Evaluation System for Component Level

Using this evaluation system, attacks were performed by various groups. In both cases weak countermeasures, such as low entropy in random number in authentication or a small FV saturation number resulted in successful attacks. These results show that even if measures are taken, improper configurations in an implementation turn out to be vulnerable.

③ Information Security

Research and Development Project for Automobile Security for Utilization of Information Obtained by Communication such as V2X

4.2. Development of Vehicle Simulation System for Security Evaluation

In the security evaluation of in-vehicle systems, actual vehicles are sometimes used, but there are some difficulties in sharing the results of security research, because of differences in architectures and interfaces depending on vehicle type.

Therefore, it is considered effective to construct an evaluation environment that can be commonly used by many organizations and engineers. Here, the vehicle simulation system based on the in-vehicle system architecture in Fig. 3 was developed as an open platform security testbed that can be used to verify and evaluate security technology.

We developed the prototype of the testbed in the SIP project, and the testbed shown in Fig. 6 in the METI project.

The test bed is composed of a telematics control unit (TCU) for communication with the outside world, an in-vehicle gateway (central gateway) receiving communication data from the outside world, ECUs with models for controlling motors, a steering and brakes. These elements simulate the in-car system of a simple electric vehicle (EV). In addition to the TCU, a Wi-Fi connection, as well as a wired communication function equivalent to the OBD-II port, are implemented.

A dedicated CAN port to monitor what is happening inside the evaluation environment is provided, and detected illegal message is displayed.

These functions make cybersecurity research and evaluation of countermeasures on connected cars possible.

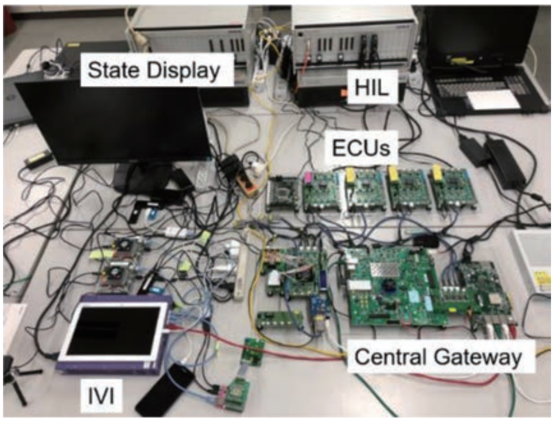

Fig. 6 Security Testbed

5 Study of Omitting Message Verification in V2X Communication

The V2X communications being put into practical use in Europe and the United States, all messages are signed in order to prevent spoofing or other tampering. Basically, all messages must be verified. However, since the signature verification processing requires a relatively long computation time, the messages can not all be processed in the V2X on-board unit when many cars are around and thus many messages are received.

In order to deal with this problem, a Verify-on-Demand scheme (VD scheme) has been proposed as a verification omitting scheme in the United States. In this article, we proposed a message verification scheme with priority that can deal with advanced DoS attacks better than the VD scheme.

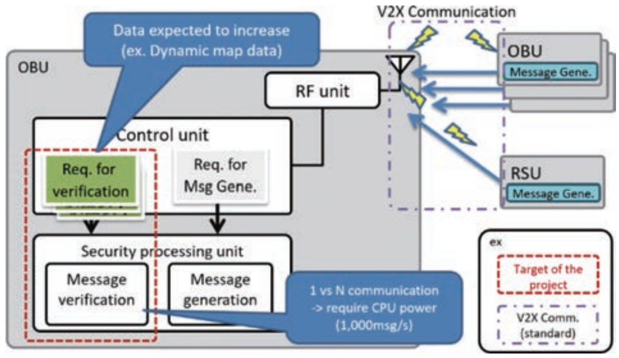

Fig. 7 Message Verification Scheme for V2X in OBU

A virtual environment was constructed to verify the effectiveness of each scheme. As a result of the evaluation, the prioritized message verification scheme showed higher tolerance than the VD scheme against advanced DoS attacks. Both schemes exhibited low tolerance to DoS attacks focused on filter conditions and algorithm.

6 Conclusion

In the research project, we assessed the three themes of threat analysis, security evaluation technology, and omitting signature verification in V2X communication.

For threat analysis, we set up an in-vehicle system architecture to analyze and develop a common platform as a tool for efficient threat analysis.

For security evaluation technology, we built component-level / in-vehicle system level evaluation systems, and verified the susceptibility to attacks when a vulnerability existed. Also, we developed a simulated vehicle system for security evaluations.

For the omission of message verification, we proposed a new message verification scheme with priority, and showed its effectiveness.

References

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II Development of Basic Technologies to Reduce Traffic Accident Fatalities and Congestion, and Initiatives to Raise Social Acceptance

Development of Core Technology for Reducing Traffic Accident Fatalities and Traffic Congestion, and Creating Social Acceptance of Automated Driving

Hiroyuki Kanemitsu (Toyota Motor Corporation)

1 Introduction

This chapter describes mainly the results of studies related to the reduction of traffic accident fatalities. The numerical target of the Japanese government is to reduce the annual number of traffic accident fatalities to fewer than 2,500 by 2020. The use of automated and connected technologies is considered a prerequisite for achieving this target. This article presents an overview of these studies.

2 Traffic Accident Analysis

The study presented here analyzed Japanese traffic accidents over five years. First, it identified common accident types that cause many fatalities each year. Next, it integrated similar accident types into a pattern. The results of this integration defined more than 200 patterns. These patterns can be considered as representative of traffic accidents in Japan. Analyzing these patterns every year can reveal increasing or decreasing trends for the number of fatalities of each pattern. As a result, it was revealed that accident patterns involving collisions between pedestrians and vehicles are not showing a decrease in fatalities.

3 Vehicle and Pedestrian Communication Systems

Accident analysis found that the main cause of vehicle and pedestrian accidents was recognition error. Therefore, the study presented in this section describes technologies that use communication systems to assist the recognition of pedestrians. The main system is a direct communication system between vehicles and pedestrians. Both pedestrians and vehicles are equipped with a small device that functions as a communication and positioning system. These devices exchange their position, speed, and direction to enable mutual recognition. The key technologies of this vehicle-to-pedestrian (V2P) system relate to pedestrian positioning and estimation of pedestrian states. This study realized these technologies by eliminating GPS multi-path errors and implementing pedestrian dead-reckoning using map technology. The effectiveness of these technologies was verified in field operation tests. Under another approach, a new infrastructure sensor for detecting pedestrians and a system that provides detected information from infrastructure to vehicles were studied. Moreover, another study provided high-definition moving pictures for the front visual field of the vehicle for the development of in-vehicle sensors.

4 Simulations

The presented study describes some simulation technologies. Its efforts focused on the development of a simulation system capable of estimating traffic accidents using automated and connected technologies. This simulation technology uses a multi-agent system capable of showing many independent agents as drivers, pedestrians, and other traffic participants. The agent can implement individual recognition, decisions, and operations based on models derived from experimental data. Here, traffic accidents occur in cyberspace by some error in agent behavior. This simulation system was used to calculate the potential reduction in accidents due to the effects of V2P systems. Moreover, each vehicle in the cyberspace has its own emissions model. The emissions model changes in accordance with the behavior of the vehicle depending on the use of automated and connected technology. The simulation system can observe the amount of CO_2 emissions for the various models. Therefore, it can calculate the potential reduction in CO_2 emissions achieved by these technologies.

5 Impact Assessment

The presented study reviews the impact of automated driving technologies on society and industry by drawing a future vision utilizing several automated driving systems. It also considers specific issues about future society and public reception.

6 Conclusion

The multi-agent simulation system described in this study is capable of calculating the numbers of accidents and observing the negative effects of automated driving systems on trust and so on by creating appropriate agent behavior models. This simulator is regarded as a promising means of estimating the effects of various technologies.

Pedestrian Safety Support Using V2P Communication Technology

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Tatsuhiko Hirabayashi (KDDI Research, Inc.)

ABSTRACT: Pedestrians and cyclists account for almost half of traffic accident fatalities. To achieve the national goal of reducing traffic fatalities to 2,500 or less by the year 2020, it is critical to establish a vehicle-to-pedestrian (V2P) communication system that can help to prevent collisions by exchanging position data between pedestrians and vehicles. This research establishes the fundamental technologies for a V2P communication system. Furthermore, we have created prototypes of the pedestrian terminal and the in-vehicle terminal for experiments and verified their effectiveness.

1 Overview

In 2017, the number of traffic accident fatalities was 3,694. Pedestrians (36.5%) and cyclists (13%) account for almost half (49.5%) of this number[1]. There is an urgent need to take measures to prevent traffic accidents involving pedestrians and cyclists. V2P communication systems are being research and developed with the aim of preventing collisions by exchanging position data between pedestrians and approaching vehicles.

In this research, we developed two types of technologies: direct communication technology using a newly developed pedestrian terminal capable of 760 MHz communication (the ARIB STD-T109) with an in-vehicle system, and technology using mobile phone networks.

Because technology using conventional mobile phone networks has a communication delay of up to 10 seconds, this can be used to notify pedestrians in cases where there is longer than 10 seconds before a predicted collision. In contrast, direct communication technology should be adopted in cases where the response time is less than 10 seconds. The results are presented below.

2 Direct Communication Technology

With direct communication technology, the pedestrian terminal and in-vehicle terminal communicate directly with each other using 760 MHz ARIB STD-T109 communication, by broadcasting their own position data (latitude and longitude), speed, and moving direction. Both terminals estimate the future paths and predict a collision when these paths overlap. When a collision is predicted both terminals issue alerts. Figure 1 shows an overview of direct V2P communication.

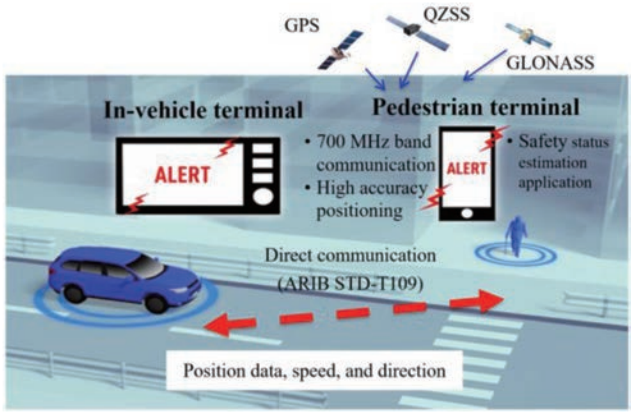

Fig. 1 Overview of V2P communication

2.1. Range of Support

This system only supports people (pedestrians and drivers) by issuing alerts via the V2P communication system. Support for automatic vehicle control systems (e.g., automatic emergency braking (AEB)) is beyond the scope of this research. Although the main beneficiaries of the system are pedestrians, driver support is also discussed. The following sections describe the selected scenarios in which support is required and those in which support is not required.

2.1.1. Scenarios Requiring Support

To focus on high-priority scenarios, we first analyzed historical data of traffic accident fatalities involving pedestrians, and then selected the top ten scenarios with the highest fatality rate by referring to an existing research report[2]. By combining patterns occurring at the same location and under similar situations, the five scenarios shown in Fig. 2 were finally selected as the scenarios in which pedestrians require safety support.

① Initiatives to Reduce Pedestrian Accidents

Pedestrian Safety Support Using V2P Communication Technology

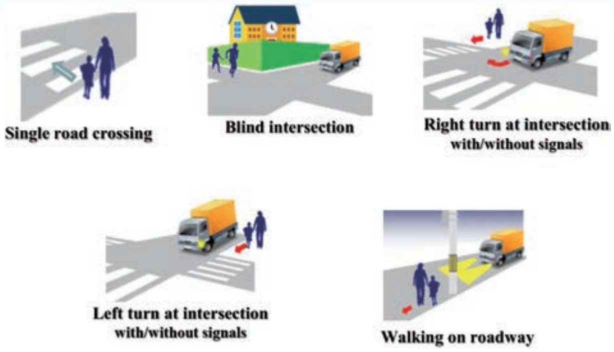

Fig. 2 Scenarios requiring support

Notifications are known to be more effective when issued on multiple levels (e.g., by providing information, warnings, and then alerts) depending on the time to collision (TTC).

The timing to start providing pedestrian support was determined by referring to the results of a monitor evaluation described in the survey report on requirements for vehicle-to-pedestrian communication[3]. The timing to start providing driver support was determined by referring to ASV4[4]. However, we determined that cases when the TTC is less than two seconds should be handled by automatic vehicle control (e.g., AEB), and our system does not provide support for such cases. The cases in which our system provides support are defined in Table 1, where information provision, warnings, and alerts are adopted as the multiple support levels up to a TTC of two seconds.

Table 1 Support timing

	TTC (time to collision)	
	Pedestrian support	Driver support
Alert	Less than 2.0 seconds	Less than 2.0 seconds
Warning	6.5 – 2.0 seconds before	3.7 – 2.0 seconds before
Information	10 - 6.5 seconds before	6.0 – 3.7 seconds before

2.1.2. Scenarios not Requiring Support

Support is not required when the pedestrian is in a safe location. To define such scenarios, we first considered life patterns showing what people spend most time doing during the day. Referring to a survey report on how Japanese people spend their time[5], we selected two scenarios in which safety support is not required (inside a building and inside a vehicle).

In addition, we selected three other scenarios in which support is not required, considering their relationship to the scenarios defined as requiring support: on a sidewalk, on a pedestrian overpass, and on/under an overpass. In total, we selected five scenarios not requiring support, as shown in Fig. 3.

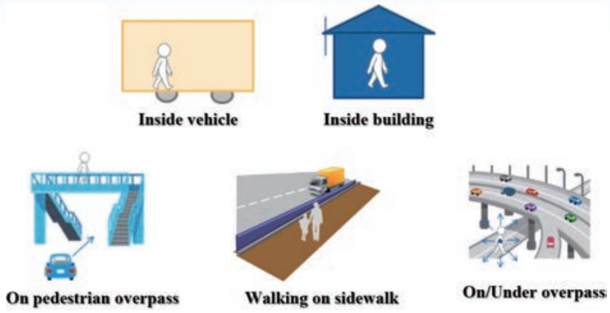

Fig. 3 Scenarios not requiring support

2.2. Performance Target

We set a performance target for our V2P communication system considering the scenarios defined as requiring or not requiring support. Based on the guidelines provided by the system commercialization working group (WG), the target was defined using two values: a correct support operation rate of 80% or higher for scenarios requiring support and a false support operation rate of 20% or less for scenarios not requiring support. We conducted our study based on these target values.

2.3. Research Plan

A viable V2P communication system requires three fundamental technologies: (1) accurate pedestrian positioning, (2) advanced risk prediction technology that can provide appropriate support even if some pedestrian positioning error occurs, and (3) a communication protocol that launches direct communication only when necessary to reduce power consumption. We have developed all these technologies as described in Fig. 4. It is planned to conduct an extensive field test with ordinary users, consisting of five vehicles and twenty pedestrians, during the final year (FY2018) of the project. To confirm the effectiveness of the system, we created and provided prototypes of the in-vehicle and pedestrian terminals with improved communication distance and battery duration performance.

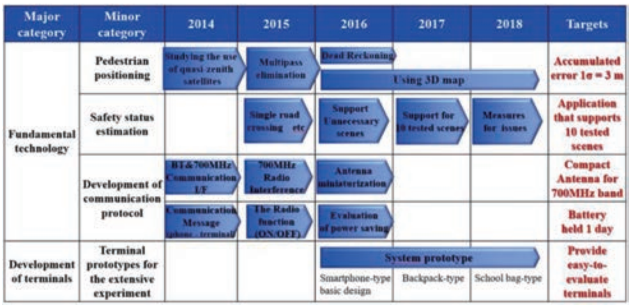

Fig. 4 Research plan

2.4. Pedestrian Positioning

To achieve 80% or higher correct support operation rate, the target pedestrian positioning error was assumed to be around 3 m considering the standard width of a road. In addition, to facilitate stable positioning in business districts, we tested integrated positioning using GNSS and sensors, as well as 3D map positioning using an accurate 3D map.

2.4.1. Integrated Positioning

In addition to satellite positioning with GNSS, we developed the following technologies to improve GNSS: An integrated positioning system also incorporating direction and speed detection using Doppler frequency deviations, and automated navigation for relative positioning using pedestrian dead reckoning (PDR) with motion sensors such as acceleration sensors. The process flow of the integrated positioning is shown in Fig. 5.

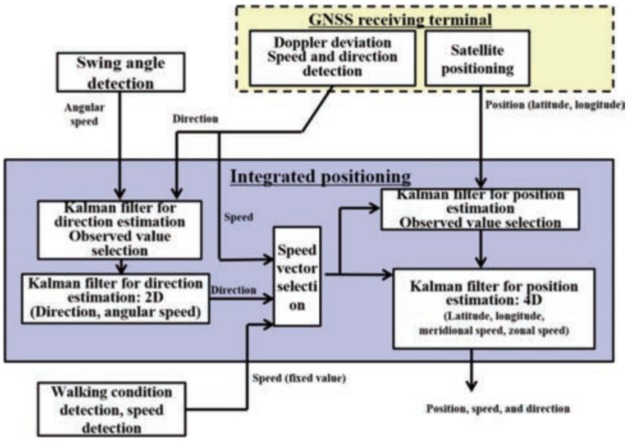

Fig. 5 Integrated positioning

The evaluation result in the Odaiba area, where the planned extensive experiment will also be carried out, is shown in Fig. 6.

In an open area, an accumulated error of 68% corresponds to a horizontal error of 3.3 m, while in an obstructed area, the error becomes 5.9 m. From Fig. 6, one can easily see that the horizontal error is closely related to the field of view. The 3 m level is achieved in an open area in which there are no obvious obstructions. In contrast, the positioning accuracy is worse in the area with obstructions such as railroads, because the field of view is restricted. As it was assumed that the field of view would deteriorate further in an area with high-rise buildings, thereby creating even more severe positioning conditions, we investigated an alternate method that is described in the following section.

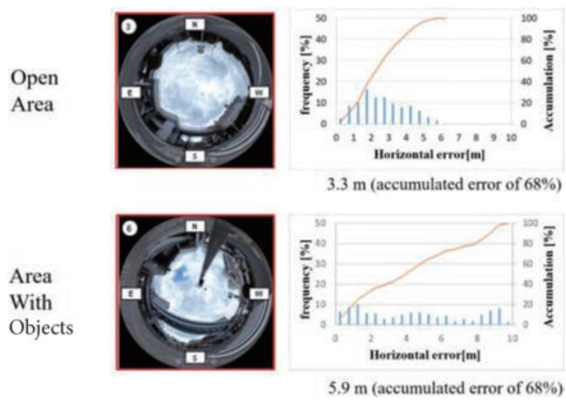

Fig.6. Results of integrated positioning

2.4.2. 3D Map Positioning

We tested a 3D map positioning method with dedicated 3D map data developed by Kamijo Laboratory of the Institute of Industrial Science at the University of Tokyo.

Factors causing positioning errors can be categorized into two groups: satellite related (e.g., orbit data, clock) and transmission path related (e.g., ionospheric delay, tropospheric delay, multipath). Particularly, multipath interference significantly affects positioning accuracy. Errors due to the satellite or delays in the ionosphere or troposphere can be corrected using multiple frequencies and DGPS. However, errors caused by multipath interference are difficult to correct with these measures and a different approach is needed. A technique of improving positioning accuracy by determining whether the received radio wave from a satellite is on a line of sight (LOS) or behind an object (NLOS: non-line of sight) using 3D map data, which includes height data of structures such as buildings, was proposed. LOS/NLOS distinction is achieved with ray tracing. Errors can be distinguished between cases due to interference between the LOS and NLOS signals and cases due to shadowing as the LOS signal is sufficiently small compared to the dominant NLOS signal. We tried to improve positioning accuracy with 3D map positioning for the latter case, in which the effect is greater.

In addition to Odaiba, Shinjuku, Hitotsubashi, and Shinagawa were added for evaluation as areas containing

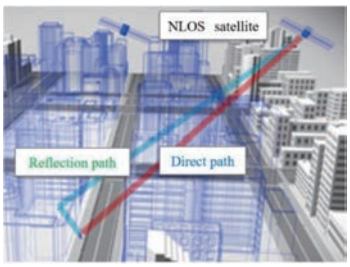

Fig. 7 3D map positioning

cumulative frequency(68%)	Shinjuku	Hitotsubashi	Shinagawa	Odaiba
without 3D Map (GPS, GLONASS, QZSS, Galileo)	10.14	4.05	9.36	5.73
with 3D Map (3D: GPS, GLONASS, QZSS)	5.72	3.68	6.54	5.60

[m]

Fig. 8 Results of 3D map positioning
(Map data source: Google Earth)

high-rise buildings where the conditions are severe. The evaluation results are shown in Fig. 8.

The above results show that the use of a 3D map generally improves accuracy, and that the 3 m error level was achieved at Hitotsubashi. The reason for this improvement was the suitable use of reflected waves, which were a major cause of positioning error previously.

In the future, to achieve a horizontal error of around 3 m in the remaining three areas, we will try to improve positioning accuracy by adding the Galileo Satellite and by applying correction using the reference station data (DGPS).

2.5. Risk Prediction

A risk predication algorithm was developed and applied to each of the five selected scenarios requiring and not requiring support. For the former, the correct support operation rate was examined with respect to the target rate of 80% or higher. For the latter, the false support operation rate was examined, with respect to the target rate of 20% or less.

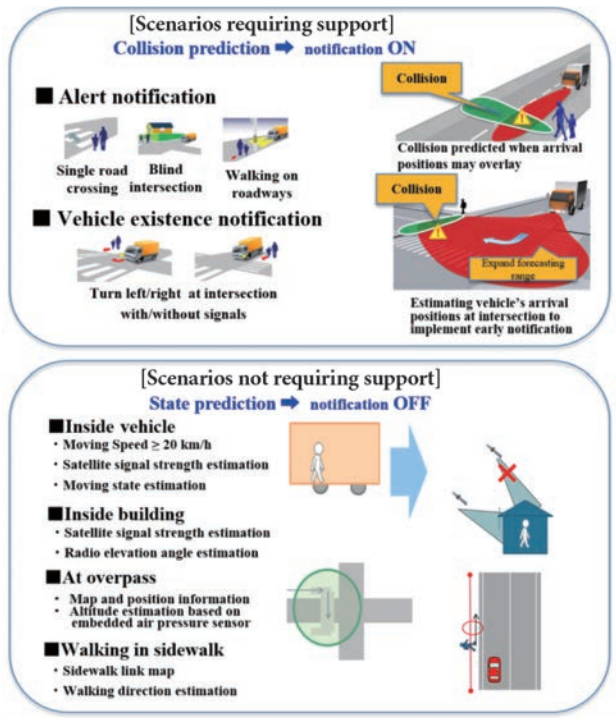

Fig. 9 Risk prediction (support required and not required)

2.5.1. Scenarios Requiring Support

For the scenarios of a single-lane road crossing, blind intersection where a collision may occur, and walking on a roadway, support is provided based on collision prediction. In detail, terminals communicating each other via V2P communication share position, speed, and moving direction data and then predict the possibility of a collision. When a collision is predicted, the terminals alert the pedestrian and the driver respectively. Because errors will occur in the communicated data in a real-world environment, the collision prediction algorithm also takes into account the error when predicting a collision. Collision prediction with errors incorporated is illustrated in Fig. 10.

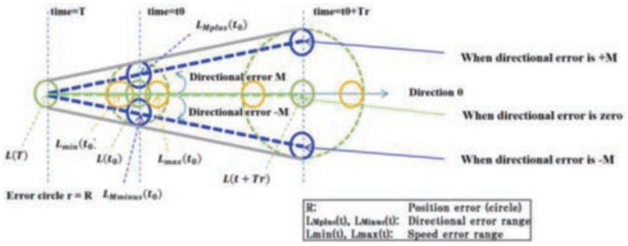

Fig. 10 Collision prediction with errors incorporated

The above collision prediction algorithm is not applicable to the case of a right or left turn at an intersection because it uses linear extrapolation. Large errors in predicted position may delay the provision of correct support.

Hence, a new function to notify the presence of a pedestrian was added for the case of a right/left turn at an intersection. When both the pedestrian and the vehicle are present within an intersection, the prediction range on the vehicle side is expanded to include possible collisions during a right/left turn. Whether a vehicle or a pedestrian is within an intersection is decided based on map data containing the intersection information.

2.5.2. Scenarios not Requiring Support

For the five selected scenarios (inside a vehicle, inside a building, on a pedestrian overpass, on a sidewalk, and on/under an overpass) an algorithm was developed to confirm the safety status and suppress the provision of support information to pedestrians and drivers.

A pedestrian is determined to be inside a vehicle in the case of two patterns. If the moving speed and duration are high and long enough and no step movements are detected, the pedestrian is assumed to be inside a moving vehicle. When the carrier to noise (CN) value of the radio signal from a high elevation angle satellite is poor while no step movements are detected, the pedestrian is assumed to be inside a stopped vehicle. The pedestrian is determined to be inside a building when CN values below a specified threshold continue for a certain duration. The pedestrian is determined to be on or under a pedestrian overpass or overpass based on map data of the sidewalk and roadway networks with the necessary attribute values, and pressure data from pressure sensors.

The pedestrian is determined to be on a sidewalk by first determining whether a sidewalk exists based on map data of the sidewalk and roadway networks. Even if a sidewalk exists, the system also determines whether the pedestrian facing a roadway. No support is provided when a pedestrian is on a sidewalk but is not facing a roadway. Support is necessary if the pedestrian is facing a roadway since the pedestrian may step into the road.

2.6. Communication Protocol for P2V

This section focuses on the technique to reduce mutual coupling with existing systems using adjacent frequency bands, and on the communication protocols for power saving.

2.6.1. Coexistence with existing systems

Radio frequency interference with the 760MHz band cellular system (LTE Band 28) is a problem for the operation of a P2V system using the 760 MHz band. It occurs when antennas for different wireless systems are placed in close proximity (Fig. 11). When these antennas are built into one terminal, it is one of the most severe conditions for operating a P2V system.

Figure 12 shows the proposed mutual coupling reduction structure for ensuring isolation between these radio frequency (RF) front-end circuits. A cellular antenna and P2V communication antenna were built into a unit carried by pedestrians. For cellular multi-input multi-output (MIMO) communication, there are two cellular antennas as the main antenna and aux antenna. Three parasitic elements are installed around these antennas to reduce mutual coupling. Band pass filters for cutting off the signal of the other system are mounted in the RF front-end circuit.

Figure 13 shows the improvement of isolation characteristics between these RF front-end circuits by the proposed method. The red line in the figure is the target value for suppressing interference between these systems[6]. Isolation between these antennas is greatly improved and meets the target value. From the result, it can be seen that the P2V system can coexist with existing systems even under severe conditions, such as being built into one terminal by applying this mutual coupling reduction technique.

2.6.2. Communication Protocol for power saving

In the future, power saving will be necessary to promote the use of the pedestrian terminals. Figure 15 shows the current consumption of the pedestrian terminal. Assuming that the power consumption when sending data (radio function: ON) is 100%, 25% consumption is achieved when the radio function is OFF.

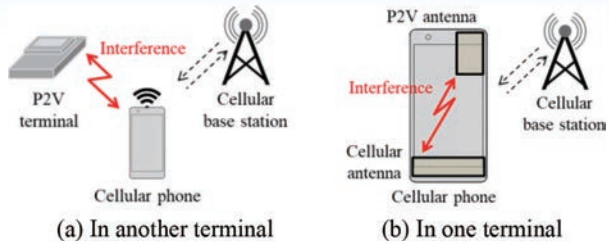

Fig. 11 Condition of radio frequency interference

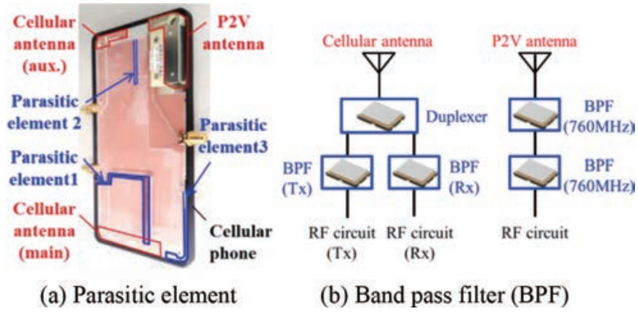

Fig. 12 Mutual coupling reduction technique

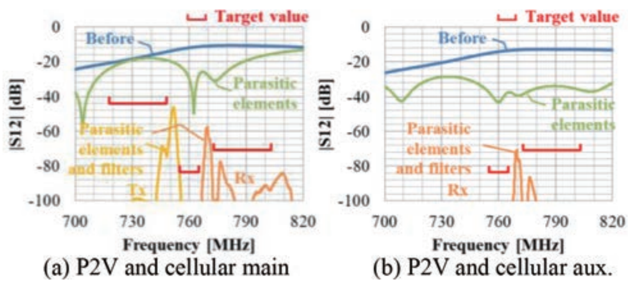

Fig. 13 Isolation between RF front-end circuits (S12)

Next, we examined the life patterns of the target users. According to Traffic Statistics[7], a high proportion of pedestrians involved in traffic accidents are elementary school students. We recorded the behavior of elementary school students, and studied their life patterns based on the National Time Use Survey[5]. It was found that elementary school students spent 8 to 11 hours outside and 1 to 4 hours traveling.

We evaluated the battery specifications by calculating the daily power consumption based on the time that elementary school students spend outside. This time was categorized between scenarios requiring support (i.e., Radio function ON) and scenarios not requiring support (Radio function OFF). Figure 14 compares the current consumption with reference to a smartphone battery.

From the above results, the power consumption of the pedestrian terminal can be suppressed and the terminal can be operated for one day by switching the radio function ON or OFF according to the scenario.

① Initiatives to Reduce Pedestrian Accidents

Pedestrian Safety Support Using V2P Communication Technology

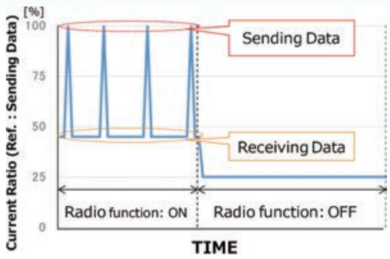

Fig. 14 Comparison of current consumption

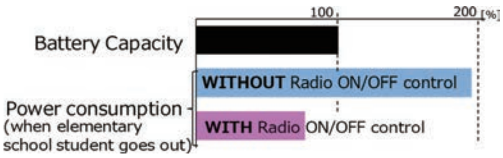

Fig. 15 Comparison of battery capacity and power consumption

2.7. Prototype of Terminals

2.7.1. Overview

To achieve efficient use of the system, the pedestrian terminal and the in-vehicle terminal share the same hardware configuration as illustrated in Fig. 16. They are distinguished by different working modes: pedestrian mode and vehicle mode.

Prototypes were developed considering usability and battery duration performance so that they can be handled easily and tested smoothly.

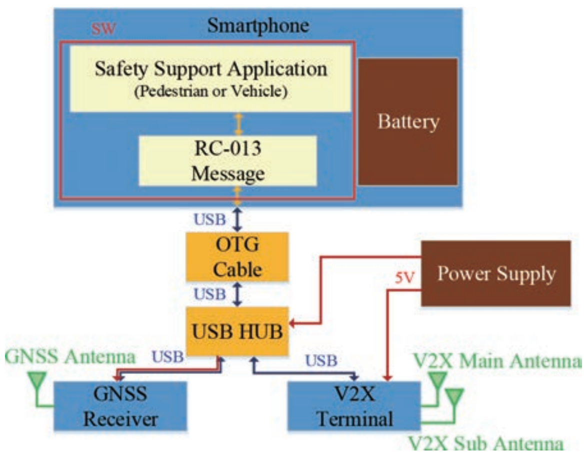

Fig. 16. System configuration of terminal prototypes

Fig.17. Exterior views of terminal prototypes

A backpack capable of holding every piece of equipment was selected as the pedestrian terminal with ease of usability for the tester. Antennas were installed on the backpack. A dedicated antenna for the in-vehicle terminal was selected, and power is supplied to the terminal via a cigarette lighter socket as shown in Fig. 17.

2.7.2. Antenna Design

For the pedestrian terminal, the performance of the antenna should be ensured considering the effect of the body of the pedestrian carrying the backpack.

The antenna selected for the pedestrian terminal requires a ground aluminum plate. Hence, the antenna was installed on a plate, which was placed in the cover pocket of the backpack.

As shown in Fig. 18, the main antenna and the sub antenna for V2X communication were placed at the edge of the ground plate to achieve performance compensation through reception diversity, while maintaining gain in the forward direction when placed in the backpack. A GNSS antenna was placed between the above two V2X antennas. It was also placed on the ground plate and faces the zenith direction.

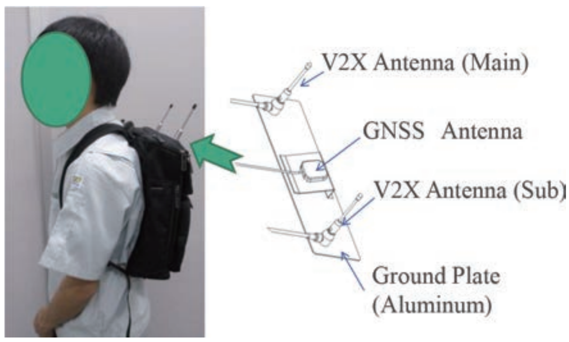

Fig. 18 Antenna configuration of pedestrian terminal

Figure 19 shows the communication distance distribution. It is measured through the antenna gain when the prototype terminal is actually placed on a human body.

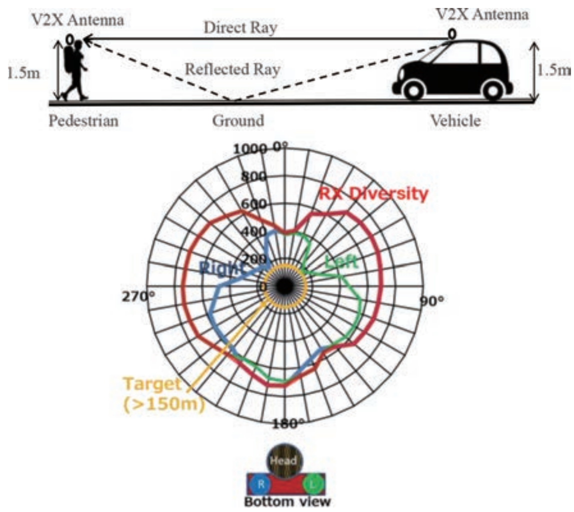

Fig. 19 V2P communication distance

The distance becomes shorter at angles at which the head and the antenna overlap, but it still can reach the target value of 150 m or longer (400 m or longer is achievable with reception diversity).

Figure 20 shows the performance of the GNSS antenna. The antenna gain becomes poor at angles at which the head and the antenna overlap under vertical plane conditions (2), but it is still -6 dBi or greater at angles between -30 and +30 degrees (0 degrees is the zenith position).

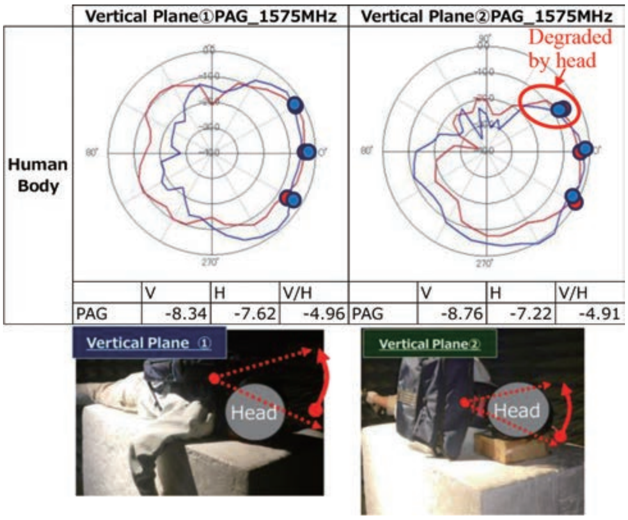

Fig.20. GNSS antenna characteristics

2.7.3. Pre-Test Results

A test was conducted in the Odaiba area before the planned extensive experiment by providing the pedestrian and in-vehicle terminals described in Section 2.7.1. For the scenarios requiring support, alerts below a TTC of two seconds were not counted and were excluded from the research scope. Successful instances of presence notification at the intersection, information provision, and warning/alert provision were counted. The correct support operation rate was calculated based on the ratio of successful instances with respect to the number of tests. In the case of the five scenarios not requiring support, the provision of any support information was counted as a false support operation. The false support operation rate was calculated based on the ratio of false information provision with respect to the number of tests.

Results of the pre-test are shown in Table 2. The main factor that lowered the correct support operation rate was poor adaptation to vehicle speed fluctuations. The main factors that lowered the false support operation rate resulted from the testing method, as well as positioning and moving direction errors. This pre-test verified the effectiveness of the developed technology for improving the V2X communication distance and GNSS accuracy, and no obvious problem occurred.

Fig.21. Pre-test

Table 2 Pre-test results

Scenarios requiring support (Succes Rate≥80%)			Scenarios not requiring support (Failure Rate≤20%)		
No.	Scene	Result	No.	Scene	Result
1	Single road crossing	95%	1	Walking on sidewalk	0%
2	Blind intersection	100%	2	Inside vehicle	0%
3	Right Turn at intersection	100%	3	Inside building	0%
4	Left Turn at intersection	100%	4	On pedestrian overpass	0%
5	Walking on roadway	100%	5	On/Under overpass	0%

3 Mobile Phone Network Utilization Type Technology

Risk prediction was the target for the technology using mobile phone networks. Pedestrian positioning detection in intersections and data collection/broadcasting technology using Web technology for risk prediction are reported below.

3.1. Pedestrian Detection within Intersection

3.1.1. Overview

Safety support measures for pedestrians are desirable. Experiments were carried out using an application to detect pedestrian positioning information and the like within an intersection to help reduce traffic accidents.

3.1.2. Purpose of Experiment

The experiment assumed that highly directional BLE beacons were installed in the vicinity of the traffic lights at a simulated intersection. This experiment aimed to verify and clarify the pedestrian detection areas in the intersection area shown in Fig. 22

① Initiatives to Reduce Pedestrian Accidents

Pedestrian Safety Support Using V2P Communication Technology

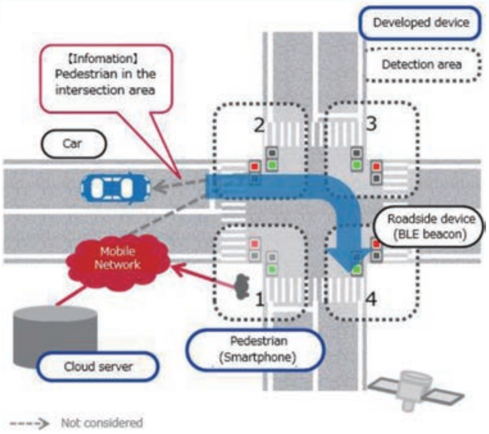

Fig. 22 Illustration of pedestrian detection in intersection area

3.1.3. System Overview

To help reduce traffic accidents, pedestrians in the intersection area are detected by signals received by pedestrians (smart phones) transmitted by the BLE beacons.

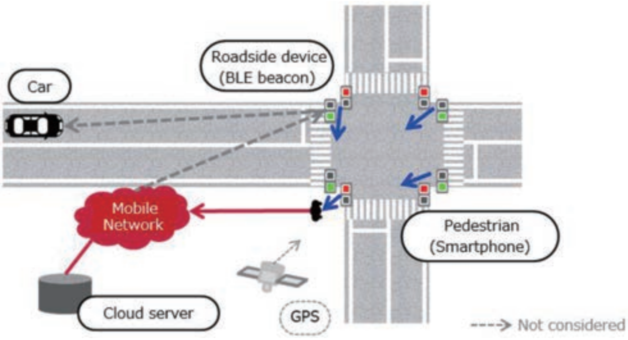

Fig. 23 System overview

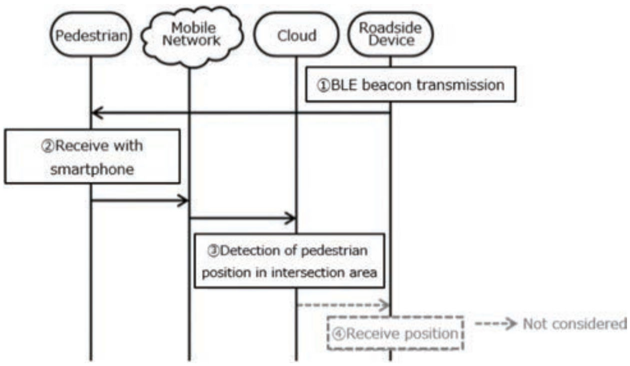

Fig. 24 Sequence Diagram

3.1.4. Consideration

Based on the experimental results, it is possible to identify only the neighboring BLE beacon as shown in Fig. 22 by setting a threshold value. As a result, as shown in Fig. 23, it is possible to detect a pedestrian in the intersection.

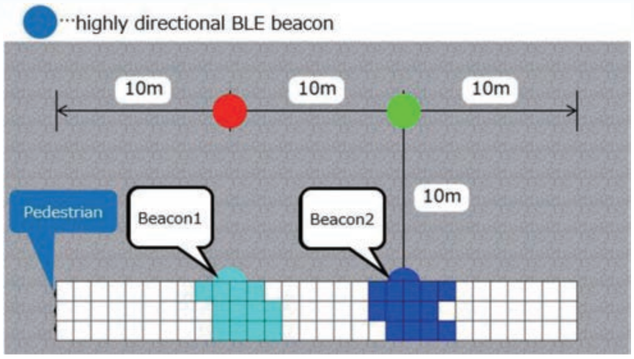

Fig. 25 Pedestrian detection result (threshold: -62 dBm)

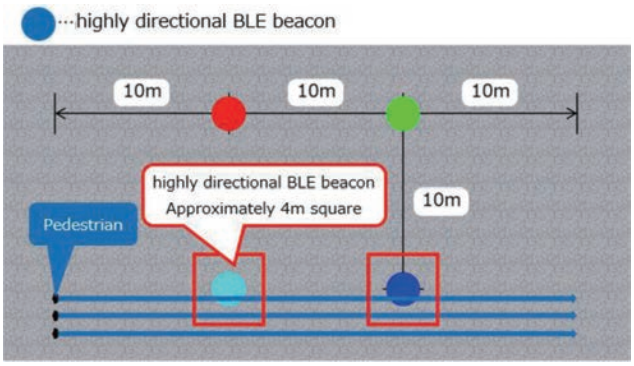

Fig. 26 Detection of pedestrian pool

3.2. Development of Information Collection and Distribution Subsystem using Web Technology over Mobile Networks

3.2.1. Basic Concepts of R&D Subsystems

This approach is a basic way to both collect information from moving vehicles and deliver information to moving vehicles and pedestrians over a mobile cellular network from the standpoint of service coverage. The types of pedestrian-related information for predicting risk and warnings can be summarized as shown in Fig. 27. For example, if you know a crowded crosswalk is ahead, then you can minimize collision risk by turning left a block earlier.

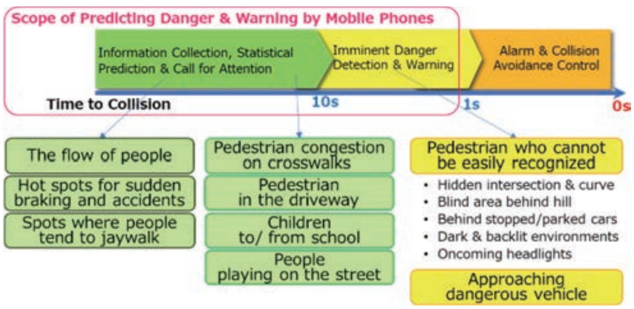

Fig. 27 Pedestrian-related information

The identification of such data, including other vehicle data (e.g. vehicle speed and hard braking) from cars that have already passed through an area on all roads using the

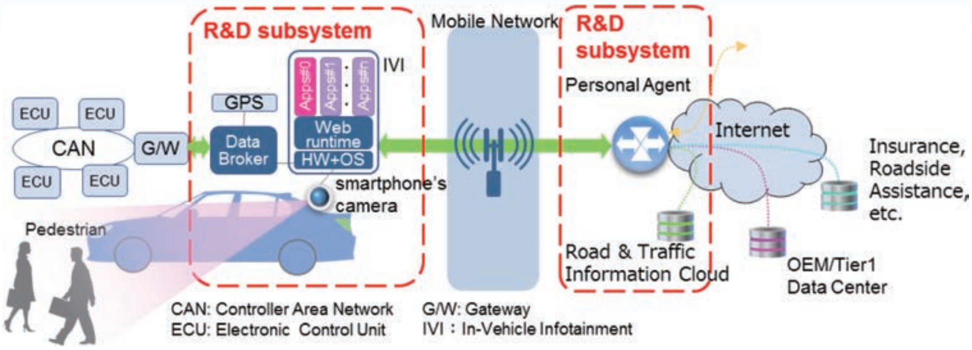

Fig. 28 Overall configuration of mobile network-based web platform for next generation ITS

mobile cellular network has already been proved effective in earlier research.

In contrast, mobile phones and installed OS commonly have built-in WRT (browsers), enabling the universe of compatible devices to be maximized, and minimizing the impact of heterogeneous OS and apps. Rapid and global deployment can be expected by using the Vehicle Web APIs and generic sensor API currently being standardized by W3C. Based on such concepts, we developed a mobile network-based web platform as a part of the next generation ITS as shown in Fig. 28.

3.2.2. Development of Web Runtime

We developed and implemented a W3C Vehicle API to web runtime in two ways: as a native WRT and as a polyfill, enabling us to replicate real-world browser heterogeneity. The native version has been fine-tuned for memory optimization.

3.2.3. Providing Situational Awareness of Pedestrians to Drivers

We developed a subsystem to upload short videos from smartphones to the cloud when the car is stopped or if hard braking occurs (as shown in Fig. 29), as well as a pedestrian-related information API for quantifying pedestrians and detecting sudden hard braking.

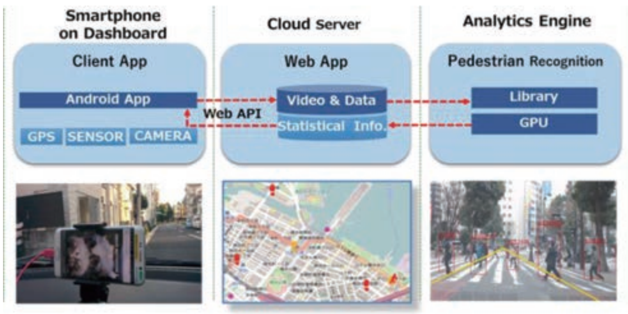

Fig. 29 Pedestrian-related information subsystem

3.2.4. Privacy Protection Measures

Privacy protection strategies will be required in circumstances where the driver can be easily identifiable by some key data or by statistical analysis of the driving context.

An individual may drive a car driven by others. An individual may drive multiple cars and use various apps. To whom does this data belong? Are there exceptions, such as emergencies? Privacy settings will be adjusted each time a different driver drives the car.

To cope with such issues, we have developed what we call a Personal Agent, which is composed of a proxy server for privacy protection and which controls data transfer by managing privacy settings per the preferences of the individual and the situation.

4 Conclusion

As fundamental technologies to achieve a V2P communication system, we developed an accurate positioning technology for pedestrians and an advanced risk prediction technology to predict possible collisions even with some positioning errors. We also developed a communication protocol that launches direct communication only when support is required, thus reducing power consumption. The effectiveness of these technologies was confirmed in a pre-test.

To enable installation of the system in a smart phone, a compact 760 MHz band communication antenna was developed and correlation with cellular antennas was lowered to enable coexistence. We also analyzed the usage scenarios of the pedestrian terminals and confirmed that 760 MHz band communication terminal could run for 24 hours using a smart phone battery.

Pedestrians are detected using BLE beacons at intersections. By detecting pedestrians on the intersection sidewalks, positioning data of the pedestrians can be provided to vehicles.

A mobile network-based web platform has been developed in line with the current W3C activities, enabling the collection of pedestrian-related information including other vehicle data (e.g. vehicle speed and hard braking) from cars that have already passed through an area on all roads, and the provision of alerts.

In addition, a new privacy protection mechanism has been implemented in the above subsystem.

Our aim is to contribute to reducing pedestrian traffic fatalities to zero by popularizing pedestrian terminals. Future work includes examining the feasibility of installing the system on smart phones, studying the commercialization of the system, and improving the terminals.

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Research and Surveys for Enhancing Driving Safety Support Systems (DSSS) Utilizing Radio Waves, and Research and Surveys for Establishing Technology to Provide Vehicle/Pedestrian Detection Information Toward the Realization of Automated Driving

Masafumi Kobayashi (UTMS Society of Japan)

ABSTRACT: To promote the realization of safe driving support and automated driving, it is essential to observe the conditions surrounding the vehicle, including beyond the vehicle's line of sight, and to provide vehicles with traffic information in real time that contributes to the prevention of traffic accidents using roadside sensors. Therefore, research and surveys were conducted into a system that provides vehicles with constantly changing traffic information using radio communication. In fiscal 2014 and 2015, research and surveys were conducted into the enhancement of driving safety support systems (DSSS) promoted by police, and the specifications of low cost versions of the systems, with the aim of implementing the systems across the country. In the following fiscal year of 2016, examinations were carried out with an eye toward the realization of automated driving. These involved the classification of traffic accident types and vehicle behavior at intersections, identification of the types of moving objects (vehicles, pedestrians, bicycles, and the like) that need to be detected, together with the required range of detection to ensure vehicle safety in each accident scenario, followed by an examination of the configuration of roadside sensors required for detection.

1 Purpose of the Research and Surveys

Safe driving support and automated driving systems are expected to have the following effects: (1) reducing traffic accidents, (2) mitigating traffic congestion, (3) reducing environmental burden, (4) providing mobility support for the elderly, and (5) increasing the comfort of driving. In particular, at a time when Japan is becoming a super-aging society, and as a country aiming to achieve the world's safest road traffic environment, realizing the practical use of safe driving support and automated driving systems, and making them widely available at an early stage is of extreme importance. Also, to enable safe driving support and automated driving, it is important to observe the conditions surrounding the vehicle, including beyond the vehicle's line of sight, and to provide vehicles with traffic information in real time that contributes to the prevention of traffic accidents using roadside sensors. Therefore, these research efforts and surveys were designed to enhance driving support systems through the development and verification of a system that provides vehicles with constantly changing traffic information utilizing radio communication with 700 MHz band. This report presents the results of the research and surveys conducted over a period of three years from fiscal 2014 through 2016.

2 Procedure of the Research and Surveys

2.1 Research system

Through the examination, research, and development of intelligent transport systems (ITS), the UTMS Society of Japan promotes ITS for surface roads and pursues standardization activities for domestic and international ITS. From the end of the 1990s, UTMS Japan has promoted research and standardization activities for driving safety support systems (DSSS) with the aim of reducing traffic accidents by supporting driver recognition, judgment, and operation using ITS technologies, to create conditions for comfortable driving. Before launching these research efforts and surveys, a new examination body (the DSSS Enhancement Examination Sub-working Group) was established within the Vehicle-Infrastructure Cooperation Systems Working Group, which has promoted the research and standardization of DSSS.

3 Research Results for Fiscal 2014

Services regarded as having the potential to produce the desired effects on DSSS were developed as shown in Table 1 from the perspective of the types of traffic accidents that occur at intersections or curves with poor visibility due to driver inattention, and from the perspective of the violation of traffic regulations such as traffic signals and road signs.

Table 1 List of safe driving support services

Classification	Name of service
Based on accident types	Crossing collision prevention service
	Right-turn collision prevention service
	Left-turn collision prevention service
	Crossing pedestrian collision prevention service
	Rear-end collision prevention service
Based on the perspective of traffic violations	Signal violation prevention service
	Traffic regulation violation prevention service

For each of the developed services, the functions and operational flow required for each of the components of the infrastructure system, that is, the traffic control center, signal controllers, vehicle-to-infrastructure radio communication devices, as well as roadside equipment including roadside sensors and on-board systems, were compiled in a system definition document. The research also examined communication protocols to establish secure communication between vehicles and roadside infrastructure even in an environment where vehicle-to-vehicle and vehicle-to-infrastructure communications coexist, specifications for the message sets provided to on-board units via vehicle-to-infrastructure communication, and the identification of performance requirements for roadside sensors when using a 79GHz band high-resolution radar. Furthermore, to reduce installation costs for DSSS and promote nationwide implementation and broader coverage, surveys and research were conducted into low-cost versions of DSSS that would be both inexpensive and satisfy the required functions. The following proposed revisions were developed.

(1) Simplification of roadside systems aimed at reducing equipment and construction costs
  - Elimination of the need for infrared beacons that notify the location of points of origin upstream of intersections (Location reference by GPS)
  - Integration of roadside equipment (integration of information relaying and determination devices with ITS radio equipment)

(2) Standardization of management functions of traffic control centers
  - Reduction of the number of central computers supporting DSSS and streamlining through standardized processing
  - Reduction of data preparation costs through revisions to road shape information requirements

(3) Revisions to detection areas to reduce the number of roadside sensors.

Figure 1 shows the proposed architecture reflecting these proposed revisions.

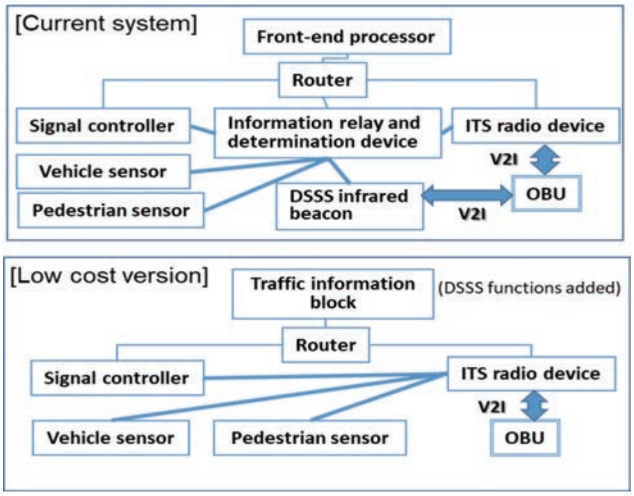


Fig. 1 Proposed revisions to system architecture

5 Research Results for Fiscal 2015

To verify the revisions developed based on the surveys and research into the low cost versions of DSSS conducted in fiscal 2014 (i.e., the revisions to road shape information requirements, revisions to the detection areas of DSSS pedestrian sensors, and revisions to the detection areas of DSSS vehicle sensors), a verification experiment was carried out using roadside systems installed on a test course in fiscal 2014 by the National Police Agency for a research project called "Creation of an internationally open research and development environment" (NPA 6). System acceptance was assessed through a questionnaire survey. Based on the results of the experiment, constraints under which the revisions to the detection areas for pedestrians and vehicle sensors can be applied, such as the range of sight of oncoming traffic from a right-turning vehicle, were defined. Also, with respect to infrastructure maintenance in cases where road shape information was changed due to road improvements or other reasons, which had been an issue for system operation, guidelines relating to the operation and maintenance of road shape information were developed.

6 Research Results for Fiscal 2016

In fiscal 2016, research and surveys for establishing technology to provide vehicle/pedestrian detection information towards the realization of automated driving was conducted. The configuration of the roadside sensors required for detection were examined after classifying traffic accident types and vehicle behavior at intersections and identifying the types of moving objects (vehicles, pedestrians, bicycles, and the like) that need to be detected, together with the required range of detection to ensure vehicle safety in each accident scenario. These efforts also examined a new DSSS for left-turn support using radio communication based on an existing right-turning support system. Functional specifications for a pedestrian recognition (at left turns) enhancement system were examined and a model system was developed for verification. Furthermore, to ensure the operation and management of DSSS, research examined the functions of traffic control centers, and the operation and management of roadside equipment, including security management during the lifecycle of the roadside equipment. This includes the installation of new roadside equipment and the relocation and disposal of existing equipment.

7 Conclusion

This research project, which was carried out over a period of three years from fiscal 2014 through 2016, defined requirements for the enhancement, installation, and widespread deployment of DSSS that provide vehicles with constantly changing traffic information using radio communication. In the future, further research and surveys must be pursued on the basis that this DSSS will evolve into an infrastructure system designed for automated driving.

Development of Practical Roadside Sensor Utilizing Millimeter-Wave Radar Technology

Yoichi Nakagawa (Panasonic Corporation)

ABSTRACT: This article reports the results of a research initiative to apply high-resolution millimeter-wave radar to roadside sensors for the purpose of reducing pedestrian accidents using cooperative driving support. Millimeter-wave radar technology installed at intersections and the like can realize sensing functions, such as the detection of pedestrians and bicycles with high accuracy, regardless of the weather and time. To facilitate the practical adoption of this technology, detection processing software compatible with high-resolution radar has been developed and verified under severe weather conditions such as hard rain and snowstorms. A prototype 79 GHz band millimeter-wave radar system was installed at actual intersections to evaluate the detection performance of crossing pedestrians and so on. This report mainly describes the development of the radar technology and the progress of the public road experiment.

1 High-Resolution Radar Technology

1.1. Summary

We are carrying out a research initiative to apply the latest radar technology to infrastructure systems in consideration of the evolution of millimeter-wave devices and sensor software. Specifically, we are promoting technological development and demonstration experiments with the aim of applying high-resolution millimeter-wave radar to roadside sensors at intersections, assuming the adoption of this system by Intelligent Transport System (ITS) applications such as cooperative driving support[(1)(2)]. In order to provide so-called look-ahead information as driving support, an appropriate wireless communication technology that shares sensor data in real time will be used in addition to sensor technology that accurately measures the speed of approaching vehicles and the position of crossing pedestrians (Fig. 1).

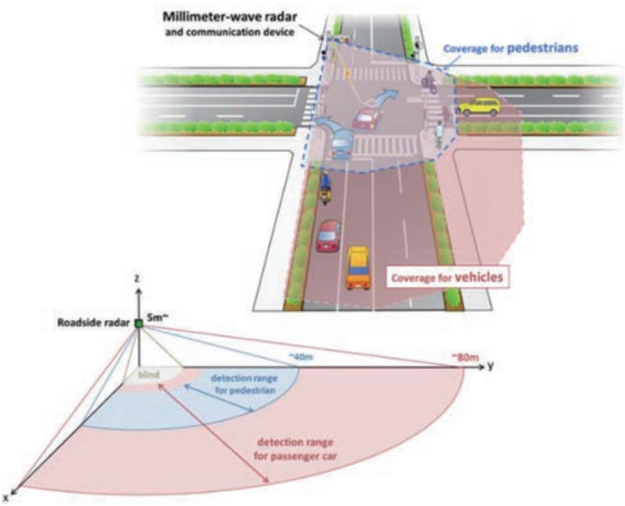


Fig. 1 Coverage of the roadside radar installed at intersection

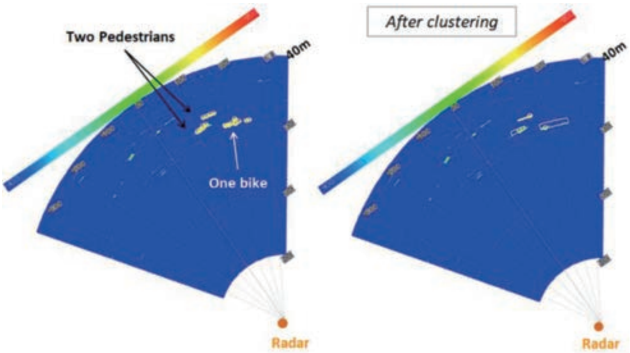
There are growing expectations for spatial imaging using millimeter-wave radar, and short-range wide-angle scanning is becoming a standard function of high-resolution 79 GHz band radar. The maximum effective detection distance of this radar is about 30 to 40 m for pedestrians and about 70 to 100 m for automobiles, depending on the radar cross section (RCS) of the target. A typical planar antenna configuration is capable of detecting the location of a target up to a field of view (FOV) of about 90°. However, this configuration can measure range up to a FOV of 150°. Further, since the usable frequency bandwidth exceeds 1 GHz, the theoretical range resolution is 15 cm or less. Therefore, scattering points existing in the same range bin are reduced, and the angular resolution is effectively improved.

In addition, since a Doppler frequency shift occurs in the echo of a moving target, the velocity of the target can be estimated from the Doppler frequency. When the carrier wave is 79 GHz, the wavelength is about 4 mm. For example, a velocity resolution of 0.1 m/s can be obtained with an observation time of 20 ms. Because of its high range resolution, radar has excellent separation performance for multiple targets that are close to each other and have slight velocity differences. For pedestrian detection, it is possible to analyze the Doppler frequency spread due to the vibration of limbs as a feature value superimposed on the Doppler shift. Indeed, understanding the echo characteristics inherent in such targets has led to the extension of radar detection functions[(3)].

1.2. Radar detection software

Algorithms for realizing millimeter-wave radar detection are generally implemented as software to increase the options of the device. This detection software often includes a filtering block for extracting candidate cells and measured values (range, angle, Doppler frequency, and power) from scan data of mesh-like cells outputted by the radar device, a clustering block for grouping multiple candidate cells for each target, and a tracking block for making time-series data frames correspond with each other. The detection result output depends on the application using the radar system, but includes information such as position, speed, movement trajectory, number of targets, and target type.

In order to improve the effective detection accuracy of a radar system, it is essential to optimize clustering and tracking based on the echo characteristics of targets (Fig. 2). For example, the echoes of vehicles observed with high-resolution radar are separated into a large number of scattering points. Therefore, it is necessary to treat spatially spread candidate cells as part of the same group using the Doppler frequency or the like. Pedestrian detection has low distance dependence when resolving scattered points, but the echo intensity drops discontinuously over time. Therefore, it is necessary to interpolate the measurement position using the preceding and succeeding data frames considering that a pedestrian is an object moving at low speed.



a) Candidate moving cells b) Pedestrian and bike clustered

Fig. 2 Radar data processing to detect targets

The roadside sensor equipment consisted of a millimeter-wave radar device as the sensor unit and an industrial personal computer (PC) as the control unit realizing the applications. When a camera is used as a roadside sensor, the control unit performs both a process to extract the target from the image data, and a process to estimate the distance and the velocity. However, with a radar system, since the distance and the velocity of the target are included in the data generated by the sensor unit, it is possible to suppress the processing and cost requirements of the control unit compared to a camera-based system.

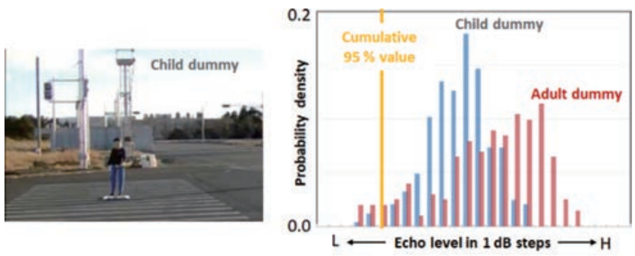
2 Roadside Sensor System

2.1. Basic design

A millimeter-wave radar with the performance and functions described above was installed at the roadside of intersections and used to detect passing pedestrians and vehicles. The radar was installed at intersections to detect pedestrians and measure the traffic flow. This configuration is considered to be applicable to both safety support and signal control systems. Although cameras are generally used to recognize objects, radar can obtain stable accuracy regardless of the weather or time to detect pedestrians and count the number of vehicles.

When this type of roadside sensor is installed, it is necessary to prevent blocking by vehicles in front of the detection target. The height of the traffic signal on which the system is installed is a guide of sensor range. For example, when the installation height is 5 m above the ground and the vertical plane beam width of the millimeter-wave radar is 10 degrees, the effective range coverage for passenger cars is calculated to be about 15 to 75 m. This is because the radio link is designed considering the regulations of 79 GHz band high-resolution radar(4), in which the sensitivity characteristics within the data frame over a period of 100 ms or less is used as an indicator.

Furthermore, since pedestrian echoes have large fluctuations in power and random variations, it is necessary to statistically analyze measurement data and identify its characteristics. Specifically, based on an experiment using standard dummies that can simulate walking, the difference in the RCS of an adult and child is about -4 dB (Fig. 3). When these fluctuation characteristics are represented by 95 % values of cumulative probability, the difference between a passenger car and pedestrian instantaneously becomes as much as -20 dB. Therefore, it was calculated that the detection distance range of pedestrians is about 20 to 40 m, although the actual range depends on the installation conditions of the radar.



a) Setup in test course b) RCS measurement data

Fig. 3 Measurement of pedestrian dummies for link design

2.2. Multiple-radar integration

This section briefly describes the features and functions of a system for installing the radar sensors at the diagonal corners of an intersection to achieve coverage of the entire intersection. This multiple sensor system is an effective way of preventing blockage by large vehicles and complementing the blind areas generated below the sensors. As these multiple sensors must be integrated to detect the positions of targets precisely, the raw data outputted by the radar devices are transmitted and aggregated in real time while ensuring time synchronization.

Cases of crossing pedestrians or bicycles passing through the blind spots of drivers are a cause of accidents at intersections on public roads. A system that simultaneously operates radars installed at the diagonal corners of an intersection can also improve detection accuracy by increasing the scan data samples (Fig. 4). When a vehicle is inside the common area within the intersection, echoes scattered from the front of the vehicle are observed by one radar and scattering from the sides and back are dominant at the others. That is, integration processing is needed to identify data indicating different positions for a target vehicle.

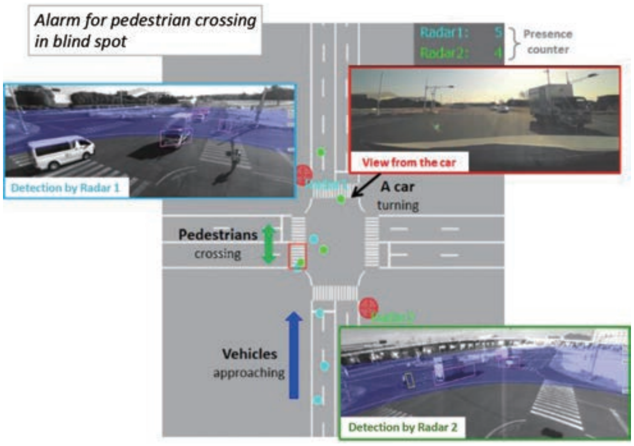


Fig. 4 Verification of simultaneous operation of multiple radars

We have also considered applying this intersection-based radar system for merging support on highways[5]. Often, the merging point of a highway is a place in which it is difficult for a vehicle moving up the lamp and a vehicle traveling on the main lane to detect the presence of each other using onboard sensors. Therefore, it may be possible to realize smooth automated driving by identifying the situation of vehicles on the main lane and that of merging vehicles in real time and transmitting this information to nearby vehicles.

3 Technical Verification under Severe Weather Conditions

3.1. Objective

For radars where stable operation is expected even in bad weather, heavy rainfall is the most severe condition. Even short-range millimeter-wave radar is unable to ignore the influence of attenuating radiating radio waves due to scattering from raindrops during heavy rainfall. In contrast, the attenuation is low during heavy snowfall despite the worsening in visibility. This is because radio waves are absorbed by water and the actual precipitation during snowfall is low, and because snow manifests as ice grains. In other words, the practical adoption of millimeter-wave radar requires technical verification assuming hard rain caused by typhoons or the like.

3.2. Design for heavy rainfall

The attenuation characteristics with respect to the amount of rainfall based on the results of experimental analysis were modeled and reflected in the radio link design of the 79 GHz radar system. Specifically, experimental rainfall data was used to obtain a relational expression concerning rain intensity and attenuation per unit distance. For example, when the line margin for detecting a pedestrian 40 m ahead is designed as +10 dB, it is possible to estimate with a margin of +5 dB at a rainfall intensity of 50 mm/h and 0 dB at 100 mm/h. Alternatively, it is also possible to estimate the effective coverage at a distance of 32 m when a link margin of +10 dB can be secured at a rainfall intensity of 50 mm/h, and 27 m at 100 mm/h in the same way (Fig. 5).

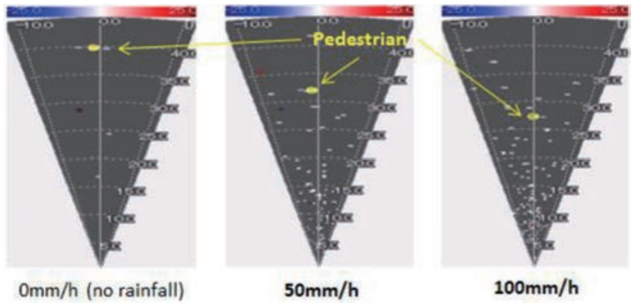


Fig. 5 Pedestrian detection performance in heavy rainfall

To reduce the sensitivity of millimeter-wave radar to echoes scattered by raindrops, it is necessary to optimize the detection threshold in order to determine the existence of the desired targets. In this optimum design, the physical characteristics of randomly generated raindrop echoes are extracted. Here, the characteristic that the received power of the raindrop echoes is inversely proportional to the square of the range is utilized. This characteristic is confirmed by analyzing measured data under heavy rainfall.

Furthermore, to reliably suppress false alarms due to raindrop scattering, the threshold of radar detection, which is a distance function, is adjusted in correspondence with the assumed rain intensity. That is, an adjustment method for uniformly shifting the threshold set in inverse proportion to the square of the range is used. It was confirmed that raindrop sensitivity can be suppressed to 0.1% or less using the rain intensity data at 50 mm/h acquired in the attenuation experiment. However, since this raindrop sensitivity and the desired target detectability have a trade-off relationship, the threshold must be set appropriately according to the system requirements.

3.3. Experiment during snowfall

In cold climates where the amount of snowfall is large, snowstorms sometimes cause poor visibility. Therefore, radar is regarded as potentially particularly effective compared to visible cameras and laser imaging detection and ranging (LiDAR). As described above, robustness during snowfall can be secured relatively easily if radar technology compatible with severe rainfall conditions can be established. This section describes experiment results for a 79 GHz band millimeter-wave radar conducted in a region with heavy snowfall.

In this experiment, a pillar was temporarily installed at the side of a single-lane road and installed with a prototype radar. To detect vehicles traveling behind large-sized vehicles, the installation angle was adjusted so that the vehicles are irradiated from the rear (Fig. 6). Moreover, the measurement accuracy was verified by counting the number of vehicles passing through to the radar detection software.

a) Appearance of prototype b) View from radar position

Fig. 6 Prototype 79 GHz radar experiment

Several consecutive 24 hours of data, including severe weather conditions such as snowstorms, were selected to verify the radar measurement accuracy. Table 1 shows the accuracy verification results (vehicle counting data) for each day with heavy snowfall, including sleet and snowstorms. Although some over-counting and non-counting occurred, a detection accuracy of 99% or more was obtained in both conditions. Furthermore, a functional verification was carried out by extracting all the time periods in which a vehicle was not present for more than two minutes, but no false alarm occurred in either condition.

When analyzed in more detail, cases occurred in which the number of large vehicles was over-counted or two vehicles driving close to each other were counted as one. However, the occurrence of these events is not attributable to weather conditions such as rainfall or snowfall. Suppressing the over-detection of large vehicles has a trade-off relationship with the separation performance of vehicles in proximity with each other. In other words, if parameters are adjusted to suppress excessive detection of trucks or the like, non-detection of multiple vehicles close to other tends to increase. In practice, algorithms and parameters will be optimized to meet the performance requirements required by roadside sensor applications.

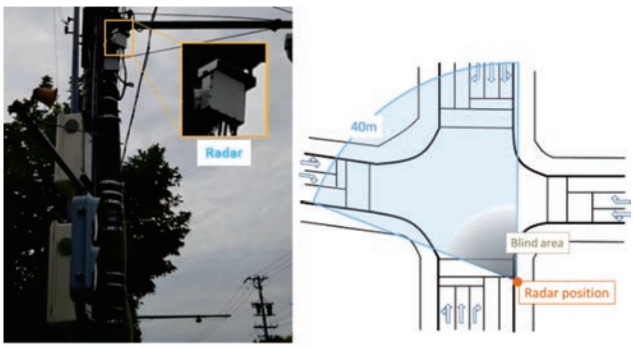
Table 1 Verification of vehicle count accuracy in snow

Weather condition	Number of vehicles	Over-counted	Non-counted	False alarms
Heavy snow (20 cm/day)	4,598	1	1	None
Wet snow & snowstorm	2,930	4	0	None

4 Detection Accuracy Verification on Public roads

An experimental 79 GHz radar system has been installed at an actual public road intersection, and the detection performance of pedestrians on the crosswalks and the measurement of traffic volumes on the roads leading to the intersection were verified. The verification field is the intersection between a single-lane road and a two-lane main road, which is common on Japanese public roads. The traffic volume of this intersection is high despite the narrow road width. Also, because it is located near a subway station, pedestrian and bicycle traffic is high in the morning and evening, when the roads are also crowded.

The experimental system was installed in an existing signal pillar, and consists of a radar unit attached 5 m above the ground and a control PC inside a cabinet. In this verification experiment, the radar device was adjusted to face diagonally across the intersection. Figure 7 shows the relationship between the detection range for pedestrians and each lane, and the radar has a field of view (FOV) on the horizontal plane of 70°. Since the vertical plane beam width of the radar antenna is about 10°, a blind area is present at ground level about 15 m from the radar installation point.



a) Installation of the radar b) Bird's eye view of the

Fig. 7 System configuration for public road experiment

The present system is set to output the scan data at a frame period of 50 ms, the maximum detection distance for a pedestrian is about 40 m, and a passenger car can be detected up to about 80 m. When the detection target is a pedestrian, the power of the echoes fluctuate randomly, so interpolation processing using multiple data frames is required. In general conditions with a walking speed of 1 ms, a moving distance of 20 cm occurs in the processing period of 200 ms. That is, even if the processing is performed in a period corresponding to multiple frames, the influence on positioning accuracy is slight. In addition, in order to avoid a collision, the moving direction of the pedestrian may be also required. In this case, the tracking process for estimating the velocity and trajectory of the target is executed using a time series of coordinate position data sets.

Samples of the evaluation results are shown in Table 2 for a case in which one of the crosswalks shown in Fig. 7 is set as the detection area. When performing interpolation processing using four frames, a detection rate of 95% or more was achieved, and a false alarm rate of about 1% was obtained. The main reason for the occurrence of false alarms is multipath scattering caused by vehicles passing in front of the desired target parallel to the crosswalk. Possible countermeasures include setting an upper velocity limit for pedestrian detection.

Table 2 Detection accuracy for crossing pedestrians

Presence	Time (frame)	Detection	False alarms
Yes	165 s (3300)	95.5%	n/a
No	402 s (8040)	n/a	1.1%

It is necessary to detect pedestrians on crosswalks in drivers' blind spots as a driving support application at intersections. From another viewpoint, for example, in traffic control applications, it is required to measure direction-specific traffic flows at intersections. In Japan, traffic flow on public roads is measured with ultrasonic sensors installed above each lane. Therefore, the total cost of deployment as an infrastructure system could be suppressed if roadside millimeter-wave radar systems installed for driving support can also measure the number of vehicles passing through multiple lanes.

5 Conclusion

As described above, we have carried out research and development for applying the latest millimeter-wave radar technology to the roadside sensors at intersections. Specifically, we implemented clustering technology for scattered echoes obtained by high-resolution radar and verified a roadside sensor system diagonally covering an entire intersection. Moreover, we demonstrated the radar detection function in rainfall exceeding 50 mm/h and during snowstorms. A 79 GHz radar prototype is currently operational at an actual intersection, and we are working to develop technology to improve detection accuracy through long-term data acquisition. In particular, it is expected that a detection rate of 95% or more and a false alarm rate of 1% or less can be achieved with respect to the detection of pedestrians and bicycles.

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Study of Japanese Traffic Accident Patterns for Estimating Effectiveness of ADAS Based on ITARDA Macro Database

Toru Kiuchi, Satoko Ito (Institute for Traffic Accident Research and Data Analysis)

ABSTRACT: In Japan, the authors analyzed accident data using automated driving systems under the auspices of the Cross-ministerial Strategic Innovation Promotion Program (SIP) of the Cabinet Office of the Government of Japan. Based on ITARDA macro data from 2013, 255 SIP accident patterns with three or more fatalities were established and studied for four years. This article describes the background, accident patterning methodology, a pattern sheet sample, analysis of sheets, and some study results using the 255 SIP accident patterns. It also introduces the future plans for these SIP accident patterns in a national accident database.

1 Background

The number of Japanese traffic accident fatalities in 2017 was 3,694, a decrease of 210 from the previous year and the lowest number since 1948 when the National Police Agency started keeping traffic accident statistics.

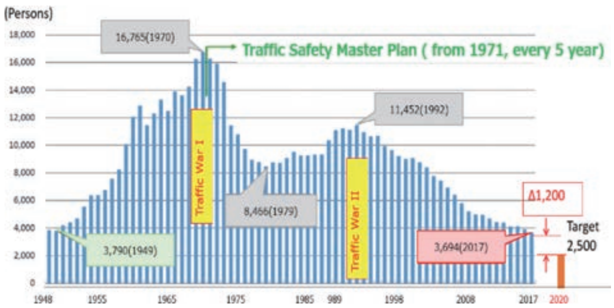

Fig. 1 Trend of traffic accident fatalities in Japan

The Institute of Traffic Accident Research and Data Analysis (ITARDA) was established in 1992 as a public benefit corporation approved by the National Police Agency and the Ministry of Transportation and Construction. It conducts comprehensive and scientific research into traffic accidents from the three standpoints (people, roads, and vehicles), and provides the results of its research to the public and private traffic safety organizations to help them realize safer road traffic. The 10th Traffic Safety Master Plan (in March, 2016) states that "by 2020, the number of traffic accident fatalities should be reduced to 2,500 or less to realize the world's safest road traffic environment." To achieve this goal, it is necessary to reduce the number of traffic accident fatalities by about 1,200 in the remaining three years.

Started with Prime Minister Abe's remarks aiming for world-leading's technologies at the 107th Council for Science, Technology and Innovation (March, 2013), the Cross-ministerial Strategic Innovation Promotion Program (SIP) is being strongly supported by the Japanese government. SIP is promoted beyond the boundaries of the ministries and sectors, and is allocated its own budget, from basic research to completion (practical application/commercialization).

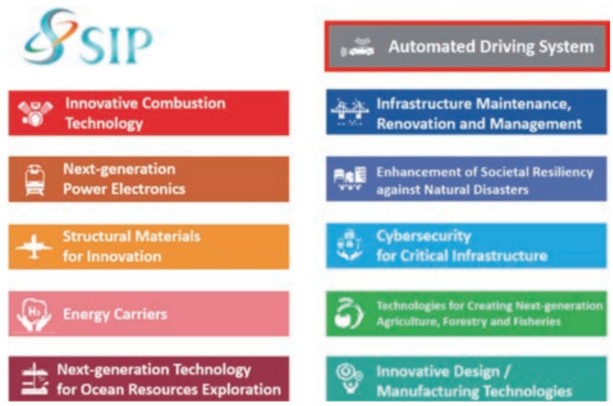

Fig. 2 Eleven projects of SIP

The 11 SIP themes launched in 2014 include one called "Automated Driving System." This theme targets the achievement of national goals such as reducing traffic accidents, the realization and dissemination of automatic driving systems, cooperative development with the Tokyo Metropolitan Government with the 2020 Tokyo Olympics and Paralympic Games as a milestone, the development and demonstration of systems including large-scale demonstration experiments, as well as the development of basic technologies to reduce the number of traffic fatalities and traffic congestion.

ITARDA has been conducting research to help estimate the effect of basic technologies on automated driving systems aiming to reduce the number of traffic accident fatalities. The title of this research is "Analysis of traffic accident patterns using the latest ITARDA macro database," and is part of a survey and study for achieving the national goal of reducing traffic accident fatalities.

This article describes the background, accident patterning methodology, a pattern sheet sample, analysis of sheets, and some study results using the 255 SIP accident patterns.

2 Patterning of ITARDA Macro Data

2.1. Methodology for patterning

In the first year of this SIP research, the ITARDA macro accident database for 2013 was studied and classified using the accident classification items shown in Table 1.

Table1 Items and classifications for patterning

Item	Classification
Type of collision	Head-on, rear-end, crossing, single, vehicle-to-pedestrian, vehicle-to-bicycle, etc.
Primary party	Car, motorcycle, bicycle, pedestrian
Secondary party	Car, motorcycle, bicycle, pedestrian
Type of road	Public road, Expressway
Location	Intersection, near intersection, curve, straight, bridge, tunnel, other
Traffic control	Signal, stop sign, no control
Traveling maneuver	Going straight, turning left, turning right, etc.
Relative position of secondary party	Same direction, opposite direction, right side, left side, other

Table 2 at the bottom of this page shows the numbers of fatalities and patterns classified by combinations of accident types and primary or secondary parties. Changing the threshold of the number of fatalities to five or more, four or more, or three or more increases the number of both fatalities and patterns, as well as the coverage ratio. Consequently, we chose three or more fatalities as the threshold to cover over 80% of the total traffic accident fatalities in 2015. This resulted in 255 SIP patterns.

2.2. Pattern sheet example

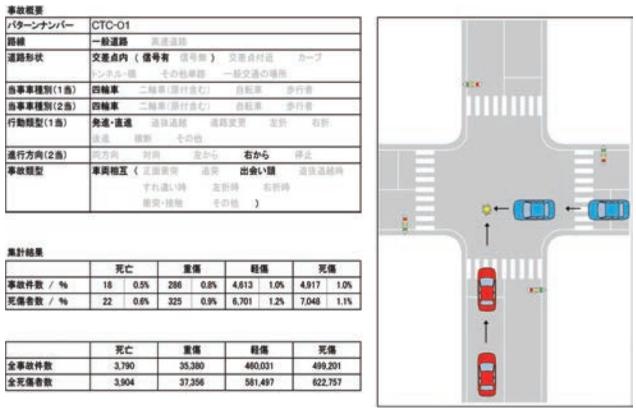

Fig. 3 Example of SIP accident pattern sheet (Japanese only)

Figure 3 shows an example sheet of the 255 SIP patterns. This pattern sheet shows car-to-car crossing accidents at signalized intersections on public road excluding expressway. The secondary party (blue car) is coming from the right side of the primary party (red car). The accident summary table at the top left shows the keywords from the classification items for patterning shown in Table 1. An accident diagram is shown on the right. The middle table shows the number of accidents involving fatal, serious, and minor injuries included in this pattern, and the number of fatalities, seriously injured, and slightly injured occupants.

In addition, the bottom table shows the total number of accidents and casualties for the year as a reference.

Table 2 Numbers of fatalities and patterns, and ratio covered (note: numbers are not revised)

Road type	Accident type	Primary party	Secondary party	Code	Fatlities involved	Fatlities categorized			Numbers of patterns		Ratio covered	
						Fatalities ≥5	Fatalities ≥4	Fatalities ≥3	Fatalities ≥4	Fatalities ≥3	Fatalities ≥4	Fatalities ≥3
Public road	Vehicle to vehicle	Car	Car	CTC	636	546	574	583	25	28	90.3%	91.7%
		Car	Motor cycle	CTM	283	172	196	211	17	22	69.3%	74.6%
		Car	Bicycle	CTB	359	272	276	300	20	28	76.9%	83.6%
		Motor cycle	Car	MTC	204	133	137	140	12	13	67.2%	68.6%
		Motor cycle	Motor cycle	MTM	13	0	0	3	0	1	0.0%	23.1%
		Motor cycle	Bicycle	MTB	8	0	0	3	0	1	0.0%	37.5%
		Bicycle	Car	BTC	132	80	80	89	4	7	60.6%	67.4%
		Bicycle	Motor cycle	BTM	5	0	0	0	0	0	0.0%	0.0%
	Single vehicle	Car	–	SCA	650	501	525	552	38	47	80.8%	84.9%
		Motor cycle	–	SMA	214	120	148	163	18	23	69.2%	76.2%
	Vehicle to pedestrian	Car	Pedestrian	CTP	1297	1143	1143	1173	40	50	88.1%	90.4%
		Motor cycle	Pedestrian	MTP	37	23	23	26	3	4	62.2%	70.3%
		Pedestrian	Car	PTC	126	100	100	106	8	10	79.4%	84.1%
		Pedestrian	Motor cycle	PTM	6	0	0	0	0	0	0.0%	0.0%
Expressway	Vehicle to vehicle	Car	Car	HCTC	95	66	66	72	6	8	69.5%	75.8%
		Car	Motor cycle	HCTM	7	0	0	3	0	1	0.0%	42.9%
		Motor cycle	Car	HNTC	7	0	0	0	0	0	0.0%	0.0%
		Motor cycle	Motor cycle	HMTM	0	0	0	0	0	0	—	—
	Single vehicle	Car	–	HSCA	82	51	63	69	8	10	76.8%	84.1%
		Motor cycle	–	HSMA	18	0	4	4	1	1	22.2%	22.2%
	Vehicle to pedestrian	Car	Pedestrian	HCTP	14	0	0	3	0	1	0.0%	21.4%
		Motor cycle	Pedestrian	HMTP	0	0	0	0	0	0	—	—
Total					4193	3207	3335	3500	200	255	76.3%	80.0%

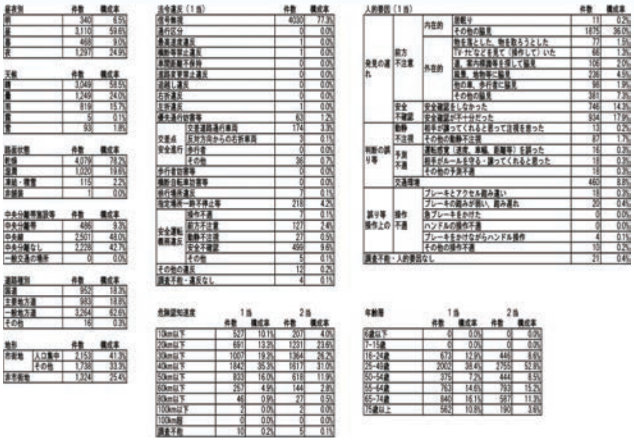

Fig. 4 Example of detailed SIP analysis sheet (Japanese only)

Detailed analysis was carried out for each pattern and analysis results. Information such as whether the accident occurred during the day or at night, in fine or rainy weather, or on urban or rural roads, whether the primary party violated any regulation, as well as the travel speed, human factors, and age group in the accident pattern were clarified. The results of this detailed analysis were prepared for all accident patterns.

3 Application of 255 SIP Patterns

Over four years of studies, the 255 SIP patterns were applied to various topics, including the following.

1) Estimation of the effectiveness of ADAS provided with pedestrian detection technologies for reducing fatal car-to-pedestrian accidents
2) Estimation of the effectiveness of ADAS provided with lane keeping technologies for reducing accidents in which single cars run off the road
3) Identification of patterns with 20 or more fatalities and a fatality rate of 5% or more among fatal car-to-bicycle accidents
4) Identification of trends in the number of accidents and fatalities of each pattern over nine years, and to investigate the reasons for these trends

Details of the results of these topics are introduced in annual reports published by ITARDA (see the references).

4 Issues to be Solved and Future Plans

From the standpoint of fixed point observation, the 255 SIP patterns have been maintained for the past four years. However, the coverage rate has been decreasing year by year because of the decreasing total number of road fatalities in Japan. In the first year, 255 SIP patterns were established using 2013 accident data, and the fatalities categorized in these patterns accounted for 80.0% of the total traffic accident fatalities. However, in 2015, after only two years, the coverage rate fell to 76.8% and to 75.5% in 2016.

Currently, in the final year of the research project, we plan to review the existing patterns and identify potential new patterns to improve the coverage rate. For example, in single-vehicle accidents involving a car or motorcycle, these patterns are extremely fragmented according to the classification of the traffic accident statistical codes. In the case of single-vehicle accidents, cars or motorcycles that depart from their lane for some reason might collide with fixed objects, or collide with nothing and drive off the road. In such cases, the collision object is decided by the road environment. Therefore, to improve the coverage rate, we are investigating the possibility of reducing the number of accident patterns by combining collision objects. From the standpoint of active safety, there is an idea that all colliding objects may be integrated. In contrast, from the standpoint of passive safety, it is necessary to separate collision objects with high fatality rates such as utility poles and sign posts.

In addition, we are also studying patterns in which the number of traffic accident fatalities has increased in recent years, and new patterns such as single-bicycle accidents, which were not covered four years ago.

After these studies, it should be possible to finalize new SIP patterns in a national traffic accident database for Japan.

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Development and Substantiation of Simulation Technology for Estimation of Detailed Traffic Accident Reduction Effects

Sou Kitajima (Japan Automobile Research Institute)

ABSTRACT: The aim of this project is to develop novel multi-agent traffic simulation software capable of predicting the impact of automated driving systems on traffic safety. The software is designed to incorporate variables for human perception and recognition, decision-making, and errors, dependent on age and gender. In this study, the software was applied to a 6 x 3 km^2 area in Tsukuba city. Over a simulated period of time that included more than 500 agents (vehicles, drivers, and pedestrians), the software simulated and identified at least five types of accidents. Different automated driving technology penetration scenarios were applied to conduct preliminary estimations of the potential impact of these technologies on safety.

1 Introduction

Automated vehicles are regarded as a promising means of helping to achieve safer roads[1]. Comprehensive estimations of the potential impact of such vehicles on traffic safety at a national level require the application of simulation methodologies. Within the Japan SIP-adus strategic research program, the aim of this project is to develop and verify a multi-agent traffic simulation methodology capable of estimating the safety improvement potential of automated vehicle technologies.

2 Methodology

2.1. Simulation Concept

Automated driving systems have the potential to help achieve the Japanese government's target of realizing the world's safest traffic environment. Although studying methods of assessing the impact automated driving functions is an important part of this approach, there are several challenges, such as the development of pragmatic behavior models of various traffic participants. From the standpoint of research ethics, we cannot assess impacts on fatality reduction by field operational tests (FOTs) in the real world. Therefore, research is under way into the development of macro traffic simulation software that consists of multi-agent traffic participants. This simulation aims to generate both normal traffic flows and critical traffic situations.

2.2. Simulation components

2.2.1. Overall structure

Figure 1 shows the composition of the multi-agent traffic simulation. The simulation is composed of scenario files, road data, and a simulation module. The simulation module includes three management modules and two traffic participant models. If an accident occurs during a simulation, log data such as collision velocity, collision angle, and the driver's age are recorded to calculate the probability of serious injury.

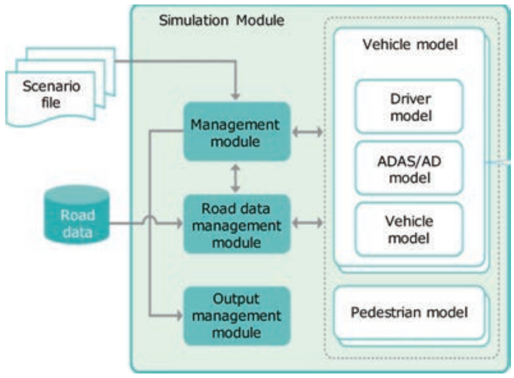


Fig. 1 Composition of multi-agent traffic simulation

2.2.2. Behavior model of traffic participants

(1) Driver behavior model

The driver behavior model is composed of three main processes including perception/recognition, decision making, and actions. This simulation incorporates two types of driver visual fields to simulate various safety confirmation actions (Fig. 2). Various typical driver errors, such as inattentive driving, aimless driving, misjudgment, and inade-

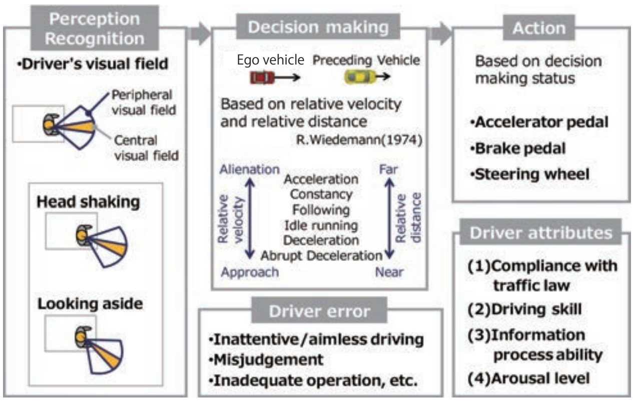


Fig. 2 Outline of driver agent model

quate operation are reproduced by utilizing the driver behavior model. Furthermore, since drivers have diverse characteristics due to age, gender, character, and driving style, the simulation also includes four different driver personality attributes.

(2) Pedestrian behavior model

Figure 3 indicates the pedestrian behavior model used to reproduce road crossing behavior. In Japan, about 25% of fatal accidents are collisions with a crossing pedestrian at a non-intersection area. It is important to develop a pragmatic model based on pedestrian safety confirmation actions. There are six parameters for reproducing road crossing behavior, such as walking velocity. The distribution of parameters was reflected in the behavior model based on fixed-point observation and examination[2].

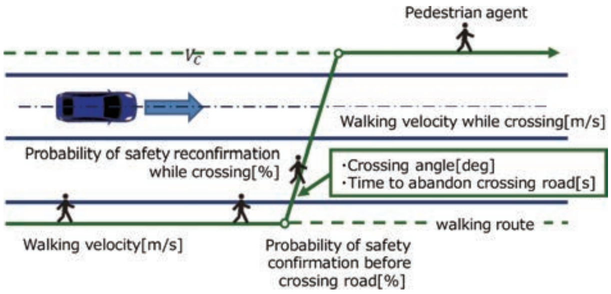


Fig. 3 Outline of pedestrian agent model

2.2.3. Advanced driver assistant system (ADAS)/automated driving

Advanced driver assistant system (ADAS) and automated driving specifications can be defined by the number of sensors, detection range, and angle. Figure 4 shows an example of an automated driving system. In this article, the estimation of accident reduction effects is computed through this system.

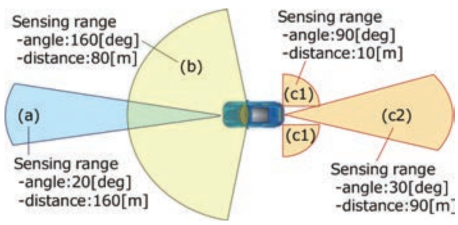


Fig. 4 Specifications of sensors for automated driving system

2.3. Functional testing of multi-agent traffic simulation

2.3.1. Road network

Figure 5 shows a simulated area that was created for the detailed modeling of a part of Tsukuba City. The road network is composed of various routes, such as an expressway, major roads, and narrow streets.

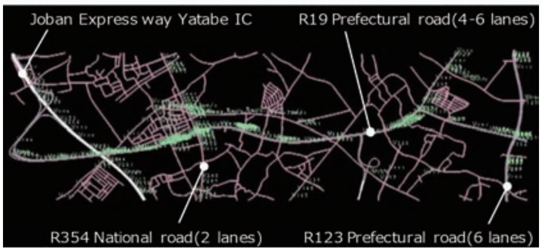


Fig. 5 Road network for functional testing

2.3.2. Simulation conditions

Typical automated driving penetration rates were applied to compute and compare the results of diverse technology penetration scenarios. The simulation contains multiple driving modes, including manual driving, autonomous emergency braking (AEB), lane departure warning (LDW), and automated driving (Table 1). It is important to set up mixed scenarios consisting of various driving modes to estimate safety impacts more practically.

Table 1 Technology penetration scenarios

Simulation Scenarios	*1*	*2*	*3*	*4*	*5*
Manual Driving (MD)	100	50	25	25	-
Autonomous Emergency Braking (AEB)	-	50	25	-	-
AEB + Lane Departure Warning (LDW)	-	-	50	50	25
Automated Driving (AD)	-	-	-	25	75

3 Simulation Results

3.1. Reproduction of realistic traffic flows

To obtain pragmatic estimations of accident reduction effects, it is essential to reproduce realistic traffic flows via simulation. The current simulation can reproduce approximately 500 agents with individual behavior (Fig. 6). Traffic densities and travel velocities are set beforehand based on road traffic census data.

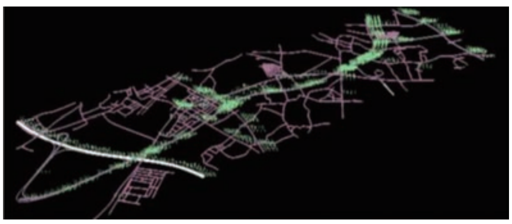


Fig. 6 Multi-agent traffic simulation including 500 agents

3.2. Reproduction of accidents

Typical accidents such as head-on collisions occur occasionally due to driver agent error. Figure 7 shows an example of an accident. The driver agent started to depart from the driving lane because of driver error (i). Lane departure continued even though the vehicle reached the opposite lane (ii). Although the driver agent perceived the lane departure and began an emergency operation (iii), it was not effective at avoiding a collision (iv).

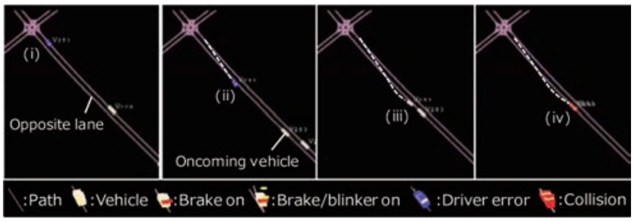


Fig. 7 An example of a head-on collision at a basic road section

3.3. Comparison between simulated results and accident statistics

Figure 8 compares simulated results for 100% manual driving with traffic accident statistics. These accidents occurred in proportions and locations similar to those of real-world accidents.

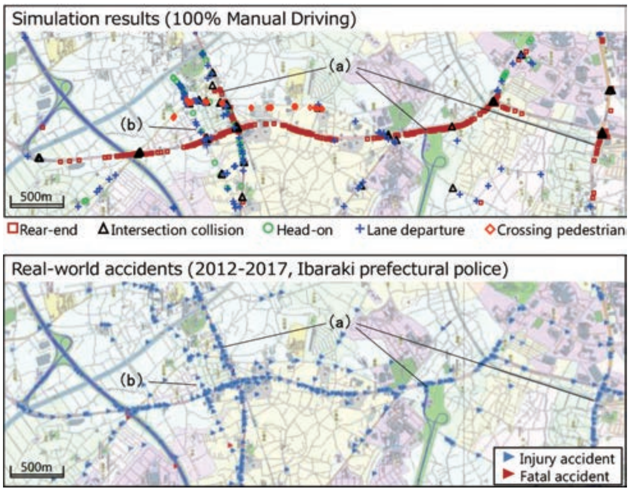
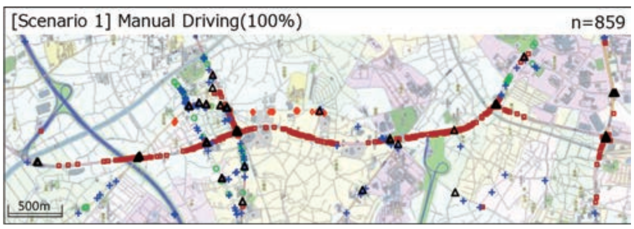


Fig. 8 Comparison of accident occurrence locations between simulation results and real world accidents

3.4. Frequency and occurrence locations under different simulation conditions

Figure 9 shows the simulation results under different simulation conditions to estimate the accident reduction effect of different systems. Each result shows different characteristics in terms of frequency and occurrence locations. This simulation is an effective way of quantitatively estimating the safety impacts of different levels of penetration of advanced driving assistant systems or automated driving.



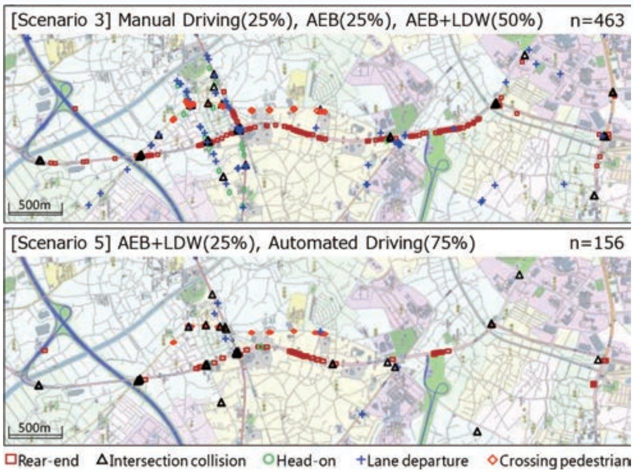


Fig. 9 Comparison of accident occurrence locations (scenarios 1, 3, 5)

The simulation can adopt different automated driving technology penetration scenarios to estimate the potential impact of different technologies on safety.

3.5. Comparison of number of accidents and accident rate

Under 100% manual driving, the system simulated a total of 859 accidents of five types. The number of predicted accidents decreased as the level of automation increased, falling to 156 accidents at the highest simulated automation level (25% of vehicles with AEB + LDW and 75% with level 4 automated driving) (Table 2). Figure 10 shows that all the considered technologies contributed to an absolute decrease in accidents. This decrease was dominated by reductions in rear-end and lane departure-related crashes.

Table 2 Synoptic table of simulation results

No.	*Total*			*MD*	*AEB*	*AEB LDW*	*AD*
	NoA [Freq.]	*AR* [Freq. /km]	*RAR* [%]	*RAR* [%]	*RAR* [%]	*RAR* [%]	*RAR* [%]
1	859	0.011	100	100			
2	622	0.008	70	101	41		
3	463	0.006	56	113	46	36	
4	430	0.005	46	116		30	14
5	156	0.002	16			29	12

NoA: Number of Accidents, AR: Accident Rate, RAR: Relative Accident Rate

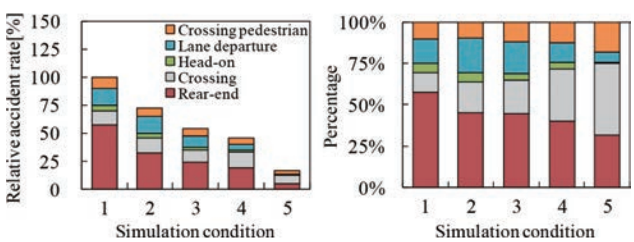


Fig. 10 Comparison of relative accident rates and compositions

4 Concluding Remarks

Novel multi-agent traffic simulation software was developed and applied to an 18km^2 area in Tsukuba City, Japan. Over a simulated period of time with more than 500 agents, the software simulated and identified five types of accidents. Different automated driving technology penetration scenarios were applied to estimate the potential impact of different technologies on safety. Future work will also address the validation of behavior models and the expansion of the current methodology to wider regions.

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Development and Evaluation of Technologies for Constructing Driving Video Database

Kazunori Nomoto, Hiroshi Tanigawa, Akito Adachi (Japan Automobile Research Institute)

ABSTRACT: The safety of automated driving systems, which are regarded as a promising means of helping to reduce traffic accidents, is greatly dependent on functions for recognizing pedestrians and objects, and on making early and accurate judgments of potential collision risks. The collection of large volumes of driving data and the development of technologies and tools for using this data efficiently are recognized as common issues for strengthening competitiveness in the development of such recognition and judgment functions. This article describes efforts undertaken to research and evaluate the utility of a driving video database and simulation evaluation technology needed for developing camera image recognition technology.

1 Development Aim

Human error is the cause of over 90% of traffic accidents, and nearly all fatal accidents occur on ordinary roads. Implementing automated driving on ordinary roads is being promoted as a national project in Japan with the aim of reducing fatal traffic accidents.

There is intensifying competition to research and develop techniques capable of accurately judging at an early timing the presence and potential risk of a collision with pedestrians and two-wheeled vehicle riders, who account for a large percentage of traffic accident fatalities. In addition to automated driving systems for ordinary roads, application of these techniques is also being targeted at advanced driver assistance systems (ADASs) that have already been implemented in production vehicles, and efforts are being made to further improve them and expand their application.

Original equipment manufacturers (OEMs) and suppliers are proceeding with R&D activities using data collected in driving tests conducted using vehicles equipped with proprietary systems developed by each company. However, an enormous amount of time and expense is required to obtain the large volumes of driving video data needed for training image recognition engines and for conducting simulations to evaluate the recognition performance of these systems. Meanwhile, the camera image data collected by these proprietary systems is highly dependent on the hardware used, such as the specifications and mounting positions of the cameras. Moreover, companies cannot easily share their data with others since images may contain confidential information about products under development. Consequently, there is a need to construct a large-scale driving video database that is premised on shared use by every company involved.

The aim of this project is to improve R&D efficiency and competitiveness by providing large volumes of teaching data to OEMs and suppliers for use in developing automated driving technologies, as well as to universities, research institutes, IT business ventures, and the like, which are looked to for research on cutting-edge technologies such as artificial intelligence (AI). Such data is needed for developing recognition engines for pedestrians and two-wheeled vehicle riders along with artificial intelligence for predicting the risk of a collision using driving environment recognition systems based on camera images.

2 Overview of Research and Development Work

In this driving video database project, large volumes of driving video data (approximately 1,500 hours, 4.2 petabytes (10^{15}) and 100,000 scenes) were collected for use in developing and evaluating the performance of pedestrian recognition systems. The associated key technologies for constructing an easy-to-use database were also developed, including functions for tagging data and conducting data searches.

Over a three-year period from fiscal 2014, activities were undertaken to develop and verify an automated driving system for universal services, as well as technologies for constructing a driving video database in the Cross-Ministerial Strategic Innovation Promotion Program (SIP). From fiscal 2017, this project commissioned by the Ministry of Economy, Trade and Industry was launched to research, develop and verify an advanced automated driving system for social implementation. This project undertook research and development work necessary for achieving an advanced automated driving system.

2.1. Research and development objectives

2.1.1. Construction of driving video database

The image data collected in this database is limited to scenes involving pedestrians, two-wheeled vehicles, including bicycles, and motor vehicles, based on the opinions of people concerned with the development of automated driving technology. In addition, the camera system used was configured to take wide-angle forward images and 360-degree images of the surroundings in order to record the presence and movement of pedestrians, two-wheeled vehicles, and other objects around the vehicle. This is because one of the issues raised in the Euro NCAP (European New Car Assessment Programme) 2020 Roadmap is the prevention of accidents at intersections.

The vehicle-mounted cameras used in automated driving systems have different specifications depending on the manufacturer, and their performance is being improved every year as result of further technological progress. This driving video database is intended to provide teaching data for use in simulations to evaluate the performance of such camera systems. The image quality must be as good as or better than that of the vehicle-mounted cameras to be evaluated. Taking into account the specifications of cameras currently used in ADASs and projected performance improvements over the next five years, it was concluded that the cameras should have approximately twice the number of imaging elements as current cameras and a wider horizontal angle of view, among other specifications. Accordingly, a Hi-Vision (high-resolution two-megapixel imaging element) camera system was adopted to provide the desired performance.

Existing image recognition databases are capable of recognizing faces and handwritten characters, and the volume of data needed at the level of practical performance is said to be in the order of several million items. The pedestrian databases currently provided by research institutes in other countries contain still images, but video image data is needed to analyze pedestrian behavior at intersections and other places.

Based on these considerations, it was decided to record four million frames of different pedestrian types, including men, women, and children of all ages, in different postures and carrying different objects, and 107,497 video images of walking scenes, including walking along the side of roads, at intersections, crossing roads, and other situations.

2.1.2. Construction of simulation evaluation environment

Data collected by driving test vehicles on public roads provides useful information for use in technological development because it includes various types of real-world traffic environments, such as different road structures, natural environments and the presence of pedestrians, nearby vehicles, and other objects. However, it would be impossible to record every driving situation that might occur in the real world. One conceivable way of complementing actual equipment evaluations and simulations using recorded driving data would be to build a virtual environment and to conduct simulations under a variety of given conditions. Based on actual recorded images, computer graphics (CG) technology, like that widely used in the video game industry and elsewhere in recent years, was applied to create a virtual space on a computer. In this way, an evaluation environment was constructed for conducting simulations under virtual conditions and its utility was verified. Various adverse circumstances were created for use in the simulations by freely combining natural conditions, such as daytime, nighttime, and rain, as well as the positions and movements of pedestrians and nearby vehicles.

2.1.3. Promotion of database use by the private sector

The existence of the driving video data recorded in this project was publicized widely among OEMs and suppliers that are developing automated driving systems, as well as among research institutes, universities, IT venture businesses, and other entities involved in cutting-edge core technologies such as AI. Sample data was made public in order to collect a wide range of information about various aspects, such as needs concerning insufficient data, as well as technologies or tools for practical use of the database.

3 Construction of Driving Video Database

3.1. Data collection

Various types of sensors are available for detecting a vehicle's direction of travel and surrounding circumstances, including cameras, millimeter radar, LiDAR devices and ultrasonic sensors, among others. A monocular camera system was selected for recording forward wide-angle and all-around image data because the data volume is smaller than a stereo camera system and high-resolution wide-angle images can be obtained. Because the distance accuracy of a monocular camera system to potential object is inferior, long-range scanning LiDAR sensors were used in parallel. A system was adopted for synchronized collection of both image data and LiDAR data.

The camera system consisted of five 2.3-million pixel monocular Hi-Vision cameras. One was a forward remote monitoring camera with an angle of view of approximately 90° and the other four had an angle of view of approximately 180° and were positioned at the front and rear and on both sides of the vehicle. Corresponding to the cameras were five LiDAR sensors and large-capacity data recording devices with a maximum recording time of six hours. The vehicle was equipped with two types of GPS devices for measuring its position. The appearance of the vehicle that was developed for collecting driving video data is shown in

Fig. 1.

Fig. 1 Vehicle developed for collecting driving video data

3.2. Data processing

In order to use large volumes of data efficiently and effectively according to a particular purpose, it is necessary to be able to comprehensively search all the related data by specifying certain priority conditions These might include driving scenarios such as straight-ahead travel or turning right or left at an intersection, conditions such as daytime, nighttime, or rain, and the presence, positional relationships, and other aspects of pedestrians or nearby vehicles. For that purpose, it is essential to classify scenes so that objects of interest can be found in specific time frames in individual driving scene files that contain, for example, scenes of pedestrians or bicycles crossing the road. Therefore, all the images in this driving video database have been classified into 27 types of scenes.

Figure 2 shows a breakdown of the overall 258,364 driving scenarios. The database contains 107,497 pedestrian scenes obtained from city streets, shopping/entertainment streets, sightseeing areas, and cold regions, and 6.45 million frames of pedestrian image data. As a result of analyzing, classifying and organizing all the data, the development targets of 4 million frames of pedestrian image data and 107,497 scenes of pedestrians walking were ultimately obtained.

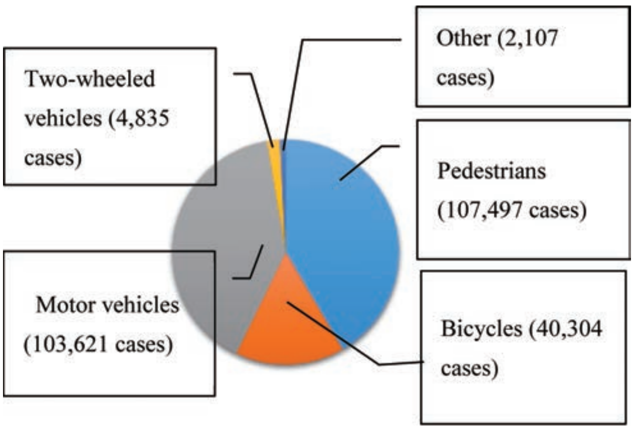

Fig. 2 Breakdown of the numbers of targeted objects in driving scenarios

3.3. Database evaluation

A portion of the driving video database was provided to the representatives of eight organizations, including OEMs, suppliers, and research institutes in order to perform a multifaceted evaluation of the data with respect to quality, ease of use, utility, and other aspects. Although the results confirmed the utility of the database, room for further improvement was also found.

In addition, four briefing sessions were held from January to March 2018, which were attended by 112 participants from 81 organizations. Figure 3 shows one of the nine sample driving scenarios shown to the attendees. The aim was to encourage use of the database by organizations engaged in R&D work on cutting-edge core technologies, including the development of recognition engines for pedestrians, two-wheeled vehicles, and the like, as well as the development of AI for predicting the risk of a collision. People from research institutes and other organizations accounted for approximately 35% of the total attendees, which shows that the aim of broadening the range of R&D activities was accomplished. JARI has also independently taken the initiative to supply 288 sample datasets to interested parties, and has launched activities to encourage use of the driving video database by private sector organizations.

Fig. 3 Driving video data showing a pedestrian crossing the road against sunlight

4 Construction of a Simulation Evaluation Environment

It would be difficult to record every situation that might occur in the real world, including various weather conditions, near misses and so on, by driving test vehicles on public roads to collect driving video data. Constructing a virtual environment and conducting simulations under a wide variety of given conditions is regarded as a more effective method. For that reason, a simple prototype simulation environment was constructed and its utility was verified.

Specifically, some of the recorded driving data was used to extract playbook-like scenarios of vehicle behavior of the vehicles, pedestrians and other traffic participants appearing in those scenarios. In addition, from among the models of structures, people, vehicles and the like developed by the private sector, ones closely resembling actual objects were selected and various simulation conditions were determined, including the weather. Computer graphics technology was then used to recreate virtual driving scenarios on a computer. It should be noted that the models of structures, people, and vehicles used were prepared in advance on the basis of actual photographic materials so that they would be equally recognizable by image recognition engines and AI in the same way as actual objects. Consequently, they could be used in the evaluation of image recognition performance and eliminated any concerns concerning personal information.

Evaluations performed in a prototype virtual simulation environment were compared with evaluations of driving scenarios obtained using test vehicles. This was accomplished by positioning people and vehicles on a test course in the same manner as in the virtual driving scenarios and then recording images of the test driving scenarios. Differences between the two driving scenario datasets were evaluated using the same recognition engine, and the utility of the virtual simulation environment was verified by the fact that nearly identical results were obtained.

In order to verify the safety and utility of an automated driving system, driving tests must be conducted using test vehicles equipped with the system to be evaluated. A prototype environment was constructed that can use virtual simulation evaluations to verify object recognition and vehicle control algorithms at the design and development stage before conducting actual driving tests. The utility of this environment was also verified in this project.

The simulation evaluation environment was constructed with a high level of reality by combining digital map data (accurate road structures, lane configurations, and the like) and object assets (nearby structures, guardrails, trees, and the like) using MATLAB/Simulink and Prescan, as an example of a general-purpose evaluation environment. This was carried out to realize a usable simulation environment for conducting comprehensive safety evaluations of the recognition and judgment functions of automated driving systems.

5 Conclusion

Efforts were undertaken in this project to research and evaluate the utility of a driving video database and simulation evaluation technology needed for developing camera image recognition technology. As a result, approximately 1,500 hours of driving image data amounting to 4.2 petabytes and 107,497 scenes of pedestrian image data were collected in the database. The utility of a simulation evaluation environment using computer graphics technology was also verified.

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(2) Report on Development and Verification of Autonomous Driving System and Technologies for Constructing a Driving Video Database in the Cross-Ministerial Strategic Innovation Promotion Program (SIP) in Fiscal 2015 (in Japanese).

(3) Report on Development and Verification of Autonomous Driving System and Technologies for Constructing a Driving Video Database in the Cross-Ministerial Strategic Innovation Promotion Program (SIP) in Fiscal 2016 (in Japanese).

(4) Report on Research and Demonstration Project for Social Deployment of Highly Automated Driving: Automated Valet Parking Demonstration Experiment and Automated driving system Research and Development, in Fiscal 2017 (in Japanese).

Development of Tool for Assessing Impact of Automated Driving Systems on Traffic Flow and CO_2 Emissions

Daisuke Oshima and Takashi Kurisu (Pacific Consultants Co., Ltd.)

ABSTRACT: We have developed a tool for visualizing the CO_2 emissions of vehicular traffic, which can quantitatively evaluate how the introduction of automated driving systems might affect traffic flow and, consequently, changes in the amount of CO_2 emissions from vehicular traffic. To develop this evaluation tool, we combined traffic simulation with CO_2 emissions models and performed necessary verifications in accordance with an international joint report issued as part of NEDO's "Development of Energy-saving ITS Technologies" project. In addition, we used the tool to evaluate certain automated driving systems in specific scenarios, where the tool proved applicable to the evaluation of those systems.

1 Purpose

Automated driving systems are expected to reduce traffic fatalities and alleviate traffic congestion, possibly resulting in lower CO_2 emissions. This project aims to develop an evaluation tool for visualizing the CO_2 emissions of vehicular traffic, which can quantitatively evaluate how the introduction of automated driving systems might affect traffic flow and CO_2 emissions from vehicular traffic, as a tool for assessing the social impact of such systems. The evaluation tool is intended to help set priorities for the technological development of various automated driving systems, help determine how best to implement such systems in society, and help raise public awareness through visualization of the amount of CO_2 emissions, thus promoting the practical and widespread use of such systems.

2 Development Plan

2.1. Basic configuration of evaluation tool for visualizing CO_2 emissions of vehicular traffic

As a technique for estimating CO_2 emissions based on changes in vehicular traffic flow, a method that combines traffic simulation with CO_2 emissions models was established in the "Development of Energy-saving ITS Technologies" project (Energy ITS project) conducted from FY2008 to 2012. This method involves simulating the movements of all vehicles traveling in a study area, calculating CO_2 emissions based on the reproduced vehicle movements using CO_2 emissions models, and summing the results for all vehicles to estimate the CO_2 emissions from all the vehicular traffic (Fig. 1).

An international joint report titled "Guidelines for assessing the effects of ITS on CO_2 emissions" issued as part of the project specifies the requirements to be met in the calculation process. The results of calculations that comply with these requirements are deemed internationally reliable. To develop the evaluation tool, we combined the traffic simulation with CO_2 emissions models in accordance with the international joint report.

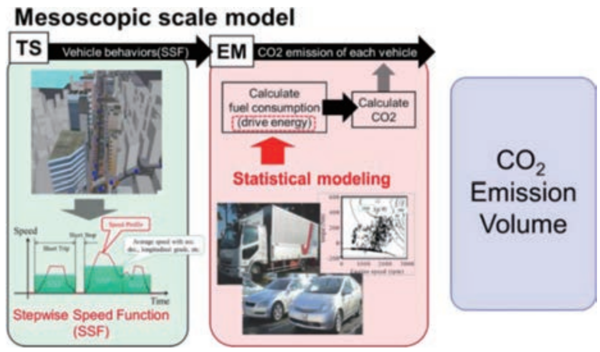


Fig. 1 Method for estimating CO_2 emissions from vehicular traffic flow[1)]

2.2. Scope of evaluation

The following five automated driving systems were selected for evaluation by the tool:

- Green wave driving utilizing traffic signal control information, etc.
- Advanced Rapid Transit (ART) (smooth acceleration and deceleration of buses)
- Truck platooning
- Automated driving on expressways and general roads
- Local traffic control systems (automated last-mile transport and automated valet parking)

The introduction of automated driving systems might have the following three main effects leading to lower CO_2 emissions: (1) changes in travel demand caused by improvements in the convenience of automobiles, (2) changes in vehicle behavior caused by system control, and (3) fewer traffic jams caused by traffic accidents (Fig. 2). The area enclosed by the dotted lines in Fig. 2 was selected as the scope of application of the evaluation tool, and the effects shown outside the dotted box were regarded as given conditions. That is, the technology does not estimate how introducing automated driving systems will change travel demand or reduce traffic accidents.

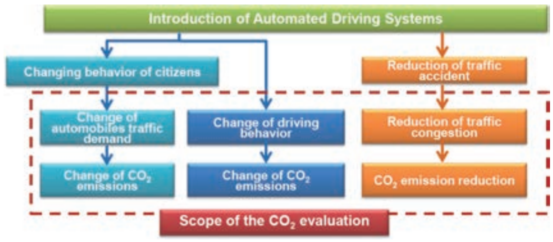


Fig. 2 Effects of automated driving systems on CO_2 emissions from vehicular traffic

3 Development of Local Traffic CO_2 Emissions Visualization Technology

3.1. Modeling of changes in traffic flow caused by introduction of automated driving systems through traffic simulation

3.1.1. Identification of CO_2 emissions reduction mechanisms and determination of requirements for the assessment tool

The international joint report states that the mechanisms of how the measures under evaluation might affect driver and vehicle behavior and help reduce CO_2 emissions should be represented by diagrams called "reference models". Additionally, the report recommends using the reference models to verify that the assessment tool appropriately considers these mechanisms and that, in actual evaluations of automated driving systems, their effects are quantified based on the models.

Therefore, in preparation for simulation-based modeling, we defined a mechanism for reducing CO_2 emissions for each automated driving system being evaluated. As an example, Fig. 3 shows a reference model of truck platooning.

Next, based on the mechanisms of how the automated driving systems might help to reduce CO_2 emissions (represented by the created reference models), we identified the requirements for the simulations to be performed to evaluate each system.

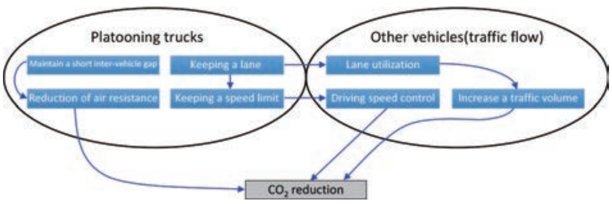


Fig. 3 Reference model of truck platooning

3.1.2. Modeling of automated driving systems and implementation of models in traffic simulations

In accordance with the requirements identified in 3.1.1, we modeled the automated driving systems and implemented these models in traffic simulations. For example, we modeled platooning trucks that maintained a consistent following distance (modeling of truck platooning) and automatic overtaking and merging maneuvers (modeling of automated driving on expressways) and implemented the models. Then we tested the operation and confirmed that the automated driving systems were represented by the traffic simulation as intended.

3.2. Development of technology for estimating emissions from changes in driving behavior caused by automated driving

3.2.1. Expansion of CO_2 emissions models

We used existing CO_2 emissions models as base models (some of which were created in the Energy ITS project). However, because CO_2 emissions models of diesel passenger cars and hybrid minivans (which are becoming more popular in recent years) and buses (evaluated in this project) were not available, we bench-tested these types of vehicles to obtain data on their driving behavior and CO_2 emissions, and created CO_2 emissions models for them based on the data.

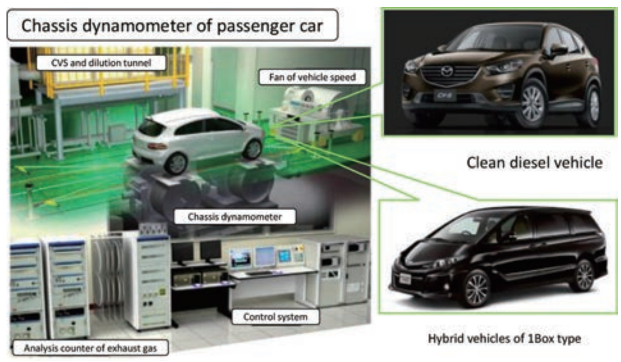


Fig. 4 Bench-testing to create CO_2 emissions models

3.2.2. Creation of CO_2 emissions models assuming automated driving systems have been introduced

We created CO_2 emissions models assuming that automated driving systems have been introduced and have affected the driving behavior of vehicles. For truck platooning, for example, we created a CO_2 emissions model that reflects the reduced air resistance of following trucks due to the shorter following distance; for automated driving on expressways and general roads, we created a CO_2 emissions model that reflects optimal starting (acceleration), cruising, and stopping (deceleration) maneuvers.

3.3. Development of technique for estimating CO_2 emissions reductions due to reduced traffic accidents

In order to estimate CO_2 emissions reductions due to fewer traffic jams caused by traffic accidents (Fig. 2), it is necessary to perform calculations while randomly changing the locations of accidents prevented by the automated driving systems. Therefore, we adopted a method of estimating CO_2 emissions reductions by using a simplified evaluation simulation and macro CO_2 emissions models. (The simplified evaluation simulation technique assesses the impact of a reduction in the traffic capacity while taking into account the space-time propagation of congestion. This technique is based on the simplified kinematic wave theory using data obtained from a dynamic traffic flow simulation that assumes normal traffic conditions not affected by accidents or other incidents.)

To determine the impact of accidents on traffic flow (to be used as an input value in simplified evaluation simulation), we analyzed traffic congestion caused by accidents using probe data and data on accidents on general roads in the 23 wards of Tokyo.

4 Evaluation in Model Cities

We evaluated automated driving systems using the developed evaluation tool. Before conducting evaluations, we compared observed data (such as traffic volume and travel speed) with the results from the traffic simulation to verify that the current traffic conditions in the study area were accurately reproduced by the simulation, as recommended in the international joint report. Here, evaluation results for truck platooning are described as an example.

4.1. Simulation conditions

We performed calculations for the Tomei–Shin-Tomei network (Yokohama-Aoba IC – Toyota JCT – Tomei-Miyoshi IC) (shown in Fig. 5) assuming 24 hours of travel between 4:00 a.m. on a weekday and 4:00 a.m. on the next weekday in September 2016. We also assumed that:

- 50% of heavy vehicle trips between Tokyo and Nagoya were made by platoons of four vehicles maintaining a following distance of 4 m (approximately 3,000 trips made by platooning vehicles, which account for 1.7% of the total number of heavy vehicle trips (approximately 182,000 trips) on the Tomei–Shin-Tomei network).
- 1,000 of the 3,000 vehicles departed at night (between 9:00 p.m. and 1:00 a.m. the next day).
- The platooning vehicles traveled on the Shin-Tomei route (shown in red in Fig. 5) at a target speed of 80 km/h (the target speed of conventional heavy vehicles is 75–95 km/h).

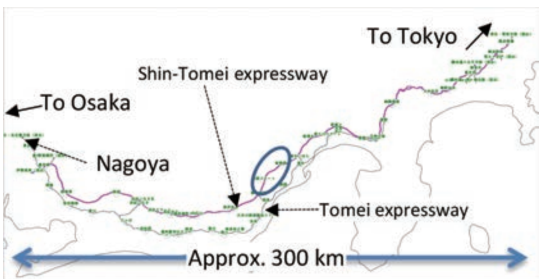


Fig. 5 Network used for platooning simulation

4.2. CO_2 emissions estimation results

The reduction in CO_2 emissions from the base case level was estimated at 0.3% for the 1,000 platooning vehicles (midnight), and 0.8% for the 3,000 platooning vehicles (24 hours). The main possible causes of these reductions are the reduction in the air resistance of following vehicles due to platooning and a reduction in the average speed of the surrounding traffic due to the vehicle platoons traveling at an average speed of about 80 km/h. In this project, the evaluation focused on weekdays, when congestion is low. We believe that platoons of vehicles traveling on weekends or holidays might yield a more significant reduction because platooning helps to reallocate road space.

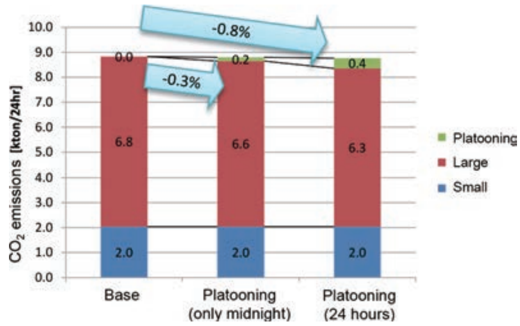


Fig. 6 Evaluation results of truck platooning

5 Conclusion

We have developed an evaluation tool that can quantitatively evaluate how the introduction of automated driving systems might affect traffic flow and CO_2 emissions from vehicular traffic. Although automated driving systems are expected to help alleviate traffic congestion and reduce CO_2 emissions, they may fail to deliver the expected benefits, especially during the transition period in which such vehicles and conventional vehicles share the road. The evaluation tool can be used to find the desired parameters, such as the performance or penetration rate of automated driving systems, and to predict and evaluate what effects the systems might have under various conditions. We hope that this tool will be used in various studies to enhance the potential benefits to society of introducing automated driving systems.

Reference

(1) "Report: Establishment of Reliable International Evaluation Methods," Development of Energy-saving ITS Technologies project, New Energy and Industrial Technology Development Organization, 2013

Analysis of Social and Industrial Aspects of Developing and Popularizing more Advanced Automated Driving Systems

Yoshihiro Suda, Takashi Oguchi, and Koichi Sakai (The University of Tokyo)

ABSTRACT: The following are regarded as preconditions for encouraging the development and widespread use of more advanced automated driving systems (ADS): Clarification of the impacts on society and industry inside and outside Japan, as well as the risks that will result from such changes, the implementation of measures to mitigate these impacts and risks, the formulation of scenarios from a long-term perspective, and greater understanding of ADS on the part of the general public. This study clarified the evolution of ADS, proposes a future vision for these systems and scenarios for issue resolution, and defined specific actions to prepare for the implementation of ADS through a study team composed of academic specialists from various fields.

1 Aims of This Study

The following are regarded as preconditions for encouraging the development and widespread use of more advanced automated driving systems (ADS): Clarification of the impacts on society and industry inside and outside Japan, as well as the risks that will result from such changes, the implementation of measures to mitigate these impacts and risks, the formulation of scenarios from a long-term perspective, and greater understanding of ADS on the part of the general public. A study team was established to clarify the evolution of ADS, propose a future vision for these systems and scenarios for issue resolution, and define specific actions to prepare for the implementation of ADS.

2 Establishment of Study Team

The team that was established to conduct this study is primarily made up of key figures from universities in wide-ranging areas such as traffic engineering, mechanical/robotics engineering, informatics, urban planning, cybersecurity, and other engineering fields, as well as public economics, civil procedures, technology management, and other socioeconomic fields, in addition to the fields of education, cultural anthropology, and so on.

3 Evolution of Automated Driving Systems

Level 2 and 4 systems are regarded as most likely to respond to societal needs (Fig. 1).

Level 3 ADS are affected by issues such as whether users will be able to resume driving tasks in response to system requests while engaged in secondary activities such as napping, and whether users will respond positively to such systems. It is possible that level 3 systems will be developed as a part of the technological progress toward level 4 systems.

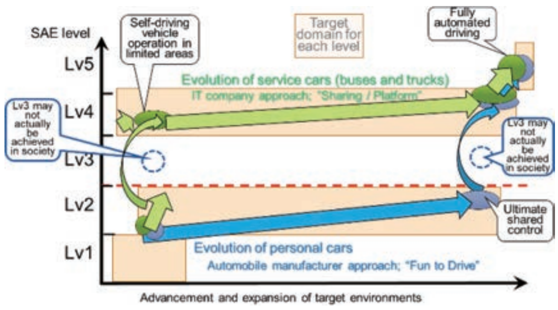


Fig. 1 Evolution of automated driving systems

Although level 3 systems may be popular with professional drivers and other people with advanced driving skills, such systems are not expected to be favored by the average driver. Therefore, it is possible that they may not actually be adopted in society.

4 Future Vision for Automated Driving Systems and Scenarios for Issue Resolution

4.1. Preconditions for study

Based on the two-level evolution discussed in Section 3 above, analysis was conducted for two different time frames: the near future (by around 2025) and the medium-to long-term (by the late 2030s). Figures 2 and 3 show the anticipated technological development and dissemination status for each of these time frames.

4.2. Future vision from the standpoint of societal needs

Societal needs can be categorized from the standpoint of road traffic issues, public transport systems, and logistics systems. This section will consider in greater detail ways to ensure mobility for vulnerable transport users (both those who drive and those who do not have a driver's license) within the category of public transport systems, as well as the future of logistics systems (ways to resolve the driver shortage and reduce logistics costs).

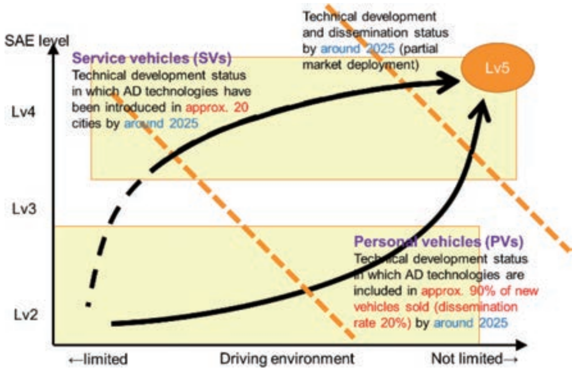


Fig. 2 Technological development and dissemination status by around 2025

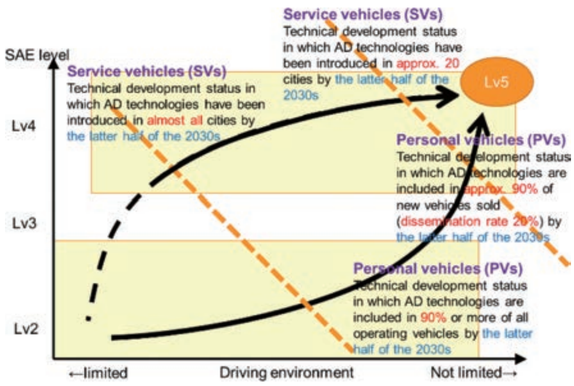


Fig. 3 Technological development and dissemination status by the late 2030s

4.2.1. Ensuring mobility for vulnerable transport users (when users drive themselves)

By around 2025, level 2 private vehicles with advanced driving safety support systems are expected to appear. Restriction-relaxed licenses will enable these vehicles to be operated by everyone, from young people to senior citizens. Legal systems will evolve along with technological progress, such as through the establishment of new restriction-relaxed licensing classifications that enable people to drive only vehicles equipped with advanced driving safety support systems.

By the late 2030s, although such systems will handle almost all driving tasks, fully-featured shared control systems (level 2) will exist that make it seem as though the driver is operating the vehicle by himself or herself.

4.2.2. Ensuring mobility for vulnerable transport users (users without driver's licenses)

By around 2025, low-speed, small-ridership transport services using level 4 ADS will appear, although these will be limited to certain areas such as sparsely populated regions, planned housing developments, and dedicated roads.

By the late 2030s, level 4-5 ADS dedicated vehicles (ADS-DV) will be employed for regular route buses and ridesharing services. In addition, new modes of transport will appear. Level 4-5 ADS-DV for car sharing services that provide a private transport environment will be available for individual use, and on-demand and shuttle type level 4-5 ADS-DV small-ridership type ridesharing services will also be available.

4.2.3. Resolution of the driver shortage and reduction of logistics costs

By around 2025, there will be widespread use of level 2 vehicles as lead vehicles and electronically coupled trucks (level 4 vehicles) as following vehicles on certain expressway sectors. On ordinary roads, level 2 restriction-relaxed licenses for truck drivers will make it unnecessary to have advanced driving skills to operate trucks. There will also be mixed passenger and cargo transport on regular route buses and in ridesharing services (also with level 2 restriction-relaxed licenses), in accordance with demand.

By the late 2030s, it will be possible to operate level 4-5 ADS-DV in all sectors of both expressways and ordinary roads. There will also be mixed passenger and cargo transport and ridesharing services using level 4-5 ADS-DV regular route buses, in accordance with demand.

4.3. Social impacts and issues of automated driving systems from the standpoint of societal needs

Tables 1 through 3 show specific issues as viewed from the perspective of societal needs, scenarios for progress in technological development, social impacts, negative impacts and issues, and scenarios for issue resolution.

5 Actions in Preparation for Implementation of Automated Driving systems

The key specific issues that must be resolved through cooperation among industry, government, and academia to implement driving automation systems in society are as follows:

- Human factors
- Cooperation on infrastructure, urban planning, and mobility support (collaboration with society)
- Technologies for self-driving cargo transport (contribution to economic activities)
- Legal systems and insurance systems

⑥ Analysis of Social and Industrial Aspects of Automated Driving

Analysis of Social and Industrial Aspects of Developing and Popularizing more Advanced Automated Driving Systems

Table 1 Social impacts and scenarios for issue resolution related to ensuring mobility for vulnerable transport users (when users drive themselves)

Category	Item
Societal needs	Ensuring mobility for vulnerable transport users (senior citizens, physically disabled, young people)
Scenarios for progress in technical development	Level 2 private vehicles with advanced driving safety support, provided by means of restriction-relaxed licenses that enable users from young people to senior citizens to drive
Social impacts	Ensuring mobility (increased opportunities and expanded environment for driving oneself), health improvement by driving oneself
Negative impacts and issues	•Need to establish requirements for restriction-relaxed licenses (driving capacity assessment) •Need for policies to disseminate level 2 vehicles, etc.
Scenarios for issue resolution	•Establishment of requirements for restriction-relaxed licenses (driving capacity assessment) and establishment of new systems for licensing and training *[G]* •Obligation of people who do not meet restriction-relaxed license requirements to surrender license *[G]* •Study of measures to disseminate level 2 vehicles *[I&G]*, etc.

* *I*: industry, *G*: government, *A*: academia

Table 2 Social impacts and scenarios for issue resolution related to ensuring mobility for vulnerable transport users (users without driver's licenses)

Category	Item		
Societal needs	Ensuring mobility for vulnerable transport users (senior citizens, physically disabled, young people), Measures to alleviate the shortage of public transport drivers and reduce operating costs, and ways to improve profitability of public transport operators		
Scenarios for progress in technical development	*[by around 2025]* •Regular route buses through level 2 restriction-relaxed licenses and ridesharing services •Low-speed, small group transport services (limited routes, and/or dedicated area level 4 system)	➔	*[by the late 2030s]* •Level 4-5 ADS-DV regular route buses and ridesharing services •Level 4-5 ADS-DV individual use of car sharing type self-driving vehicles, use of on-demand type and patrol type level 4-5 ADS-DV services for small group ridesharing
Social impacts	Ensuring mobility (maintenance of public transport etc.), regional stimulus, emergence of level 4 car sharing service operators, emergence of mobility providers and other platform providers, alleviation of driver shortage and crew specialized in conductor tasks		
Negative impacts and issues	*[by around 2025]* •Need to ensure societal acceptance for level 4 vehicles •Need to construct the infrastructure required for level 4 vehicles, clarify maintenance standards and devise measures for early deterioration •Need to establish social systems relating to level 4 vehicles, such as legal and insurance systems •Need to organize requirements for establishment of business models, etc.	➔	*[by the late 2030s]* Return to compact cities, concern for increased costs throughout society as a whole, etc.
Scenarios for issue resolution	*[by around 2025]* •Promotion of public understanding and societal acceptance of Lv4 vehicles *[I, G, society &A]* •Study of infrastructure requirements for level 4 vehicles *[I, G&A]* •Study of legal systems and insurance systems for level 4 vehicles *[I, G&A]* •Fee structure for business establishment and assessment of corporate structure from the standpoint of social welfare and social efficiency *[I&A]*, etc.	➔	*[by the late 2030s]* •Reassessment of urban transport strategies to add ADS technologies, including road charges and tax systems *[G]*, etc.

* *I*: industry, *G*: government, *A*: academia

Table 3 Social impact and scenarios for issue resolution the driver shortage and reduce logistics costs

Category	Item		
Societal needs	Measures to resolve the driver shortage and reduce logistics costs		
Scenarios for progress in technical development	*[by around 2025]* Level 2 restriction-relaxed licenses, and/or level 4 in limited environments (electronically coupled vehicles operating in limited areas or on dedicated routes including expressways)	➔	*[by the late 2030s]* Level 4-5 ADS-DV operation
Social impacts	Improvement of driver shortage, reduction of logistics costs, high-efficiency logistics, reorganization of business scheme		
Negative impacts and issues	*[by around 2025]* •Need for establishment of environment (requirements for restriction-relaxed licenses, legal status of electronically coupled vehicles, securing of location for forming electronic coupling, status in terms of labor management, optimization of location planning for logistics centers, establishment of system for mixed cargo and passenger transport etc.) •Need to carefully assess conditions for establishment of business models •Need to increase acceptance on the part of drivers of surrounding vehicles, etc.	➔	*[by the late 2030s]* •Need to carefully assess new costs (maintenance, operation, tax and fee systems) •Need for advanced management of people and goods (including study of redeployment of logistics facilities) •Need to deal with the creation of monopolies and oligopolies due to increased size of operators as a result of reduced costs including personnel costs, etc.
Scenarios for issue resolution	*[by around 2025]* •Environment establishment above mentioned *[I, G&A]* •Study of establishment of business models *[I, G&A]* •Study of human-machine interface with surrounding vehicles (including need for standardization) *[I&A]*, etc.	➔	*[by the late 2030s]* •Study of costs and tax and fee systems *[I&A]* •Study of advanced management for people and goods *[I&A]* •Measures for creation of monopolies and oligopolies *[I, G&A]*, etc.

* *I*: industry, *G*: government, *A*: academia

6 Conclusion

The following items were conducted in this study.

- Establishment of study team
- Clarification of ADS evolution
- Proposal of future vision for ADS and scenarios for issue resolution
- Proposal of specific actions in preparation for the implementation of ADS

Future Needs of Automated Driving Systems, and Analysis and Research of Issues Arising out of such Needs

Akiko Narita (SC-ABeam Automotive Consulting)

ABSTRACT: To create social acceptance of automated driving systems, public events called "citizens' dialogues" have been held since FY2016. These events provide information about automated driving to the public to facilitate understanding of these systems. In addition, we have been sorting and analyzing new awarenesses and visions of these systems based on opinions and responses, including the concerns and expectations of the public, to provide input for guiding future research and development activities, as well as to foster social acceptance. At the dialogue sessions held over the past two years, opinions were exchanged among a variety of stakeholders, accurate information on automated driving was provided, and expectations and concerns about automated driving were extracted. The positive outcomes of the initial events and acceptance of the activities are illustrated by dissemination of the activities to provincial areas during FY 2018.

1 Background and Objectives of the Research

It is essential to create social acceptance of the Strategic Innovation Promotion Program (SIP) - Automated Driving for Universal Service (adus) in order to direct research and development outcomes toward practical application, commercialization, and deployment within society. In doing so, it is important to further social acceptance of automated driving systems through public events to facilitate understanding of driver support systems whose trials are already in progress, as well as the technologies and benefits of automated driving now being studied and developed. It is also important to assess and validate the opinions and responses presented at such events.

Toward this objective, events called "citizens' dialogues" started in FY2016 as a forum for interactive communication in which participants discussed and exchanged opinions about the social needs of automated driving systems and the various associated constraints. Thus, to realize the goals of automated driving at the societal level, efforts are being made to heighten social acceptance by providing information to the public and by addressing community concerns and public needs.

2 Activities and Outcomes of Research

2.1. Activities in FY2016

In FY2016, three public "citizens' dialogue" events were held. The first dialogue recruited university students, who will forge the next-generation of car users, and opinions were exchanged on the theme "Social change: the realization of automated driving." In this of age of fewer and fewer young people holding a driver's license or owning a car, views were shared on what university students expect from automated driving and what kind of society they believe they have to build from various perspectives, including the perspective of drivers and inhabitants. When asked about the characteristics of a future that accepts automated driving vehicles, participants responded that it will allow effective utilization of time, increase convenience in regions without public transportation, and create a new use of roads. The first citizens' dialogue ended with a summarizing conclusion that "a network is being formed to discuss social innovation and ethics through public-private cooperation. This kind of movement will become important from now onward."

The second citizens' dialogue invited professional drivers and transport industry workers. Under the theme "Connections between automated driving and society," views were exchanged regarding how society and future automated driving are mutually connected from the viewpoints of people working at transportation sites and elsewhere. The topics of discussions included how a society that has realized automated driving would differ from the present society, how the relationship between vehicles and society would change, and whether lifestyles and other aspects of life would change in terms of fears, expectations, and even education. Labor shortages and the aging of the population were highlighted as problems of those holding vehicle-related jobs. At the same time, high expectations for automated driving were presented. Concerns about automated driving were the usage of automated driving itself as well as the problematic aspects of trying to foresee the extent to which such systems would be built. Concern was also expressed about who should take responsibility in the case of an accident and whether the division of the roles of the system and humans at level 3 would work properly. Regarding education targeting correct understanding of automated driving, it was suggested that it would be important to effectively use automated driving through the involvement of and education by people from different walks of life such as education by manufacturers, education by those experienced in automated driving, and dissemination of information by motor journalists.

The third citizens' dialogue invited legal and insurance professionals and university law students to participate in a discussion session themed "The rights and responsibilities of drivers," which had been touched upon in the first and second dialogues. Should the law protect drivers or manufacturers? In the context of issues at each stage of the evolution of automated driving, legal professionals, law students, and business professionals representing the automobile industry, who also participated in the second dialogue, exchanged opinions on the future relationship between humans and artificial intelligence (AI) from a legal perspective. As for the problems of fully automated driving, various views were presented from the positions of business and legal professionals. Concern was expressed that it would take a long time for society to understand automated driving, because the safety of automated driving vehicles remains unconfirmed. Some participants emphasized that it was difficult to discuss who should bear responsibility in general, because the situation would differ from case to case, such as the matter of maintaining accountability for functional limitations. Participants also said that the scope of product liability should be extended to programs and data rather than limited to tangible goods, that a scheme similar to the compulsory automobile liability insurance has to be established, and that because the first priority is to identify the cause of accidents, the persons in question should cooperate in the cause-identification process rather than being held liable for negligence. Therefore, criminal punishment should be avoided."

2.2. Outcomes achieved in FY2016

The citizens' dialogues in FY2016 achieved the following outcomes:

Creation of social acceptance of automated driving was discussed in the three SIP-adus citizens' dialogues. Various parties including university students and business and legal experts actively shared their views from a variety of angles. Their conversations deepened understanding of the technology, benefits, and issues related to the automated and cooperative driver support systems that are already realized. They also suggested directions automated driving should take in the future. In particular, it is a significant achievement of the citizens' dialogues that ideas generated by university students and other young people who, as mentioned earlier, will forge the future of automated driving, contributed innovative suggestions to existing norms. Furthermore, a survey of participants conducted after the citizens' dialogues showed that over 80% of participants were satisfied, that their understanding of automated driving had deepened, and that their expectations for the realization of automated driving had increased. These results demonstrate that this activity heightens social acceptance.

2.3. Activities in FY2017

In FY2017, SIP organized two citizens' dialogues as a forum for interactive communication to extract and analyze future needs, to discuss new awarenesses and visions, and to gain new insights through exchanges with the public. SIP conveyed accurate information through panelists, the general audience, and others who participated in the citizens' dialogues, and the outcomes, published on the SIP-adus website, received broad media coverage. While built on the achievements of the previous fiscal year, the FY2017 citizens' dialogues featured the following five elements:

(1) Collaboration with the Tokyo Motor Show: this popular event allows information to be spread widely among the public

(2) The first dialogue was designed to focus on the distribution of information and the second on dialogue among the public

(3) Active utilization of the ideas and perspectives of youth, who are the next- generation leaders

(4) Theme setting based on the perception of automated driving as an ecosystem, such as a city or MaaS rather than as an independent system

(5) The introduction of new approaches including online posting tools and graphic-enhanced recordings to collect the opinions of a large segment of the population and, as a result, activate dialogues

The first citizens' dialogue held in collaboration with Tokyo Motor Show was made possible through the joint cooperation of the event's organizer, the Japan Automobile Manufacturers Association. Through the positive effects of teaming with a large-scale external event, the SIP-adus citizens' dialogue attracted 399 applications and 311 visitors. The theme "Mobility and urban design" was decided with the intention of allowing the general public to find a personal relevance in automated driving in terms of travel and daily life by considering both transportation and cities as a combined living space, and to extract needs from future-oriented and public viewpoints by considering future urban design.

The session was divided into three parts: (1) imagining an ideal life and travel based on the issues and needs of current mobility and cities, (2) presentation of opinions on automated driving technologies necessary for an ideal life and travel, and on the ideal form of cities that adopt automated driving, and (3) sharing of opinions on the elements required to realize these ideals and future mobility and cities.

The audience was given an opportunity to post opinions online. In a post-event survey, 372 questions were posted online and 216 questionnaires were returned, providing many useful insights. The results of analysis of online responses are summarized below.

(1) The need to accurately convey information on automated driving

Many respondents perceived that the activities of SIP-adus were not correctly understood, expressed concerns about automated driving in terms of mixed traffic, and placed importance on safety and security. This made clear the need to correctly convey what is possible and what is not in order avoid overestimations or distrust of automated driving, and it made clear the existence of issues of how to convey what is possible and what is not. In addition, there was the opinion that sharing the vision for the future is an effective way of helping people to understand the yet-to-be realized technologies associated with automated driving.

(2) Responding to diverse needs

Although citizens' dialogues have been ongoing in Tokyo since the first year, a large part of the audience suggested the need for diversity, such as the participation of people from non-urban areas and the elderly. Also, some felt that the development of flexibility and agility would be necessary to respond to diverse needs.

(3) Attention also needs to be paid to factors other than the automobile industry

It is necessary to think about automated driving not as a singular thing but within a whole design that encompasses various elements, such as urban planning, changes in ways of working, regions, and attributes. Additionally, some respondents felt that logistics and parking-lot management may be improved by automated driving.

The second dialogue in FY2017 set the theme as "Future society and MaaS." Based on mega-trends including aging of the population, urbanization, and globalization, ideas were discussed on what kinds of needs would be created in life and travel in the year 2030, what kinds of services would meet those needs, what would be required to realize those services, and what roles automated driving would play in that context. The second citizens' dialogue led to awareness of the following:

(1) Future needs for MaaS

In addition to just moving to a destination, travel itself or other aspects can be the purpose of travel. The purposes of travel will become increasingly more diversified.

Travel can also become an opportunity for socialization and communication with others.

(2) Ideas for addressing needs

Data linkage will be important in service deployment. One issue is how to share data already owned by individual firms. In addition, increased added value by packaging, for example, will possibly spread and expand services.

(3) Toward realization of services

Another issue is how to best show people automated driving services that have not yet been realized.

Moreover, the concept of data collection and utilization in the minds of the public will change. The introduction of Internet of Things (IoT) technology may create opportunities for decentralized automated transportation that suits each region. Another issue is the necessity of a platform to consolidate travel-related data. Published data will be combined and used in transportation. It will be further processed by the private sector to provide customized services.

Collaboration will also become important. Existing transit guidance is effective in everyday life, but it cannot comprehensively address unexpected situations. Guidance for the best modes of travel requires data linkage.

2.4. Outcomes achieved in FY2017

The outcomes of the citizens' dialogues in FY2017 are summarized below. These indicate the directions of future research and development.

(1) Consideration of a decentralized automated model in line with regional characteristics

In the dialogues, the needs and issues concerning mobility were approached by members of the general public on the panel. A wheelchair user said, "I can drive by myself now, but as I get older I'm worried whether I'll be able to move about as freely as I can now." An exchange student from France commented that travel in Japan in the middle of the night was inconvenient. Also, while there were unique perspectives such as "ultimately I'd love for my house to move," it was also pointed out that in a disaster-hit area movement that is important to one person might be considered unreasonable to another. From the individual environments and backgrounds of the public panelists it became clear once again mobility is perceived as having diverse needs and issues.

Also, in metropolitan areas, particularly in the center of cities, public transportation networks are well developed and, although there are issues such as with commuting, it is non-urban areas that tend to have the most deep-rooted concerns in terms of regular transport. This was reflected in the opinions of the public panelists, and also in many of the people who responded to the questionnaire survey and online posting tool.

Many people also voiced expectations that automated driving systems could respond to more diverse needs. As shown in the survey analysis of the first dialogue and the awareness brought about from the second dialogue, opinions were that decentralized automated services would be an effective way of addressing needs that vary regionally. A nationally unified infrastructure environment should probably be somehow secured, also from a public notion. However, instead of simply expanding a standardized service, a decentralized automated model that matches different traits and regions, while securing a fixed platform for the whole of society, will probably be accepted by each regional area as something sustainable.

(2) The necessity of perceiving automated driving not as a singular thing but within the common social foundation

In the first dialogue about cities, and the second one about MaaS, it was understood that better services should be created by considering these services within the common social foundation, in which a variety of players are involved as an ecosystem. One of the speakers in the second dialogue explained that "there is a need for a platform that can smoothly and seamlessly match the needs of users who want to move with the suppliers of mobility, including trains and buses." People affected by the heavy snowfall in January raised the problems of fragmentary information on public transport operation and that information fails to respond to true mobility needs. For this reason, there should be a platform where data is linked and utilized across different businesses. However, multiple issues need to be resolved before such a platform can be built and operated. Also, in order to realize automated driving services, governments and private enterprises must work together on a common social foundation, fulfilling their respective roles as part of an ecosystem, thereby preserving sustainable socioeconomics.

(3) Offering a platform to convey information

Since the citizens' dialogues have a mission to bring about social acceptance, conveying information is an important function of these events.

While more information related to automated driving systems has become available in recent years, accurate information will not be conveyed to the public unless it is actively obtained out of interest. This is reflected in the first session's survey results that found around half of the participants were unaware of SIP-adus activities. There is a need to convey correct information on automated driving systems to those whose response to these systems is passive, and to avoid overestimations and information that is untruthful.

The citizens' dialogues were planned as a forum to bring together SIP-adus members, intellectuals, and the general public for mutually meaningful communication. Properly offering accurate information to the public at these occasions is highly significant in bringing about social acceptance.

There was also the opinion that actualizing services will also deepen understanding of these systems, further identify system needs, and cause these systems to be seen as something attractive.

(4) Future possibilities for citizens' dialogues

The first dialogue attracted a wide general audience by teaming the event with the Tokyo Motor Show. The fact that the dialogue was able to convey information to a large number of the general public can be considered a significant outcome in this research, whose objective is to foster social acceptance.

Conversely, we held the second dialogue with interested parties only. In terms of the dialogue with the public and the needs that were pointed out, the benefit of a smaller scale event is that it allows deeper conversations.

A total of 18 panelists from the general public participated this year. The event was held in the dialogue form to focus on interactive discussions, which resulted in a limited number of panelists per dialogue. Additionally, because the event was held in Tokyo, it was not possible to source issues and needs related to non-urban areas.

Another opinion expressed in the two dialogue sessions was that transport should match the separate issues of individual regions. This issue is best understood by the people living in these regions. It was concluded that, by holding citizens' dialogues in regions where interests are diverse, inviting participants from different walks of life, including the elderly and people engaged in child rearing, perhaps the needs and issues of mobility not understood in Tokyo will start to come forth.

2.5. Activities in FY2018

Over the past two years, the citizens' dialogues have revealed that in metropolitan areas public transportation networks are well developed, and that, although there are issues related to commuting, it is non-urban areas that tend to have the most deep-rooted issues. In these non-urban areas, while the aging of the population and depopulation accelerate the scrapping of public transportation networks, new means of travel are required to meet the needs of growing tourism. In addition, a sense of insecurity about mixed traffic still exists. Therefore, automated driving has to be accurately understood so that it is not overestimated or distrusted as it spreads socially.

Taking the above matters into account, FY 2018 activities will pay attention to regions interested in introducing automated vehicles as a public transportation system. In regions without public transportation and when the administrators of these regions express willingness to introduce roadside stations and automated driving systems across hilly and mountainous terrain, a dialogue-form meeting will be held on a per region basis to discuss the adoption of automated driving. Furthermore, at the Tokyo Motor Festival to be held in early October, a symposium on the safety and security of automated driving will be held with the aim of eliminating concerns and correcting/facilitating understanding about automated driving. In this way, efforts to create and increase social acceptance will be made to help realize automated driving.

3 Conclusion

Having started in FY2016, this project is now in its third year. The project has provided information on automated driving to various stakeholders and audiences, and has provided a platform for exchanging, summarizing, and analyzing the opinions expressed. The project has also provided a platform for extracting the needs, expectations, and concerns about automated driving. Guided by the project results, efforts have been made to further social acceptance of these systems. This activity has facilitated understanding of these systems through dialogues with the general public. It has demonstrated that it is a useful means of creating social acceptance for the incorporation of automated driving into the societal structures of Japan.

Next Generation Transport

Masayuki Kawamoto (University of Tsukuba)

ABSTRACT: As Japan's society ages, the percentage of traffic accident fatalities involving elderly people is increasing. For this reason, it is necessary to develop more flexible, efficient, and useful public transport systems. With this background, the SIP-adus Next Generation Transport Working Group decided to develop a partially automated driving system, in addition to the related services and advanced infrastructure applications for public transport. These services and applications include a precise docking system, an advanced public transportation priority system (PTPS) application, an Advanced Rapid Transit (ART) information center, and a walking assistance service system for vulnerable road users. We set the 2020 Tokyo Olympic and Paralympic Games as the milestone for the initial implementation of these systems.

Fundamental needs of Public Transport

More than half of traffic accident fatalities are people aged 65 years and older, and about 70% of those are pedestrians and bicycle users. Furthermore, more than 50% of elderly traffic accident victims lose their life within 500 meters from their home. To reduce the overall number of traffic accident fatalities, countermeasures are required from the standpoint of both vehicles and pedestrians.

Advanced driver support systems that assist elderly drivers whose driving skills have decreased with age have been proposed. However, since these systems include several controversial points, the best way to help elderly or handicapped people lead active lives through mobility is to promote more flexible transport systems with advanced accessibility characteristics.

Public transport systems are becoming more and more important. However, the limitations of public transportation, such as the relatively lower fares that can be earned from these systems and the necessity of making them available to all, make them hard to operate in depopulated areas. Although a fully automated bus service has the potential to reduce driver costs, high initial costs make these systems difficult to deploy. One potential solution is a combination of new technologies with a completely evolutional business model that has yet to be practically realized.

Advanced Rapid Transit (ART)

The initial objectives of this project were to improve the quality of urban public transport and to resolve the shortage of highly skilled bus drivers. One of the first working items was to develop an automated precise docking system for buses. This is a control technology that enables a bus to come alongside a bus stop precisely, without any large gap between the bus entrance and the edge of the bus stop. This will help wheelchair users and visual impaired persons to get on and off the bus without missing their step. Even skilled drivers need this system because it is a hard task to perform every time, especially when it is dark. Of course, this system will also help less experienced bus drivers as well. Buses using this system were given the name Advanced Rapid Transit (ART).

Development of Precise Docking System

SIP-adus was requested to implement some of items from our activity by the 2020 Tokyo Olympic and Paralympic Games. However, we realized that it would be too difficult to complete and transfer the specifications to a potential manufacturer within a year (considering that vehicle man-

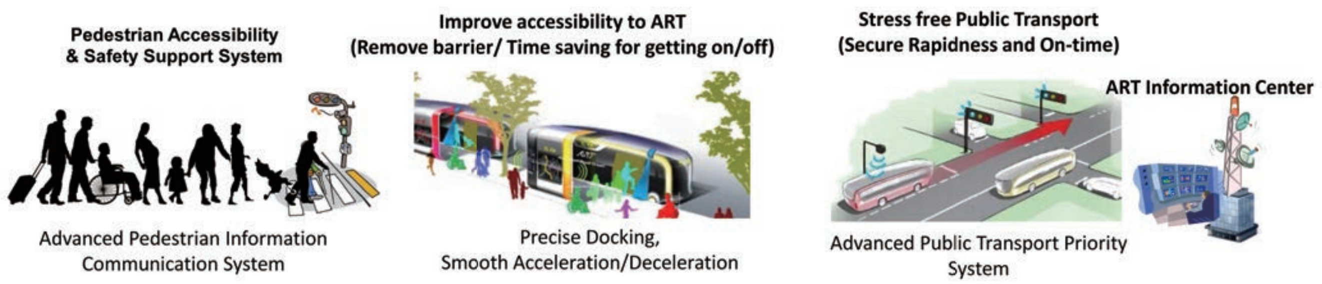


Fig.1 SIP-adus Next Generation Transport WG activity

ufacturers usually require a further three years for their work). Although we decided to utilize our basic specifications as much as possible, more reliable sensor hardware was needed to achieve production level quality, which meant that we had to use an existing product already on the market.

This tentative solution uses a dedicated optical guideway on the road surface. One concern about this solution was the possibility that general road users might misunderstand the meaning of this visible guidance line (unlike some examples in Europe, we planned to put this line on general roads).

To evaluate this concern, two types of experiments were conducted. One involved selecting the color of the guidance line to reduce the impact on general road users while also allowing robust detection by the precise docking system. Another involved proving ground testing with a variety of test subjects to see whether they misunderstand the line. According to these test results, road authorities were approved to use this system within limited locations. The authorities also asked us to develop a new system that does not use dedicated visible markers instead of this short term solution.

New System Development for Precise Docking

Two different approaches were conducted.

One used an invisible guidance line created by infra-red (IR) reflective paint that only IR cameras can detect and cannot be confused by general road users. One issue of this system is heat radiation from the road surface during sunny days in summer. Although some potential countermeasures were identified, we needed to give up this approach at the end of the fiscal year for several reasons.

The other approach involved a sensor fusion system that uses existing roadside objects, including road signs and structures around the bus stop, to detect the precise location. This system does not require any dedicated infrastructure. As some experiments have found very positive results, ensuring robustness would be a final key to reach the goal.

Advanced PTPS

Lack of speed and chronic operational delays are major reasons why bus transit loses value and service quality. Advanced public transportation priority systems (PTPS) can help to resolve these issues. These systems have a wide range and can cover large numbers of buses simultaneously around a targeted intersection using radio wave beacons. This feature provides the new capability of coordinating which bus of several approaching the same intersection should be prioritized. Flexible prioritization factors can be adopted, such as the number of passengers in the bus, or whether the bus is critically delayed or classified as an express. These factors and the priority threshold values can be controlled as required at the ART information center.

ART Information Center

From the standpoint of operational information, buses have the disadvantage of unstable time delays compared to other transportation, such as airplanes and trains.

In addition to the active involvement of PTPS prioritization, the latest AI and big data technologies can be used to estimate the delay time to individual destinations for each passenger more accurately with good probability. These are major requirements for the ART information center, as well as the two data handling requirements described below.

Congestion Prediction

Rather than vehicle congestion on roads, the ART information center handles congestion caused by the motion and behavior of pedestrians. The timing and method of information provision is important for people wishing to go to an event. Both congestion prediction before the event and real time feedback of the on-going situation are very important for information users. This information provision should also carefully consider various psychological factors.

Walking Assistant System

People using public transportation have to walk from their origin, as well as to their final destination. Walking assistant systems will be very helpful, especially for vulnerable road users such as wheelchair users, the visually impaired, and elderly people to find the optimum route with smaller barriers. One challenge of this approach includes the creation of a standardized open database. Although many kinds of trials are under way in several places, it will not be easy to gather the data from these trials into one single information platform. This project aims to provide an open template for this information.

Survey about Feasibility of Requirements for Next-Generation Urban Transportation System

Tatsuya Hashimoto (Advanced Smart Mobility Co., Ltd.)

ABSTRACT: To make it easier for bus users, including wheelchair users, to get on and off the bus, a survey was conducted to help develop an automated control technology that stops the bus so that the gap between the bus entrance and the bus stop is minimized. Section 1 reports the results of an investigation about the permissible gap and step between the bus entrance and the bus stop. Sections 2 and 3 describe the performance of recognition technology used for controlling the accurate arrival of the bus at a bus stop. Section 4 describes the performance of the arrival control using the recognition technology described in Section 3.

1 Clarification of Permissible Gap for Accurate Arrival Control of Bus at Bus Stop

1.1. Purpose of investigation

This survey investigated the steps and gaps between a bus stop and bus entrance, and defined the permissible steps and gaps that would allow wheelchair users to get on and off the bus.

1.2. Outline of experiment

As shown in Fig. 1, we made a wooden pedestal frame to simulate a bus stop, and used the terrace at the entrance of a building to simulate the entrance of a bus. We used a manual wheelchair and an electric wheelchair for the experiment. The test subjects were six healthy volunteers (ages: 20s to 60, one female test subject), who participated in the experiment after learning how to handle both the manual and the electric wheelchair adequately. There was no assistant, and the experiment was carried out in the ingress/egress environments listed in Table 1. Accessibility was evaluated using the four levels listed in Table 2.

Fig. 1 Experimental situation

Table 1 Implementation content

Evaluation Object	state
Step (4 pattern)	06mm, 18mm, 30mm, 42mm
Gap (4 pattern)	30mm, 45mm, 60mm, 75mm

Table 2 Evaluation index

Evaluation	Description
○	Easy access
△	Requires some effort
▼	Barely possible
×	Assistance required

1.3. Results of the experiment

Tables 3 and 4 show the results for the different step heights using the manual and electric wheelchair, respectively. Tables 5 and 6 show the results for the different gaps. From the evaluation results shown in Tables 3 to 6, the permissible step height was set to 30 mm and the permissible gap was set to 60 mm.

Table 3 Step difference evaluation using manual wheelchair

Step Value	Subject A	Subject B	Subject C	Subject D	Subject E	Subject F
06mm	○	○	○	○	○	○
18mm	○	○	○	○	○	○
30mm	△	△	○	○	×	△
42mm	×	▼	▼	▼	×	▼

Table 4 Step difference evaluation using electric wheelchair

Step Value	Subject A	Subject B	Subject C	Subject D	Subject E	Subject F
06mm	○	○	○	○	○	○
18mm	○	○	○	△	○	○
30mm	△	○	○	○	○	○
42mm	×	▼	▼	▼	×	▼

Table 5 Gap evaluation using manual wheelchair

Gap Value	Subject A	Subject B	Subject C	Subject D	Subject E	Subject F
30mm	○	○	○	○	○	○
45mm	○	○	○	○	○	○
60mm	○	○	○	○	○	○
75mm	▼	○	○	▼	▼	△

Table 6 Gap evaluation using electric wheelchair

Gap Value	Subject A	Subject B	Subject C	Subject D	Subject E	Subject F
30mm	○	○	○	○	○	○
45mm	○	○	○	○	○	○
60mm	△	○	○	○	○	○
75mm	×	○	○	▼	▼	▼

2 White Line Detection for Accurate Arrival Control of Bus to Bus Stop

A white line is laid along the path of the bus to the bus stop, and accurate arrival control is performed based on the amount of deviation between the white line as detected from the camera image and the bus.

2.1. White line detection algorithm

White line candidate points are extracted using the white line width. The widths of the white lines in the input images are made constant by converting the images to a bird's-eye view. Therefore, pairs of edge points with a fixed width can be extracted as white line candidate points. The white lines are detected by applying Hough transformation to the white line candidate points. Figure 2 shows example images from each processing step. The deviation amount is calculated by converting the image coordinates to the bus body coordinates.

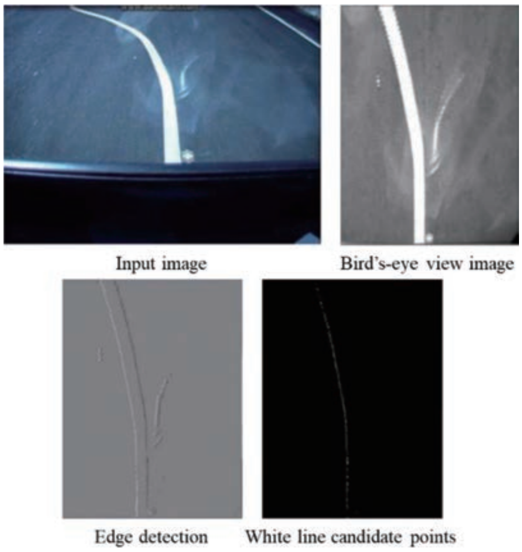


Fig. 2 Image processing example

2.2. Evaluation of white line detection

Figure 3 shows an example result of white line detection, and Figure 4 shows the evaluation results of the deviation amount, which indicates the detection accuracy. The amount of deviation was defined as the lateral distance between the white line and a point 3 meters ahead of the bus. In Figure 4, the vertical axis indicates the detection result, and the horizontal axis indicates the actually measured value. White lines were detectable with an error of ±15 mm up to a deviation amount of 0 to 1350 mm.

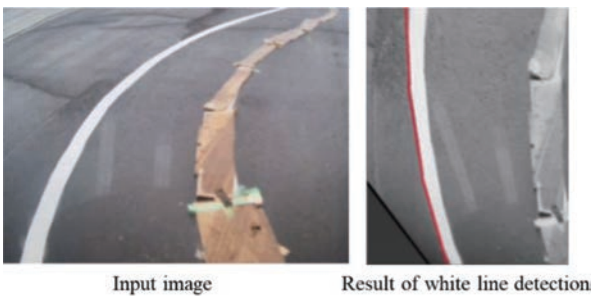


Fig. 3 Example of white line detection result

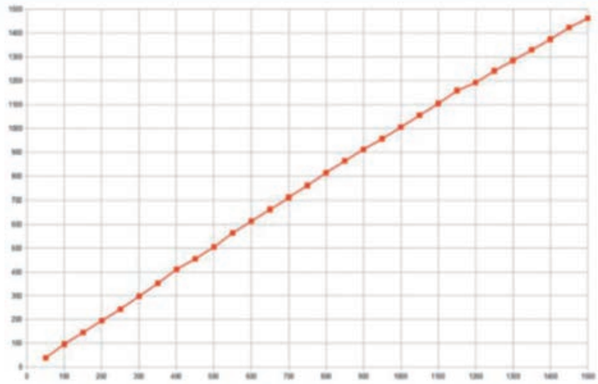


Fig. 4 Evaluation results of deviation detection accuracy

3 Curbstone Detection for Accurate Arrival Control of Bus to Bus Stop

The amount of deviation between the curbstone and bus is detected from a point cloud obtained using LiDAR, and accurate arrival control is performed based on the detected deviation amount.

3.1. Curbstone detection algorithm

The distance deviation d and angular deviation θ between the curbstone and bus as shown in Figure 5 are detected from the point cloud obtained by LiDAR. The normal of

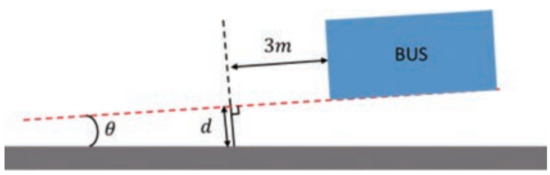


Fig. 5 Relationship diagram of required deviation amount

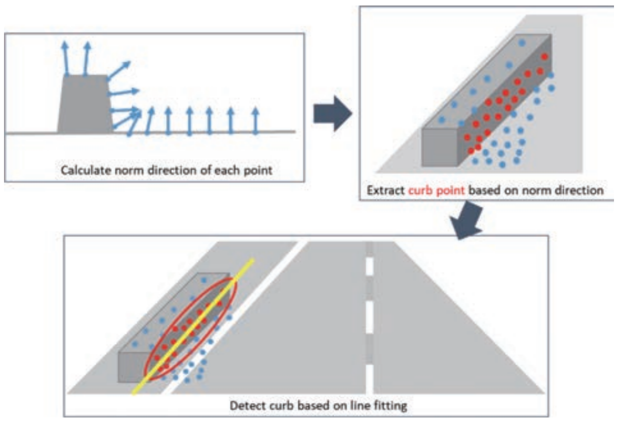


Fig. 6 Flow of curb detection process

each point is calculated, and points on the solid surface as indicated by the red points in Figure 6 are extracted as the curb candidate point cloud. The required amount of deviation is calculated by approximating the curbstone candidate point cloud with a straight line.

3.2. Evaluation of curbstone detection

As shown in Figure 7, LiDAR was attached to the front of the bus, and the accuracy of the detected deviation amount was evaluated using the arranged blocks as a simulated curbstone. Table 7 shows the detection results of the distance deviation amount. The deviation was detected with an error of 0.01 m or less. Table 8 shows the detection results of the angle deviation amount. The angle deviation was detected with an error of 0.7 degrees or less.

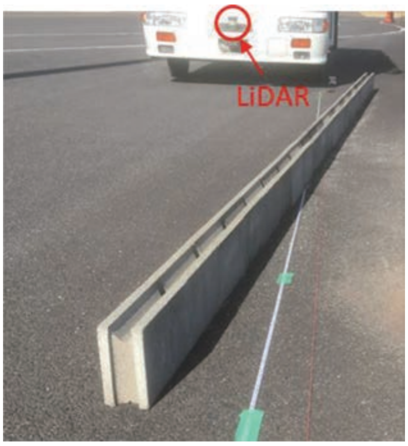


Fig. 7 Evaluation scenario

Table 7 Detection results of distance deviation

Observed value [m]	1.40	1.11	2.30	2.36
Detection value [m]	1.41	1.11	2.30	2.37
Error value [m]	0.01	0.00	0.00	0.01

Table 8 Detection results of angle deviation

Observed value [deg]	1.1	5.6	-5.3	1.5
Detection value [deg]	1.4	5.9	-4.9	2.2
Error value [deg]	0.3	0.3	0.4	0.7

4 Accurate Arrival Control of Bus to Bus Stop Based on Curbstone Detection

The arrival control accuracy of a bus to a bus stop based on curb detection using LiDAR was evaluated. Figure 8 shows the system configuration based on path-following control (1). From the results of the wheelchair ingress/egress experiment in Section 1, the target of the gap between the bus entrance and the curb at the bus stop was set to 4 cm ± 2 cm. As shown by the experimental results in Figure 9, an evaluation was performed 10 times and confirmed that the bus arrival control can be performed with the target accuracy.

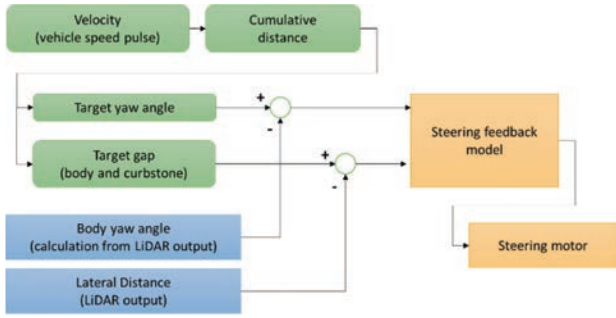


Fig. 8 system configuration

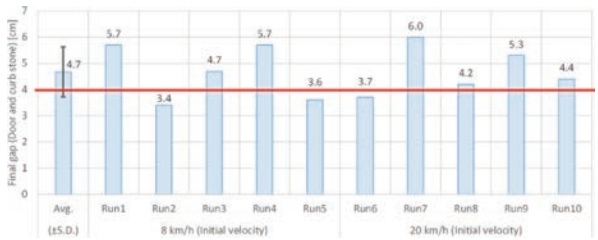


Fig. 9 Results of bus arrival control experiment

Reference

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

About the author

1) Tatsuya Hashimoto, Environmental Recognition Technology Development, Engineering Div., Advanced Smart Mobility Co., Ltd.

Development of Sensing and Control Technology for Precise Docking of Advanced Rapid Transit system

Sadahiro Kawahara (JTEKT Corporation)

ABSTRACT: This research is part of the Strategic Innovation Promotion Program(SIP)/Autonomous driving system project and examines the issues of the so-called Advanced Rapid Transit (ART) automated driving system, which is considered to be a promising next-generation transport system for urban areas. This article describes the docking control project, which aims to clarify basic control issues related to sensing, steering linkage, integrated control with the brakes, and so on. These items are being researched and development to realize docking maneuvering technology with excellent functionality.

1 Overview

A precise docking control system, i.e., an automated precision docking control strategy that aims to minimize the gap between the entrance of a bus and a bus stop, is an important part of realizing a high-quality advanced Rapid Transit (ART) system. Automated precise docking control should contribute to the smooth and safe embarkment and disembarkment of passengers, including the disabled and parents with strollers. This system must be robust in various environments and achieve the best route for docking even in severe conditions. It should also achieve smooth braking and steering control to prevent accidents on the bus and improve passenger comfort. Cooperative docking control with the bus driver should also contribute to enhanced safety.

2 Issues for Precise Docking Control

Steering systems for large vehicles like commercial buses or trucks usually have a complicated structure. The transfer characteristics of the steering system may be asymmetric or non-linear because of long linkages or free play at mechanical connection points. This is one of the difficulties that must be overcome to realize a precise docking control system. Since this issue is difficult to solve through mechanical improvements, the addition of a phase advance control algorithm that compensates for the asymmetric or non-linear steering system characteristics may be an effective countermeasure.

This section described the measurement of steering system characteristics such as phase delay. Factors related to precise docking ability were investigated based on measured steering and vehicle behavior, and a concept for precise docking control was identified.

2.1. Test mule and system structure

2.1.1. Test mule

A large bus was used as a test mule. Figure 1 shows the appearance of the test mule and Table 1 lists its specifications. The axle load was measured with the driver present.

Fig. 1 Appearance of test mule (large bus)

Table 1 Specifications of test mule (large bus)

Wheelbase (mm)	6,000
Track (mm)	Front: 2,065, rear: 1,820
Axle load (kg)	Front: 3,545, rear: 6,590

2.1.2. Precise docking control system

Figure 2 shows the structure of the precise docking control system. Calculation for the docking control is performed using an integrated control ECU (dSPACE GmbH: MicroAutoBox II(*a)). Distance to the lane separation line is supplied by a camera (Mobileye, Inc.: ME560(*b)) and RTK-GPS system (GeneSys Elektronik GmbH: ADMA-G-ECO+(*c)). Vehicle yaw angle, yaw rate, and acceleration values are supplied by a gyro sensor (MEMSIC, Inc.: NAV440(*d)) mounted on the floor of the passenger compartment close to center of vehicle gravity. The vehicle velocity and running distance are calculated from wheel speed pulses.

The steering angle and deceleration commands calculated by the integrated control ECU are sent to the steering actuator ECU and braking control ECU.

(*a) Trademark of dSPACE GmbH
(*b) Trademark of Mobileye, Inc.
(*c) Trademark of GeneSys Elektronik GmbH
(*d) Trademark of MEMSIC, Inc.

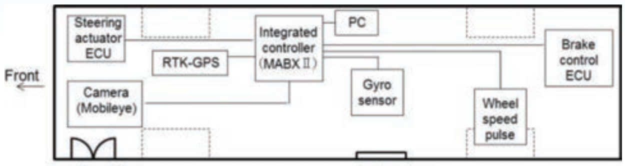


Fig. 2 Control system

Calculation for steering angle commands is based on the path following control method.[1] The basic concept of this method involves following an assumed trajectory (target trajectory).

The target angle δc is calculated by equation (1).

$$\delta_c = \frac{MV}{2K_f}\left[\frac{2(K_f l_f - K_r l_r)}{MV^2}\gamma + \frac{2(K_f + K_r)}{MV}\beta + \omega_r - K_2 e_2 V - K_3 \sin e_3\right] \quad (1)$$

V : velocity, M : vehicle weight, β : slip angle, γ : yaw rate,
lf : distance from gravity center to front axle,
lr : distance from gravity center to rear axle,
J : yaw moment of inertia, Kf : cornering power of front tire
Kr : cornering power of rear tire
e_2 : deviation of x direction,
e_3 : deviation of yaw angle,
ωr : yaw rate of reference vehicle,

Figure 3 shows a block diagram of the control system. The target trajectory is installed as a lookup table to define the lateral distance between the vehicle and the lane separation line against the travel distance. The lateral gap e_2 between the measured and target value is estimated. The heading angle difference e_3 is estimated from the heading angle output of the camera or the RTK-GPS system.

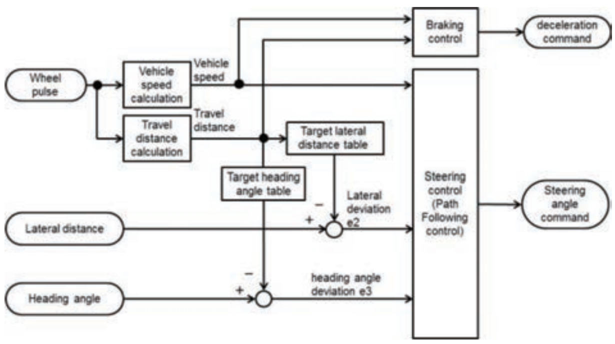


Fig. 3 Control system block diagram

2.1.3. Steering system

The steering system of the test mule consists of hydraulic power steering integrated with a ball screw type gear box. Figure 4 shows an overview of the steering system. The actuator for steering angle control is mounted on the steering column. This actuator receives commands from the integrated controller and controls the steering angle using the PID control algorithm. The lateral displacement of the tie rod is measured as an alternative value to the tire angle.

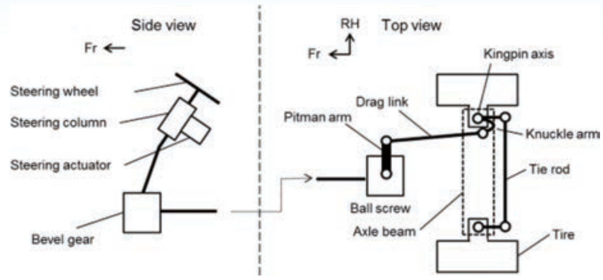


Fig. 4 Overview of steering system

2.1.4. Brake system

An electronically controlled brake system (WABCO Holdings Inc.: EBS[*e]) controls the braking force along with signals from other controllers. Figure 5 shows an overview of the braking control system.

The braking control ECU receives deceleration commands from the integrated controller, calculates the air pressure for each wheel, and sends commands to the braking control unit.

[*e] Trademark of WABCO Holding Inc.

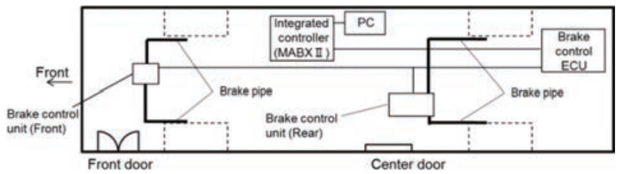


Fig. 5 Overview of braking control system

Table 2 compares the target and actual deceleration value. The characteristics are not linear and the variation is not small.

Table 2 Comparison of average target and actual deceleration (N: 5)

Target value [m/s^2]	Actual value [m/s^2]	Actual/Target
−0.2	−0.198	0.98
−0.5	−0.636	1.27
−1	−1.25	1.25

To avoid the effect of these characteristics, the following control method was introduced to achieve a precise longitudinal stopping position. The target deceleration is calculated from the travel distance S, the assumed stopping position St, and velocity v, using equation (2).

$$a = \frac{v^2}{2(St - S)} \quad (2)$$

a : deceleration, S : travel distance,
St : assumed stopping position, v : velocity

When the difference between the actual and target deceleration, or the deceleration deviation is large, the target deceleration is compensated continuously to adapt to the situation at that time using this calculation. This method also helps to reduce jerk. The target deceleration is also corrected to reduce the adverse effects of the difference between the actual and target deceleration following equation (3).

$$a' = \frac{a}{x} \quad (3)$$

a' : Corrected deceleration, x : Coefficient for correction

The correction coefficient x is estimated considering the deceleration at that timing, based on the results shown in Table 2.

2.2. Improvement of precise docking system algorithm

2.2.1. Optimization of control gain

In the current control method, gain k_2 for compensating the lateral distance is constant in the docking control and other modes. Figure 6 shows an example of lateral distance results using constant control gain k_2 fitted for a straight line trajectory. This result indicates that the error increases during docking control after a distance of 180 meters.

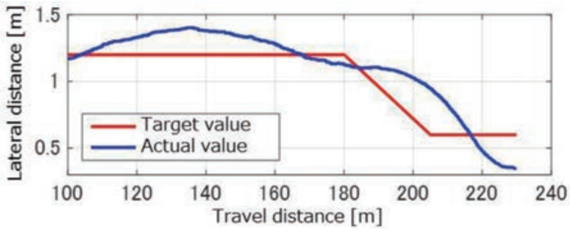


Fig. 6 Vehicle movement under control gain fitted for straight trajectory

A control method was introduced that selects one of two values for gain k_2 based on whether the bus is traveling in a straight line or performing a docking procedure. Figure 7 shows the example of the results using this gain selection method. The difference between the target and actual values is reduced, demonstrating that this is an effective control method for achieving the planned trajectory.

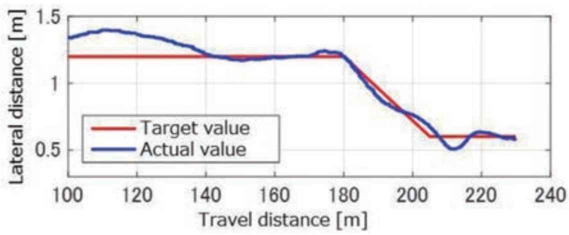


Fig. 7 Vehicle movement under separate control gains fitted for straight or docking trajectories

2.2.2. Compensation for free play of steering linkage

Mechanical free play exists in normal steering systems, and the free play in the steering system of large vehicles, such as this test mule, is larger than in normal passenger cars. This large free play has adverse effects such as delay on the control results. A compensation control method was studied to improve this issue. Figure 8 shows the relationship between the steering and tire angles in a sine wave command. The tire angle response is delayed from the steering angle. The amount of free play is estimated as a steering angle of 11 degrees.

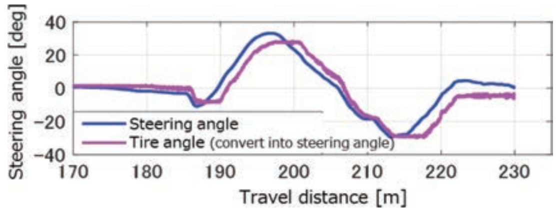
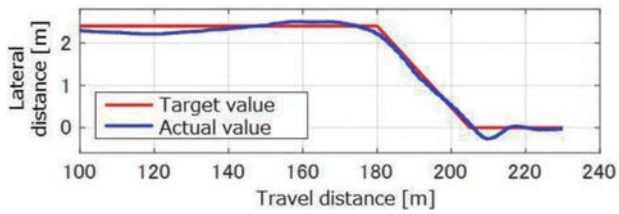
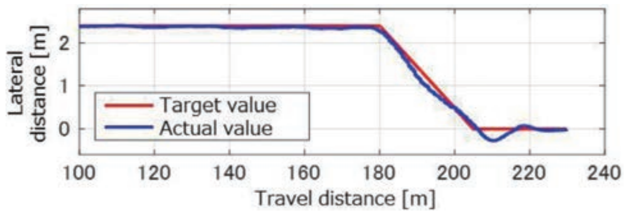


Fig. 8 Relationship between steering and tire angles

The steering angle command is estimated considering these characteristics created by mechanical free play. When the angle command direction is reversed, the free play value is added to the angle command. Figure 9 shows the difference in trajectory with and without free play compensation. Lateral movement is reduced especially on straight trajectories.



(a) Without compensation of steering free play



(b) With compensation of steering free play

Fig. 9 Improvement by compensation of steering free play

2.2.5 Braking control

The brake system is controlled based on equation (2). The deceleration command is 0.5m/s^2 in the initial braking area

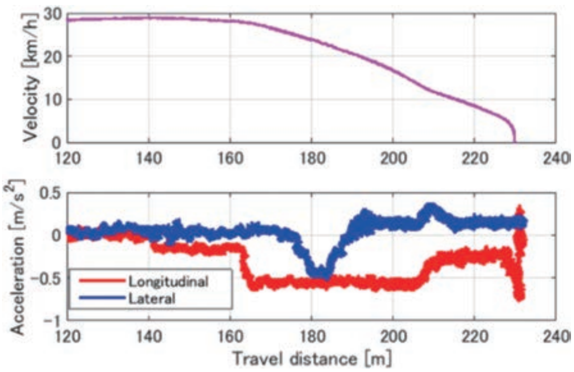


Fig. 10 Vehicle movement under braking control

and 0.2m/s^2 at the stopping position. This method contributes to reducing the braking distance and accidental deceleration deviation at the bus stop. Figure 10 shows an example of vehicle behavior with braking control.

3 Study of Issues Toward Minimization of Infrastructure

A fundamental study into multiple sensing methods and cooperation between sensors is in progress with the aim of realizing more precise docking.

3.1. Characteristics of RTK-GPS and front camera

To build a better sensing device selection method, the characteristics of the RTK-GPS and front camera system were measured. Figure 11 indicates the lateral position difference between the RTK-GPS and front camera. This value relates to the actual distance. The value from the camera is delayed compared to the value from the RTK-GPS (0.3sec).

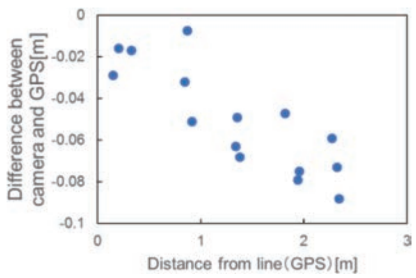


Fig. 11 Distance difference between camera and RTK-GPS

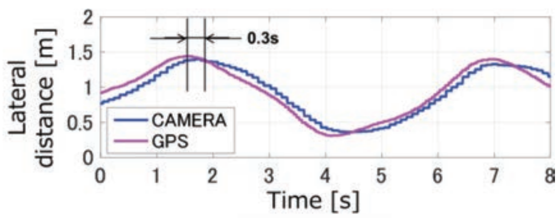


Fig. 12 Time difference between camera and RTK-GPS

The lateral movement is at a similar level as shown in Fig. 13.

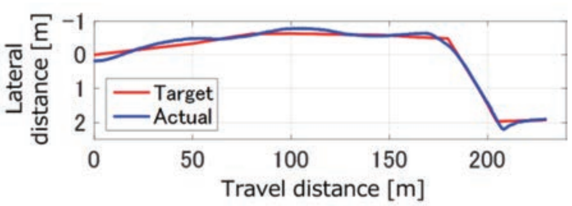


Fig. 13 Vehicle movement using RTK-GPS data

3.2. Future study of sensing for precise docking control

The sensing resolution with RTK-GPS or front camera images is insufficient to realize further accurate control, and additional infrastructure is necessary. For example, specific guidance lines or magnetic markers on the road, side cameras for boundary and position detection of painted lines or curbstones to improve accuracy, and Lidar should be considered.

Multiple sensing methods are preferable to achieve sufficient accuracy under every condition, and a better sensing method should be selected or a cooperative sensing procedure should be adopted.

4 Compatibility of Driver Operation and Automated Control

In the case of a level 1, 2, or 3 automated system, the driver is required to avoid pedestrians and other objects during the docking procedure. Since one of the concerns in this procedure is a delay in the driver's avoidance operation, sharing of responsibility by the driver and automated driving system is preferred. In this case, the driver should always be aware of the driving operation.

This research proposed and evaluated the effect of a prototype system operated based on driver intention (measured using an input force from the driver). This system proposes that the driver should always be touching the steering wheel. Driver steering characteristics using the proposed system were evaluated and analyzed using a driving simulator.

The adoption of a shared control method in the automated docking control system should be studied based on this result.

5 Conclusion

The effect of steering system delay with respect to vehicle behavior was investigated as part of the study into actuators and controls for an ART system.

The prototype system described above was evaluated, and it was found that the proposed system concept of shared control is effective.

However, since the targets for this system are difficult to achieve with current buses, items to be developed to achieve integrated steering and braking control are being investigated.

Current position recognition capabilities are not sufficient to achieve the targets under all environments. Difficult to detect disturbances must also be considered, for example the impossibility of detecting objects in the dead areas of vehicle-mounted sensors.

Further research and studies to solve these issues are required in the future.

References

(1) Jun Yoshida, Toshiyuki SUGIMACHI, Takanori FUKAO.: Autonomous Driving of a Truck Based on Path Following Control. Transactions of the Japan Society of Mechanical Engineers Series C., Vol.77, No.783, p. 4125-4135 (2011).

(2) Sadahiro Kawahara, JTEKT Corporation, BR Next Generation Transpotation System Promoting Section, General manager, Vehicle dynamics and Human machine interface

Survey about Precise Docking of Next-Generation Transportation Systems for Strategic Innovation Program (SIP) – Automated Driving System

Ryohta Wakai (The Institute of Behavioral Sciences)

ABSTRACT: Precise docking at bus stops is a key technical requirement for achieving the practical implementation of the next-generation Advanced Rapid Transit (ART) transportation system. Among the control methods for precise docking that are being studied in this research and development project, the road surface guidance lines described in this article are regarded as an effective means of reducing control error. However, some concerns remain, such as their use on roads not used by buses, on which they may cause needless driver confusion. This study investigated guidance lines for precise docking that are readable by cameras mounted on ART vehicles, and conducted several verification experiments to confirm their safety. The effect of this precise docking system on the driving behavior of ordinary vehicles and the recognition rate of these guidance lines were investigated in experiments held at a test course.

1 Introduction

1.1. Purpose of the Survey

This project studied guidance lines for precise docking that are readable by cameras mounted on Advanced Rapid Transit (ART) vehicles, and several verification experiments to confirm their safety were conducted. Through verification in the laboratory and on a test course, we investigated how well the vehicle-mounted cameras recognized the guidance lines, the effect of the guidance lines on the driving behavior of ordinary vehicles, as well as the recognition rate and control error of a precise docking system.

1.2. Study Flow

This study was conducted in the following order:

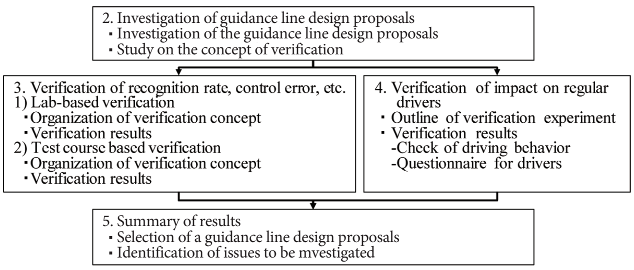


Fig. 1 Study Flow

2 Investigation of Guidance Line Design Proposals

2.1. Guidance Line Design Candidates

When a vehicle passes over guidance lines installed on the road, drivers are inclined to turn the steering wheel toward the roadside or step on the brakes. Therefore, we must consider design proposals for guidance lines that ordinary drivers will not confuse with official traffic lines and that can be recognized by vehicle-mounted cameras. Specifically, we studied guidance line design proposals taking the following into account.

1) Colors used for road markings such as white, yellow, red, and blue should not be used.
2) To allow the camera to recognize the guidance lines, use a guidance line color with a high contrast ratio with the color of the underlying pavement.
3) A proposal that includes putting markings on the road to indicate bus-only use should be considered.
4) We also considered a design that changed the shape of the guidance lines.

* The guidance lines are double-dotted lines that can be recognized by the camera to be used.

Based on the above, the following six proposals were used as the design proposals.

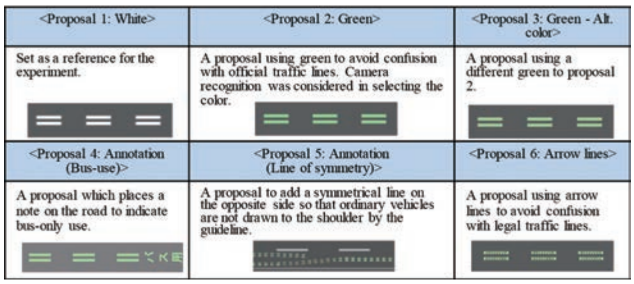


Fig. 2 Guidance Line Design Proposals

2.3. Narrowing Down the Guidance Line Design Proposals

Finally, we selected one proposal from these six proposals based on the results of verification performed in the laboratory and on the test course. The criteria for narrowing down the proposals were as follows, based on the results of preliminary consultations with relevant organizations.

Table 1 Narrowing Down the Guidance Line Design Proposals

Performance index	Overview
1) Likelihood of confusion by ordinary drivers	It is necessary to confirm that there is no negative influence on ordinary drivers, such as noticeable effects on driving behavior.
2) System recognition performance	System recognition performance might be lower due to using green instead of white.
3) Legal compliance	Displays that could be confused with official traffic lines could violate the Road Traffic Act.
4) Construction practicality	In the real-world implementation phase, it is necessary to consider construction and maintenance costs, as well as the construction period.

3 Lab-based Verification

3.1. Overview of Verification

We verified the guidance lines in the laboratory by measuring the image contrast ratio of camera recognition for the different guidance line colors under various lighting conditions, etc. Since the experiment results showed that the recognition performance of the system was satisfactory, the guidance line color and other specifications were selected.

In the laboratory experiment, test pieces consisting of different guidance line colors and underlying pavements were exposed to light simulating daytime sunlight and nighttime street lights, to measure the image contrast ratio of camera recognition. The conditions used in the verification experiment in the laboratory to confirm the system recognition performance were as follows.

Table 2 Conditions of Verification Experiment in the Laboratory

<table>
<tr><td colspan="2" rowspan="3">Test Piece</td><td>Color</td><td>White, green A, green B, green C, orange, pink, purple, blue</td></tr>
<tr><td>Reflecting material</td><td>Glass beads, AWT, Bright Grip</td></tr>
<tr><td>Base</td><td>Asphalt, red iron oxide, heat-insulating pavement</td></tr>
<tr><td rowspan="4">Time</td><td rowspan="3">Day</td><td>Sunshine</td><td>Morning, midday, evening (reproduced with lights)</td></tr>
<tr><td>Light dir.</td><td>Front-lit, backlit, angle</td></tr>
<tr><td>Wetness</td><td>Dry, wet</td></tr>
<tr><td>Night</td><td>Street lamps</td><td>With/without street lamps</td></tr>
</table>

3.2. Overview of Verification Results

The following results were obtained from the lab verification:

1) Guidance line colors

While both green B and A had an image contrast ratio close to white during the day, green B had a higher measured image contrast than A. Therefore, green B was used as the candidate for green.

2) Reflecting material

The contrast ratio of the glass beads and AWT (a high-performance product) was almost equal, and the "Bright Grip" product had a slightly lower contrast ratio. Since AWT costs 1.5 times as much as (general-purpose) glass beads, a relatively inexpensive general-purpose material can be used.

3) Base material

The contrast ratio of red iron oxide is approximately 0.1 lower than that of asphalt. Even white guidance lines cannot be recognized by the system on top of heat-insulating pavement.

4) At night

Even green B has a contrast ratio which is approximately 0.1–0.2 lower than that of white guidance lines. The required luminosity is 60 lux or more.

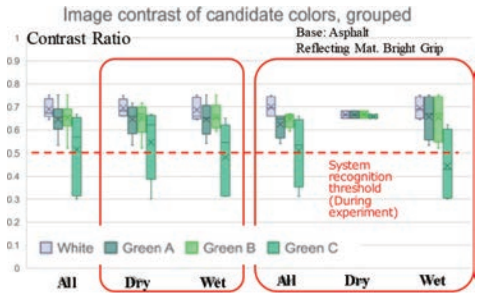


Fig. 4 Basic Performance Evaluation: Morning / Sun / Evening + Dry / Wet

4 Test Course-Based Verification

4.1. Overview of Verification Experiments

4.1.1. Overview of Verification Experiments

The effect of the guidance lines on ordinary drivers was studied on the test course. Test drivers drove on a test course marked with guidance lines while their driving behavior was monitored, and driver awareness during driving was then evaluated by a form-based survey.

The verification experiments were carried out for three days (Sunday, Feb. 11 to Tuesday, Feb. 13, 2018). We used the V2X Urban Proving Ground Course in Tsukuba, which is owned by the Japan Automobile Research Institute (JARI) as the test course. A total of 32 test drivers participated in the experiments, considering the balance between genders and age groups.

Based on the results of prior investigation, we selected proposal 1 (reference) (guidance line 2: white), proposal 2 (guidance line 1: green), proposal 4 (guidance line 3: "For Buses" marking) as the guidance line patterns used in the verification experiments.

A schematic diagram of the test course is shown below:

① Development of Next-Generation Urban Transportation Systems

Survey about Precise Docking of Next-Generation Transportation Systems for Strategic Innovation Program (SIP) – Automated Driving System

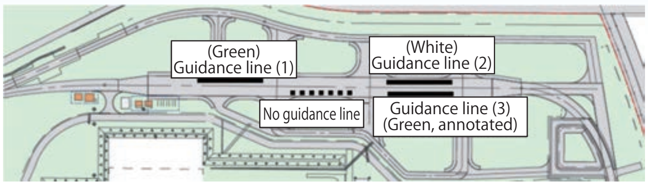


Fig. 5 Test Course for Driving Experiments

4.1.2. Details of Verification Experiments

In the verification experiments, each test driver drove through four sections: three with guidance lines and one without. We measured the traveling speed and position (lateral direction) to check the operating situation of the brakes and steering wheel while driving along the guidance lines, and observed the physical effects. Here, we used GPS data at one-second intervals to measure the traveling speed and recorded the traveling position by taking video images showing the distance to the roadside line using a camera mounted on the vehicle. We also conducted a form-based survey immediately after the test drivers drive over the guidance lines for the first time and after passing over all the guidance lines to ask them how they reacted when they noticed the guidance lines. Because drivers are especially strongly affected when seeing the guidance lines for the first time, the test drivers were grouped into three groups and the driving routes were set so that each group experienced a different type of guidance line first.

4.2. Verification of Effect on Drivers Passing along Guidance Lines

4.2.1. Effect on Braking

The effect on braking when passing through the guidance line section was verified. During the first experience (first sight) of the guidance lines, the average traveling speed of all the test drivers and the standard deviation variance did not differ depending on the type of the guidance lines. Although the behavior of individual test drivers showed no rapid deceleration (defined as 0.3 G as a value indicating a sudden surprise), some test drivers released the accelerator to reduce speed a little.

4.2.2. Effect on Steering

The effect on steering when driving through the guidance line section was examined. Although no major differences were observed depending on the type of the guidance line, there was an overall tendency to drift to the right. No major differences were observed between the areas with and without guidance lines. The behavior of individual test drivers showed a lateral change of approximately 20 cm for each guidance line.

For the guidance lines 2 (white) and 3 (text marking), we checked the driving behavior of three test drivers with large steering wheel operation. One driver drove to the right side within the range of the lane in the case of guidance line 2 (white), while the other two misunderstood that guidance line 3 (text marking) was a bus-only lane, and drove along the guidance line section from right to left.

4.3. Verification on Effect of Guidance Lines on Driver Awareness

The main results obtained from the form-based survey about the guidance lines after the first experience and after passing over all the guidance lines were as follows:

Table 4 Main Answers to Form-based Survey

	Main answers
First experience	・For guidance line 1 (green), one test driver was uneasy because there was no explanation. ・Three test drivers recognized guidance line 2 (white) as an indication to move to the left. Two test drivers moved to the right to avoid driving on the line. ・Six test drivers saw the “For Buses” marking of guidance line 3 (text marking) and recognized the marking as being for a bus lane.
Second experience	・Among the test drivers who first drove on guidance line 3 (text marking), one test driver correctly recognized guidance lines 1 and 2 as “Being related to buses, and not for me.” ・One test driver saw the “For Buses” marking for guidance line 3 (text marking) during the second drive, and changed lanes thinking that it was a bus lane.

4.3. Verification Test Results on Test Course

Based on the results of both the lab-based and the test course-based verification, we decided to employ guidance line 1 (green).

Table 5 Results of Guidance Line Selection

No	Guidance line (1)	Guidance line (2)	Guidance line (3)
Characteristics	Green	White	Text marking: For Buses
Legality	Good	Bad	Good
System recognition performance	Good	Best	Good
Construction practicality	Good	Good	Good
Likelihood of confusion	Good	Good	Fair

*We evaluated construction practicality based on the results of interviews with suppliers who mark road surfaces.

5 Conclusion

This study verified the color and other elements used for guidance lines for precise docking from the viewpoints of legal compliance, system recognition, construction practicality, and likelihood of confusion with official traffic lines. As a result, we decided to employ guidance line 1 (green B). However, in the real-world implementation phase, it will be important to let various users on public roads understand that these guidance lines are for buses, together with the benefits realized by precise docking in order to increase safety. It will be necessary to convey the importance of the guidance lines and precise docking among the general public, verify the recognition performance of the guidance lines under conditions other than the test environment (on public roads, at night, etc.), and investigate how to install, maintain and manage the guidance lines in the real-world implementation phase.

Examination of Enhancement of Bus Priority Control in Next-Generation Urban Transport Systems

Toru Mabuchi (UTMS Society of Japan)

ABSTRACT: Next-generation urban transport systems are being developed in order to ensure safe and smooth traffic around the venues of the 2020 Tokyo Olympic and Paralympic Games, and to secure means of transportation for the elderly in Japan's super-aging society. The UTMS Society of Japan developed a system that performs bus priority control using vehicle-to-infrastructure communication via the 700 MHz radio frequency and conducted verification through field operational tests. The equipment specifications and communications standards established in this development will be adopted as standard specifications to promote future the introduction and dissemination of the system.

1 Purpose and History of the Development

1.1. Purpose of PTPS enhancement

The Universal Traffic Management System promoted by the National Police Agency of Japan aims to realize a safe, comfortable, and environmentally friendly traffic environment through the provision of real-time traffic information to drivers using two-way communication with individual vehicles via infrared beacons, and through the active management of traffic flow. As a sub-system of UTMS, Public Transportation Priority Systems (PTPS) have already been put into practical use.

In recent years, driving safety support systems (DSSS) using vehicle-to-infrastructure communication via the 700 MHz radio frequency band have been practically implemented. Because the roadside radio equipment of these systems is installed near intersections and provides a communication range of several hundred meters, this radio equipment also has the potential to be utilized for PTPS. In order to resolve various issues with the existing PTPS, the UTMS Society of Japan is working to enhance these systems using vehicle-to-infrastructure communication via the 700 MHz band.

1.2. Background of the development

In fiscal 2014, studies and research were carried out, including surveys about the current situation of public road transport, as well as current situation surveys and literature surveys and analyses about bus priority control.

In fiscal 2015, requirements for the enhancement of PTPS were identified and a basic design was developed.

In fiscal 2016, a central computer was developed by equipment manufacturers in accordance with the basic design and a model system was set up in Tokyo by the Tokyo Metropolitan Police Department. An on-board unit supporting the system was also developed by an automotive manufacturer. In parallel, design verification was conducted through simulations.

In fiscal 2017, using the above-mentioned model system, effectiveness verification was performed in a real-world environment involving vehicles.

2 Details of PTPS Enhancement

2.1. System design policies

This system was designed to enhance PTPS, which are currently realized by infrared beacons, through the utilization of the 700 MHz radio frequency band. The enhanced system was designed to satisfy the main PTPS upgrade requirements shown in Table 1. These enhancement requirements were compiled and determined based on the results of questionnaire surveys performed at each prefectural traffic control center, as well as the results of interviews bus companies, with consideration also given to the viability of the system.

Table 1 Main requirements for enhanced PTPS

No	Requirements
1	The performance of priority control must be improved by taking advantage of the benefits of wireless communication
2	Equipment costs, construction costs, etc. must be reduced by covering multiple routes with one unit of equipment
3	System construction costs must be low (modification costs for the existing equipment must be low).
	Coverage of PTPS must be expanded.
4	Routes with bus stops
5	Routes where infrared beacons cannot be installed (bridges, elevated roads, etc.)

2.2. Bus priority control function

(1) Purpose

A PTPS that uses infrared beacons estimates a bus arrival time at an intersection using bus passage information collected by infrared beacons installed upstream of the intersection. However, because the arrival time is predicted using a design speed containing a certain margin, one issue is the wasted green traffic signal time resulting from the difference with the actual speed. To resolve this issue, the performance of the priority control was improved.

(2) Functional overview

Figure 1 shows a conceptual diagram of the system and Fig. 2 shows an example of green traffic signal extension ("green extension") control operation. The ITS roadside radio equipment receives real-time vehicle information (described below as "vehicle-to-vehicle communication information") transmitted over the 700 MHz radio band from a bus equipped with an on-board unit supporting the system and traveling toward the control target intersection.

Based on the vehicle location data included in the vehicle-to-vehicle communication information received from the bus, the system determines the passage of the bus through the first bus passage check point (passage determination point), estimates the arrival time of the bus at the intersection using a design speed close to the actual speed, decides whether to provide priority control at the intersection, as well as the operations to be provided (green extension/red truncation), and then performs signal control. The system further determines the passage of the bus through the second passage check point located around 50 m upstream of the stop line, estimates the bus arrival timing at the stop line using a design speed with an adequate margin, and provides a further green extension as needed.

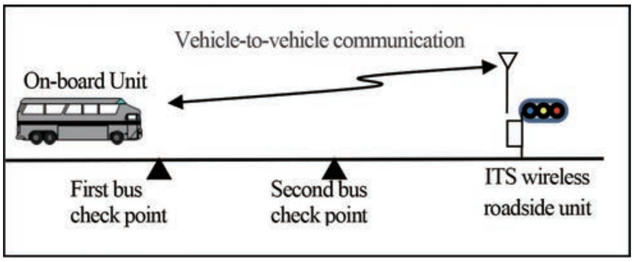


Fig. 1 System image

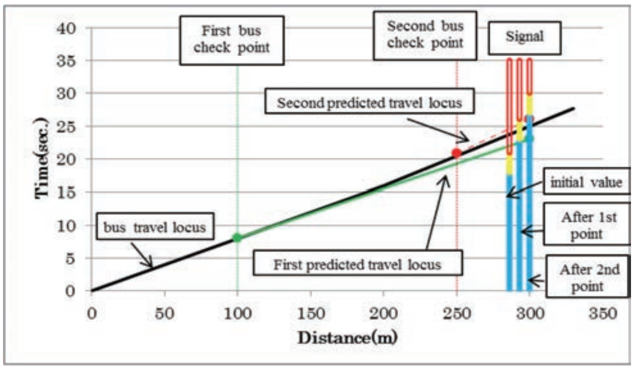


Fig. 2 Example of green extension control

(3) System configuration

Figure 3 shows the system configuration. The bus ID, priority request information indicating the presence of a priority request, and vehicle-to-vehicle communication information are sent from the on-board unit to the ITS wireless roadside unit. Service information, such as the bus passage checkpoint loci, maximum green extension time, maximum red truncation time, and the like are sent from the ITS wireless roadside unit to the on-board unit.

The ITS wireless roadside unit determines the passage of the bus through the bus passage check point and sends the priority request information to the central computer. The central computer sends signal light information to a signal controller based on the timing of the priority request information, by which signal control is performed.

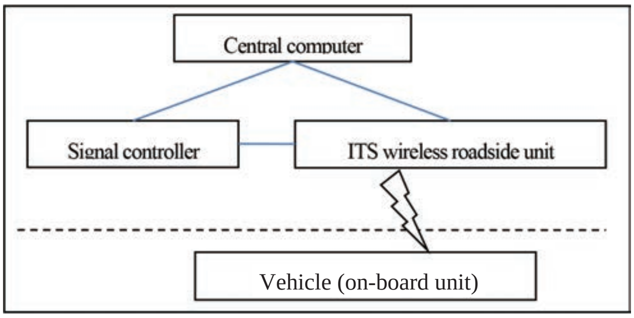


Fig. 3 System configuration

3 Effectiveness Verification

3.1. Effectiveness verification by simulations

(1) Outline of effectiveness verification

The purpose of the effectiveness verification by simulation was to confirm the system's effectiveness in advance and in theory prior to verification with a model system, and also to confirm effectiveness under various conditions that cannot be tested with a model system. To this end, verification was carried out using a microscopic traffic flow simulator on a virtual route of about 3.5 km with ten intersections and on a model route with the target intersection in front of Tokyo Wangan Police Station.

(2) Main verification items and results of verification on virtual route

The verification of basic functions in dedicated bus lanes confirmed that the enhanced PTPS can reduce bus travel times by 4% or more compared to the existing PTPS. Even without dedicated bus lanes, the enhanced PTPS was able to reduce bus travel times by about 3.9% to 5.8% compared to the existing PTPS.

The analysis of maximum green extension times confirmed that bus travel times can be further reduced by about 8% by changing maximum green extension times from 10 to 20 seconds. However, since this increases travel times on minor roads, a decision needs to be made for each intersection on which the system is to be introduced.

Analysis of the negative effects of GNSS positioning errors confirmed that, when positioning errors are within the range of +/- 30 m, the effect on the reduction in travel time is 0.5% or lower.

(3) Main verification items and results of verification on model route

The verification of basic functions confirmed that the enhanced PTPS can reduce bus travel times by about 2% compared to the existing PTPS. This value is almost identical to the expected value calculated in theory. Therefore, the priority control was judged to be operating as designed.

To validate the number of bus passage check points, a simulated comparison was made between cases with two and three points, the results of which confirmed that bus travel times can be very slightly reduced by 0.1% when three points were provided. However, considering that the existing signal controllers cannot be used for realizing such a system and because of the low cost effectiveness of providing three points, a system with two check points was judged optimal.

3.2. Effectiveness verification using model system

(1) Outline of effectiveness verification

The purpose of the effectiveness verification using a model system was to verify system operation under various real environmental conditions, to verify design methods, and to identify the influence of parameters on the effectiveness of the system, thereby obtaining findings capable of maximizing the effects of such parameters with a view to implementing the system in other areas in the future.

The verification was conducted using the model system installed in fiscal 2016 by the Tokyo Metropolitan Police Department at the intersection in front of Tokyo Wangan Police Station and test vehicles (two buses, one light truck and three passenger cars) prepared by automotive manufacturers.

https://maps.gsi.go.jp/

Fig. 4 Test site (Tokyo Odaiba area)

(2) Main verification items and results of verification

Before implementing the bus priority control, the range of ITS wireless communication using the 700 MHz band and the GNSS accuracy were checked. Some routes are covered by radio communication with a range of about 300 m or more, and others with a range of about 200 m. Therefore, confirmation is necessary for each area where the system is introduced. GNSS accuracy errors are a few meters or less in most areas, with relatively large errors observed on route 3, which was assumed to be due to the effects of buildings beside the road.

In the verification of bus priority control operation, three operation cases (with green extension control, without red truncation control, and without control) were confirmed to be operating normally based on the logs in the on-board units and central computer. In particular, it was confirmed that green extension times were extended appropriately at bus passage check point 2 (see “Figure 5 Green extension control results”).

The effectiveness evaluation at the intersection downstream of the bus stop confirmed that effective priority control can be achieved by setting the first bus passage check point further upstream, although it is difficult to predict the bus acceleration status.

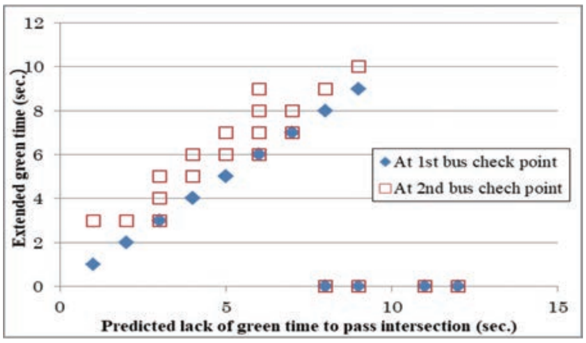


Fig. 5 Result of the green extension control

4 Conclusion and Future Issues

Through the real-world verification using ITS wireless roadside units, on-board units, and a central computer supporting the enhanced PTPS, it was confirmed that bus priority control using the 700 MHz ITS wireless communication is achievable.

The operation verification required time and effort because logs had to be collected from on-board units and the central computer, respectively for analysis. It would be desirable to realize a function that can readily determine the success, failure, and effectiveness of bus priority control. Also, when applying the system to intersections where large GNSS errors are detected, it is recommended that the accuracy of GNSS be confirmed in advance and the occurrence of wasteful green traffic signal time be verified after applying the system.

A Study on the Speediness and Safety of Advanced Rapid Transit

Daisuke Oshima, Akira Mitsuyasu, Takane Imagawa (Pacific Consultants Co., Ltd.)

ABSTRACT: This study on the speediness and safety of the Advanced Rapid Transit (ART) system involved the building of on-board units for a Public Transportation Priority System (PTPS), and the evaluation of the effectiveness of the resulting Advanced PTPS. Specifically, the basic requirements were designed for the advanced PTPS on-board units, which communicate with roadside units that control traffic signal timings (i.e., to extend the green light interval or truncate the red, based on bus locations sent by the on-board units). These units also have a priority arbitration function, which grants priority over other buses when a bus meets the criteria for priority, as well as an HMI function, which notifies the priority status information and supports passage through the intersection. The extent to which Advanced PTPS improves timeliness and speediness, and its effects on general traffic were evaluated. It was clarified that Advanced PTPS and priority arbitration can improve both speediness and timeliness.

1 Overview

A Public Transportation Priority System (PTPS) is a means for improving the timeliness and speediness of buses running among general traffic. PTPS ensures priority for public transportation by means of priority signal control, which controls the timing of traffic signals to allow public transportation vehicles to pass through signalized intersections without stopping, and includes the introduction of priority roads for public transportation. PTPS has been introduced throughout Japan. A vehicle-to-infrastructure communication system using optical beacons, which is conventionally used in PTPS, communicates once before the vehicle enters an intersection. In contrast, the National Police Agency, which oversees traffic managers across Japan, considered that more flexible priority signal control could be realized by utilizing the 760 MHz band that had been allocated to ITS following the digitalization of terrestrial television broadcasting, and the Agency has been examining the development of roadside units (roadside ITS radio sets, hereinafter referred to as “roadside units”) for that purpose. Therefore, the following research and development has been conducted in the current project from FY2015 to FY2018:

(1) Examination of the functional requirements for on-board units that communicate with Advanced PTPS roadside units and the building of prototypes

(2) Simulated evaluation of the extent to which Advanced PTPS improves timeliness and speediness and how it affects general traffic

(3) Evaluation of the effectiveness and influence of Advanced PTPS through a field operational test

(4) Research into the introduction requirements, issues, and effectiveness of the nationwide deployment of Advanced PTPS

2 Examination of Functional Requirements for On-Board Units that Communicate with Advanced PTPS Roadside Units and Building of Prototypes

2.1. Functions of Advanced PTPS

A conventional PTPS detects the passage of target vehicles using an optical beacon installed at only one point upstream of an intersection, predicts the timing of arrival of the vehicle at the intersection, and extends the green signal or truncates the red. Meanwhile, by using 760 MHz band radio communication, Advanced PTPS can (1) improve communication performance over obstacles and distance, (2) allow continuous communication, (3) allow interactive communication, and (4) cover buses on all approach routes with one beacon. These measures will help to overcome the restrictions on installation locations for PTPS roadside units, reduce the introduction cost, react to vehicle speed changes in real time, inform the bus driver of the status of priority control on the relevant approach route, and detect the approach of multiple buses and determine which bus is to be prioritized. This research aimed to develop on-board units with the following three functions.

The first is a function for communicating with the roadside units. A roadside unit has two determination points (the first and second virtual beacon positions) upstream of an intersection to detect the passage of a bus, predicts the time of arrival of the bus, which is making a priority request, at the intersection at each point, and controls the signal timing (extends the green light interval and truncates the red) in two stages accordingly. Meanwhile, the on-board unit transmits position information, the validity of the priority request, and other information to the roadside unit so that the unit can detect the passage of the bus. The second function is the HMI, which allows the on-board unit to identify the priority control status by receiving downlink information (e.g., DSSS signal information)

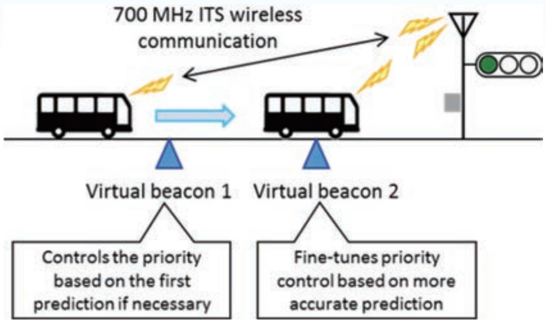


Fig. 1 Image of multistage control in Advanced PTPS

from the roadside unit so that the unit can assist passage through the intersection (acceleration/deceleration support), while providing the driver with priority request information. Figure 2 shows the intersection passage support on the screen of the HMI under development. If the signal turns yellow when a bus enters a signalized intersection and the bus brakes hard, it is dangerous since it may cause passengers in the bus to fall over. Therefore, minimizing the frequency of buses stopping in signalized intersections, while providing drivers with intersection passage support information, contributes to safer bus operation. The third function is priority arbitration. For example, if several buses approach an intersection at the same time, this function transmits "Priority request: Valid" to the roadside unit only for a bus that urgently requires priority due to a significant delay or the like, and "Priority request: Invalid" for other buses of lower priority, so that the bus in urgent need is prioritized. The validity of the priority request is determined by the on-board unit by comparing the vehicle status index with the preset threshold (the criterion for priority). For the priority index, the delay time, congestion degree, combinations thereof, and specific time zone and route designation were examined. In addition, more appropriate priority arbitration may be possible by identifying the bus that urgently needs priority in real-time from the real-time operation status of multiple buses. Therefore, two approaches were tried: the first used a fixed threshold preset in the on-board unit (static threshold), and the second used a threshold that was successively updated based on the operation status of multiple buses (dynamic threshold) in collaboration with the ART Information Center function, which is separately conducting

Fig. 2 Intersection passage support screen

research and the like. Determining the threshold based on the operation status of multiple buses was accomplished by multiplying the highest priority index by a certain coefficient. Among the priority indices, "crowdedness" was defined based on an approximate classification of the number of passengers estimated by the ART Information Center function using in-vehicle cameras.

2.2. Examination of functional requirements for on-board units and building of prototypes

An Advanced PTPS on-board unit was designed to transmit and receive information using a 760 MHz band radio set, identify the vehicle status from the information provided by GPS and CAN, obtain information in collaboration with existing bus location systems and the ART Information Center function, which is separately conducting development, determine the priority request necessity, and provide appropriate information to the driver using HMI such as displays. The main requirements are listed in Table 1. In addition, an on-board unit that meets the requirements was developed. As shown in Fig. 3, the unit consists of an on-board PC connected with a 3G USB dongle for 3G communication, a sensor unit for receiving GPS information and vehicle speed pulses, a monitor with an HMI function, an antenna for 760 MHz communication, and a 760 MHz radio set.

2.3. Functional verification

Functional verification of the developed on-board unit was carried out using passenger cars and the roadside unit installed at the intersection in front of Tokyo Wangan Police Station in FY2017. The results confirmed that the on-board unit worked as designed: that the setting information can be transmitted correctly between the vehicle and infrastructure, and that the HMI of the on-board unit is accurate enough to inform the driver of the priority status. Figure 4 shows the difference in time required for vehicles to pass through the signalized intersection resulting from the extension of the green signal, which was confirmed through the verification. The priority arbitration function was also verified. Specifically, the on-board unit was confirmed to be able to determine the validity of the priority request of the vehicle based on the threshold preset in the unit and to transmit the validity information to the roadside unit. Furthermore, the on-board unit was confirmed to be able to determine the threshold after considering the ART statuses (the delay time and congestion degree) of multiple vehicles in collaboration with the ART Information Center function, and then determine the validity of priority request accordingly.

Table 1 Main requirements for an Advance PTPS on-board unit

Requirement	Description
Communication	· Transmit the vehicle status, including the vehicle position and vehicle speed, as well as PTPS priority request to the roadside unit. · Receive information on the availability of the PTPS service, signal information, and other information from the roadside unit. · Transmit and receive bus operation information and management information to and from the ART Information Center.
Situation identification and determination	· Obtain information on the shape of the intersection, positions of virtual beacons, and signal indications. · Identify the operational status, including the delay time and congestion degree, in collaboration with the bus location system and the ART Information Center. · Identify the signal information and the validity of priority request. · Determine whether the vehicle can pass through the intersection during a green signal and calculate the target deceleration.
Information to driver	· Inform the driver of the validity of the PTPS priority request. · Provide the driver with intersection passage support information.
Priority arbitration	· Compare the priority index of the vehicle with the threshold for priority request in collaboration with the ART Information Center, and transmit the priority request to the roadside unit if the index exceeds the threshold.

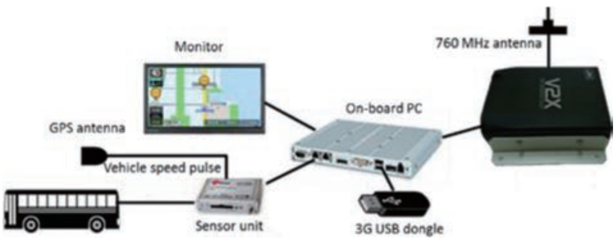


Fig. 3 Configuration of the Advanced PTPS on-board unit

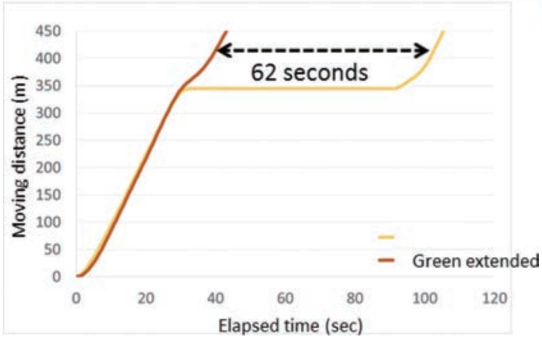


Fig. 4 Difference in transit time due to extension of green signal time

3 Simulation Evaluation of the Extent to which Advanced PTPS Improves Timeliness and Speediness and How it Affects General Traffic

The extent to which Advanced PTPS improves timeliness and speediness, and how it affects general traffic were evaluated through simulation using the micro traffic simulation software "VISSIM."

3.1. Verification on Tokyo Ring Road No. 2

Simulated verifications were carried out in some sections (Kachidoki intersection, Harumi 5-chome intersection, and Toyosu New Market intersection) of Tokyo Ring Road No. 2, as shown in Fig. 5. The results showed that introduction of PTPS reduced the travel time by approx. 30 seconds (about 7%) (Fig. 6). Priority arbitration decreased the maximum delay from the schedule by 69 seconds (about 8%). Priority arbitration also decreased the average delay time by approx. 30 seconds (about 13%). Furthermore, due to variation in delay time, the dynamic threshold is less dispersed than the static threshold after priority arbitration (Fig. 7).

3.2. Simulated verification assuming a virtual local city

Simulated verification assuming a local city other than Tokyo was carried out by constructing a virtual network as shown in Fig. 8. A network was constructed to include a main road running east–west and two narrow east–west streets sandwiching it, intersecting with five main roads running north–south and several narrow streets parallel to them. Then, the road through which the eastbound and westbound buses pass (hereafter referred to as the "center main road," see Fig. 8) was changed to a two-, four-, or six-lane road in order to simulate several cases of road structures and regulations. Advanced PTPS was set up at each of three signalized intersections in the center of the center main road.

② Sophisticated Local Transportation Management

A Study on the Speediness and Safety of Advanced Rapid Transit

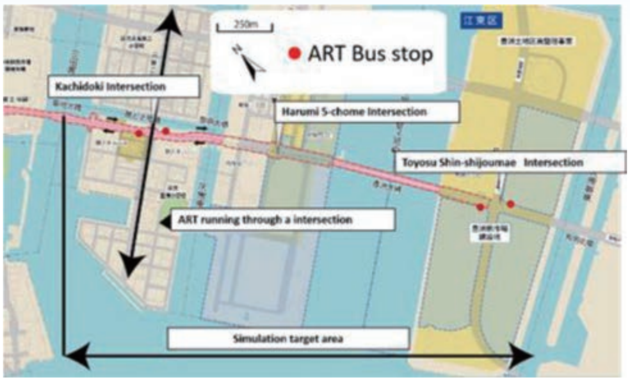


Fig. 5 Simulated verification sections of Tokyo Ring Road No. 2

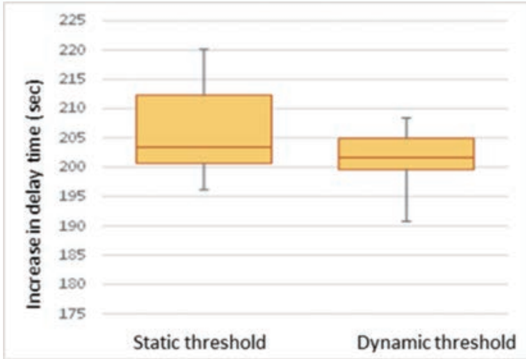


Fig. 7 Results (Variation in delay time)

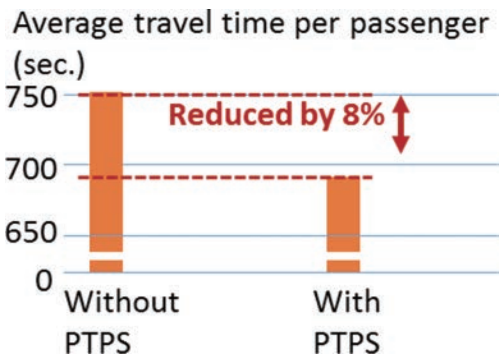


Fig. 6 Results (travel time)

As a typical result, Fig. 9 shows the number of buses delayed by five minutes or more in terms of average travel time per passenger on a six-lane road. On the four- or six-lane road with a dedicated bus lane, the average travel time of buses was found to be significantly reduced, also resulting in less variation in travel time. Moreover, it was shown that additionally introducing Advanced PTPS reduced the average travel time by more (reduced by 16% in the case of a six-lane road), significantly improving the speediness and timeliness of buses.

4 Evaluation of the Effectiveness and Influence of Advanced PTPS through Field Operational Test

To verify the improvement effect on the speediness of buses, a field operational test using the roadside units installed at three points on Tokyo Ring Road No. 2 is scheduled to be conducted from November, 2018. Two route bus-size buses will be used for the test. The test is scheduled to be performed along a section from the Toyosu Market Entrance to the Ariake Station area on Tokyo Ring Road No. 2 where Advanced PTPS roadside

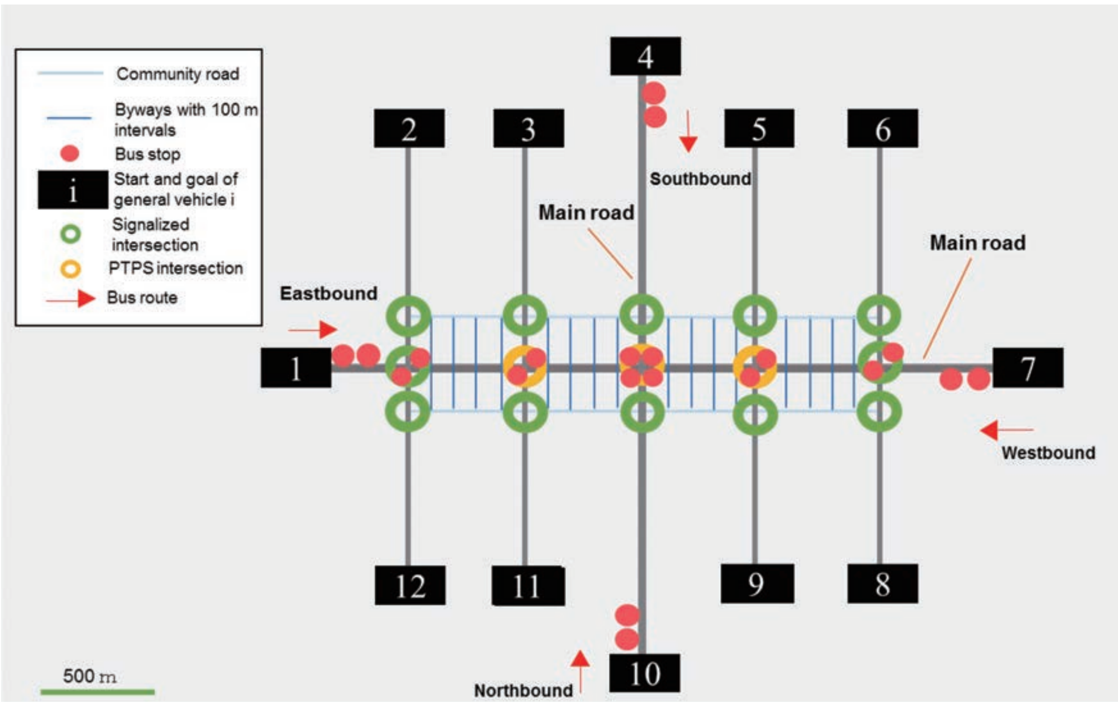


Fig. 8 Simulated virtual network assuming a local city

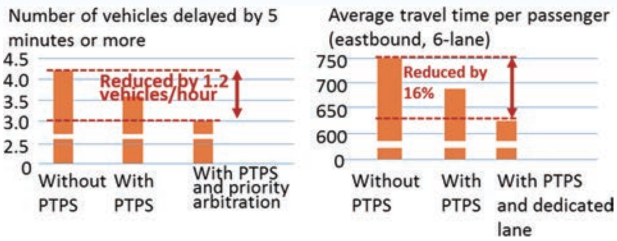


Fig. 9 Results (Average travel time and number of delayed vehicles)

units have already been installed. For details, refer to "Large-scale Field Operational Tests on Advanced Rapid Transit."

5 Research into Introduction Requirements, Issues, and Effectiveness of Nationwide Deployment of Advanced PTPS

5.1. Introduction requirements and issues

To identify the feasibility of introducing Advanced PTPS in cities across Japan, a survey of relevant organizations such as local governments and bus companies was conducted mainly in areas where bus rapid transit (BRT) was recently introduced and areas that are considering introducing BRT. The results showed that the challenge ahead is how to ensure the speediness and timeliness of buses and that many local governments, especially those that are considering introducing BRT, need to introduce PTPS in order to solve the challenge. However, issues of project cost and gaining a consensus on introducing PTPS were also found. In one area where PTPS using optical beacons has already been introduced, there was an opinion that although beacons need to be updated, it is difficult to quickly introduce new types of facilities due to the cost. Meanwhile, Advanced PTPS controls multiple routes and intersections with one roadside unit. Therefore, if the superiority of Advanced PTPS over optical beacons in the initial installation cost can be demonstrated, it may possibly persuade organizations to introduce Advanced PTPS. There was also an opinion that it is difficult to gain a consensus on introducing PTPS. To do so, it is important to present the quantitative effects of PTPS by, for example, estimating the effects on general traffic in addition to the improvement in speediness and timeliness of buses.

5.2. Simulation verification assuming a local city

In the future, we plan to select two cities from the area surveyed, simulate bus operations on actual bus routes in the cities, and verify the effects of introducing Advanced PTPS.

6 Conclusion

This research showed the following:

(1) Regarding the examination of functional requirements for on-board units that communicate with Advanced PTPS roadside units and building of prototypes, the basic requirements for Advanced PTPS were examined, and prototypes were built based on the results. One of the features of the prototype unit is that it supports a priority arbitration function, that is, when several ART vehicles approach an intersection at the same time, the PTPS on-board unit in each ART vehicle determines the priority of the vehicle and determines the validity of the priority request, so that the vehicle to be prioritized is determined appropriately. In addition, by linking with the ART Information Center function, it was possible to dynamically control the priority considering the operation statuses of multiple ART vehicles.

(2) Regarding research into the introduction requirements, issues, and effects of the nationwide deployment of ART and Advanced PTPS, a survey of relevant organizations such as local governments and bus companies was conducted. The results showed that many local governments need to introduce Advanced PTPS but there are issues of project cost and gaining a consensus.

(3) Simulated evaluations of the extent to which Advanced PTPS improves timeliness and speediness, and how it affects general traffic were carried out using a road network in a virtual local city and Tokyo Ring Road No. 2. The results showed that Advanced PTPS and priority arbitration can improve both speediness and timeliness. In the remaining research period, we plan to conduct demonstration experiments on public roads as well as simulations in order to confirm the effectiveness of Advanced PTPS on actual public roads. We also plan to verify its effectiveness through simulation in local cities with a view to nationwide deployment. In the future, it will be necessary to coordinate actual installation with bus companies and local governments in areas where there is a strong need for PTPS, examine the HMI of the PTPS on-board unit and the method of priority arbitration after considering costs and operation, and make proposals according to the local situation, to encourage the actual introduction of Advanced PTPS.

② Sophisticated Local Transportation Management

Development of ART Information Center Function

Chiemi Tsuchiya, Kojin Yano, Miyu Tsukamoto, and Junko Ushiyama (Hitachi, Ltd.)

ABSTRACT: The functions of an Advanced Rapid Transit (ART) information center were investigated to help realize services using ART-related information and to associate various public traffic information. Experimental receiving/publishing data APIs were produced to realize five ART information center functions. A bus information-provision service for bus users was developed to exemplify the function of utilizing the information collected and stored in ART information center platform. We plan to investigate the usefulness of the information and the service provided by ART information center function in a large scale field operational test from October to November 2018.

1 Purpose

An Advanced Rapid Transit (ART) information center is an open platform for the collection and utilization of information related to public transportation. Its purpose is to help resolve transportation-related issues by providing valuable information and services to both the operators and users of public transportation, including ART (Fig. 1). In this report, we describe platforms within the ART information center and a bus information-provision service as an example of the utilization of the information collected and stored in the ART information center platform.

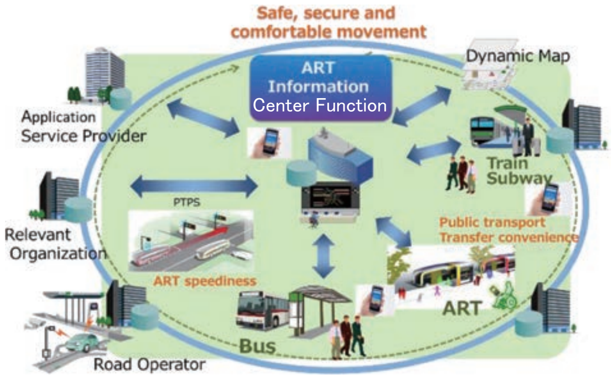


Fig. 1 Overview of ART information center function

2 Functions and Services of ART Information Center

We defined the following two rules for the ART information center. One is to collect and store information related to public transportation, such as bus operation information and various information obtained from on-board devices in the ART system or buses. The other is to modify the information collected and stored into an easy-to-use format and share it with traffic business operations and application developers. The functions of the ART information center and information provision services are shown in Fig. 2. The information collected and stored in the ART information center, such as information from the on-board devices in buses, is shown in the upper part. The information and services provided to business operators of public transportation and passengers are shown in the bottom. The following five functions of the ART information center are shown in the middle.

- PTPS priority mediation function
- Getting on/off announcement support function
- Degree of crowding announcement support function
- Dynamic connection announcement support function
- Forecasting of congestion function

The getting on/off announcement support and forecasting of congestion functions were developed in collaboration with SIP-PJ "Improving the speediness of ART with advanced PTPS" and SIP-PJ "Investigation of methods for forecasting traffic congestion and guiding congestion avoidance", respectively. These functions collect and store traffic information, which is processed in accordance with each user's requirements and shared with them. As a result, the information given by the ART information center will help passengers to utilize public transportation more conveniently.

2.1. ART information center platform

The ART information center is composed of five functions as shown in Fig. 3. In the inbound data platform (1) and data portal platform (2), the common interface and APIs are prepared so that plural business operators can utilize different data structures in various system applications. Six APIs for receiving data were developed (e.g., a bus location data-receiving API and a bus crowding information-receiving API). Six APIs for publishing data were also developed (e.g., a PTPS priority decision-providing API and a target bus estimated time of arrival (ETA)-providing API). The data format, such as longitude and latitude, depends on the business area and data processing systems. Therefore, the ART information center also has a data format transformation function. The data storage and analysis platform (3) collects data using the APIs, modifies/transforms the data in accordance with the users' purposes, and shares the data with them. The support platform for application developers (4) supplies the application developers with the data stored in the ART information center using the development support tool/function. The

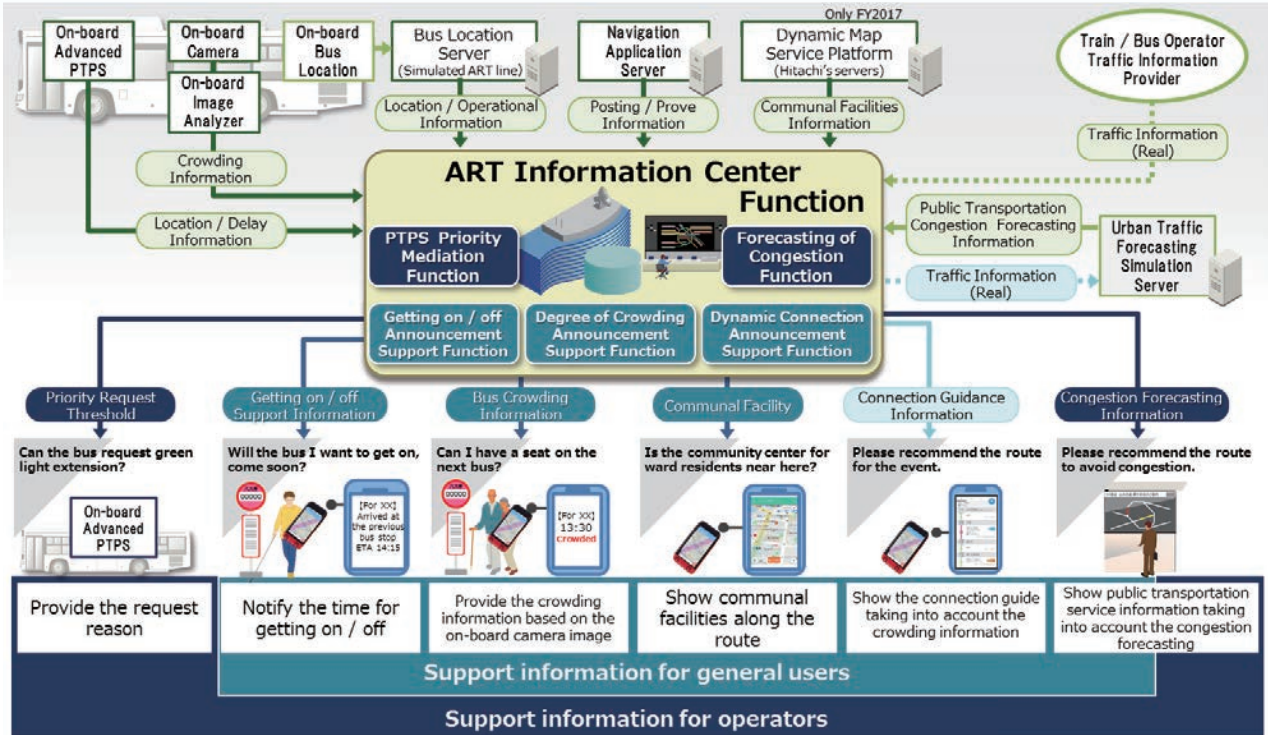


Fig. 2 Functions of the ART information center and information provision services

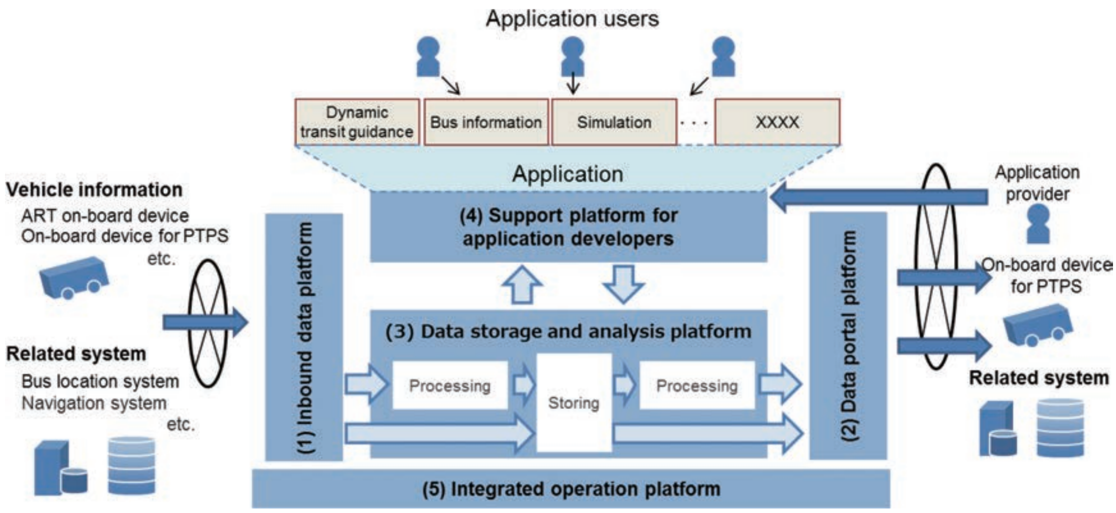


Fig. 3 Block diagram of the ART information center platform

integrated operation platform (5) manages security and resources by controlling the ART information center.

2.2. Bus information provision service

In the SIP-PJ "A research of the pedestrian support system common platform", field verifications were performed with the cooperation of people with limited movement capabilities, such as visually impaired people and wheelchair users. As a result, the necessary information for transfers was studied and evaluated. It was found that these people want to know how close an approaching bus is to them and how close their bus is to the destination bus stop. Information on approaching buses on each route is already provided in some areas. However, it is difficult to specify which bus should be selected when the bus stop serves plural routes. It is important to supply bus passengers with information about the approaching bus that they want to ride and information about how close the bus is to the destination bus stop from their point of view. We developed an application that notifies bus passengers about how close and how crowded approaching buses are to exemplify the function of utilizing the information collected and stored in the ART information center platform. The application is run on two smartphone platforms (Android OS and iOS).

The outline of the information service about how close and how crowded approaching buses (hereinafter called the "bus information-provision service") are shown in Fig. 4. The bus information-provision service can collaborate with the navigation service. The information is created using the information about the travel route obtained by the navigation system and the information stored in the ART information center platform (bus stop, crowding level, timetable, estimated arrival time, etc.), and notified to bus passengers. The information displayed on the screen can be provided audibly using a smartphone, and switched ON or OFF.

The bus information-provision service is started by pushing the button shown on the page of the route found via the navigation service (1). On the smartphone screen, the estimated arrival time and the crowding level are shown for the selected bus (2). In the development, we categorized four levels of bus crowding. In addition, we defined occupied/vacant information for wheelchair spaces. Bus passengers are notified of whether the bus they are planning to ride has reached the nearest bus stop or not and how close the bus is to their bus stop (3)(4). After getting on the bus, they are notified of whether the bus has reached the nearest bus stop and how close the bus is to the scheduled destination bus stop (5)(6). The information is notified by pop-up displays, sounds, or vibrations.

The bus crowding level is categorized using images from on-board cameras. An on-board tool for image analysis was developed in this project. The crowding level information processed by the on-board tool is sent to the ART information center platform at intervals fixed in advance. Some of the information handled by the on-board tool is shown in Table 1. The camera images are not stored in the ART information center platform from the standpoint of personal information regulations.

Last year, we took pictures of the inside of a bus and analyzed them (Fig. 5). Four cameras were used in the bus, with one focusing on the wheelchair space. As a result, it was confirmed that the analysis of the limited area observed by the four cameras was an effective way of identifying the crowding level of the whole bus. Camera images are shown in Fig. 6. It was clarified that the crowding level

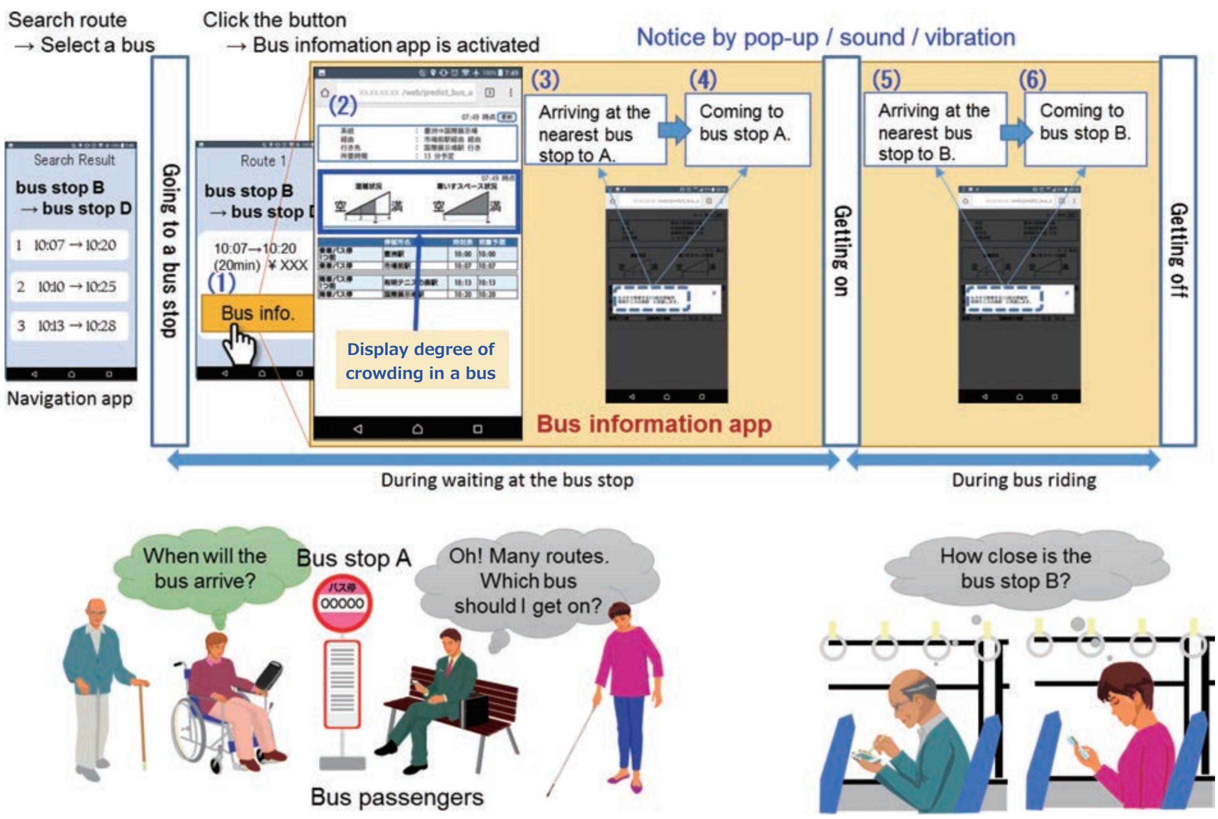


Fig. 4 Outline and use scenarios of bus information-provision service

Table 1 Information handled by the on-board tool (extract)

Item	Value
Crowding level	1～4 (1 : unoccupied seats, 2 : All seats occupied, 3 : Space in Aisle, 4 : Fully crowded)
Crowding Information	Analyzed headcount (countable)
Wheelchair space occupancy	0 : unoccupied, 1 : occupied

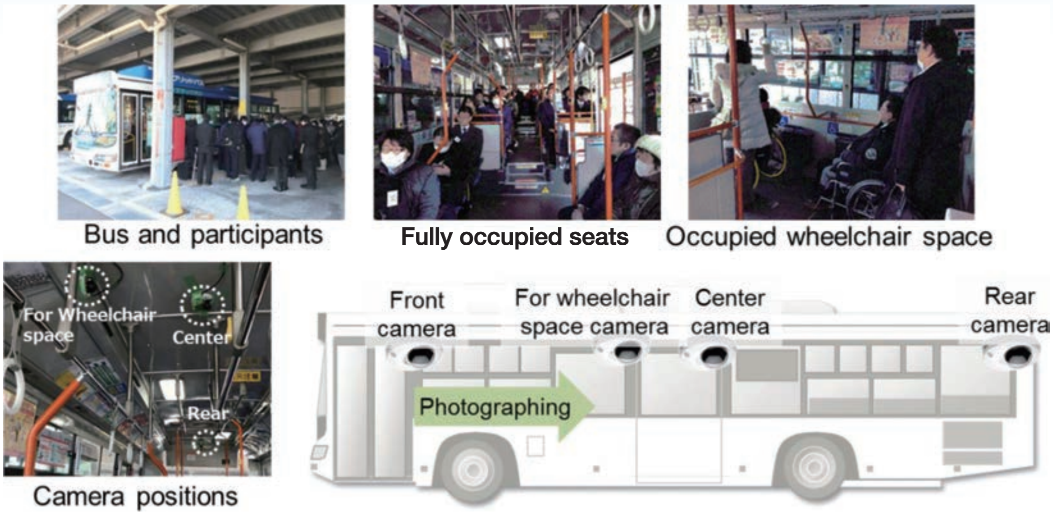


Fig. 5 Field verification of providing bus crowding information

Fig. 6 Images from on-board cameras

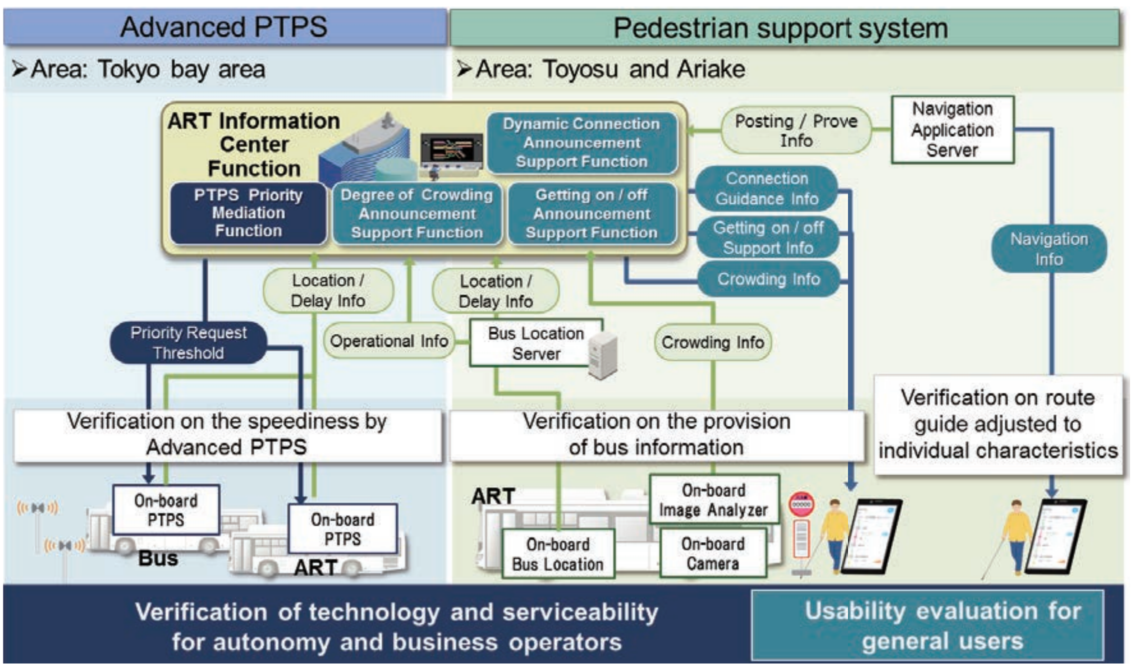


Fig. 7 Operation of the ART information center function in large-scale field operational test

of the whole bus is difficult to identify using images from the rear of the bus due to interference by standing passengers in non-step buses because the floor is higher at the rear. Therefore, to precisely understand the crowding level, we decided to use a combination of three camera images taken at the front, center, and rear.

These results will be verified in the test to be held in October.

3 Verification in Large-scale Field Operational Test

The ART information center function will correlate and share the data in the large scale field operational test to verify the results of the pedestrian support system common platform and improvements in the speediness of ART using advanced PTPS (Fig. 7). The field operational test will be conducted from October to November in 2018.

In the test to verify the improvements in the speediness of ART using advanced PTPS, the ART information center platform obtains bus position and delay data from the onboard Advanced PTPS. The ART information center platform gives it a priority request threshold set by the PTPS priority mediation function.

In the test to verify the results of the pedestrian support system common platform, the ART information center platform provides bus passengers with a bus information sharing service using the crowding degree announcement support function and getting on/off announcement support function via a smartphone application. The test participants will be asked whether these functions supply information and services as well as expected. The usefulness of the information and services will be also evaluated in the field operational test.

4 Conclusion

The ART information center is a traffic information infrastructure that collects various kinds of information on public transportation, modifies it into an easy-to-use format, and shares it to traffic business operation and application developers. Here, we developed five functions and six necessary APIs. It was confirmed that external systems can handle the data obtained by the APIs developed in this experiment. We developed an application to share the information to bus users to demonstrate how well the data processing in the ART information center platform is working. In a field operational test to be held in the near future, we will investigate the usefulness of the information and services provided by the ART information center platform.

Investigation of Methods for Forecasting Traffic Congestion and Guiding Congestion Avoidance

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ABSTRACT: The purpose of this study is to identify behavioral and psychological characteristics by analyzing a large quantity of data about major events held in Tokyo in close cooperation with relevant entities, including the Olympic Organizing Committee, the Tokyo Metropolitan Government, and railway/bus operators. We are conducting social experiments regarding behavior modification and guidance targeted at relatively major events to form and verify hypotheses of models to be used for congestion prediction. Based on these verification results, we intend to suggest a new scheme that can provide congestion predictions and traffic information appropriate for the 2020 Olympic and Paralympic Games to minimize impacts on individuals attending or affected by the games, mainly by targeting people who will visit the Olympic and Paralympic Games and citizens that live or work in Tokyo and use public transportation including Advanced Rapid Transit (ART).

1 Objectives and Goals

This study is conducting experimental surveys to estimate the effects of measures to avoid congestion, considering examples of methods to forecast traffic congestion and congestion-avoidance guidance. Then, based on these results, traffic conditions during a major event are being simulated, and draft plans for a demonstrative experiment are being drawn up. Effective traffic congestion-avoidance measures will be suggested based on the results of this demonstrative experiment.

2 Outline of Overall Information Provision Scheme

2.1. Basic understanding

To consider the prediction and mitigation of congestion during a major event like the Tokyo Olympic and Paralympic Games, a comprehensive framework is required to predict overall transportation demand based on the daily transportation demand. Especially for areas where greater transportation demand than normal is expected, this demand may not be satisfied by individual (existing) transportation facilities. Therefore, it is important for these facilities to work in cooperation with each other. In this case, citizens that usually use these transportation facilities must play an active role in reducing demand, including behavior modification.

To establish an overall scheme, it is also necessary to provide information on transportation services that matches the variety of visitors, including their nationalities, disabilities, ages, and the like, as well as their purpose of travel (including travel to Olympic venues, sightseeing, eating, and so on). At the same time, attention should be paid to provide information responding to unforeseen contingencies or emergencies.

2.2. Proposal of overall information provision scheme

For this scheme, it is necessary to 1) assume what transportation entities/purposes correspond to the following two types of transportation demand: normal daily trans-

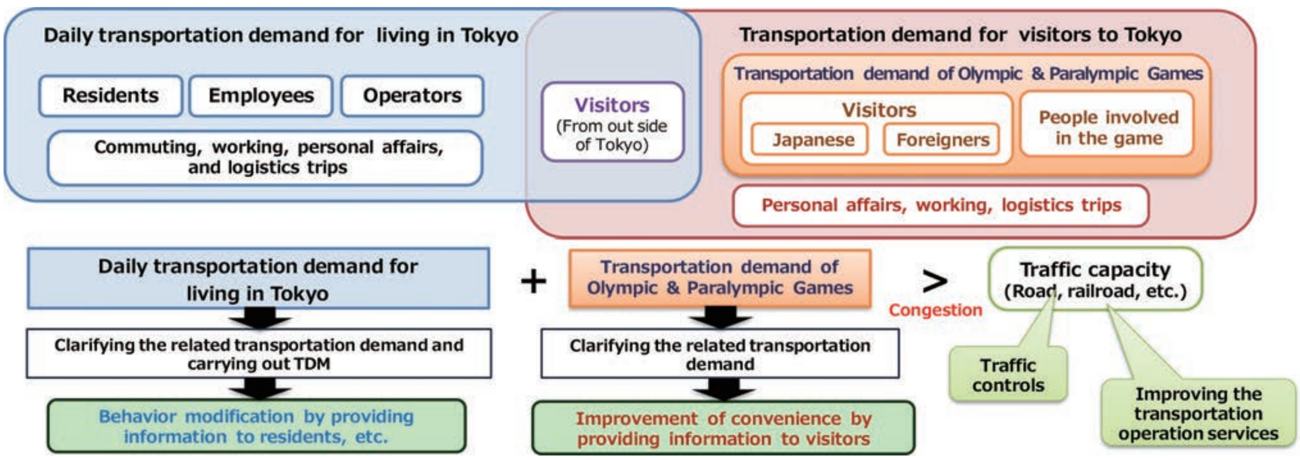

Fig. 1 Overall scheme of providing information for realization

portation in Tokyo and transportation for visitors (including transportation demand for the Olympic games), 2) provide hourly predictions for these two types of demand corresponding to the transportation entities, and 3) implement measures that allow to provide appropriate transportation services corresponding to the traffic volume.

At the same time, it is also important to provide transportation services and information for visitors of different nationalities, level of disability, age, and so on, including responses to unforeseen contingencies or emergencies. For this reason, to establish an overall information provision scheme, the issue with the highest priority is cooperation between the Organizing Committee of Olympic Games, the national and local governments responsible for transportation administration, the police, transportation operators, and other authorities. Based on this cooperation, it will be necessary to study the contents of information, how to provide the information, as well as the timing, feasibility, and impacts to encourage various transportation entities to change behavior.

3 Various Transportation Entities and Purposes to be Considered

It is necessary to focus on various transportation "entities" and "purposes" to predict congestion and to provide information for a major event. Transportation entities can be roughly divided into "individuals living in Tokyo" and "individuals visiting Tokyo." Some individuals living in Tokyo are residents of Tokyo, some are employees commuting to Tokyo, and some are "operators" who run businesses in Tokyo. Furthermore, it is necessary to consider individuals with mobility limitations, including elderly and disabled persons. Furthermore, although some visitors to Tokyo will be attending events, others will be there on business or the like. Also, some individuals living in Tokyo may also intend to attend events. By focusing on the transportation entities and purposes mentioned above, the different transportation characteristics of travelers can be identified (Table 1). For example, transportation for commuting in Tokyo is concentrated in the morning and the evening, mainly by rail. Transportation for commuting is also steady with small fluctuations.

Table 1 Transportation characteristics corresponding to various transportation entities and purposes, and matters to be considered

<table>
<tr><th colspan="2">Transportation entities
Purposes/attributes</th><th>Characteristics</th><th>Main mode</th><th>Stationarity</th><th>Matters to be considered</th></tr>
<tr><td colspan="2">Commuting</td><td>Concentrated in the morning and the evening</td><td>Rail</td><td>Steady (small fluctuations)</td><td>Cannot be controlled easily by commuters</td></tr>
<tr><td colspan="2">Working/logistics</td><td>Work occurs mainly in the daytime, but logistics occur at night as well</td><td>Vehicles (or rail if no luggage)</td><td>Rather steady</td><td>Some demand cannot be controlled when an event occurs</td></tr>
<tr><td colspan="2">Personal affairs</td><td>Mainly take place in the daytime</td><td>Rail</td><td>Unsteady</td><td></td></tr>
<tr><td colspan="2">Individuals with mobility limitations (daily transportation)</td><td>Mainly travel in the daytime</td><td>Walking/ bicycle</td><td>Rather steady</td><td>Have limited transportation modes, routes, and times</td></tr>
<tr><td colspan="2">Travel not for an event</td><td>Mainly occurs in the daytime.</td><td>Rail/ taxi</td><td>Unsteady (large fluctuations)</td><td>Some demand cannot be controlled when an event occurs</td></tr>
<tr><td rowspan="3">Event</td><td>Individuals with mobility limitations (non-Japanese people, etc.)</td><td>Occurs in addition to normal demand, and such individuals have little knowledge about transportation conditions in Tokyo</td><td>Rail/ taxi</td><td rowspan="3">Unsteady (large fluctuations)</td><td>Have limited available transportation modes, routes, and times, and cannot understand publications in Japanese</td></tr>
<tr><td>Japanese (visits from outside Tokyo)</td><td>Occurs in addition to normal demand, and such individuals have little knowledge about transportation conditions in Tokyo</td><td>Rail (some by bicycle)</td><td>Cannot access publications targeted only for the Tokyo area.</td></tr>
<tr><td>Visitors from the Tokyo metropolitan area</td><td>Occurs in addition to normal demand, and such individuals have little knowledge about transportation conditions in Tokyo</td><td>Rail</td><td>May make decisions based on daily transportation conditions</td></tr>
</table>

4 Outline of Traffic Congestion Forecasting and Congestion-avoidance Guidance (Current Situation)

We are trying to avoid traffic congestion based on a behavioral modification process, by providing the appropriate information depending on individual attributes and situations. We are also trying to forecast traffic situations dynamically in cooperation with the ART Information Center (Figs. 2, 3).

Most recently, we have simulated traffic situations using a traffic simulator (by applying agent-based modelling), integrated with behavioral modification based on the information provided (Fig. 4).

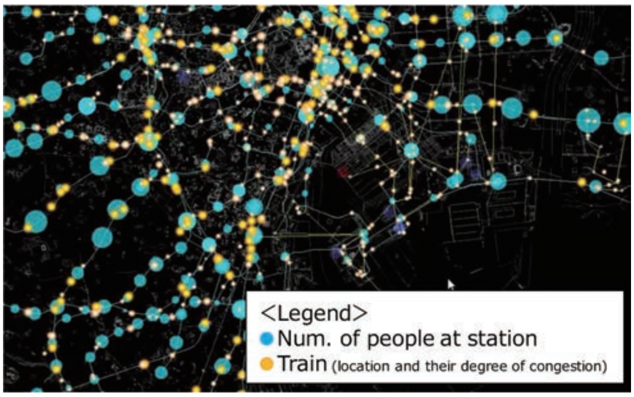

Fig. 2 Simulation output (example)

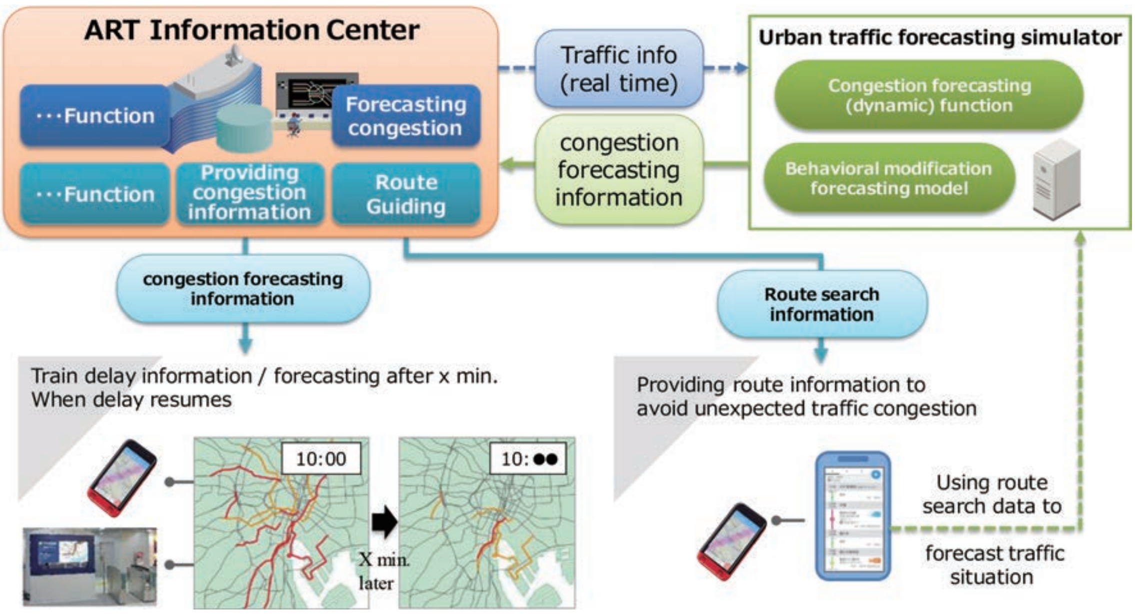

Fig. 3 Outline of traffic congestion forecasting and congestion-avoidance guidance

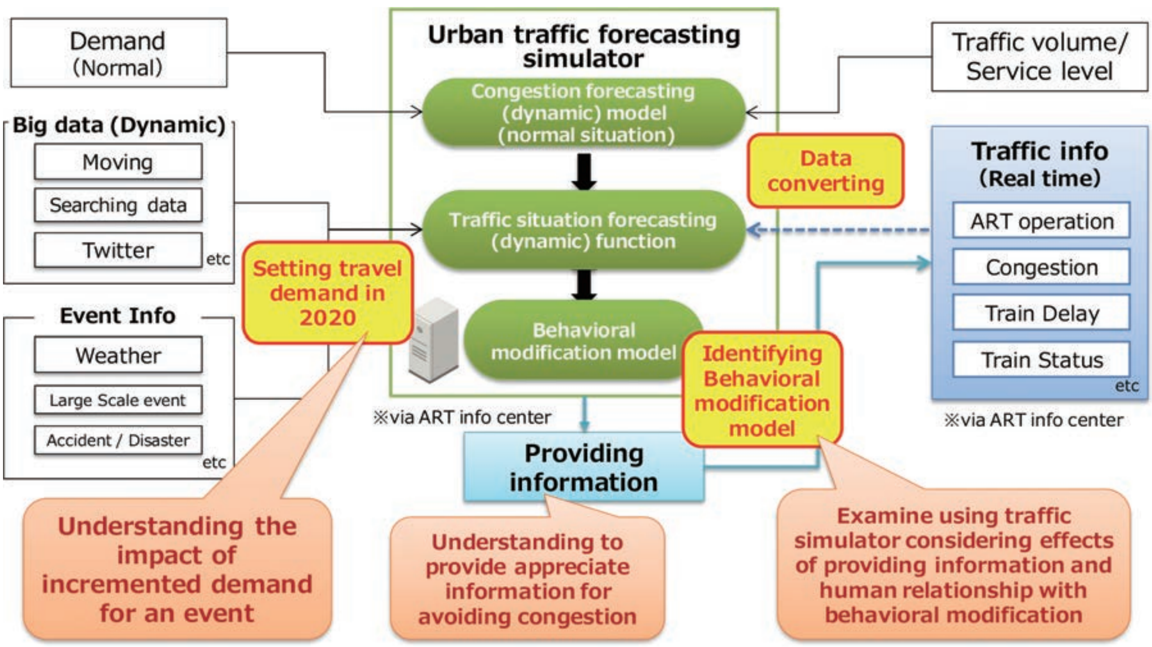

Fig. 4 Outline of urban traffic forecasting and information provision (current situation)

③ Improvement and Popularization of Accessible Transportation (Initiatives for People with Restricted Access to Transportation)

Development of Movement Support System for People with Mobility Constraints

Yukiko Hatazaki (UTMS Society of Japan)

ABSTRACT: As Japan faces a super-aging society, movement support for people with mobility constraints has become an important social issue that needs to be addressed. To cope with this situation, technology development, as well as research and surveys are in progress to help realize safe, secure, and smooth movement support for people with mobility constraints that also satisfies convenience and economic rationality requirements. The UTMS Society of Japan is working on the enhancement of the existing Pedestrian Information Communication Systems (PICS) and proceeding with studies to help realize services that provide intersection crossing support using smartphones.

1 Purpose

During the 2020 Tokyo Olympic and Paralympic Games, heavy traffic is expected due to visitors and spectators of the Games. Therefore, the provision of movement support for people with mobility constraints, including wheelchair users, has become an important element for the success of the Games. Movement support for people with mobility constraints is also a critical social issue in Japan, which needs to be addressed as the country faces a super-aging society. To cope with this situation, technological development, as well as research and surveys are in progress to help realize safe, secure, and smooth movement support for people with mobility constraints that also satisfies convenience and economic rationality requirements.

2 Background of the Development

The overall plan for the development of moving support systems for people with mobility constraints is shown in Fig. 1.

Research, surveys, and basic design activities were conducted from fiscal 2014 through 2015, during which problems in the existing systems were identified and draft measures were proposed. The results found that existing Pedestrian Information Communication Systems (PICS) are not as widely used as desired due to cost and maintenance problems resulting from the systems' high installation costs and availability, which is limited to the users of a dedicated hands-free terminal or long cane. Therefore, draft measures were proposed to provide services using smartphones that have become increasingly common, not only among people without disabilities, but also among people with mobility constraints.

In fiscal 2016 and after, an experimental system was set up and field verification is underway to identify the specifications of the system.

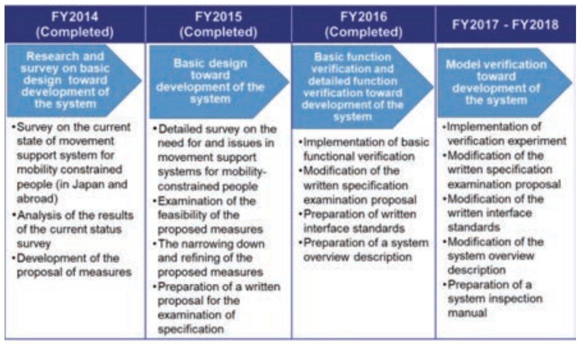

Figure 1 Overall plan

3 Outline of the New System

3.1. Services to be realized

The following two services were decided to be realized.

(1) A "signal information provision service" that provides information on the name of the intersection and the pedestrian signal status.

(2) A "pedestrian green signal time extension service" that extends the green time of the pedestrian signal.

3.2. Communication protocol

Bluetooth connection, which is standard with relatively new smartphone models, was chosen as the protocol for communication between the roadside equipment and smartphones.

3.3. User interface

Using a smartphone while walking on a busy street may result in accidents. This behavior is already recognized as a social issue. Therefore, smartphone applications were examined and a simple screen display was designed so that even people with weak eyesight can recognize the current traffic signal status displayed on the screen based on a voice or vibrotactile user interface.

3.4. Determination of service area

From the aspect of cost, it was decided that the poles on which traffic signal controllers are installed should be used for the Bluetooth transmission/reception units (hereafter referred to as "BLE beacons"). As a result, the communication area is within the radius of the pole on which the signal controller is mounted, which depends of the location of the pole. If the service is realized using one BLE beacon, it is necessary to transmit radio waves to the farthest sidewalk. However, this results in differences in the area on each sidewalk in which communication can be established. As a solution, it was decided that a location should only be defined as part of the service area when it is within a certain range from the center of the intersection, based on information from the smartphone GPS receiver. The relationship between the communication area and service area is shown in Fig. 2.

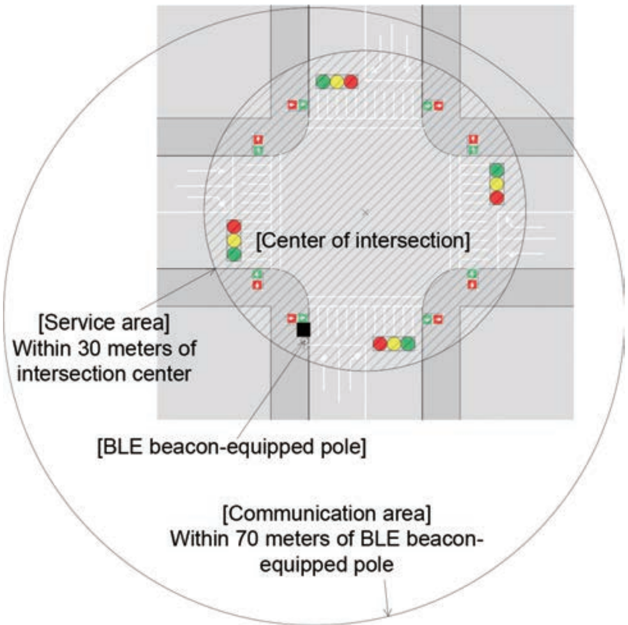

Figure 2 Service area

3.5. Application to large-scale intersections

Because the guaranteed range of radio wave coverage by one BLE transmission/reception unit is defined as a radius of 70 m, radio waves cannot cover the required range in the case of large-scale intersections. As a result, areas where tactile paving is installed for visually impaired individuals to wait to cross streets may not be covered by the service in some cases. People with visual impairment often feel unsafe when crossing intersections with long crossing distances. Therefore, it is important to provide support at large-scale intersections. To cope with this, more than one BLE transmission/reception unit must be installed at large-scale intersections to enable provision of the service.

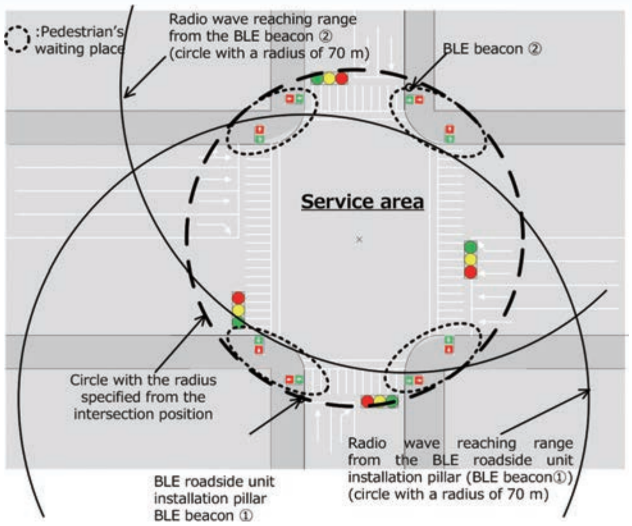

Figure 3 Range of radio wave coverage from two BLE transmission/reception units

3.6. Display of remaining pedestrian green signal time/wait time

Indication of the remaining pedestrian green signal time and the wait time until the pedestrian signal turns green has been implemented using countdown timers as a function of pedestrian signals. In order for visually impaired individuals to decide whether or not to start crossing a street, it was decided to introduce the same function to the developed system through smartphones.

Figure 4 Pedestrian signal lamp (indication of time passed)

4 Model Verification

4.1. Experiment location

A verification experiment was carried out at the Shinmisato Ekimae intersection in Saitama Prefecture in fiscal 2016 and at the Shintoshin (Nishi) intersection in Saitama Prefecture in fiscal 2017. The service was experienced by visually impaired people, and a questionnaire survey was conducted.

4.2. Results of the experiment

Evaluation was carried out using ten devices running "Andorid6.9" or higher, or "iOS" or higher and supporting

Bluetooth 4.0 or higher, with a dedicated application installed. The results found that all devices were able to properly provide the service. The questionnaire survey for visually impaired people who experienced the service showed that about 90 percent of the participants though that the service was necessary, and many comments were received to open-ended questions. The results demonstrated that visually impaired people are highly interested in this movement support service at intersections.

5 Conclusion

(1) Through model verification, it was confirmed that the developed system can be applied to real intersections.
(2) A questionnaire survey of people that experienced the service and discussions with experts confirmed the effectiveness of the movement support service at intersections using smartphones.
(3) Based on the results of the model verification and examinations, draft experimental specifications and draft standards were prepared. The draft specifications and standards prepared are described below:
  - System definition document (draft) for a movement support system for people with mobility constraints using smartphones
  - Written proposal (draft) for the examination of specifications for BLE roadside equipment
  - Standards (draft) for an application that communicates between BLE roadside equipment and smartphones
  - Written proposal (draft) for a BLE roadside equipment inspection manual
  - Written proposal (draft) for the examination of a comprehensive inspection manual for a moving support system for people with mobility constraints using smartphones

6 Future Issues

In the future, it will be necessary to develop a concrete operational procedure for the whole system, with a view toward differentiation between the new system and other existing pedestrian support systems, as well as cooperation with other applications such as navigation systems.

Research into Common Pedestrian Support System Platform

Junko Ushiyama, Masao Yamamoto, and Haru Ando (Hitachi, Ltd.)
Hideki Yamazaki, Hikari Nakazawa, and Yayoi Horie (Navitime Japan Co., Ltd.)
Satoshi Watanabe and Satoshi Hashimoto (Zenrin Co., Ltd.)

ABSTRACT: To improve pedestrian accessibility through route guidance adjusted to the individual characteristics of each pedestrian, the following studies, investigations, and developments were performed. First, the information necessary for transfers and the method of collecting this information were studied and evaluated through field verifications. As a result, data collection applications on smartphones were adopted as a low-cost and continuous method for information collection. Second, demonstration experiments to develop walking networks using the data collection application were implemented. In addition, the serviceability of common platform information was evaluated using a prototype personal navigation application on smartphones, and a field verification of route guidance corresponding to the personal attributes of pedestrians. Furthermore, cooperation between personal navigation systems and advanced PICS was studied. A large-scale demonstration experiment regarding route guidance will be performed in October 2018.

1 Outline and Objectives

Pedestrian support systems aim to realize a safe and secure traffic environment for a wide range of people, including elderly and disabled persons, by reducing traffic accident fatalities and improving the accessibility of public transportation. These systems should be able to provide public transportation information necessary for moving from a departure location to a destination (common platform information), as well as route guidance suited for different types of pedestrians. The objectives of this project are to study easy and efficient methods to collect this common platform information, and to evaluate its serviceability and acceptance through demonstration experiments in which various kinds of people with restricted transportation capabilities participate.

2 Study of Common Platform Information and Collection Methods

2.1. Investigation of common platform information

Figure 1 outlines the demonstration experiments performed between 2015 and 2017. With the cooperation of people with restricted transportation capabilities, demonstration experiments were performed in the Tokyo Bay area each year. We assumed that different information would be required in accordance with the type of person with restricted transportation capabilities (e.g., wheelchair users, visually impaired persons, the elderly, etc.). The importance of the information was investigated by extracting common platform information for each pedestrian attribute through field verifications and surveys, and through route guidance demonstration experiments.

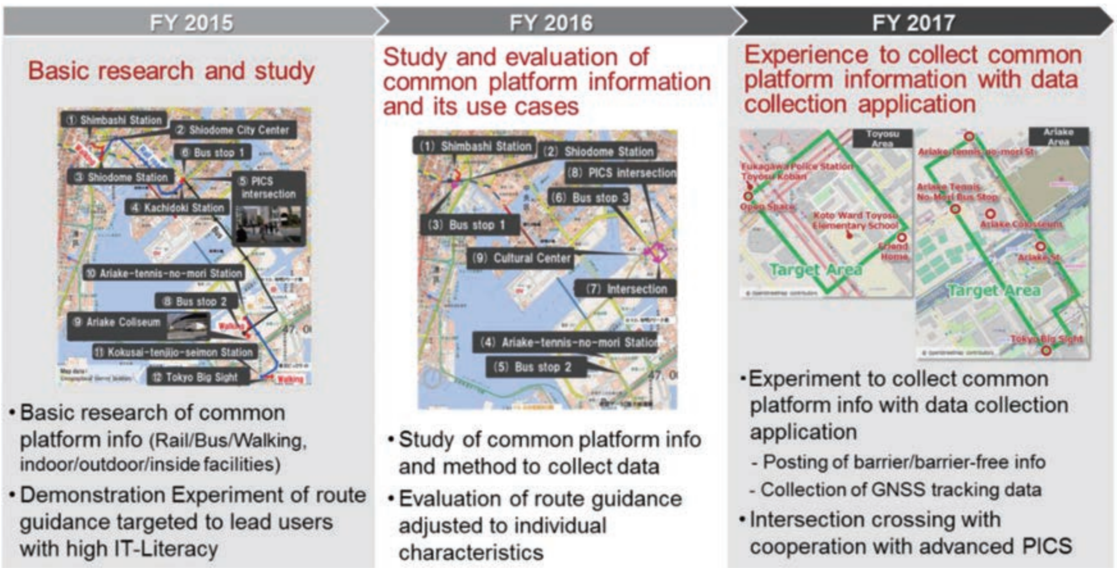

Fig. 1 Outline of demonstration experiments between 2015 and 2017

Table 1 shows the results of the investigation. The common platform information was classified into nine categories. All the people with restricted transportation capabilities responded that they required "vertical transportation" and "detailed information of public transportation". In addition, the results show that information on "crosswalk intersections", and "sidewalk road conditions" is also important. Figure 2 shows photos of the route guidance field verification.

2.2 Collection of common platform information

It is obvious that exact and updated information is the best for users. However, it is not acceptable for the sustainability of the services to expend large amounts of time and money to collect and update this information. This project used a data collection application, through which common platform information can be easily obtained through mobile devices such as smartphones and published on the Internet. The application collects common platform information by users posting information about bumps, road width, gradients, slopes, studded paving blocks, and crosswalks. In addition, we aimed to develop an accessibility map suitable for people with restricted transportation capabilities by collecting global navigation satellite system (GNSS) probe information.

A demonstration experiment to collect common platform information was performed in November 2017 (Fig. 1). Sixty-three people with restricted transportation capabilities such as wheelchair users, visually impaired persons, baby buggy users, and the elderly participated. The participants used smartphones installed with the data collection application, moved around the Toyosu-Ariake area, and posted important information using the application.

Table 2 shows a summary of posted data categorized by the attributes of the people with restricted transportation capabilities. The total number of posts was approximately 1,700 and contained features corresponding to the attributes of the users. Visually impaired persons mainly posted photos and comments, and information regarding key landmarks for transportation. Wheelchair users posted much information regarding pedestrian walkways. The elderly posted both information regarding themselves as well as other information that they thought might be helpful for other people with restricted transportation capabilities.

We investigated transportation routes in the demonstration experiment using questionnaires. GNSS tracking information and responses to the questionnaires were analyzed, and recommended routes were formulated from the analysis results. A demonstration experiment regarding route guidance adjusted to the individual characteristics of each pedestrian will be held in 2018 using a personal navigation application containing walking networks developed based on the common platform information obtained through the previous demonstration experiments and field verifications.

Table 1 Importance of common platform information (results of verification by demonstration experiments)

Attribute \ Common platform information	Vertical transportation	Crosswalk Intersection	Sidewalk Road conditions	Differences in level and slopes	Audio sign	Rest spot	Restroom	Ticket gate Station platform	Detail information of public transportation
Wheelchair	◎	○	◎	◎	–	△	◎	○	◎
Totally blind	◎	◎	◎	○	◎	△	○	◎	◎
Low vision	◎	◎	◎	○	○	△	○	◎	◎
Elderly	◎	◎	○	◎	–	◎	◎	○	◎

High ← ◎ ○ △ – → Low
Degree to be required

Fig. 2 Scenes from the field verification performed in the Shimbashi-Ariake-Toyosu area in 2016

Table 2 Results of posts classified by attributes

Attributes	Number of Posts	Information of Walkway				
		Bump	Road Width	Slope	Slant	Studded Paving Block
Total Blind	467	4	4	5	4	17
Low Vision	503	6	3	9	10	50
Electric Wheelchair	223	67	74	85	80	73
Manual Wheelchair	221	50	52	74	93	63
Baby Buggy	242	62	96	36	47	69
Elderly	45	11	12	9	13	3
Total	1701	200	241	218	247	275

Fig. 3 Sample screen of personal navigation system

3 Route Guidance Corresponding to Attributes of People with Restricted Transportation Capabilities

3.1. Prototyping of personal navigation application

A prototype personal navigation application was created to evaluate the common platform information used for route guidance corresponding to the attributes of each type of person with restricted transportation capabilities. This personal navigation application shows the results of route searches based on the attributes of the user, and navigates the preferred route. Helpful information during transportation such as barriers and barrier-free facilities are shown as pins on the guidance maps (Fig. 3).

3.2. Demonstration experiments of route guidance corresponding to attributes

In the 2018 demonstration experiment, the serviceability of the provided public transportation information will be evaluated, in addition to the serviceability of route guidance (refer to the Development of ART Information Center report). Figure 4 shows the planned scenarios of the demonstration experiment. The preliminary experiments over the last three years have proven that route guidance adjusted to individual characteristics is acceptable, and there are high expectations of providing common platform information.

4 Preliminary Experiment of Cooperation with Advanced PICS

The acceptance of cooperation between a personal navigation application for route guidance and an advanced Pedestrian Information and Communication System (PICS) was researched, and a preliminary experiment was performed to examine the feasibility of support on crossing walkways and facilitate safer transportation of visually impaired persons. In our research in 2017, we designed a PICS terminal application and a personal navigation application as separate programs, and developed a cooperation function between these applications. The demonstration experiment proved the acceptance of a personal navigation system that cooperates with an advanced PICS, especially for visually impaired persons.

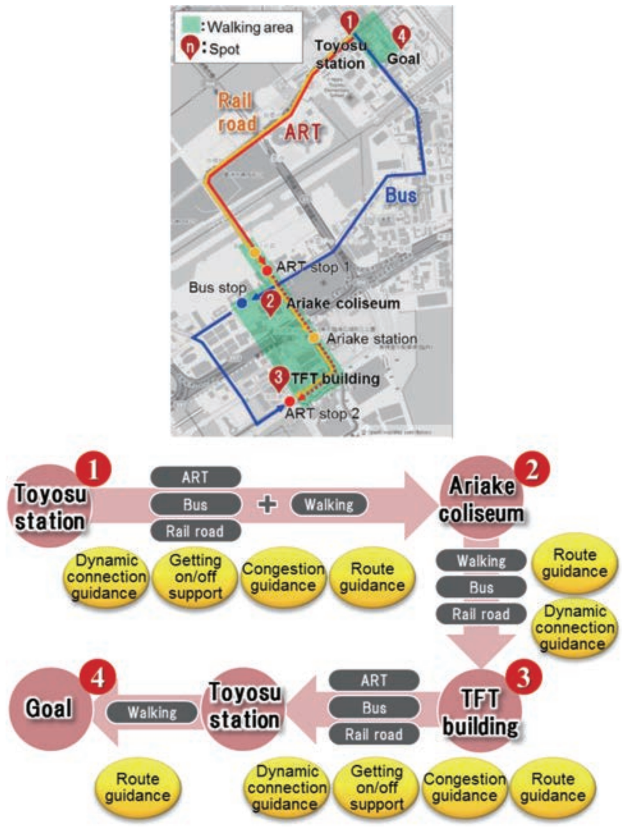

Fig. 4 Planned scenario of demonstration experiments

5 Conclusion

Three years of demonstration experiments showed that route guidance corresponding to the attributes of people with restricted transportation capabilities is highly acceptable. Continuous collection of common platform information and the practical application of route guidance adjusted to individual characteristics are likely to be implemented in the near future.

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

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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.

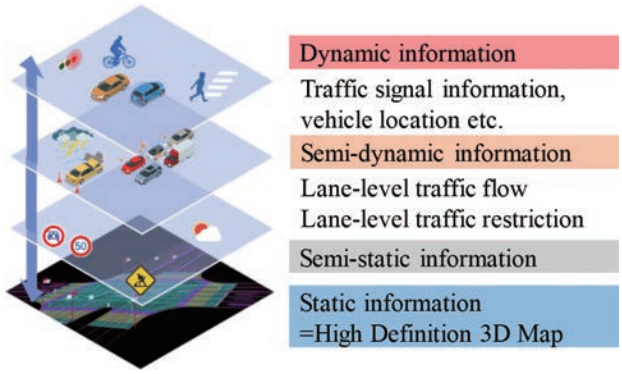


Fig. 1 Dynamic map four layer structure

2 Overview of the Dynamic Map Field Operational Test

2.1. Dynamic Map Field Operational Test Schedule

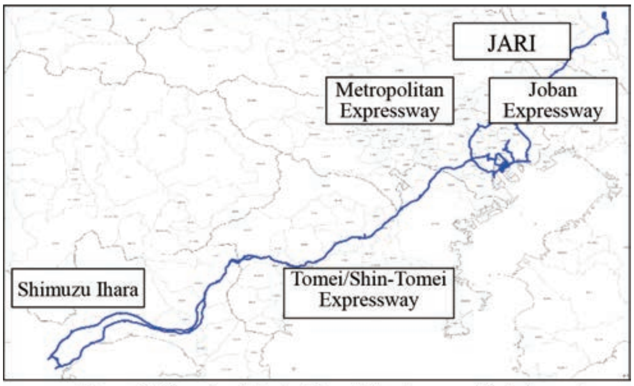
With the participation of test participants, over the 15-month period from October 2017 to December 2018, this test verified the specifications and accuracy of prototype dynamic maps, the linking of information such as dynamic information and semi-dynamic information with static information, and the 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			★												★				

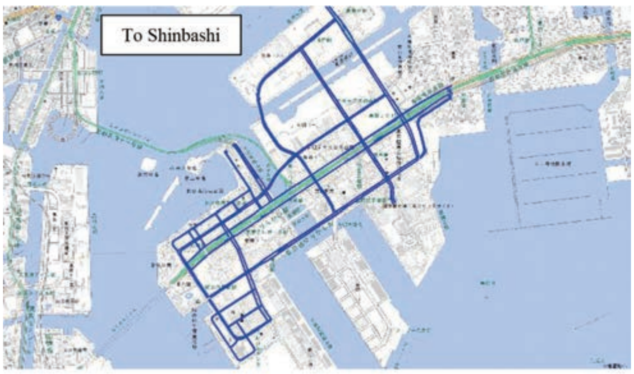
2.2. Field Operational Test Area

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.

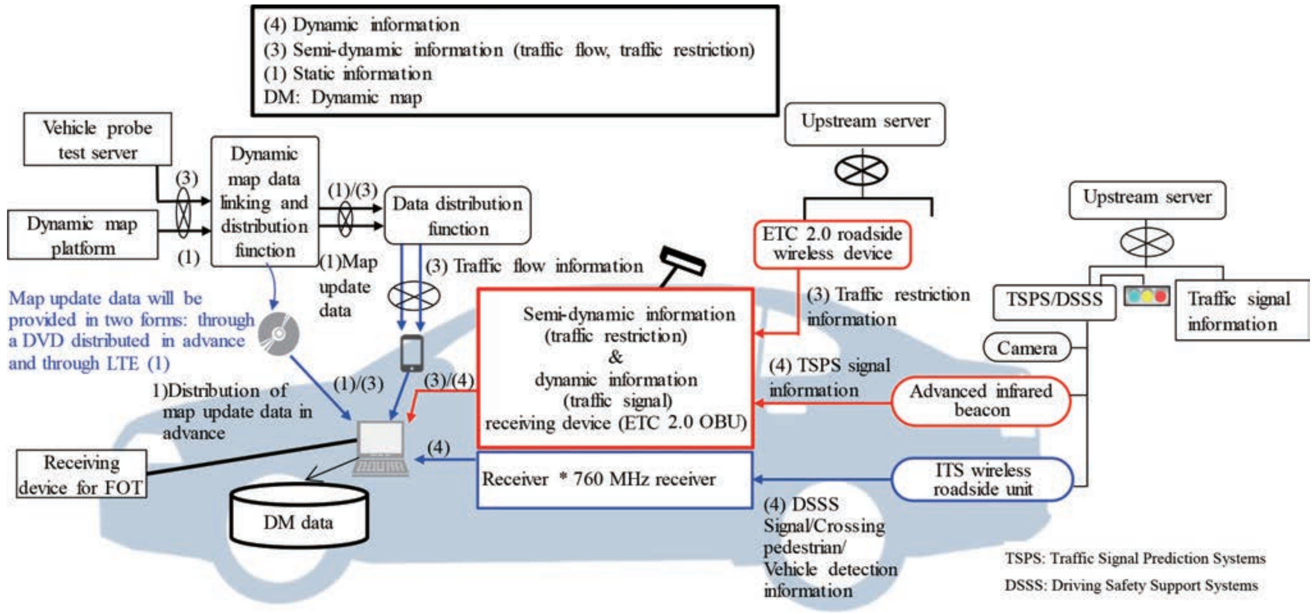
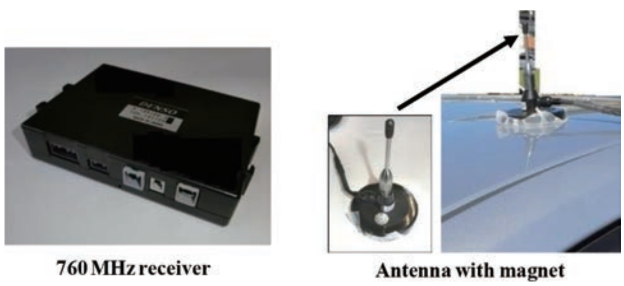


Fig. 4 Equipment and Software Used in the Field Operational Test

Source: Mitsubishi Electric Corporation

Fig. 5 ETC 2.0 Vehicle-Mounted Device

Fig. 7 Receiving Terminal



Source: DENSO CORPORATION

Fig. 6 760 MHz receiver

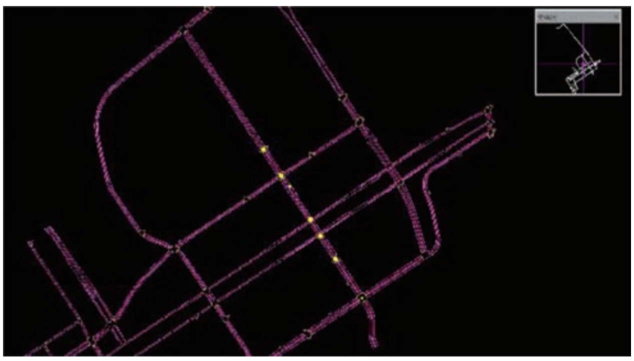


Fig. 8 Example of Traffic Signal Information for the Odaiba Area Displayed on the Dynamic Viewer

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

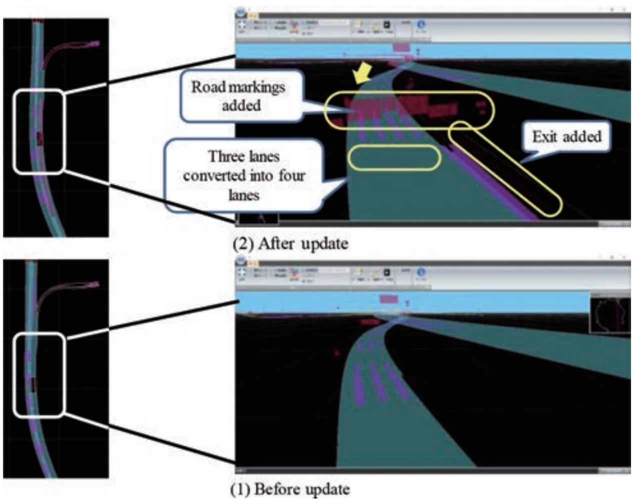


Fig. 9 Example of Map Update Data (Metropolitan Expressway - Horikiri/Kosuge Junction Inner Lanes)

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)

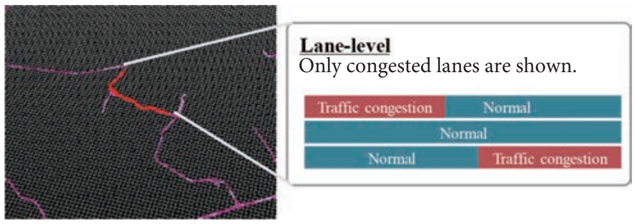


Fig. 10 Traffic Flow Information (Lane-Specific) Display Example

(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).

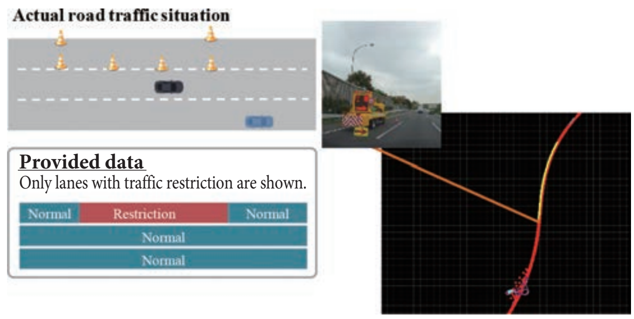


Fig. 11 Lane-Specific Restriction Information Display Example

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).

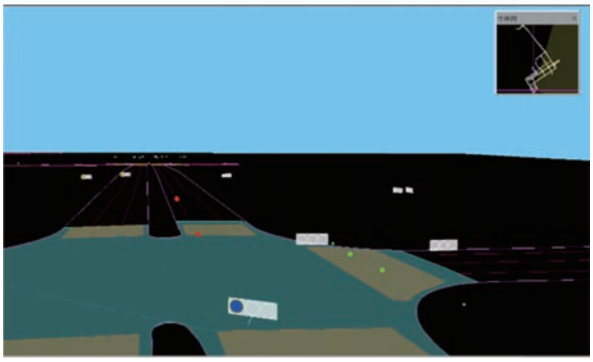


Fig. 12 Dynamic Information Display Example

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.

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(3) Dynamic Map Semi-dynamic/Semi-static Information Data Specifications (Proposal) Ver. 1.0 (2016)
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(5) Materials Related to New Advanced Digital Road Surface Information for Advanced Driving Support (Japan Digital Road Map Association)

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HMI

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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).

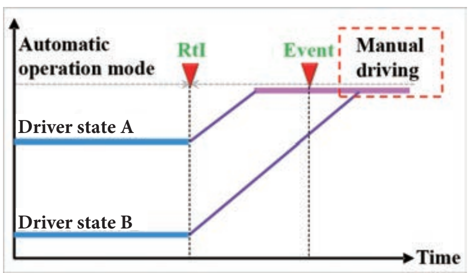


Fig. 1 Conceptual diagram of readiness

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

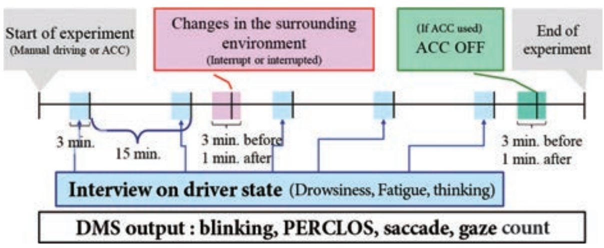


Fig. 2 Diagram of calculation of evaluation index

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.

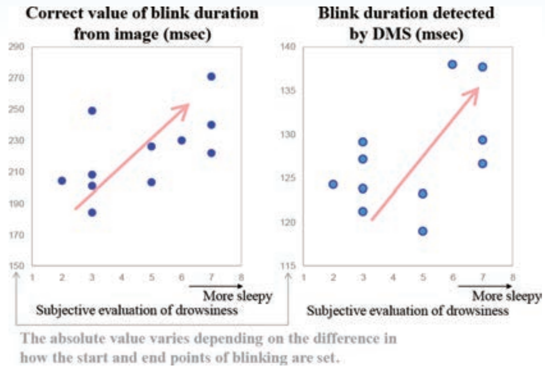


Fig. 3 Investigation of feasibility of DMS: blinking detection

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.

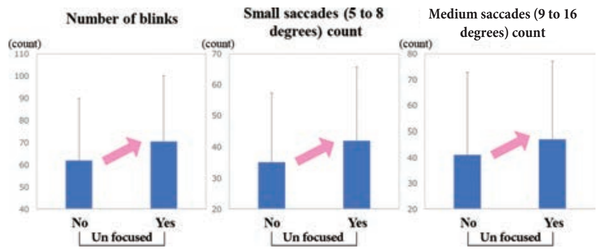


Fig. 4 Investigation of feasibility of DMS: detection of saccades

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).

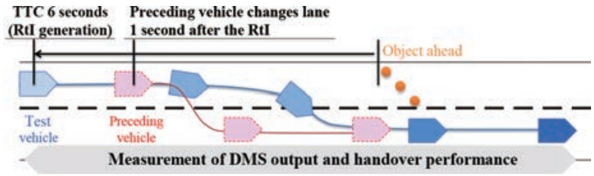


Fig. 5 Description of RtI event

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.

① Large Scale Field Operational Tests

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

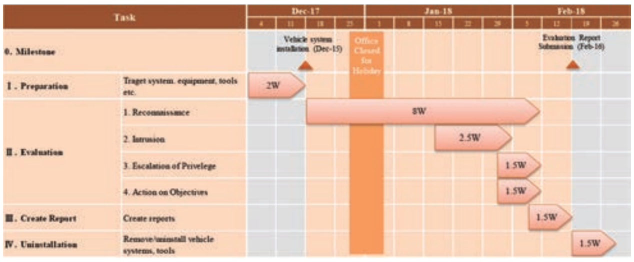
In the information security trial research, an evaluation was conducted for vehicle systems based on the evaluation method described in the draft of the Information Security Evaluation Guideline formulated in FY 2017.

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.

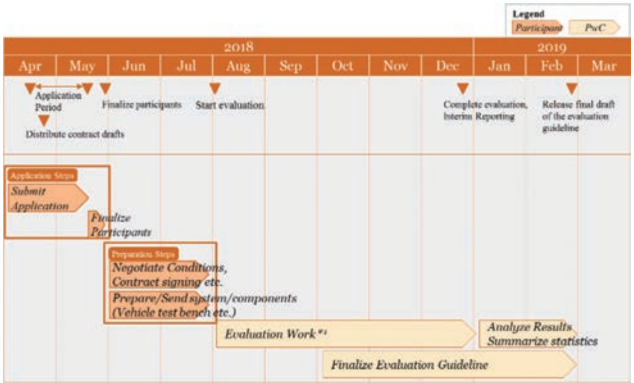
3 Management of Information Security Field Operational Test

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 [illegible] 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

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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.

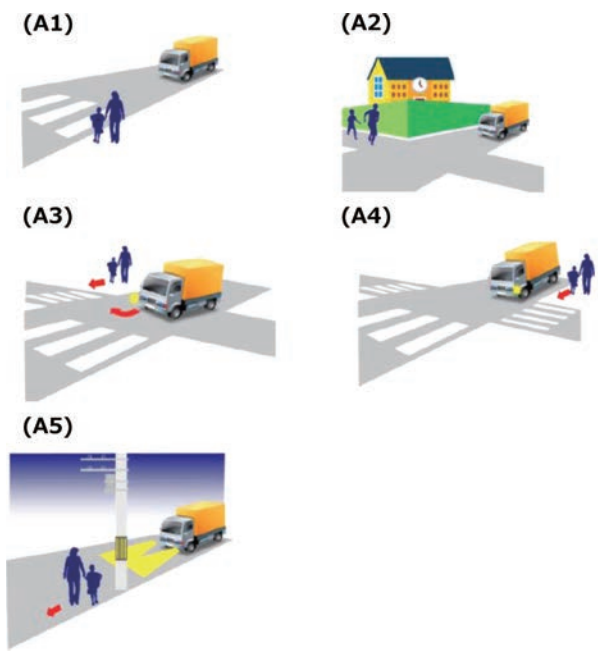

Fig. 1 (A) Five scenarios requiring support.

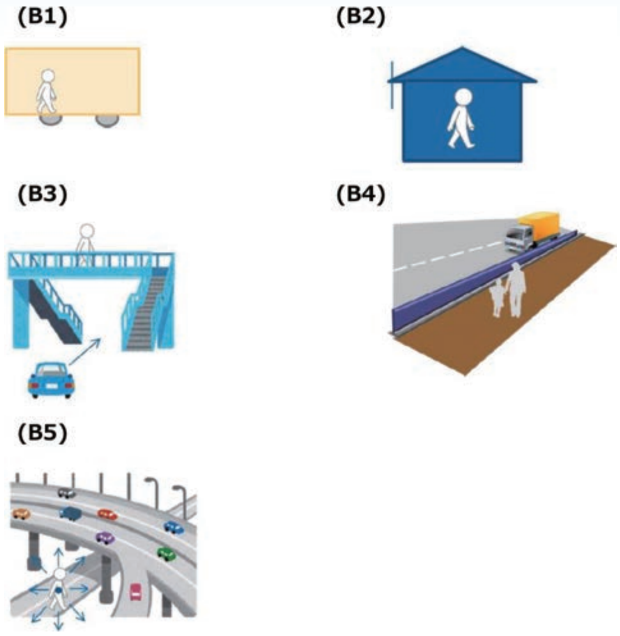

Fig. 2 (B) Five scenarios where support is not required.

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

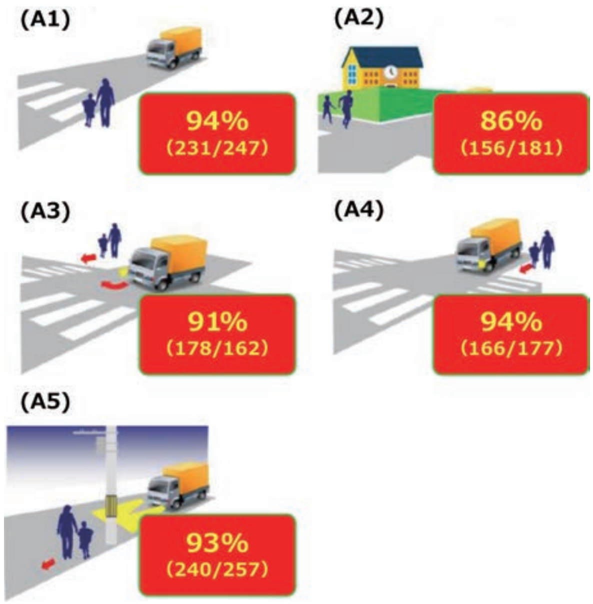

Fig. 4 Results of scenarios requiring support.

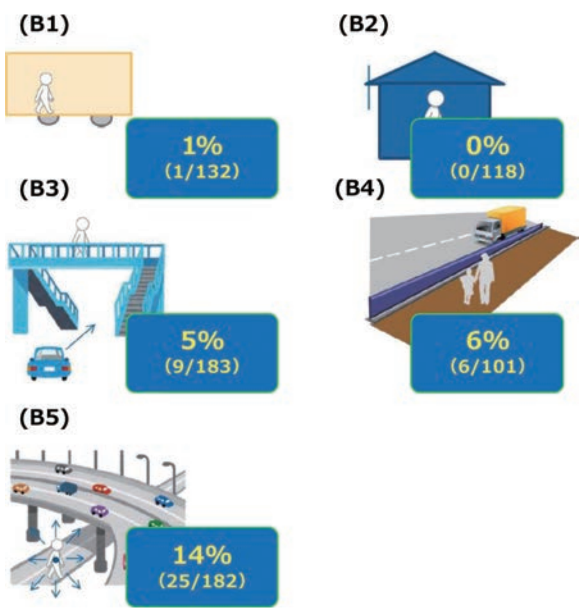

Fig. 5 Results of scenarios where support was not required.

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

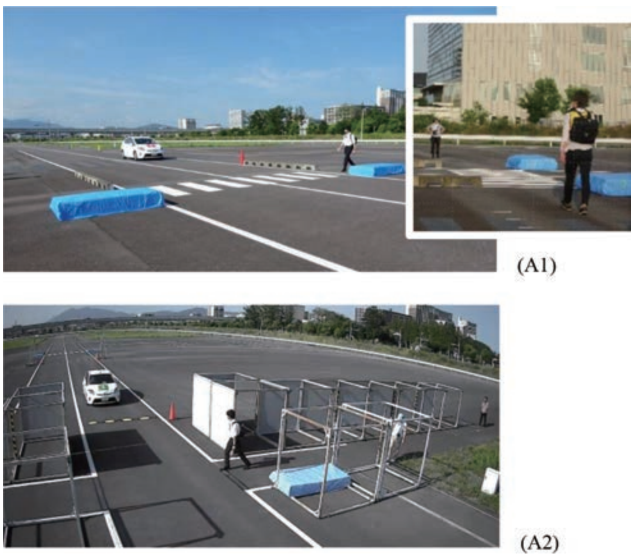

Fig. 6 Validation of behavior change **(A1, A2)**.

a scene where there were many pedestrian accidents.

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.

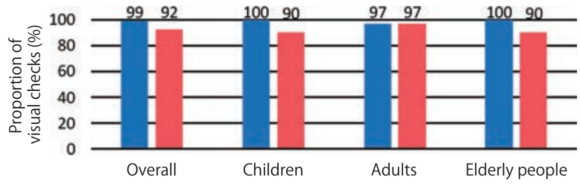

Fig. 7 Verification of pedestrian behavioral change **(A1)**.

(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.

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.

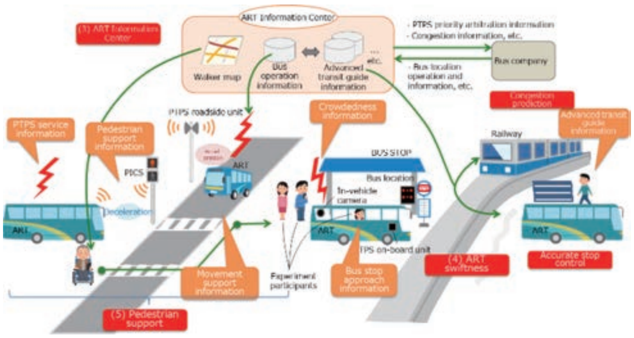

Fig. 1 Visualization of advanced rapid transit development

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)

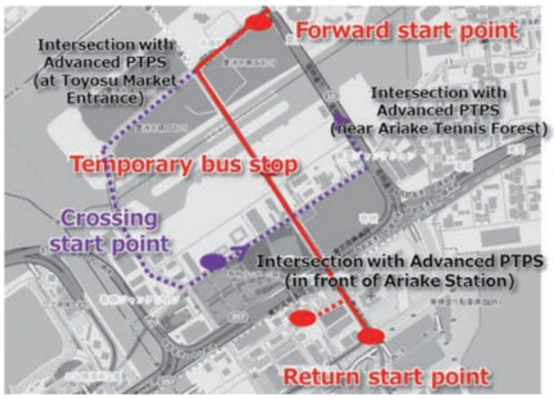

Fig. 2 Traveling route of advanced PTPS field operational test vehicles

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

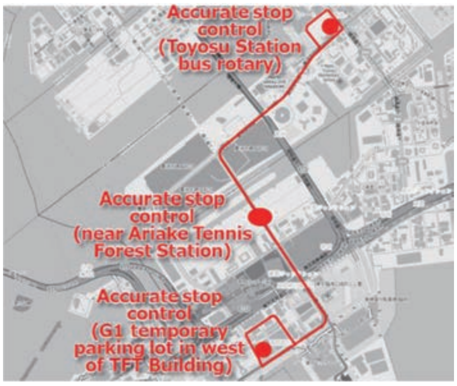

Fig. 3 Traveling route of precise docking control field operational test vehicle

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).

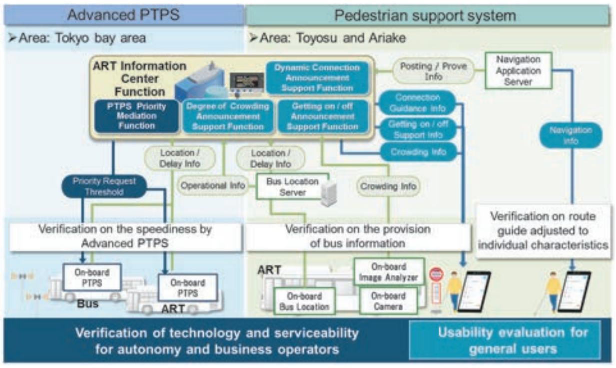

Fig. 7 Visualization of operations of ART Information Center function

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.

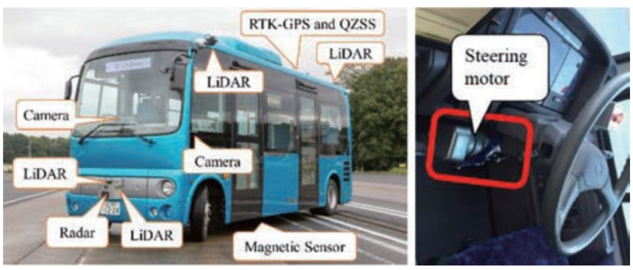

Fig. 1 Automated Driving Bus

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

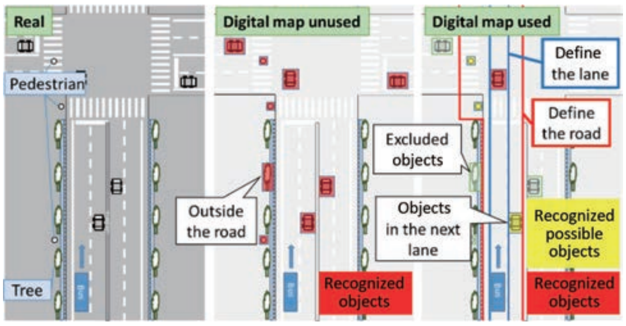

Fig. 4 Distinguishing Objects Using Road Maps

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.

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

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

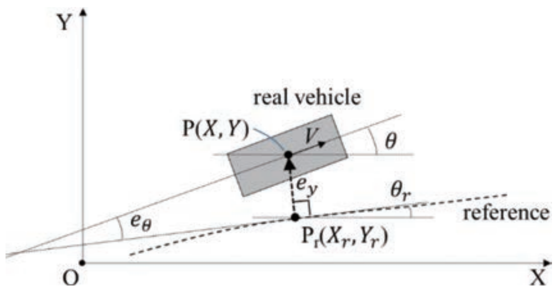

Fig. 5 Definition of Error

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.

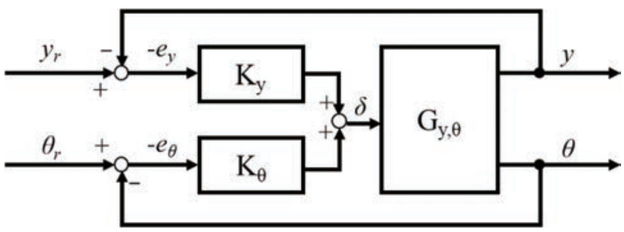

Fig. 6 Lateral Position and Yaw Angle Feedback Control

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.

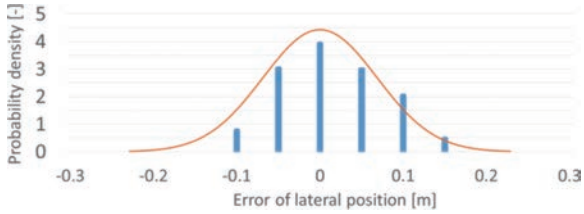

Fig. 7 Lateral Position Error

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.

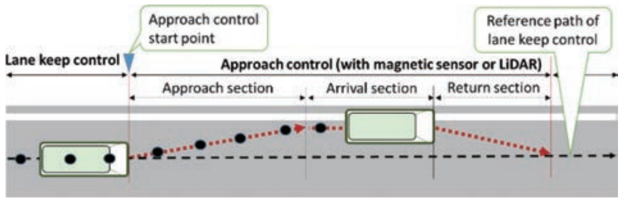

Fig. 8 Approach Control to Bus Stop

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.

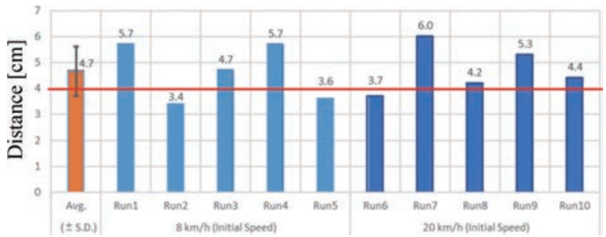

Fig. 9 Distance between Curbstone and Bus

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.

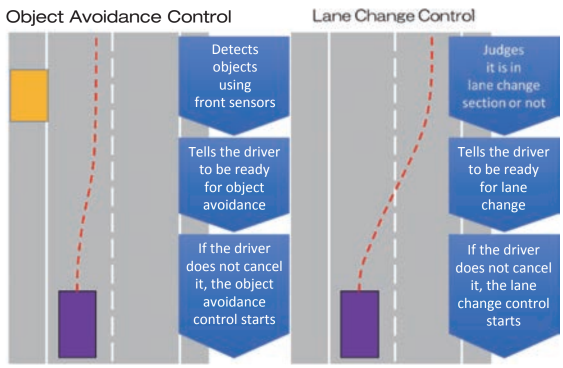

Fig. 10 Object Avoidance and Lane Change Control

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.

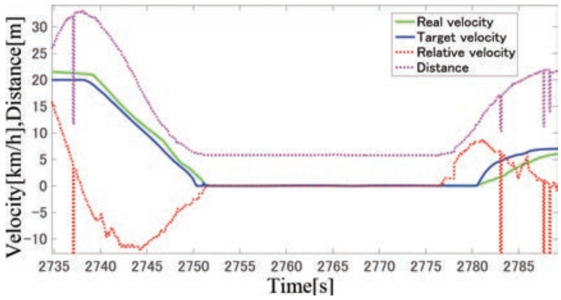

Fig. 11 ACC Results

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.

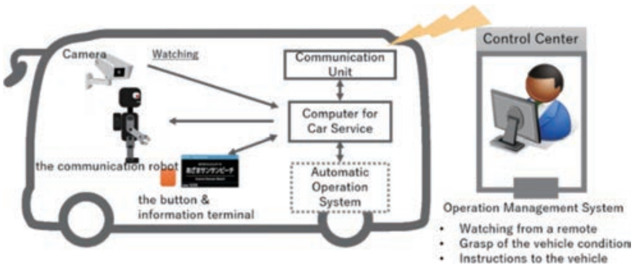

Fig. 12 Remote Monitoring System

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.

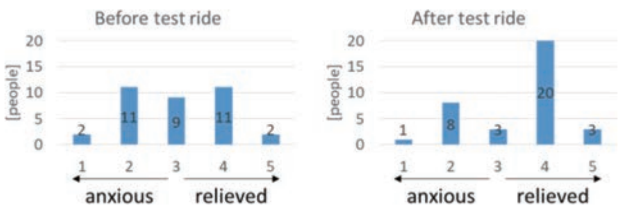

Fig. 13 Questionnaire Results

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

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

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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-

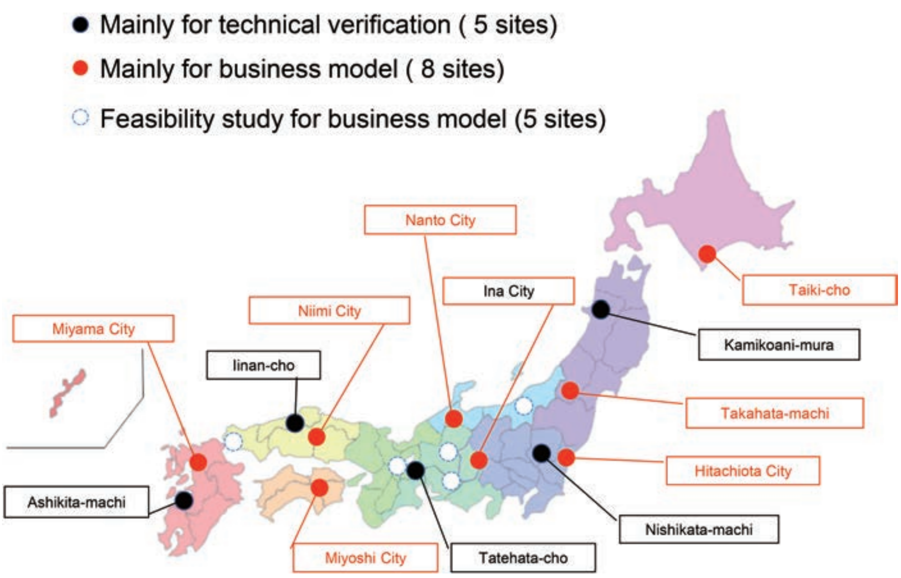

Fig. 1 Locations of FOTs in FY 2017

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.

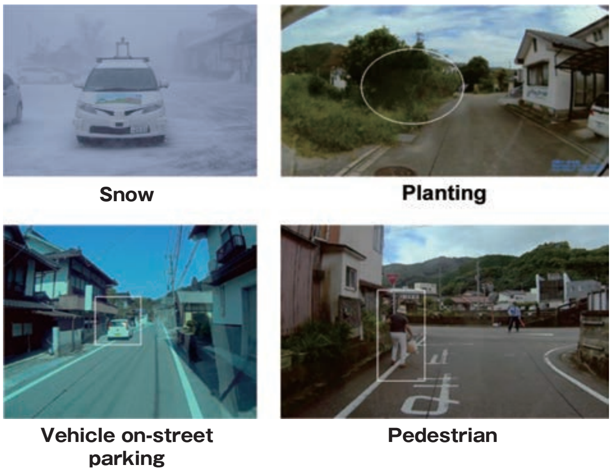

Photo 1 Scenes from FOT

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.

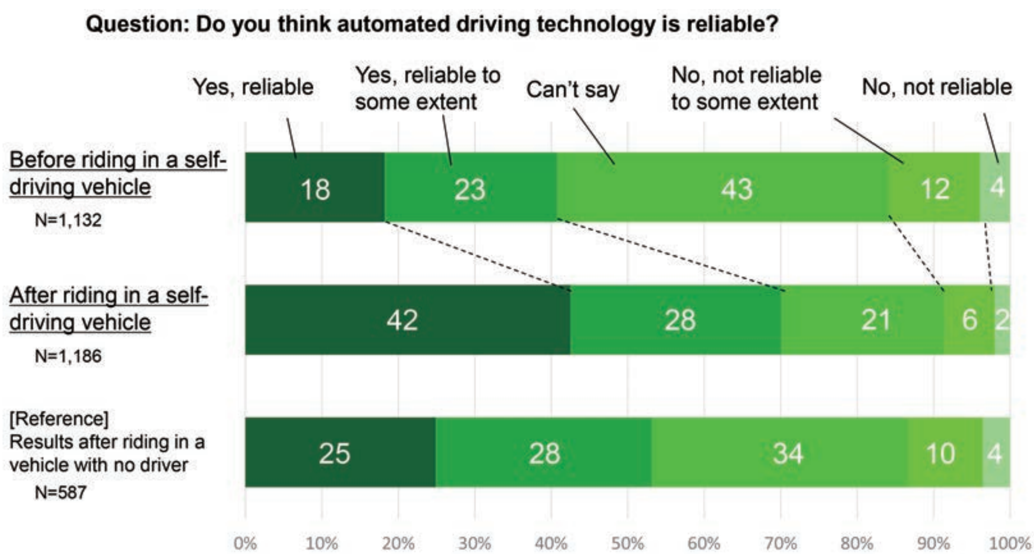

Fig. 2 Change in people's attitudes about the reliability of ADS

Overview of International Cooperation Activities by SIP-adus

Hajime Amano (ITS Japan)

1 Background

In the past ten years, technologies for automated driving have been dramatically improved not only by established automobile manufacturers, but also by startups in the information service industry. The time between the start of research and development of technologies to their deployment as commercial services is being shortened. A variety of activities have been initiated in vehicle technologies, infrastructure, standardization, regulatory issues and field operation tests in every part of the world, even though automobile manufacturers are operating in a global single market. Therefore, international cooperation from the very early stage of development is recognized as an essential aspect of connected and automated driving projects for the international harmonization of standards and regulatory frameworks.

2 Definition of the Goal of the Project

At the beginning of the project, its goal was defined for sharing with international stakeholders. The idea is described as follows.

"An inclusive society, where different people in diverse communities actively participate in generating values, will enhance both the wellness of individuals and economic development. Automated driving technologies integrated with social innovations should provide everyone with mobility to fully exercise their capabilities, enabling the sustainable development of the society."

Then the project was named SIP-adus: Cross-Ministerial Strategic Innovation Promotion program, Innovation of Automated Driving for Universal Services – Mobility Bringing Everyone a Smile –.

3 Focus Areas

The key international cooperation platform for connected and automated driving systems has been the EU-US-Japan Automated Road Vehicle Working Group, co-chaired by the European Commission, U.S. Department of Transportation and the Japanese Ministry of Land Infrastructure, Transport and Tourism. Through discussion with international counterparts, six important areas of international cooperation were identified and six leaders were assigned to coordinate that cooperation. As the project had made progress toward deployment, field operational tests were added as another area of cooperation. All international activities are aligned to those thematic areas.

3.1. Dynamic Map

Digital map databases with a layered structure built on graph network representation of roads will be expanded to include highly detailed description of the road structure and its surrounding environment. The database will be dynamically linked to real-time data from an integrated sensing system onboard the vehicle and semi-real-time data from V-to-X communications. Such databases can only be developed and maintained through collaboration across the industry sectors and public agencies.

3.2. Connected Vehicles

Higher levels of automation require a larger range of observation of the driving environment. The deployment of connected vehicle technology will be advantageous to automated driving systems. Proximity will be sensed by integrated sensors onboard the vehicle. Physically shielded vehicles will notify each other through V-to-V communication. Beyond the horizon of sensing systems, V-to-I communication will provide automated vehicles with additional information.

3.3. Human Factors

The shift between levels of automation will depend on the driving environment and driver's condition along the trip. It is important to design automated vehicle systems to effectively communicate with the driver so that the situational awareness of the driver is maintained and the transition between the levels of automation is properly performed.

3.4. Cybersecurity

A connected car is a car that has become capable of providing various services, which enhance its convenience and safety, utilizing DSRC and cellular communication. Also, it uses onboard communication networks such as CAN, LIN, and Ethernet. At the same time, however, there is a risk of exposure to cyberattacks. Cybersecurity measures will have to continue to be reinforced to keep systems secure in the future. Therefore, it is essential to share information and promote collaboration among industry and government across the conventional boundaries between sectors.

3.5. Impact Assessment

Enhanced safety is the objective with the highest priority in vehicle automation. However, automated vehicle technology is only one part of measures to avoid traffic accidents. Field research on vehicle crashes, the modeling vehicle behavior, and the evaluation of a variety of measures are the foundations to take an integrated approach that makes the most effective use of new technologies.

Socioeconomic impacts are also important aspects of the assessment, which will provide a foundation for fostering social acceptance of connected and automated vehicle deployment

3.6. Next-Generation Transportation Systems

In the central districts of large cities with high-density travel demand, a pedestrian-centered multimodal transportation network is anticipated to offer efficient and sustainable mobility. Innovative transit systems featuring automated driving technologies and on-demand operation will reduce travel time while making trips comfortable for passengers, and enhance efficiency for operators. In contrast, small vehicles with enhanced driver assistance for personal use are also anticipated to provide aged or handicapped users with a level of mobility that will encourage them to actively engage in social activities.

4 Major International Cooperation Activities

4.1. Networking

The members of SIP-adus have actively participated in international conferences to share ideas and experiences. Those opportunities include the Automated Vehicle Symposium hosted by the Transportation Research Board and Association of Unmanned Vehicle System International, and the European Conference on Connected and Automated Driving hosted by the European Commission.

4.2. SIP-adus Workshop on Connected and Automated Driving Systems

Annual workshops have been organized for in-depth discussion among international experts. The Workshop is composed of plenary sessions with a series of presentations open to the public, and closed workshops for in-depth discussion with invited experts. Each plenary session is paired with a workshop for a focus area of international cooperation. Presentations and poster sessions on SIP-adus subprojects were organized. Trial rides of prototypes and commercial models with connected and/or automated driving technologies were provided for international participants.

4.3. Internationally Open Platform of Field Operation Tests with Shared Resources Provided

Large scale field operation tests on public roads started in 2017, and are open to any party meeting the minimum qualifications to participate. Test facilities and operation management are provided. Dynamic map data for the test sites and equipment for connected services are provided at no charge. The only requirement for the participants is to actually use those shared resources, submit evaluation reports, and engage in review discussion to improve and accelerate standardization. Participants who test their vehicles have to arrange all other resources by themselves.

4.4. Standardization

Results from SIP-adus, namely human factors, dynamic map and vehicle control systems, have been reflected in international standardization activities at ISO TC22 Road Vehicles and TC204 Intelligent Transport Systems. In addition, collaboration with industry standardization bodies has expanded.

5 Conclusion

SIP-adus has been actively engaged in international cooperation, gained recognition, and developed a network among global experts. This is quite a unique achievement for the Japanese community, which generally has a reputation for being closed.

About the author:
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① Leading International Debate on the Six Key International Collaborative Themes

Dynamic Maps

Satoru Nakajo (the University of Tokyo)

ABSTRACT: The international harmonization of dynamic maps was pursued based on the results of SIP-adus research activities within Japan. The main task of the activities was to broaden the result of R&D to professionals outside Japan and to get feedback for the direction of the further research. The international harmonization activities include fostering international understanding of dynamic maps, arrangement of static map features arrangement, the promotion on SIP-adus FOTs, and moving standardization activities forward. The relationship with related activities in other countries is just at the beginning stage. Continuous action will be needed to achieve international harmonization of dynamic maps.

1 Basic Approach

The international harmonization of dynamic maps was pursued based on the results of SIP-adus research activities within Japan. The main task of the activities was to broaden the result of R&D to professionals outside Japan and to get feedback for the direction of the further research. The activity started at the beginning of the SIP program in 2013.

The main actions included:

- Making presentations at international conferences, including the ITS world congress, the Transportation Research Board (TRB) annual meeting, the Transport Research Arena (TRA), the Autonomous Vehicles Symposium (AVS) and other related events within and outside Japan.
- Organizing SIP-adus workshops (dynamic map session) in Tokyo.
- Discussing the topic at the EU-US-Japan Trilateral Automation in Road Transport (ART) working group.
- Preparing for, and holding discussions at, meetings related to the above, as well as discussing with other related stakeholders within and outside Japan, including the International Standard Organization (ISO) and the Open Auto Drive Forum (OADF).

The main outcomes of the actions included:

- International understanding of dynamic maps.
- Arrangement of static map features.
- Promotion of SIP-adus field operation tests (FOTs).
- Moving standardization activities forward.

2 International Understanding of Dynamic Maps

2.1. Preparing visual contents

The concept underlying dynamic maps was defined as four layers of data progressing from static, semi-static, semi-dynamic to dynamic. There were several use cases involving employing dynamic maps in automated driving systems. The international cooperation team created presentations to facilitate understanding. Figures 1 and 2 present the results of that work. Figure 1 shows the whole concept underlying dynamic maps and their creation. It illustrates the four layers of data and was created from 3D common platform data including point clouds, graphics and probe data. It also shows that it was possible to use the data directly from vehicles via an API, as well as via OEM servers.

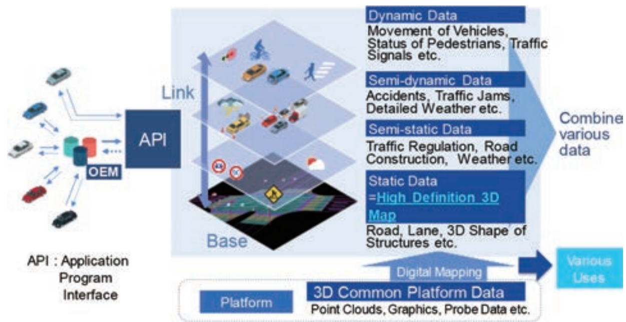

Fig. 1 Concept underlying dynamic maps

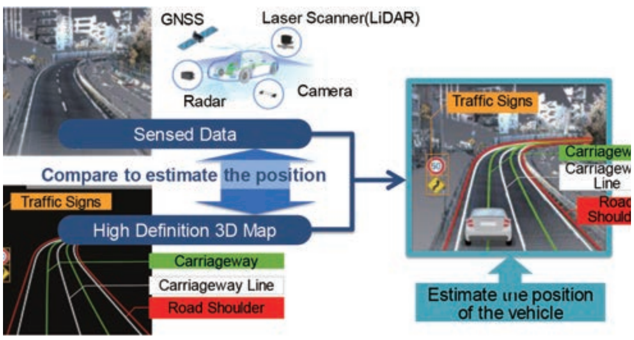

Fig. 2 Example of dynamic map use

Figure 2 shows an example of dynamic map use. It is possible to estimate the position of a vehicle by comparing the high definition 3D map data and the sensed data.

2.2. Presentations at conferences

Based on the results of the R&D and other prepared materials, the international harmonization team made presentations at conferences, including the ITS world congress, events held by TRB, TRA, AVS, and the European

Road Transport Telematics Implementation Coordination Organization (ERTICO), the OADF, the EU-US-Japan Trilateral ART WG and SIP-adus workshops. The team made presentations outside Japan ten times during FY 2017.

3 Arrangement of Static Map Features

SIP-adus has endeavored to harmonize static map features. The research team surveyed the automated driving systems use cases provided by the Japan Automotive Manufacturers Association (JAMA) and existing specifications in FY 2015 and selected 34 features. The team also discussed with major map providers in other countries and selected five features to harmonize.

In FY 2016, the team remodeled the map data based on the data list provided by JAMA, and re-selected 14 basic static map features. Table 1 shows the basic map features and the map features to harmonize internationally, which include:

- Center line
- Lane lines
- Lane edges
- Stop lines
- Pedestrian crossings
- Carriageway links

Table 1 List of features to harmonize

Category	Basic Features	
Real feature	Road Shoulder <u>Center Line</u> <u>Lane Line</u> <u>Lane Edge</u>	<u>Stop Line</u> <u>Pedestrian Crossing</u> Road Marking Traffic Signal Road Sign
Virtual feature	<u>Carriageway Link</u> Lane Link Common Location Reference Node	Intersection Lane Link Intersection Area

*Underlined features are the features to harmonize internationally

4 Promotion of SIP-adus FOTs

The research team and the international harmonization team actively worked to promote participation in FOTs from outside Japan. The contributions included translating related documents and specifications into English, preparing test static map data covering over 700 km, and presenting the FOT plans extensively.

As a result, 21 organizations participated in the FOTs. The organizations include major Japanese and German original equipment manufacturer (OEMs) and suppliers. Table 2 shows the participants in the FOTs.

Table 2 List of FOT participants

Daihatsu Motor Co., Ltd.	Mazda Motor Corporation
Continental Automotive Corporation	Mitsubishi Electric Corporation
Meiji Logitech Co., Ltd.	Mercedes-Benz Japan Co., Ltd.
Toyota Motor Corporation	Omron Corporation
Pioneer Corporation	Subaru Corporation
Suzuki Motor Corporation	Bosch Corporation
BMW Group Japan	Nissan Motor Co., Ltd.
Honda Motor Co., Ltd	ZMP Inc.
Alpine Electronics, Inc.	Saitama Institute of Technology
Volkswagen Group Japan KK	Nagoya University
Calsonic Kansei Corporation	Valeo Japan Co., Ltd.

*FOT participants are for dynamic maps or the human machine interface (HMI)

5 Support for Standardization

5.1. Support for ISO activities

SIP-adus supported several dynamic map-related ISO standardization items with ISO/TC204/WG3 members, include;

- ISO 17572-4: Precise relative location referencing.
- ISO 22726: Dynamic data and map database specification for connected and automated driving system applications.
- ISO 14825: Geographic data files (GDF).

In the context of international harmonization activities, the team supported the organization of a joint meeting with ISO/TC204/WG3 and the OADF. The meeting was held in July 2017 in Aix-en-Provence, France. At that meeting, both organizations informed each other of their status at the time and agreed to discuss further corroboration.

5.2. Collaboration with the OADF and Related Organizations

SIP-adus has discussed collaboration with the OADF several times since 2016. The team participated on an ongoing basis starting with the 5th meeting in October 2016 in Beijing, China. The team started to make presentations on SIP-adus dynamic maps at the 6th meeting.

SIP-adus and the OADF worked together to hold 8th OADF meeting in Tokyo in conjunction with SIP-adus WS 2017. The meeting was held in the same week as the WS, and many digital map professionals attended both events. The team also supported further collaboration, such as the SENSOR Interface Specification (SENSORIS) specification and the ERTICO workshop in Japan in 2018.

At the ITS world congress 2018 in Copenhagen, SIP-adus and the OADF organized a Special Interest Session (SIS). In that session, both representatives discussed related topics for further collaboration. Figure 3 shows one of the slides presented at the SIS. It explains the relationship between SIP-adus and other related standardization organization within the OADF.

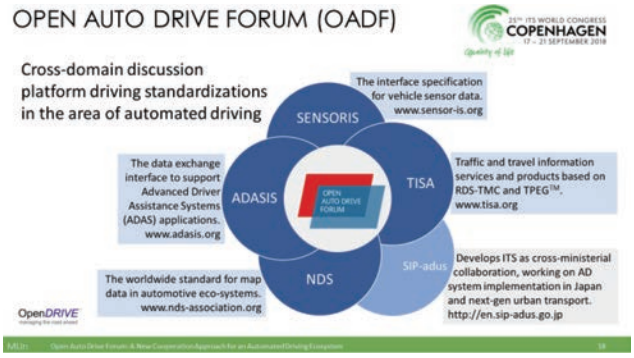

Fig. 3 Presentation at ITS world congress 2018

6 Conclusion

International harmonization activities for dynamic maps were actively pursued, and included fostering international understanding of dynamic maps, the arrangement of static map features, the promotion of SIP-adus FOTs, and moving standardization activities forward.

The R&D on dynamic maps and related dynamic data distribution by SIP-adus will continue. The relationship with related overseas activities is just at the beginning stage. Continuous actions will be needed to achieve the international harmonization of dynamic maps.

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① Leading International Debate on the Six Key International Collaborative Themes

Connected Vehicles

Norifumi Ogawa (Mazda Motor Corporation)

1 Introduction

In terms of international cooperation activities concerning connected vehicles, we have focused on sharing information from Japan about how cooperative ITS with radio communication systems is being applied to automated driving, surveying the trends in Europe and the United States and transmitting the information we obtained to the people involved in Japan. The detailed activities include leading the SIP-adus Breakout Workshop, sharing and collecting information on the trilateral conference among Japan, the U.S, and Europe, participating in the international conferences on automated driving in Europe and the United States, as well as making presentations at conferences, visiting various projects conducted in Europe and the United States, exchanging information among members, and more. The activities are shown below.

2 Activities Summary

2.1 Conferences Attended

The conferences we attended are shown below.

(1) Oct., 2015 SIP-adus Workshop and Trilateral Meeting
(2) Apr., 2016 Transport Research Arena and Trilateral Meeting
(3) May, 2016 Grand Cooperative Driving Challenge, Final Event
(4) July, 2016 Automated Vehicle Symposium and Trilateral Meeting
(5) Nov., 2016 SIP-adus Workshop and Trilateral Meeting
(6) Jan., 2017 Transport Research Board and Trilateral Meeting
(7) Apr., 2017 Connected and Automated Driving Conference and Trilateral Meeting
(8) June, 2017 Drive Me (visiting) and Adaptive, Final Event
(9) July, 2017 Automated Vehicle Symposium and Trilateral Meeting
(10) Oct., 2017 ITS World Congress
(11) Nov., 2017 SIP-adus Workshop and Trilateral Meeting
(12) Jan., 2018 Transport Research Board and Trilateral Meeting
(13) Apr., 2018 Transport Research Arena and Trilateral Meeting
(14) June, 2018 ITS America Annual Conference, Connected Vehicle Pilot Program (NYC) (visiting) and Smart Columbus (visiting)
(15) July, 2018 Automated Vehicle Symposium and Trilateral Meeting

2.2 Conference Summary

Summaries of the conferences listed above are presented below.

(1) Oct., 2015: SIP-adus Workshop and Trilateral Meeting

Session

The U.S. Department of Transportation (USDOT) introduced V2X and truck platooning, which were conducted in New York, Tampa (Florida), and Wyoming, as a Connected Vehicle Pilot Deployment Program (CV Pilot).

The EU introduced truck platooning as well as a cooperative ITS corridor to connect the Netherlands, Germany, and Austria. They also introduced communication interoperability between European countries, the privacy of probe information, cybersecurity as future issues.

Breakout Workshop

The Michigan DOT from the U.S., a Dutch organization from the EU, as well as the Ministry of Internal Affairs and Communications, the Metropolitan Police Department, the National Institute for Land and Infrastructure Management, auto manufacturers, and electrical manufacturers from Japan took part in this workshop.

They exchanged information on current and future activities in their own countries, and shared issues about reducing accidents through the spread of connectivity.

(2) Apr., 2016: Transport Research Arena (TRA) and Trilateral Meeting

With respect to connected vehicles and security, it was agreed in the Trilateral Meeting that the exchange of information would continue. Also, the EU introduced the Declaration of Amsterdam, which was issued as a joint statement on automated driving by the Ministers of Transport in EU countries.

In TRA, a great deal of time was spent on automated driving and energy issues. We are facing the question of how to solve issues that cross national borders, such as the integration of measures from various countries and the commonization of communication infrastructures.

(3) May, 2016: Grand Cooperative Driving Challenge, final Event

The project started in 2011 and concluded in 2016. A large-scale verification test on the highway from Helmond, the Netherlands, was carried out over two days, demonstrating the performance of the cooperative vehicle–infrastructure systems with lane changes between platooning vehicles. After the event, we were able to have an information exchange with TNO (a research institution), which has been leading the project, allowing us to foster ties with Europe.

(4) July, 2016: Automated Vehicle Symposium and Trilateral Meeting

The EU reported that the AdaptiVe project, which made a comprehensive study of automated driving technology, the development of laws, and other factors, would complete the final demonstration at the end of June, 2017.

The U.S. announced that Columbus, Ohio had been chosen for the Smart City Challenge project aimed at solving overall urban transportation problems.

Japan introduced the national projects, such as a large-scale verification test starting in 2017 conducted as part of SIP activities.

(5) November 2016: SIP-adus Workshop and Trilateral Meeting

Session

The results of a SIP study indicated that a V2V emergency vehicle approach warning system could reduce the delay before the arrival of emergency vehicles. In addition, communication between vehicles on a main road and merging vehicles was reported to facilitate smooth merging.

Finland introduced its E8-Aurora project designed to offer a driving testing environment.

Breakout Workshop

The list of participants includes the European Commission, the Finnish MaaS Project, Spain, and Belgium from the EU, as well as automakers and electronic manufacturers from Japan.

With Japanese members introducing their activities related to various services utilizing signal information, the participants shared information of the status of practical use of ITS and held a Q&A session.

(6) January 2017: Transport Research Board and Trilateral Meeting

At the Trilateral Meeting, members discussed future connectivity-related activities and confirmed that information sharing would be their main focus.

The U.S. announced the guidelines for automated driving and the issuance of "Notice of Proposed Rule-making" concerning the mandatory installment of in-vehicle V2V devices. The EU announced its expected launch of a comprehensive project on automated driving. Some updates were shared with members, including the holding of the first international conference on automated driving.

(7) April 2017: Connected and Automated Driving Conference and Trilateral Meeting

This was the first expert conference on automated driving held in Europe.

There were many political reports presented, including the agreements on cross-border test zones (Cross Border Self-driving Test Zone between France and Germany), and cross-border legal frameworks for tests. Meanwhile, the industrial sector is actively working on matters such as situation-based use of 5G mobile networks and DSRC, with an eye toward automated driving.

(8) June 2017: Visit to Drive Me and Adaptive final event

Drive Me is a large-scale test conducted using 100 automated vehicles (Volvo-made). For one year starting in September 2017, it investigated the level of driver confidence in Level 4 automated vehicles and the level of traffic participants capability to interact with them, with the aim of elucidating the challenges involved in automated driving.

The Adaptive project is aimed at solving HMI related issues and legal challenges, including the social impact of the realization of automated driving (e.g., decreased CO_2 emissions, reduced number of accidents), through technological approaches, namely the development of automated vehicles, verification tests/simulations with those vehicles, and more.

· In the test-ride event, members test drove a Volvo truck performing automated driving on the Autobahn.

(9) July 2017: Automated Vehicle Symposium and Trilateral Meeting

Members visited Gomentum Station (a test course for automated driving). Currently, automated driving tests, safety support system tests, and last-mile evaluations using the EasyMile self-driving bus for unmanned driving, are underway.

At AVS, there were many reports on studies that center around automated vehicles being conducted to improve transportation services as part of more comprehensive efforts encompassing public transportation systems in the context of national- and state-level projects.

At the Trilateral Meeting, it was reported that many projects were brought to an end around 2017 in Europe, which has entered a new phase for launching next-generation projects.

(10) October 2017 ITS World Congress

In both America and Europe, measures to reduce traffic accidents, congestion, and CO_2 emissions have been taken by applying connected vehicles featuring automated driving and communication technologies. Such activities are progressing from the research to the large-scale test phase. The activities are taking comprehensive approaches that include not only the development of automated driving technologies but also the creation of legal systems and safety standards.

(11) November 2017 SIP-adus Workshop and Trilateral Meeting

Session

The United States team introduced two tests, the Connected Vehicle Pilot Deployment program and the Smart City Challenge. The European Commission started its Cooperative ITS (C-ITS) activities in 2014 and, in cooperation with automotive makers and public agencies released a report on C-ITS Platform Phase 1 in 2016. The following year, it announced Phase 2, which specified the tasks to address in 2017, and a revised version is planned for release in 2018.

Breakout Workshop

The participants included ERTICO and suppliers from the EU, USDOT and other groups from the U.S., and representatives of the Ministry of Land, Infrastructure, Transport and Tourism, vehicle manufacturers, electronics manufacturers, communication carriers, and other industries from Japan.

In terms of information sharing, issues concerning cross-border communication infrastructure and 5G usage were presented by the EU, while the U.S. talked about the CARMA project and investments in DSRC and other tests. Also, the expansion of the infrastructure remains an issue in each area.

(12) January 2018 Transport Research Board and Trilateral Meeting

In the U.S., the details of the CV Pilot have been made clear.

CARMA, a new automated driving project run by USDOT (FHWA), started considering a software platform for column traveling, speed adjustments, and crossing control.

Europe will launch the 5G Car project, which focus on studying communication systems for automated driving using mobile networks.

(13) April, 2018 Transport Research Arena and Trilateral Meeting

The EU issued the specification for the final stage of the ITS-G5 (DSRC), and announced that tests were to be performed in various countries, as it aims to achieve practical application starting 2019. In the meantime, the pace of forward-looking activities, including lively discussions on the 5G communication system (next-generation portable communication), has quickened.

(14) June 2018 ITS America Annual Meeting, Visit to Connected Vehicle Pilot Program (NYC), and to Smart Columbus

We visited the NYC Transportation Bureau (NYC DOT) and investigated the progress of the CV Pilot project and were given an on-site tour of a traffic control center in the NYC DOT.

At the ITS America annual meeting, Mark Reuss, VP at GM, gave a keynote speech on automated driving functions and V2X (DSRC) installation plans, which attracted the interest of the audience. Also, a number of reports on tests of safety driving support systems using V2X performed throughout the U.S. were provided at the session, indicating the steady progress of activities aimed at the practical applications of these systems.

We visited Columbus, Ohio to observe the Smart Columbus initiative, which studies the application of the latest technologies to achieve efficient urban transportation. The project will conduct tests on transportation as a whole, including the provision of traffic information to information terminals, automated driving technology to cover the last mile after the end point of public transportation routes, the use of electric vehicles, and truck platooning.

(15) July, 2018 Automated Vehicle Symposium and Trilateral Meeting

A report comparing the performance of DSRC and Cellular V2X was made by Qualcomm.

Cellular V2X has a longer wave propagation distance than DSRC. However, there were objections from the DSRC side.

The ICT4CART (an EU project) aims to utilize level 4 automation operations in the real world using various ICT technologies such as C-ITS, C-V2X, LTE, and G5 to increase the reliability of V2V, V2I, and V2N during transitions between each mode of communication.

① Leading International Debate on the Six Key International Collaborative Themes

Human Factors

Satoshi Kitazaki (National Institute of Industrial Science and Technology)
Makoto Ito (University of Tsukuba)
Tatsuru Daimon (Keio University)
Kiyozumi Unoura (Honda R&D Co. Ltd)
Hiroki Mori (Toyota Motor Corporation)
Takashi Sunda (Nissan Motor Co. Ltd)

ABSTRACT: The EU-US-Japan trilateral cooperation on human factors has been active since Japan joined the cooperation framework in 2015. The human factors WG has been discussing specific topics. The first topic was the Out-of-the-Loop Concept. The outcome of the discussions was summarized and published as a technical paper in 2018. The WG then started discussion on the next topic, mental models, and is planning to publish a paper in 2019. The human factors sessions in the SIP-adus Workshop have been great opportunities to promote the research and development activities on human factors in Japan, as well as to obtain valuable feedback for the project. Through international cooperation, the presence of Japan in the field of human factors has grown extensively.

1 Trilateral cooperation on Human Factors

1.1. Position of the Working Group

The Human Factors Working Group (WG) is officially placed under the Steering Group and expected to work on general human factors issues. However, the WG has been focusing on human factors in automated driving since Japan joined the WG in 2015. Therefore, the Human Factors WG and Human Factors Sub-Group under the Automation WG became one and the same (Fig. 1).

1.1. Members

The Trilateral Human Factors WG has been led by three co-chairs, Chris Monk, NHTSA, US, Johan Engström, Volvo, EU, and Satoshi Kitazaki, AIST, Japan. Emma Johansson (Volvo) took the co-chair position of EU when Johan Engström left in 2017. In each region, 5 or 6 human factors experts from academia, industry and government form a team under the leadership of the co-chair (Table 1).

1.2. Statement of Work made in 2018

Objective

- To share understandings of human factors in automated driving.

Scope

- Exchanging information about plans and findings of research on human factors in automated driving in each region.
- Identifying and discussing critical human factor issues that have not been highlighted.

Possible deliverables

- Reports/papers that summarize discussion

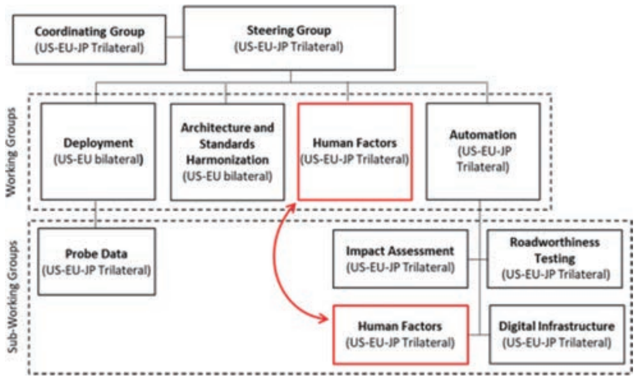

Fig. 1 Trilateral cooperation organization as of 2017.

Table 1 Members of the Human Factors WG (as of 2018)

United States	
Chris Monk, co-chair	NHTSA
Paul Rau	NHTSA
Dan McGehee	University of Iowa
Johan Engström	Waymo
Chuck Green	General Motors
Brian Philips	FHWA
European Union	
Emma Johansson, co-chair	Volvo group
Trent Victor	Volvo cars
Andreas Keinath	BMW
Anna Schieben	DLR
Natasha Merat	University of Leeds
Klaus Bengler	TU Munich
Japan	
Satoshi Kitazaki, co-chair	AIST
Kiyozumi Unoura	Honda
Hiroki Mori	Toyota
Takashi Sunda	Nissan
Makoto Itoh	University of Tsukuba
Tatsuru Daimon	Keio University

1.3. Achievements

1.3.1. Out-of-the-Loop Concept Paper

The loop concept is important in understanding driver engagement in the driving task with level 2 and level 3 automated driving systems. However, the terms, in-the-loop and out-of-the-loop, have been used with different concepts. Natasha Merat of the University of Leeds took the leadership of the project on this issue and invited more human factor experts to the WG in 2016. The WG worked on a technical paper to precisely define the concept and how it can be measured based on reviews of concepts in the literature. The definitions are given below. The paper was published online (Merat et al., 2018).

In the loop: In physical control of the vehicle and monitoring the driving situation.

On the loop: Not in physical control of the vehicle, but monitoring the driving situation.

Out of the loop: Not in physical control of the vehicle, and not monitoring the driving situation, OR in physical control of the vehicle but not monitoring the driving situation.

1.3.2. Mental models

The next focus, which had been discussed in the WG in parallel to the final phase towards the publication of the loop concept paper, was determined to be mental models. Trent Victor of Volvo volunteered to lead this new project in 2018. The user mental model may be considered the internal "picture" the user has of the system functions based on given knowledge. It may also grow through experiencing the system. An appropriate mental model is expected to shift a knowledge-based understanding of the system functions to a rule-based one, and make necessary driver responses quicker and faster. However, incorrect mental models may cause negative effects on users such as misuse or overtrust. The challenge is to design the system to foster an appropriate mental model in the driver. The target of the WG is to publish a paper in 2019.

2 SIP-adus Workshop

The field of human factors has been one of the areas of focus in plenary sessions and breakout sessions of the SIP-adus Workshop. The presenters in plenary sessions were from academia, industry and government in the EU, the US and Japan (Table 2). Activities, findings and plans concerning human factors in various sectors in various regions have been shared among the experts and the audience. The breakout sessions were organized as round-table or group discussions on specific topics (Table 3). The topics were chosen to be relevant to the SIP-adus human factors research project for the purpose of feeding discussion outcomes into the project. Posters were also presented every year on the progress of the SIP-adus human factors research project.

Table 2.1 Presenters and titles of presentations in the human factors plenary session at SIP-adus Workshop 2015

2015 Moderator: Satoshi Kitazaki, AIST

Presenters		Title of presentation
Myra Blanco	VTTI, US	Moving Ahead with Vehicle Automation
Tyron Louw	U of Leeds, UK	An Overview of European Activities on Human Factors of Vehicle Automation
Makoto Itoh	U of Tsukuba, Japan	Towards smooth and safe trading of control from machine to human
Eckard Steiger	Robert Bosch, Germany	HMI for Automated Driving
Motoyuki Akamatsu	AIST, Japan	Human Factors Issues in Interactions Between Human and Automated Vehicle
Steven Shladover	U.C. Berkley, US	Human Factors Challenges for Driving Automation Systems
Kiyozumi Unoura	Honda R&D, Japan	Humans and Automated Driving Systems: Human error and performance are two side of the same coin

Table 2.2 Presenters and titles of presentations in the human factors plenary session at SIP-adus Workshop 2016

2016 Moderator: Satoshi Kitazaki, AIST

Presenters		Title of presentation
Myra Blanco	VTTI, US	Mixed-Function Automation: Naturalistic Driving Study
Chris Monk	NHTSA, US	Automated Vehicles Research
Emma Johansson	Volvo, Sweden	HUMAN FACTORS IN VEHICLE AUTOMATION - Activities in the European project AdaptIVe
Natasha Merat	U of Leeds, UK	What information do cyclists and pedestrians want when interacting with a fully automated road transport systems
Daniel McGehee	U of Iowa, US	Engineering consumer understanding of higher levels of automation
Thomas Sheridan (Makoto Ito)	MIT, US (U of Tsukuba)	Some remarks on human factors in driving automation (vedeo); Makoto Ito ontroduced Sheridan
Satoshi Kitazaki	AIST, Japan	SIP-adus Human Factors and HMI research : on-going project

Table 2.3 Presenters and titles of presentations in the human factors plenary session at SIP-adus Workshop 2017

2017 Moderator: Satoshi Kitazaki, AIST

Presenters		Title of presentation
Daniel McGehee	U of Iowa, US	Assessing Driver Performance and Understanding in Automated Driving Systems
Brian Philips	FHWA, US	Opportunities for Connected Automation to Improve Safety
David Yang	AAA Foundation	Vehicle Technologies & Automation - Research on the "User Issue"
Peter Burns	Transport Canada, Canada	Safe Human-Machine Interfaces (HMI) for Automated Vehicles
Panos Konstantopoulos	Secured by Design, UK	In-Car Displays: Customer Expectations, Trends and Human Factors
Natasha Merat	U of Leeds, UK	Overview of Human Factors research on Automated Vehicles at Leeds
Makoto Ito	U of Tsukuba, Japan	SIP Human Factors Research Project Task A: Effects of system information on drivers' behavior in transition from auto to manual
Toshihisa Sato	AIST, Japan	SIP Human Factors Research Project Task B: Assessment of driver states in automated driving and Investigation of driver controllability in transition from automated to manual driving
Tatsuru Daimon	Keio U	SIP Human Factors Research Project Task C: Study of Communication between Automated Vehicle and Other Road User

Table 2.4 Presenters and titles of presentations in the human factors plenary session at SIP-adus Workshop 2018

2018 Moderator: Satoshi Kitazaki, AIST
Common theme: "What have we found? What's the next?"

Presenters		Title of presentation
Klaus Bengler	Technical U Munic, Germany	Communication and Interaction between automated vehicles and other road users
Peter Burns	Transport Canada, Canada	Human factors : unknowns, knows and the forgotten
David Yang	AAA Foundation	What have we found ? What's next Takeaways from AAA foundation's research
Michiaki Sekine	NTSEL, Japan	Issues related to human factors in international regulation activity of automated driving technologies
Satoshi Kitazaki	AIST, Japan	"What have we found? What's the next?"

Table 3 Topics of human factors breakout session at SIP-adus Workshop

Year	Topics
2015	What are the human factors problems / issues?
2016	TOPIC 1: Non-verbal communication between AV and other road users TOPIC 2: Driver monitoring
2017	Users' mental models and HMI/HMInteraction design, education and training
2018	What have we found? What's the next?

3 Conclusions

The trilateral cooperation framework and the annual SIP-adus Workshop have produced great opportunities to promote the research and development activities on human factors carried out in Japan, as well as to obtain valuable feedback to the project. Satoshi Kitazaki has been invited as the Principal Investigator of the SIP-adus human factors research project to many international workshops, conferences and meetings to present the progress and findings of the project. Through international cooperation, the presence of Japan in the field of human factors has grown extensively.

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Information Security

Takashi Imai (President, Toyota InfoTechnology Center Co., Ltd.)

1 Security

1.1. International Trends in Measures against Cyberattacks on Vehicles

Governments and industry groups are currently working on development of laws, regulations and guidelines in order to respond to cyberattacks on vehicles. The United States was the first to take action. In July 2015, the SPY Car Act was introduced in the Senate. The bill includes requirements to develop cybersecurity standards to protect vehicle control systems from hacking, standards to ensure privacy of the data collected in the vehicle and a cyber dashboard to rate how well vehicle security and privacy are protected. In 2016, Auto-ISAC and the National Highway Traffic Safety Association (NHTSA) issued, in January and October respectively, best practices related to automotive cybersecurity. Although some issues remain since the guidance introduced in these best practices were merely conceptual, they serve an important role in that certain degree of guidelines were presented by the government and industry groups that are in a position to impose directives on automakers. Along with these guidelines, the Society of Automotive Engineers (SAE) issued J3061 in January 2016 which specifies process-based cybersecurity measures. J3061 covers cybersecurity measures to consider in each phase of the product lifecycle from planning, development, and operation to the disposal of the product after its launch. However, much room remains for improvement, as no specific methods regarding threat analysis and risk assessment were identified in the guideline. In September 2017, the SELF DRIVE Act was passed by the House of Representatives. Section 5, CYBERSECURITY OF AUTOMATED DRIVING SYSTEMS, notably, requires auto makers to develop cybersecurity plans. The act applies to all non-commercial road vehicles to be sold after it comes into effect, and automakers must be aware of its importance as violating that law means they will not be allowed to supply any automated driving systems (including partially automated vehicles) to the US market. In Europe, hardware design for vehicle network and chips were studied in the EVITA project from 2008 to 2011. In the Working Party on Automated/Autonomous and Connected Vehicles under the United Nations WP.29 forum, Europe has been working to lead the development of a guideline to ensure cybersecurity and data protection for connected cars and automated driving. The contents were published in 2016 and will be updated as necessary in the future. In Japan, the Japan Automobile Manufacturers Association (JAMA), JasPar, and the Ministry of Land, Infrastructure, Transport and Tourism are working together to establish minimum mandatory standards for vehicle cybersecurity. Separately, the Society of Automotive Engineers of Japan (JSAE) has issued a cybersecurity analysis guide that summarizes the procedures for security activities ranging from threat analysis to the definition of cybersecurity requirements. The above presents the major trends in the United States, Europe and Japan, all of which are currently in a period of transition, which means that laws and guidelines are not fully established. The ISO and SAE aim to develop an international standard (ISO 21434) based on international consensus by 2020. Until that standard is issued, automakers will be required to takes into consideration the laws, regulations and guidelines previously mentioned and make their own decisions in establishing frameworks to ensure the security quality of their products.

1.2. Efforts to Share the Outcome of SIP-adus Globally

With these international trends in mind, we are working on the development of a security evaluation guideline to protect against cyberattacks as part of SIP-adus information security activities. The guideline simulates actual cyberattacks and is considered highly effective. The novelty in the evaluation method used in this guideline is that it specifies common procedures and evaluation criteria for penetration testing, the effectiveness of which is generally considered to be highly reliant on the individual skills of the tester. To assess the direction and necessity of the new evaluation method, we are closely monitoring trends in Japanese automotive industry groups such as JAMA and JasPar, as well as international standards (ISO 21434) and WP.29 initiatives while working to foster common understanding and urge the spread of penetration testing in the industry. In addition, we are consulting with the JSAE, which is in charge of ISO 21434 and the National Traffic Safety and Environment Laboratory, which is promoting discussion on information security at WP.29, in order to ensure that our project contributes to leading international discussions.

About the author

1) Takashi Imai, President, Toyota InfoTechnology Center Co., Ltd.

Impact Assessment

Nobuyuki Uchida (Japan Automobile Research Institute) and Hiroaki Miyoshi (Doshisha University)

ABSTRACT: Automated vehicles have the potential to transform the world's road transportation system. Expected benefits include traffic safety, transport network efficiency, energy/emissions, and personal mobility. Furthermore, as the existing transport systems are complex, prior to implementation, automated vehicle technology must be understood and its effects carefully predicted prior to implementation to plan for that transformation. This article introduces the international activities of SIP-adus with regards to assessing the impact of automated vehicles from the following three perspectives: the Trilateral Impact Assessment Sub-Group for ART, as well as both safety and socioeconomic impacts.

1 Introduction

Automated vehicles (AVs) have the potential to transform the world's road transportation system. The potential benefits include traffic safety, transport network efficiency, energy/emissions, and personal mobility. As it is being introduced into existing complex transportation systems, AV technology must be understood and its effects carefully predicted prior to implementation to adequately plan for that transformation. In this article, we introduce international activities with regards to assessing the impact automated vehicles from the following three perspectives: the Trilateral Impact Assessment Sub-Group for ART, as well as both safety and socioeconomic factors.

2 Trilateral Impact Assessment Sub-Group for ART

Members of the Trilateral Working Group on Automation in Road Transportation (ART WG) are working to address the complexity of the impact of AVs in various areas. European researchers are looking at the possibility of applying the Field Operational Test Support Action framework (FESTA, FOT Net 2016) to automation and sketching the mechanisms through which automation potentially affects our lives. The United States Department of Transportation (US DOT) has sponsored the development of a modeling framework that includes the areas of safety, vehicle operations, personal mobility, energy/emissions, network efficiency, travel behavior, public health, land use, and socioeconomic impact. Japan has been developing models of the impact on safety since late 2015 under SIP-adus.

To coordinate the impact assessments performed in the field of automated driving, the ART WG established an Impact Assessment sub-group in 2015. The motivation was the realization that, as field tests are expensive and mostly done on a small scale, international harmonization would be in everyone's interest. With a harmonized approach, tests and studies can be designed to maximize the insights obtained and arrange complementary evaluations around the world.

The framework aims for high-level harmonization of impact assessment studies globally. It is the first attempt at harmonization by the three regions involved (EC, US and Japan). As automated driving covers many concepts, the framework does not give detailed methodological recommendations (i.e., methods to apply for calculating the strength of various impacts) but it aims to facilitate meta-analysis across different studies. Therefore, the focus is on providing recommendations on how to describe the impact assessment study in a way that users of the results understand what was evaluated and under which conditions.

The areas of AV impact may be divided into two large groups: direct and indirect. Figure 1 depicts the impact areas (Smith, 2017). Direct impacts are those which have a clear cause-effect relationship with the primary activity or action. They are easier to capture, measure and assess, and are often (though not always) immediate to short-term in nature. In Fig. 1, they are in the upper left, and include safety, vehicle operations, energy/emissions and personal mobility. The others are indirect impacts. Indirect impacts can be characterized as secondary, tertiary, or still further removed from the original direct impact.

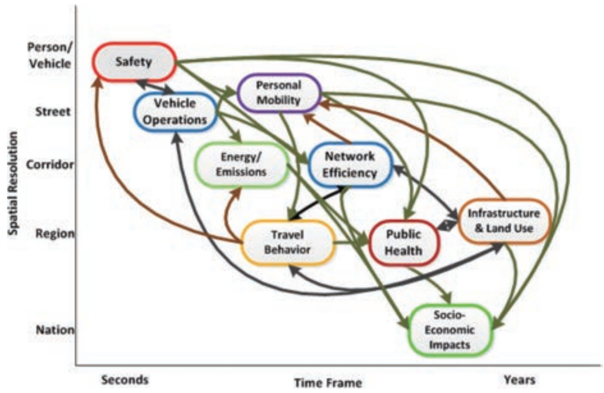


Fig. 1 Framework of impact areas (Smith, 2017)

Direct Impacts are those that can be measured in a field operational test (FOT). They then can be scaled up to a national level and will also lead to indirect impacts. An FOT can also provide insight into the infrastructure requirements of an automation application.

3 Methodology of Safety Impact Assessment

Nearly all AV applications, ranging from Level 1 collision avoidance systems to Level 5 self-driving vehicles, have potential safety impacts. Ultimately, safety should be measured by accident statistics, such as fatalities, injuries and property damage for vehicle occupants and other road users. Other road users may include pedestrians, cyclists, and slow-moving vehicles. One challenge with safety impact assessment is that actual crashes are rare events, even with a considerably large-scale FOT. Therefore, proxy measures are often used.

In Japan, a novel multi-agent traffic simulation software was developed as a part of the SIP-adus projects. The software can simulate and identify at least five types of accidents. Different automated driving technology penetration scenarios can be set to estimate the potential impact of different technologies on safety. A summary of the achievements of the research project is described below.

Figure 2 shows a simulated area created to model a part of Tsukuba City in detail. The road network was composed of various routes such as an expressway, major roads, and old narrow streets in order to verify the simulation program.

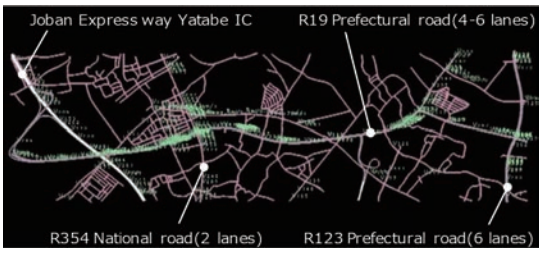


Fig. 2 Road network for verification of simulator functions

Typical automated driving penetration rates are entered in order to compute and compare the results of diverse technology penetration scenarios. There are multiple driving modes including manual driving, autonomous emergency braking (AEB), lane departure warning (LDW) and automated driving (Table 1). It is important to set up mixed scenarios consisting of various driving modes to achieve a more practical estimation of safety impacts.

Table 1 Technology penetration scenarios

Simulation Scenarios	*1*	*2*	*3*	*4*	*5*
Manual Driving(MD)	100	50	25	25	-
Autonomous Emergency Braking(AEB)	-	50	25	-	-
AEB + Lane Departure Warning(LDW)	-	-	50	50	25
Automated Driving(AD)	-	-	-	25	75

In order to estimate possible accident reduction effects, it is essential to reproduce a realistic traffic flow via simulation. There are approximately 500 agents that can behave individually in our current simulation (Fig. 3). Traffic density and travel velocity are pre-set based on road traffic census data.

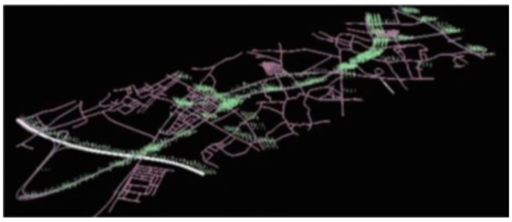


Fig. 3 Multi-agent traffic simulation including 500 agents

As shown in Table 2, under 100% manual driving, the system simulated a total of 859 accidents categorized in five types. The number of accidents predicted decreased as the level of automation increased, coming down to 156 cases for the highest automation level simulated (25% of vehicles with AEB+LDW and 75% of Level 4 automated driving). Figure 4 shows that all the technologies considered contributed to the absolute decrease in accidents, which was predominantly represented by the reduction of rear-end and lane departure-related crashes.

Table 2 Synoptic table of simulation results

No.	*Total*			*MD*	*AEB*	*AEB LDW*	*AD*
	NoA [Freq.]	*AR* [Freq. /km]	*RAR* [%]	*RAR* [%]	*RAR* [%]	*RAR* [%]	*RAR* [%]
1	859	0.011	100	100			
2	622	0.008	70	101	41		
3	463	0.006	56	113	46	36	
4	430	0.005	46	116		30	14
5	156	0.002	16			29	12

NoA: Number of Accidents, AR: Accident Rate, RAR: Relative Accident Rate

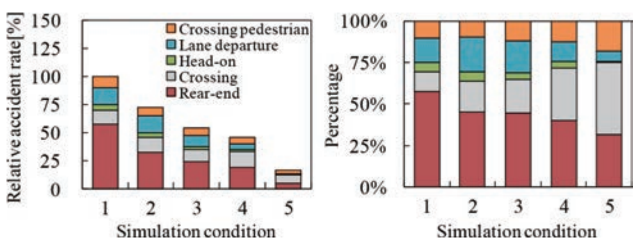


Fig. 4 Comparison of relative accident and component rates

The above results in the SIP-adus project were presented at the Autonomous Vehicles Symposium 2018 in San Francisco (Kitajima et.al., 2018) and drew the interest of the international community of experts. Several research groups expressed considerable interest in the multi-agent traffic simulation model, and future collaborative research regarding the simulation model is expected. Such international collaboration and discussions can address the methodology of safety impact assessment.

4 Economic Analysis of Safety Impacts

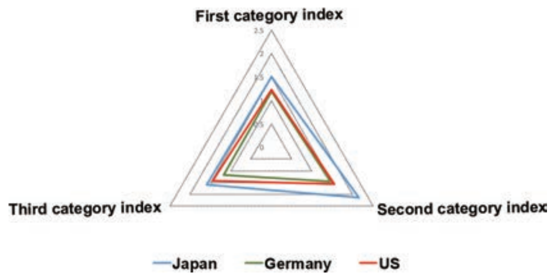
We also conducted analysis on safety impacts from the viewpoint of economic factors. Compared to passive safety technologies, one of the most distinctive features of automated driving systems lies in the fact that the economic benefits of those systems will be enjoyed not only by their users, but also by non-users. With AEB, for example, preceding vehicles will benefit more than following vehicles equipped with on-board devices, regardless of whether devices are install in the preceding vehicles or not. It can also be said that automated driving systems are safety-sharing systems. From an economics viewpoint, this implies that it is difficult for automated driving systems to be diffused properly via market mechanisms. Thus, economic incentives will be necessary to facilitate the diffusion of automated driving systems in society. We initiated international discussion on these points at several international conferences (See Miyoshi, 2017).

5 Socio-Economic Impacts

Automated driving will bring about various significant socioeconomic impacts.

The decrease in the opportunity cost of traveling when SAE levels 4 and/or 5 automated driving becomes widespread in society could dramatically change human lifestyle, for example.

The national economy will also be affected by automated driving, which will significantly change the cost and cost structure of vehicles thanks to the change of inputs. In addition, some advocates claim that automated driving will result in a decrease in vehicle sales and ownership due to the widespread use of car sharing and ride sharing. It is possible that automated driving will significantly impact the Japanese industrial structure. We estimated three categories of indexes of the power of dispersion of the automotive sector. The first category denotes the relative size of the influence on the entire industry (including the self-sector) in a case where the final demand for the industry increases by one unit. The average value is 1. The greater the value of an industry, the more heavily that industry affects the whole sector. The second and third category indexes are modifications of the first category. The third category index denotes the impacts on other sectors. The effect on the self-sector is totally excluded. In the second category, only direct effects of 1.0 on the self-sector are excluded. Figure 5 shows the three categories of indexes for Japan, Germany and the US. Japan has the largest value in each of the three categories, indicating that, among the economies of those three nations, the Japanese economy will be the most affected by the diffiusion of automated driving systems. We discussed this issue at the ITS World Congress 2017 (See Miyoshi and Kii, 2017)



Note) Calculated by author for the sector of "Motor vehicles, trailers and semi-trailers".
Data) 2011 Input-Output Tables compiled by OECD. Stat
Source) Miyoshi and Kii (2017)

Fig. 5 Indexes of the Power of Dispersion of Automotive Sector

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International Cooperation Activities for Next-Generation Transport

Masayuki Kawamoto (University of Tsukuba)

ABSTRACT: Next-generation transportation and logistics are getting more attention as practical early applications of automated vehicle technology as well as related innovative new services. Low-speed automated shuttles represent one of the major topics in this area and are the subject of demonstrations with several business models targeting improvement in quality of life. Walking always accompanies the use of public transport in daily life. Therefore walking support systems, especially for vulnerable road users, are key to promoting public transport that encompasses upcoming shared mobility. Realizing driverless vehicle is still years away, but several applications making use of automated vehicle technologies are being introduced to contribute reduction in traffic accident fatality.

Automated Public Transport Topic Trends

At almost the same time as our SIP-adus activities were launched in 2014, several existing international conferences started to include sessions relating to automated vehicle systems. At those conferences, topics relating to public transport and its services were few because the small size of the market for automated vehicles for public transport did not draw much interest from major IT and auto manufacturers. Recently, however, the situation has been changing, and automation in public transport and freight vehicles, as well as related services, has been gathering attention.

Low-Speed Automated Shuttles

The major drivers of this trend were not IT giants or major auto manufacturers, but rather small startup companies. One of the triggers for this development was the CityMobil2 project, partially funded under the auspices of the EU's Seventh Framework Programme for Research (FP7) which ran from 2007 to 2013.

EasyMile and Navya from France developed their automated shuttle for CityMobil2, which was a pilot demonstration project for automated road transport systems across Europe. BestMile from Switzerland developed operation service systems for those automated shuttles. Now EasyMile, Navya and BestMile are providing their products worldwide including in the U.S. and Japan.

Fig. 1 CityMobil2 Project

Fig. 2 EasyMile EZ10

Fig. 3 Navya ARMA

Fig. 4 2getthere

Fig. 5 Local Motors Olli

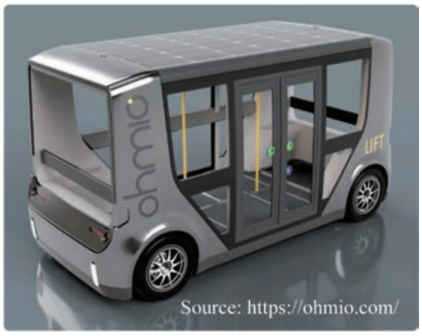


Fig. 6 Ohmio LIFT

Another automated shuttle maker that is a little older than the above companies, 2getthere from the Netherlands, has also been providing commercial operation transport products worldwide.

Olli, developed by Local Motors in the U.S., and Ohmio from New Zealand, are automated shuttles offering a unique concept and features that differ from the offerings of the French makers.

Despite a background and environment favorable to manufacturing such vehicles, Japan is still struggling to bring out original products.

The e-Palette concept from Toyota, which debuted at CES 2018, provides a ray of hope for the future of the automotive industry in Japan.

Fig. 7 e-Palette Concept

Working Vehicle Automation

One reason for focusing on low-speed automated shuttles as a practical application of vehicle automation is their limited operational domain. This makes it possible to choose or set up a less critical domain for their operation where most risks can be predicted and avoided.

Similarly, long distance freight trucks and working vehicles such as refuse trucks and road cleaning vehicles represent another area of focus for the practical application of automated driving. Automated truck platooning projects are being conducted in the EU and the U.S., as well as in Japan.

Fig. 8 Automated Refuse Truck

Fig. 9 Truck Platooning

The challenge of building self-driving trucks is being met by Einride of Sweden which is developing the T-pod, which is remotely controlled by the driver and the T-log, which features automated driving capability.

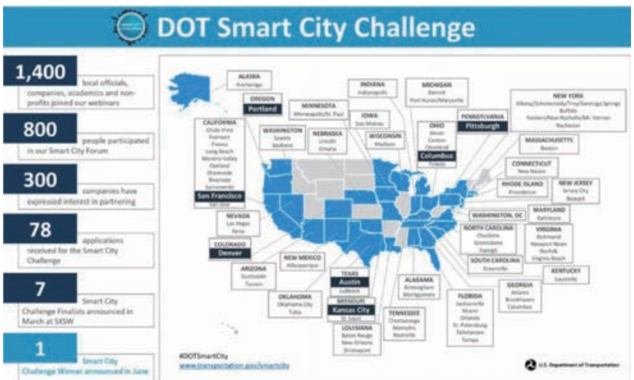
Fig. 10 T-pod

Fig. 11 T-log

Expanding Demonstrations from Small Sites to Entire Cities

In their initial stage, most automated driving shuttle demonstration projects have been carried out in relatively limited areas like private campuses or small parks. However, some of those demonstration projects are now expanding their concepts to entire cities, as exemplified by the Smart City Challenge in the U.S.

In 2016, USDOT selected the city of Columbus Ohio as the winner of its call for Smart City Challenge proposals. This kind of project is not being conducted only in Columbus, but also in several cities in the U.S., with funding from several sources.



Source: https://www.transportation.gov/smartcity/highlights

Fig. 12 USDOT Smart City Challenge

After those projects expanded to entire cities, automated mobility became only one factor in innovation. Smart cities utilizing AI, IoT, open/big data, and renewable forms of energy are targeting improvements to the quality of life for all citizens. Valuable mobility-based services have emerged as a new area of focus called mobility as a service, or MaaS.

Mobility as a Service

MaaS is one of the biggest areas of focus in current international conferences for automated vehicle systems and intelligent transportation systems (ITS). There was a period of a few years when automated vehicle-related conferences only covered the topic of mobility services in the titles of a few presentations, but it is now found in several session titles, and is sometimes even the subject of the whole conference.

The definition of MaaS is still unclear. However, it should consist of new service value associated with mobility, rather than merely simple transportation from A to B and its attendant services. New service value will follow new business models such as integrated sharing services or completely different cost allocations. It will take a little more time for industry to find practical MaaS solutions.

User Acceptance of Automated Vehicles

Some demonstration projects are venturing to conduct their operation in spaces that include pedestrians, taking maximum care to avoid accidents, in order to evaluate user acceptance of automated shuttle by both passengers riding the vehicles and the pedestrians in the vicinity of the vehicle. The GATEway project in Greenwich, UK is one example, as is the Mcity project in Michigan, USA. Of course, obtaining conclusive results concerning user acceptance applicable to various people will take time, but is also definitely an important process to implement future regular operation of automated shuttles in shared spaces and similar areas.

Fig. 13 GATEway project

Fig. 14 Mcity project

User acceptance studies have usually been conducted through questionnaires involving a limited number of participants and a short evaluation period, but their results have always included an unrealistically hopeful bias because most demonstrations were carried out under ideal conditions. A realistic user acceptance study, such as the one by PostBus in Sion, Switzerland, must consider daily regular operation in a general (rather than ideal) environment.

Fig. 15 PostBus SmartShuttle in Sion

Vulnerable Road User Support Systems

The activities of the Accessible Transportation Technologies Research Initiative (ATTRI) of USDOT have served as a reference for SIP-adus. Rather than the aging society challenge faced by Japan, the ATTRI activities address the many veterans who need mobility services providing additional care. The two situations are similar in terms of the need for mobility service offering several modes that cater to diverse groups of people.

Source: https://www.its.dot.gov/research_areas/attri/

Fig. 16 Diversified mobility services ATTRI

What We Have Learned and What We Should Do

The current results of several automated driving field tests around the world indicate that realizing fully automated driverless vehicles on public roads is still years away. In the near future, even without a driver, introducing automated vehicle services in actual markets will still require additional labor for tasks such as maintaining the vehicles and their dedicated infrastructure, securing operational safety, and providing emergency support.

Continuous step-by-step studies are still required to reach our goal, which, it must be noted, is not to develop self-driving vehicles. Our final goal is zero traffic accident fatalities. There are still issues to resolve before self-driving can improve the safety and efficiency of public transportation and logistics through the use of automated technology in preparation for future self-driving.

Activities toward International Standardization of Dynamic Maps

Hiroki Sakai (Mitsubishi Research Institute, Inc.), Sumio Nishiyama (Kiwi-W Consortium)

ABSTRACT: In order to contribute to the international community, SIP-adus has supported the development of international standards for the logical data model referenced by applications such as automated driving systems and for lane-level location referencing. For the logical data model, an input proposal was developed by examining data models that will be necessary for those applications. For lane-level location referencing, a proposal for an international standard was created from use cases, requirements and general concepts for lane-level location referencing. SIP-adus will continue to support the international standardization of dynamic maps.

1 Purpose of Activities

As part of the cross-ministerial Strategic Innovation Promotion Program (SIP) activities covering automated driving systems (ADS), dynamic maps are being developed as maps used in such systems. In order to contribute to the international community, SIP-adus aims for the international standardization of this outcome. Based on the history of ISO/TC204/WG3 (ITS database technology), which has promoted the international standardization of car navigation maps, candidates for the international standardization of dynamic maps are (1) data exchange, (2) API, (3) the data model (description of data type/attribute structure, methods of maintaining relevance between data items, etc.), and (4) lane-level location referencing method for data exchange. Data exchange is already under development as GDF 5.1 (20524), an extension of GDF 5.0, which is an existing standard in ISO/TC204/WG3. For the second candidate, it is difficult to specify API without a data model. In light of this situation, SIP-adus has supported the development of an international standard for the logical data model referenced by applications such as ADS and for lane-level location referencing.

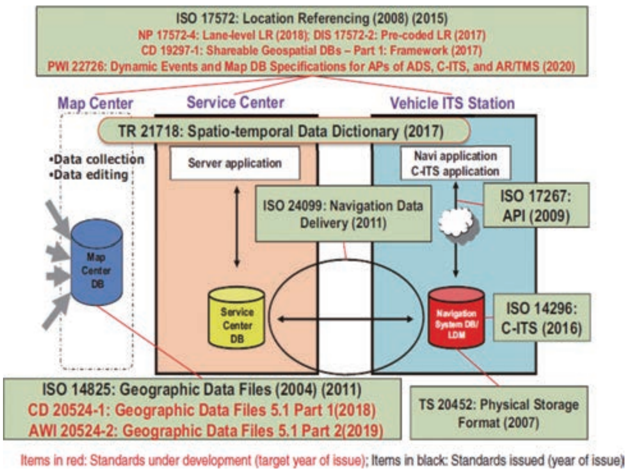


Fig. 1 Relationship between ISO/TC204/WG3 Work Items.[1]

2 Standardization of Logical Data Model

2.1. Overview

This work item standardizes the logical data model referenced by applications such as ADS.

The data envisioned for use in ADS is categorized into static data (i.e. maps for high levels of driving automation and traditional map data) and dynamic data (e.g. traffic and travel information). These types of data are interconnected to realize ADS. The data model for ADS shall have a structure specialized for driving automation and designed to be shared with other systems. GDF 5.1 provides detailed road data as static map data for ADS. ISO 14296 specifies the static map data and the attendant logical data model for car navigation systems and cooperative ITS. Furthermore, dynamic data has already been specified and used in many existing systems. Although it is necessary to specify the relationship between map and dynamic data envisioned for use in ADS, no such relationship has been provided so far.

Thus, the data system architecture related to the static and dynamic data flow was examined and, based on the results, the logical data model was assessed, and an input proposal was developed by examining other data models. The specification on map features and attributes for ADS provided by the Japan Automobile Manufacturers Association was referenced when considering the necessary features. The implementation of this specification could lead to cost reductions in the maintenance and expansion of map access libraries, as well as in the compilation and maintenance of map and map-related data for data providers, as well as for connected and driving automation/vehicle control applications.

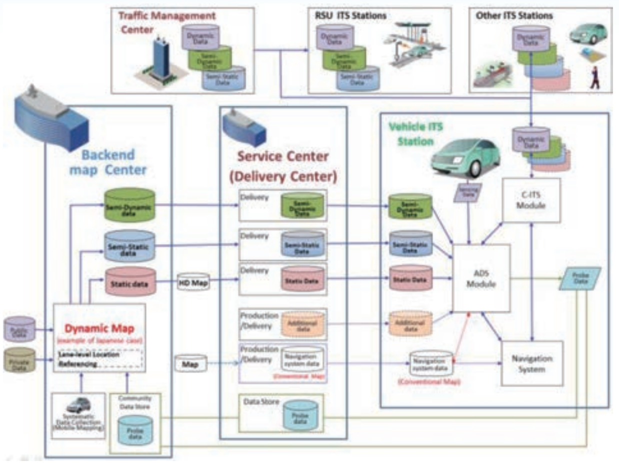


Fig. 2 Proposed Architecture for Automated Driving System

2.2. Status of International Standardization

This work item was conditionally approved as PWI (22726) in April 2017. After that, in October 2017, through expanded joint meeting with existing WGs and external SDOs, the Japanese delegation explained the scope of this work item and the contents of work to plan in the future, while ensuring that there is no conflict with the existing standards and establishing a cooperative relationship with these WGs and SDOs. At the international conference in April 2018, it was agreed to establish Part 1 as Architecture and data model for harmonization of static map data and Part 2 as Data model of static transitory and dynamic transitory data, and that the resulting documents would be published as TS. Part 1 was approved as an NP in August 2018 and it is scheduled for publication as a TS in spring 2020. Part 2 is planned to be moved to an NP proposal after a consensus on the data type classification and data items subject to standardization is reached (as of September 2018).

3 Standardization of Lane-Level Location Referencing

3.1. Overview

This work item standardizes location referencing capable of locating an object on a road within a specific lane.

ISO 17572 Part 1, Part 2 (pre-coded), Part 3 (dynamic) have been published as the international standards for location referencing methods. However, none of them handles location referencing at the lane level. Furthermore, there is no other widely used standard covering location referencing at that level. Thus, a proposal for an international standard was created from use cases, requirements and general concepts for lane-level location referencing.

There are two ways to reference location:

Method 1: Lane number counting

Method 2: Delta from a reference point

The method used is selected according to road segment type and/or usage. As a general rule, Method 1 is used to represent events in lanes (excluding intersections) and Method 2 is used to represent events at junctions. However, Method 2 can also be used to represent events in lanes.

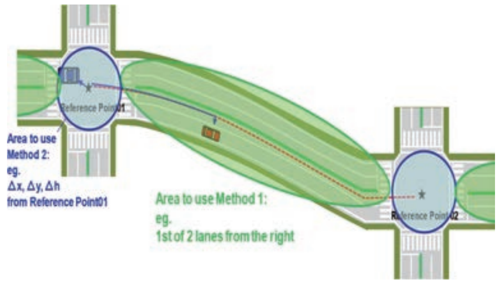


Fig. 3 Lane-Level Location Referencing Methods

3.1.1. Method 1: Lane Number Counting

The longitudinal location shall be referenced using a distance along a road section and a lane number counting rule. The distance along a road section shall be expressed as a percentage of the road section or a real distance. The vertical location shall be expressed as a distance from the road section. This method is used for the situations described below.

- Road segments that have lane information.
- Specifying the lane.

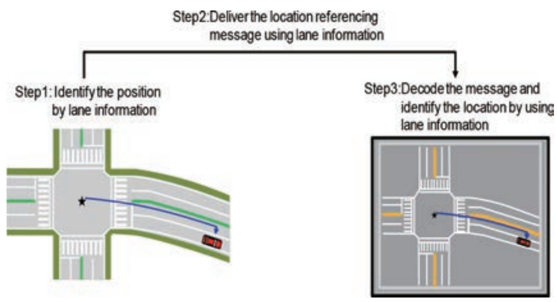


Fig. 4 Explanation of Method 1

3.1.2. Method 2: Delta from a Reference Point

The location shall be referenced using the distance from a reference point (Δx, Δy, Δh). This method is used for the situations described below.

- Road segments in junctions.
- Specifying the relative position within a road (e.g. σ<25 cm accuracy).

In order to achieve a location measurement accuracy with a margin of error of σ<25 cm with this method, the following condition shall apply:

- The method is used within a radius of no more than 200 meters from the reference point.

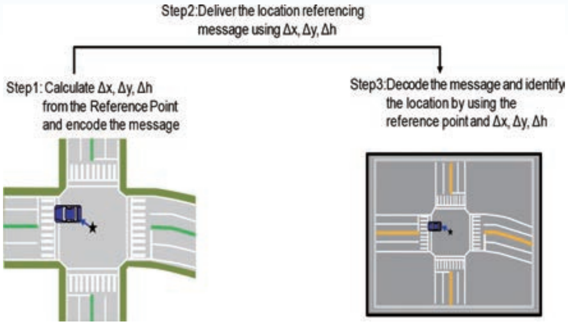


Fig. 5 Explanation of Method 2

3.2. Status of International Standardization

This work item received NP approval in April 2017. The CD ballot ended in July 2018, and CD comment resolution concluded at the international conference in September 2018. It is scheduled to move to a DIS ballot proposal in December 2018 and be published as an IS in the summer of 2019 (as of September 2018).

4 Conclusion

In order to contribute to the international community, SIP-adus has supported the development of international standards for the logical data model referenced by applications such as ADS and for lane-level location referencing. For logical data models, an input proposal was developed by examining other data models. As of September 2018, Architecture and data model for harmonization of static map data has been approved as an NP (22726-1). SIP-adus will continue to support international standardization, aiming for publication as a TS in the spring of 2020. In the dynamic maps for ADS proposed by Japan, how to associate externally provided information with map information is an important consideration. Thus, in its examination of static transitory data, dynamic transitory data and dynamic data, SIP-adus will support cooperating with existing WGs and external SDOs to avoid conflicts with related existing standards. For lane-level location referencing, a proposal for an international standard was created from use cases, requirements and general concepts. SIP-adus will continue to support international standardization, aiming for publication as an IS in the summer of 2019.

References

(1) ITS Standardization 2017: Society of Automotive Engineers of Japan,
http://hq.jsae.or.jp/its/2017_bro_e.pdf (September 12, 2018)

General Survey of International Trends Regarding International Cooperation with Dynamic Maps

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ABSTRACT: In order to contribute to the international community in the promising field of dynamic maps, a field expected to be integral to driving automation systems, SIP-adus investigated dynamic map data models and the map data structure of dynamic maps both in and outside Japan. Furthermore, this study worked to clarify differences in specifications of dynamic maps established by various nations. To achieve compatibility between industry standards in Japan and in other countries, it also aimed to reinforce cooperative ties, through exchange of views and debate, between organizations worldwide that conduct research and development in the driving automation field.

1 Research Objectives

In order to contribute to the international community in the promising field of dynamic maps, a field expected to be integral to driving automation systems, SIP-adus investigated dynamic map data models and the map data structure of dynamic maps both in and outside Japan. Furthermore, this study worked to clarify differences in specifications of dynamic maps established by various nations. To achieve compatibility between industry standards in Japan and in other countries, it also aimed to reinforce cooperative ties, through exchange of views and debate, between organizations worldwide that conduct research and development in the driving automation field.

2 Investigation of Dynamic Maps

The investigation gathered information such as the details of standardization documents and activities surrounding the formulation of industry specifications for dynamic maps. This was done through surveying public materials and exchanging information with industry players at conferences and in individual meetings.

Table 1 Main Initiatives in the Global Formulation and Development of Dynamic Map Specifications.

Standardization Level	Domestic/ Int'l	Organization	Specifications
Industry Standards	Domestic	SIP-adus	Dynamic Map Specifications for Dynamic Map Field Operational Tests
	Int'l	NDS	Navigation Data Standard Open Lane Model 1.0
		ADASIS	Advanced Driver Assistance Systems Interface Specification
		TISA	Traffic Message Channel (TMC) Transport Protocol Experts Group (TPEG)
		SENSORIS	Sensor Ingestion Interface Specification
		OADF	–
International Standards	–	ISO/TC204	22726 : Dynamic events and map database specifications for applications of automated driving systems, cooperative ITS, and advanced road/traffic management systems
			20524 :Geographic Data Files – GDF5.1

2.1. Initiatives outside Japan

The investigation compiled details concerning the activities of European organizations that are actively developing industry standards.

2.2.1. NDS

The Navigation Data Standard Association aims to develop a standard database format that is compatible with all car navigation systems.

The Navigation Data Standard (NDS) is a standard database format that maintains compatibility with all systems. It separates the software and map data, and features immediate data updates.

2.2.2. ADASIS

The Advanced Driver Assistance Systems Interface Specification Forum (ADASIS) aims to develop an interface for ADAS applications and onboard maps.

The Advanced Driver Assistance Systems Interface Specification is an application interface for vehicle control that provides map information to ADAS.

2.2.3. SENSORIS

Initiated by HERE, SENSORIS aims to develop open standards such as a format for processing and analyzing information collected in the cloud from vehicle sensors.

It is studying specifications for uplinking vehicle sensor data to a cloud center and those necessary for services that result from the realization of vehicle sensor data.

2.2.4. TISA

The Traffic Information Service Association (TISA) aims to develop open standards for traffic information and traveler information services.

It is developing two formats: TMC, for the transfer of traffic, weather and other information over FM channels, and TPEG, which uses digital broadcast to transfer information related to traffic, public transport, the weather, and more.

2.2.5. OADF

The Open AutoDrive Forum, consisting primarily of European organizations (NDS, ADASIS, TISA, SENSORIS) and related companies, is a platform that promotes cross-domain debate and coordination to advance driving automation.

It promotes the Auto Drive Ecosystem, which is a cycle of map production, delivery to vehicle, onboard cooperation with ADAS modules, and vehicle (sensors) data feedback.

It has 61 participants, including auto makers and map providers (as of Feb 2018).

It organizes meetings once every two or three months in Europe, the U.S., or Asia.

2.2. Initiatives in Japan

So far, SIP-adus has created documents defining requirements (draft) and specifications for basic map data and production (draft) for dynamic maps.

It has also created prototypes of high-accuracy 3-dimensional maps and conducted field operation tests.

As of December 2017, it has provided data for a subset of local roads and expressways.

2.3. International Initiatives

Under TC 204, the technical committee for ITS standardization within the ISO, WG3 is working on the standardization of geospatial information and related matters with ITS database technology at its core.

It defines the relationship between semi-static/semi-dynamic data and static data for dynamic maps. As of September 2018, the architecture and data model for harmonization of static map data has received NP approval.

Besides the logical data model, there is current deliberation that aims for the publication of geographic data file GDF5.1 (CD 20524-1, AWI 20524-2) and lane-level location referencing (NP 17572-4) by the ISO.

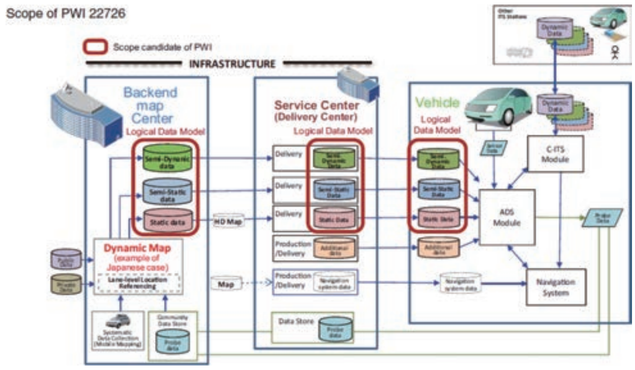

Fig. 1 Scope of PWI 22726.

Source: ITS Standardization 2017: Society of Automotive Engineers of Japan, http://hq.jsae.or.jp/its/2017_bro_e.pdf (September 12, 2018)(1)

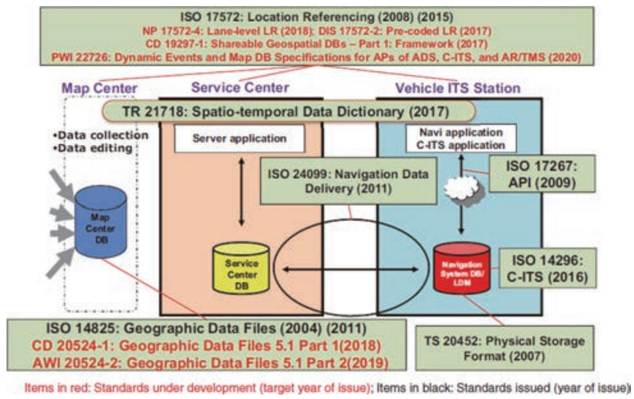

Fig. 2 Relationship between ISO/TC204/WG3 Work Items.

Source: ITS Standardization 2017: Society of Automotive Engineers of Japan, http://hq.jsae.or.jp/its/2017_bro_e.pdf (September 12, 2018)(1)

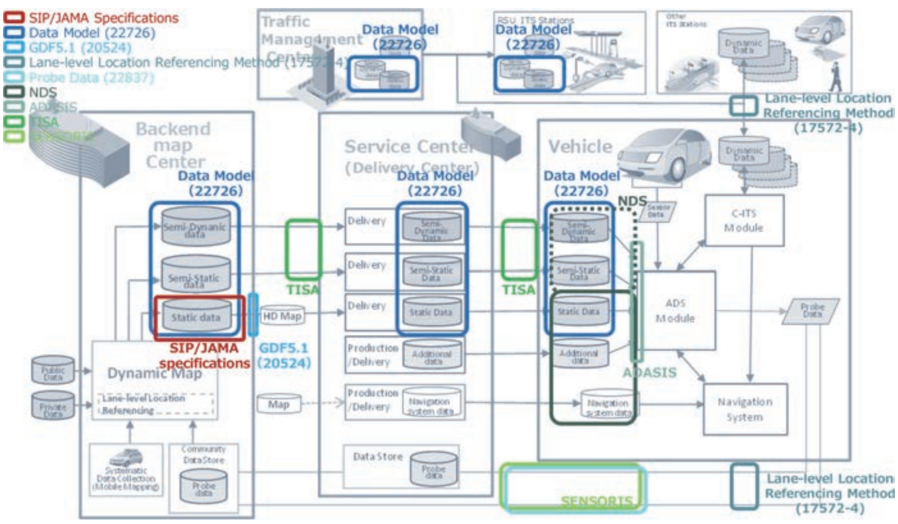

Fig. 3 Japanese and International Activities Related to Dynamic Maps

Source: Created based on ITS Standardization 2017: Society of Automotive Engineers of Japan, http://hq.jsae.or.jp/its/2017_bro_e.pdf (September 12, 2018)(1)

2.4. Japanese and International Activities Related to Dynamic Maps

Domestic and international activities related to dynamic maps are shown in Fig. 3.

3 Cooperation with Related Organizations

The investigation disseminated information regarding the progress of current initiatives in Japan, and sought cooperative partnerships with appropriate organizations through participation in conferences like OADF, as well as exchanges of information with relevant parties.

Table 2 Participation in Conferences Hosted by Relevant Organizations.

Conference	Date	Location	Conference Summary
8th OADF	November 13, 2017	Tokyo, Japan	• Presentation of current state of SIP-adus - Welcome Speech by Mr. Fukushima Overview of SIP and description of items being considered with regard to automated driving systems - Keynote Speech by Mr. Ozawa, Dynamic Map Platform Co., Ltd. Presentation of the current situation regarding the maintenance of high-accuracy 3D map data at DMP and initiatives for map data maintenance updates - SIP-adus Presentation by Dr. Nakajo, University of Tokyo Presentation of verification experiment objectives, test items, distribution data (data items) and overview of data maintenance routes, promotion of automated driving, program participants, and schedule • Agreement to continue cooperation with SIP-adus
9th OADF	March 6, 2018	Budapest, Hungary	• Presentation of the current situation of SIP-adus in concert with the report from European counterparts • Agreement to periodically share their nation's recent developments with respect to automated driving
10th OADF	July 20, 2018	Wuhan, China	• Presentation of the current situation of SIP-adus in concert with the report from European counterparts - Status of FOT (Field Operational Test) - Overview of The 2nd Phase of SIP-adus - Introduction of SIP-adus Work Shop 2018 scheduled to be held in November

4 Information Sharing with Industrial Sectors in Japan

For the purpose of sharing information among Japanese stakeholders and discussing the direction of standardization activities Japan should pursue, a conference called the Dynamic Map Standardizing Strategy Initiative was established. Members of the conference are composed of people from academia, the automobile industry and related fields.

Table 3 Dynamic Map Standardizing Strategy Initiative Schedule.

Conference	Date
1st Meeting	January 15, 2018
2nd Meeting	February 22, 2018
3rd Meeting	March 22, 2018
4th Meeting	June 20, 2018
5th Meeting	October 4, 2018

5 Conclusion

In order to contribute to the international community in the development of dynamic maps, a field expected to be integral to the automated driving system, this study investigated information such as details of the standardization documents and activities surrounding the formulation of industry specifications for dynamic maps. Furthermore, the investigation disseminated information regarding the current state of automated driving in Japan and sought out cooperative partnerships with appropriate organizations through participation in conferences like OADF and exchanges of information with relevant parties. For the purpose of sharing information among Japanese stakeholders and discussing the direction of standardization activities Japan should pursue, a conference called the Dynamic Map Standardizing Strategy Initiative was established. Members of the conference consist of people from academia, the automobile industry and related fields. SIP-adus will continue to seek out cooperative partnerships with appropriate organizations through participation in conferences like OADF, as well as the exchange of information with relevant parties.

References

(1) ITS Standardization 2017: Society of Automotive Engineers of Japan,
http://hq.jsae.or.jp/its/2017_bro_e.pdf (September 12, 2018)

International Standardization for Human Factor Issues in Automated Driving Systems

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Satoshi Kitazaki (National Institute of Advanced Industrial Science and Technology)

ABSTRACT: This article reviews ISO activities on human factors in automated driving systems. Human factors issues have been discussed in ISO TC22/SC39/WG8 (TICS on-board HMI) since 2014. Two technical reports have been published. One is for terms and definitions regarding human states and performance in the transition process. The other is for general ergonomic considerations for external HMI. Two other documents, consisting of experiment guidelines or considerations on human factor issues, are under discussion. An outline of those documents, and the contributions of the SIP-adus Human Factors and HMI research project, are also described here.

1 Discussions of Human Factors Issues in ISO Activities

International standardization activities regarding automated driving systems (ADS) have been conducted in ISO TC (technical committee) 22 and TC204. TC22 is the committee for road vehicles and TC204 is for intelligent transport systems. The main items to standardize in TC204 are the behavior of ADS, minimum functional requirements, minimum performance requirements and system testing procedures. In contrast, items covered in TC22 are more for elemental technologies, such as functional safety, design specifications, HMI/human factors, driver monitoring, event recording and component/subsystem verification. TC22/SC39/WG8 is a working group that addresses human factor issues in ADS.

The first meeting within TC22/SC39/WG8 regarding human factors in ADS was the Automated Vehicle Workshop during WG8 London meeting held in June in 2014. At that time, the SAE had already proposed the definitions for ADS levels, and VDA, Bosch, and BASt had also proposed separate, but similar, definitions. All the definitions were developed from the point of view of system functions (ability), rather than from a human-centered point of view.

During the workshop, we discussed what items should be standardized in terms of the human factor aspects of ADS. As ADS is a state of art technology, it proved difficult to reach a common agreement about target standards because the various ADS envisioned by researchers were all different. It was concluded that, in order to have a common understanding of ADS human factors issues, we needed to standardize terms/definitions and research protocols. In addition, we needed to clarify human-system interaction and system monitoring by the driver (user).

After the workshop, WG8 decided to establish a task force for ADS human factors (TF-ADS). The US delegates nominated Dr. Myra Blanco of VTTI as a candidate to lead TF-ADS. There was discussion in the national committee of Japan at the JSAE on how to deal with this matter. The committee concluded that we should step into the leadership role for ADS standardization in order to reflect the research outcomes of the SIP-adus project in international standards. Then, the Japanese committee nominated Dr. Ono of JARI (currently AIST) as a candidate to lead TF-ADS. In the end, WG8 agreed to make Drs. Myra and Ono co-leaders of TF-ADS at the Bron meeting held in November 2014. The TF-ADS activities then started in the WG8 Bron meeting. TF-ADS decided that the first document to establish as an ISO document would be a technical report with a list of ADS human factors-related terms and their definitions. The document was considered useful to achieve a common understanding of human factor issues in ADS.

2 ISO/TC22/SC39/WG8 Activities on ADS Human Factors

Since the Bron meeting in 2014, we have had two TF-ADS meetings every year. The TF-ADS members prepared materials for the terms related ADS human factor issues and their definitions in those meetings. The co-leader from the US changed from Dr. Blanco to Dr. Schaudt in 2017. After three years of discussions, the document was established as technical report TR21959 “Human Performance and State in the Context of Automated Driving: Part 1 – Terms and Definitions”. This document is now at the preparation for publication stage at the ISO secretariat.

During TF-ADS discussions before the Gothenburg meeting in May in 2017, we decided to prepare Part 2 of the “Human Performance and State in the Context of Automated Driving” document. The contents would be experiment guidelines to assess human factors in ADS. The aim of Part 2 was to include research finding and experiences obtained in the SIP-adus Human Factors and HMI research project. The proposal was approved as a new work item in the Orland meeting, and Dr. Kitazaki of AIST and Dr. Shaudt of VTTI were elected as co-leaders. The workshop for the experiment guidelines document was held in the Prague meeting in April 2018.

In the Paris meeting in November in 2016, Dr. Shutko of Ford, in the US proposed the establishment of a document for external HMI. He argued that automated vehicles would arrive soon and other road users would therefore need external HMI. These external HMI should be standardized in order to let those users understood the meaning of the HMI correctly. Then, the workshop was held at the Gothenburg meeting in June 2017. In the workshop, there were presentations, including one from the SIP-adus Human Factors and HMI research project, and discussions on the latest findings regarding external HMI. Since then, TF-external HMI has started its activities. There has been intense discussion in the TF that it is too early to establish the design guide because we still do not have enough scientific evidence to specify the external HMI design. Therefore, the first document should be a general ergonomic guide for considering external HMI. Also, the Japanese delegates offered the opinion that the first step should be to prepare a document for experiment guidelines to examine external HMI.

The followings sections introduce outlines of the documents under development in WG8.

3 TR21959: Human Performance and State in the Context of Automated Driving: Part 1 – Terms and Definitions[1]

3.1. Scope

The scope of the document is to cover basic terms and definitions related to driver performance and state in the context of automated driving. They are relevant to all levels of automated driving functions that require a human/ driver to be engaged or fallback-ready (SAE levels 1, 2 and 3). The terms are supposed to be used in human factors assessment/evaluations.

3.2. Transition process models

A process model of the transition from manual to automated driving, and a process model of the transition from automated to manual driving were proposed (Fig. 1). Terms related to takeover performance were defined in accordance with the models. "Significant driver intervention" is defined as an action initiated by the user of an automated driving system to request manual control. "Completion of driving manoeuver" is a takeover action expected of the driver to successfully handle the system limit. The time period until vehicle control performance is fully re-established after that completion is referred to as the "control stabilization phase".

3.3. Performance measures in regaining control from automation.

Several variables can be used as measures of performance regarding interventions by the driver. They can be classified into two categories. One is "time-related performance measures" and the other is "quality-related measures". "Takeover time", "system deactivation time", "intervention time" and "control stabilization time" are defined as time-related performance measures. "Safety-oriented objective takeover quality measures", such as number of crashes, and "Sensitivity-oriented takeover quality measures", such as standard deviation of lateral position of the subject vehicle, are examples of quality-related measures. In addition, expert assessments and subjective measures are included.

3.4. Measures of driver states

Attention, and the resources and tasks it demands, are defined as general terms. "Monitoring the driving environment", "monitoring ADS performance", "object and event detection and response (OEDR)", "receptivity", "situation awareness", "vigilance", "operating mode awareness", and "operating state awareness" are defined as terms for driver states required for automation. OEDR and receptivity come from SAE J3016[2]. Measures for these states are described. Some other terms are referenced from SAE J3114[3].

Terms such as "visually distracted/loaded", "visual-manually distracted/loaded", "cognitively distracted/loaded" and "mind wandering" are listed for states corresponding to non-driving related activities. Terms, such as "hands on wheel", "hand off wheel" and "foot position" are listed as driving position/ posture.

3.5. Driver readiness/availability

Readiness is a concept developed in the SIP-adus Human Factors and HMI research project. Availability is a similar concept developed in the KoHaf project in Germany. Therefore, a compromise to use both terms was reached, and they are defined as: the state of the driver during automated driving that influences successful driver intervention performance to regain control of the vehicle from the system to continue driving manually, avoid a hazard or bring the vehicle to a minimum risk condition. It is noted that readiness/availability is a concept and measures for it are to be developed.

3.6. Driver's experiences and attitudes regarding driving automation systems

As driver state and intervention performance depends on their understanding and behavioral attitude with respect to the use of the driving automation system, related terms are defined.

Prior knowledge of driving automation systems and prior expectations of driving automation systems are listed as terms for "prior system image". Knowledge of the system, functionality (purpose) of the system, functional limit and role of the user are listed as terms related to "education and training". Mental model, trust, overtrust, and trust calibration are listed as terms for "user understanding of driving automation systems". Acceptance, reliance, overreliance, underreliance, complacency, disuse, misuse and abuse are listed as terms for "user's use of driving automation system". The document provides definitions of these terms.

4 Road Vehicles: Human Performance and State in the Context of Automated Driving: Part 2 – Considerations in Designing Experiments to Investigate Transition Processes

Part 2 of the document is going to be prepared to help researchers when designing experiments to assess driver takeover performance. The title, structure and contents of Part 2 document are under discussion. Chapters that may be included are as follows. It should be noted that they are all tentative and subjects to change after discussion in the TF.

The chapter for "transition process model" describes the model that is relevant to this document. The "Human factors that influence takeover performance and methods to control/measure them in experiments" chapter will lists factors regarding human functions to be controlled or measured when conducting experiments. The "System factors that influence takeover performance" chapter will describe design elements of ADS to be specified when designing the experiment. The "Test scenario" chapter will describe how to design test scenarios. The "Takeover performance" chapter will describe performance measures collected to evaluate the system tested in the experiment. The "Testing environment" chapter will describe features, advantages and disadvantages of different types of testing conditions, such driving simulator, testing tracks and public roads.

5 TR23049 Road Vehicles -- Ergonomic Aspects of External Visual Communication from Automated Vehicles to Other Road Users[4]

This technical report describes basic ergonomic aspects to consider when designing and evaluating external HMI. This document focuses only on visual communication devices. There are eight chapters in the main body of the report.

The "Current road user communications" chapter describes communications that current road user performs. The "Potential ADS-DV communication" chapter lists possible communication contents of visual external HMI. They are vehicle state, such as vehicle speed and acceleration, and driving mode indicating that the vehicle is moving in automated mode. The "Vehicle perception" chapter explains that visual HMI should be perceived, recognized and understood. Also there is a possibility of presenting the state of the system in brief. The type of information conveyed will be "guidance information" such as prompting pedestrian(s) to start crossing the road and "intent information" such as the ADS-DV intends to stop at the crosswalk. The "Format of ADS-DV communication" chapter states that the format of the visual external HMI should be not confused with existing lighting. The chapter "Other considerations for ADS-DV communication", discusses the need to make compromises with existing laws. The "Acceptance of ADS-DVs by the public" chapter describes how trust is important for society to accept ADS-DV and how understanding the communication involved is necessary. Standardization can play a key role in that respect.

6 Conclusion

Human factors issues in ADS are a hot topic these days. When the ISO activities started in 2014, people were not aware of the importance of human factors in ADS. In this sense, WG8 made a good start. The SIP-adus Human Factors and HMI research project started in 2016 and has been able to make to important contributions to ISO activities. The current tasks in WG8 are all targeted at technical reports as ADS human factors are still under investigation. We should prepare to publish standards since they have a greater impact on society.

References

(1) ISO DTR21959: Human Performance and State in the Context of Automated Driving: Part 1 – Terms and Definitions.
(2) SAE J3016: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. 2016
(3) SAE J3114: Human Factors Definitions for Automated Driving and Related Research Topics. 2016
(4) ISO DTR23049 Road Vehicles -- Ergonomic Aspects of External Visual Communication from Automated Vehicles to Other Road Users.

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