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.

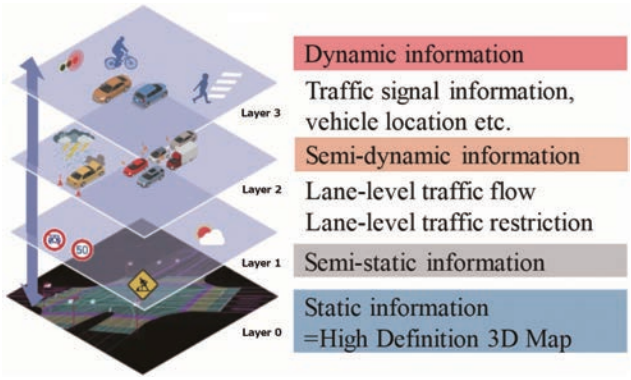

Fig. 1 Structure of a Dynamic Map

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.

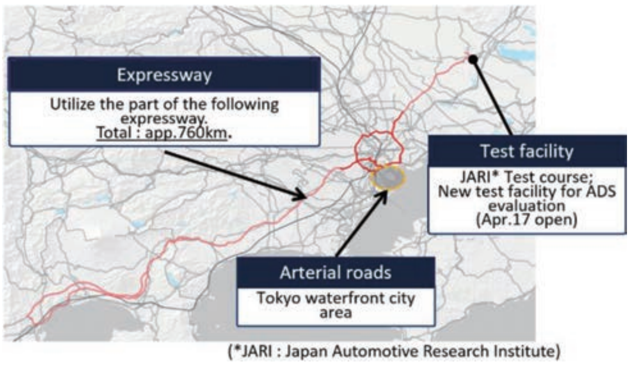

Fig. 2 Dynamic map estimation area

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.

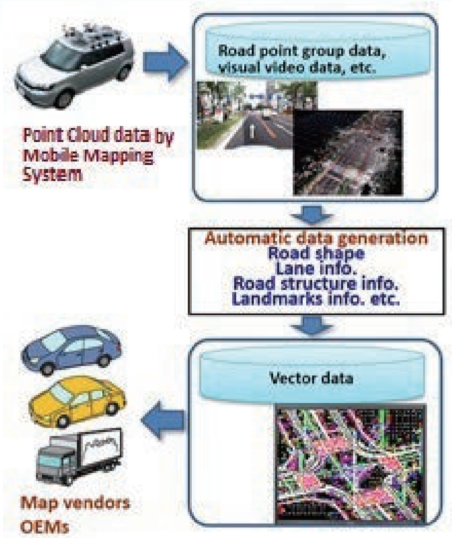

Fig. 3 Example of map database update

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.

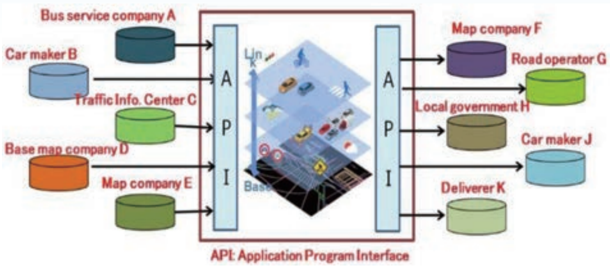

Fig. 5 Dynamic map information service platform

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.

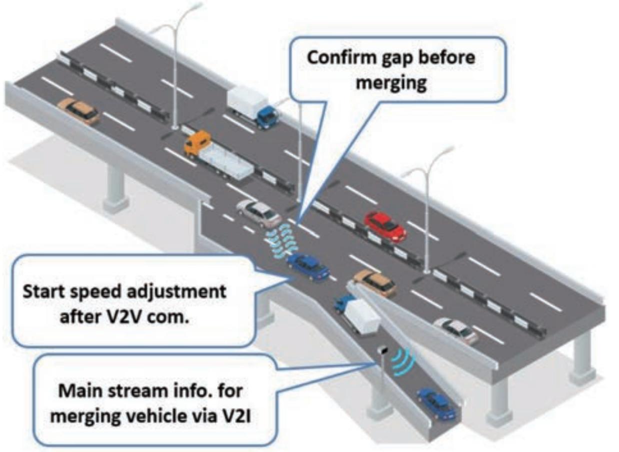

Fig. 6 Merging scenario supported by machine-to-machine communication

Fig. 7 Vehicle-to-pedestrian communication using DSRC

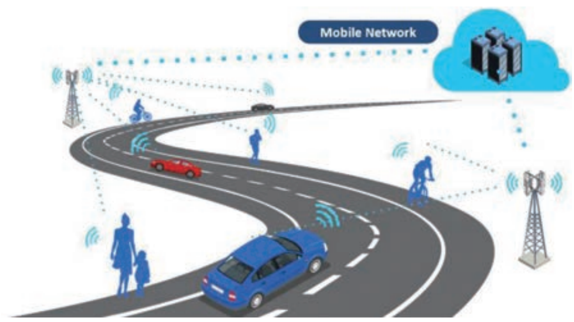

Fig. 8 Wide area communication via mobile network

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)

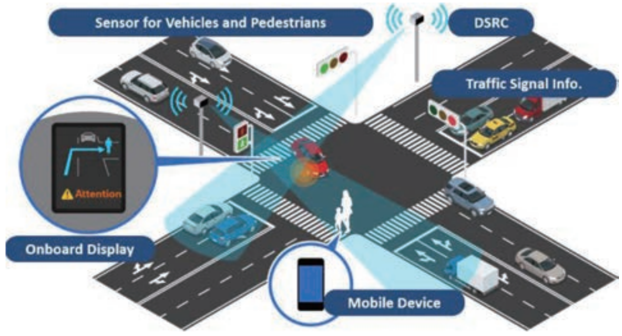

Fig. 9 ITS information services at an intersection

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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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.

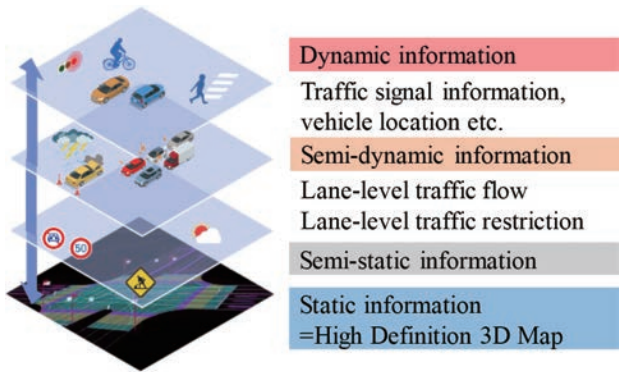

Fig. 1 Dynamic map four layer structure

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

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

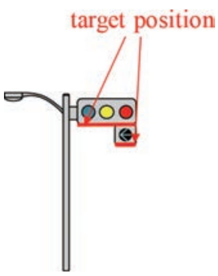

Fig. 3 Traffic signal acquisition position example

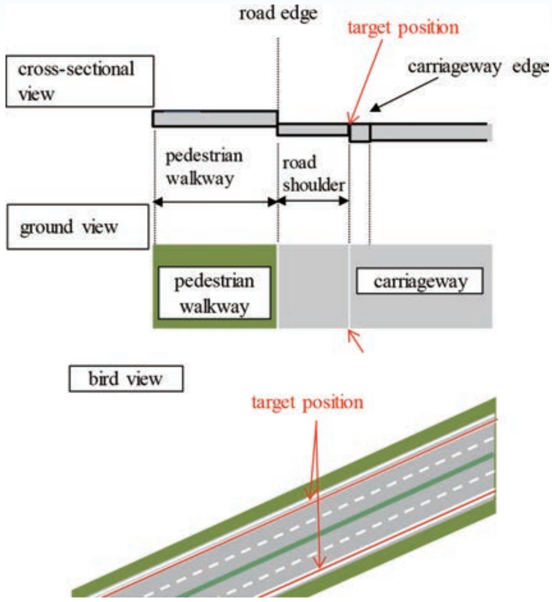

Fig. 4 Shoulder acquisition position example

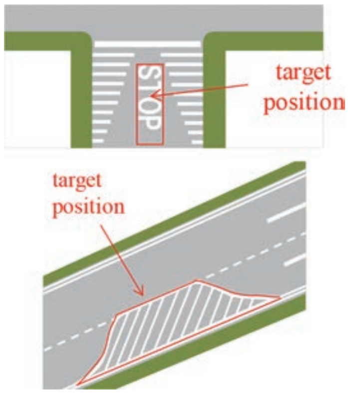

Fig. 5 Road marking acquisition position example

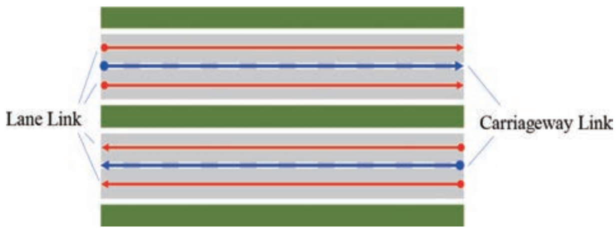

Fig. 6 Lane link and carriageway link acquisition position example

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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.

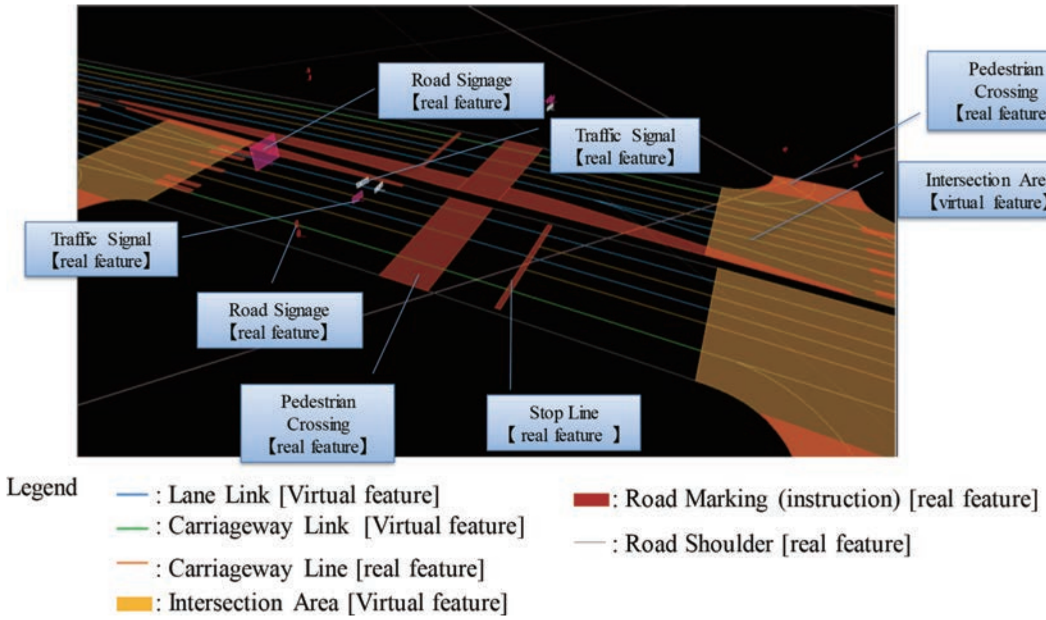

Fig. 7 Depiction of static information

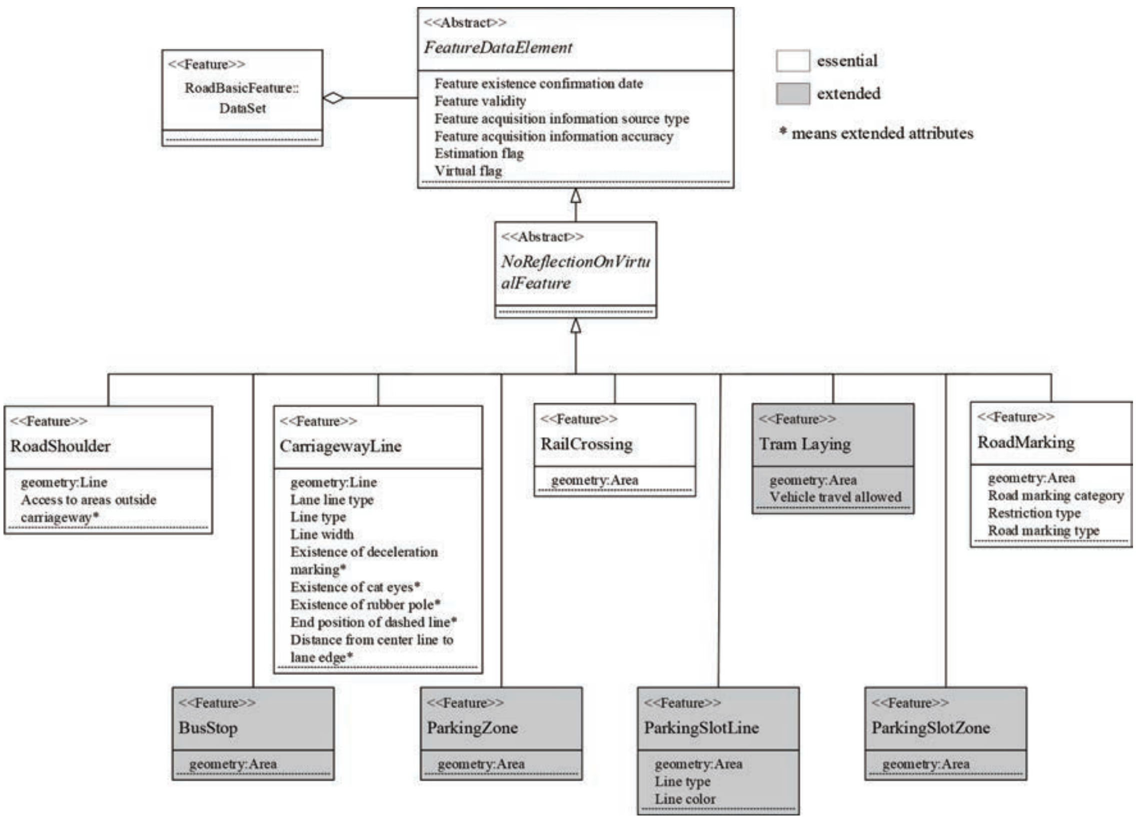

Fig. 8 Examples of definitions of feature attributes and related information

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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            </vertex>
                        :
    </laneLink>
  </featureDataRecord>
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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.

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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.

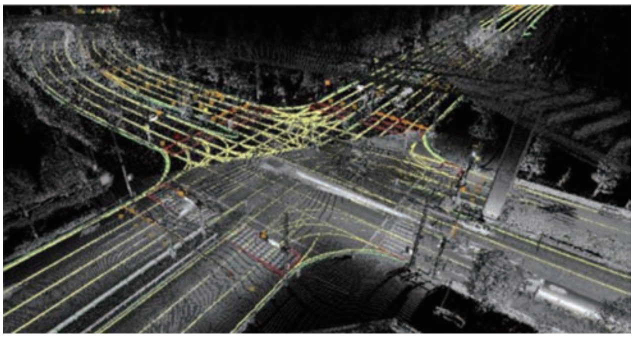


Fig. 10 Example of MMS point group data

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).

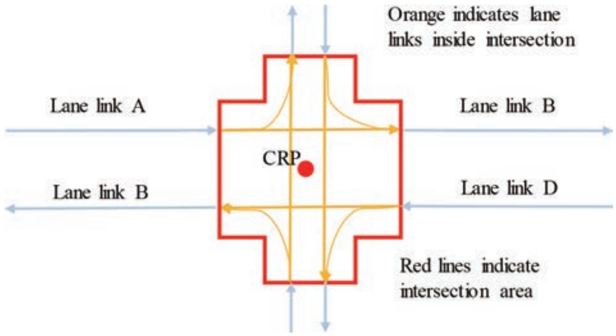


Fig. 11 Example of CRP defined for an ordinary road

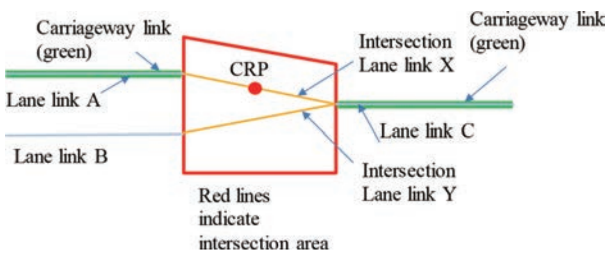


Fig. 12 Example of CRP defined for a highway

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.

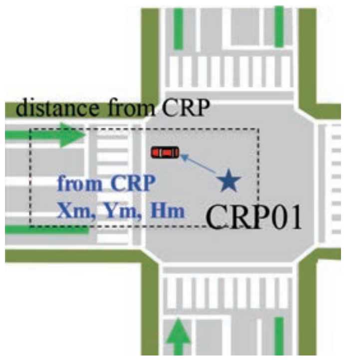


Fig. 13 Conceptual image of location information expression type 1

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.

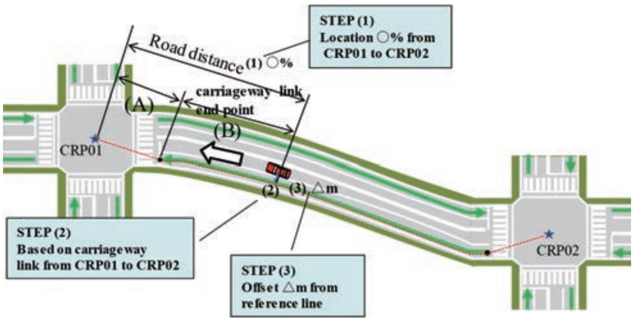


Fig. 14 Conceptual image of location information expression type 2

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).

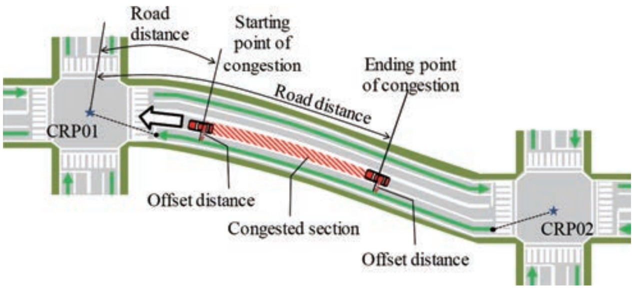


Fig. 15 Semi-dynamic information concept

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

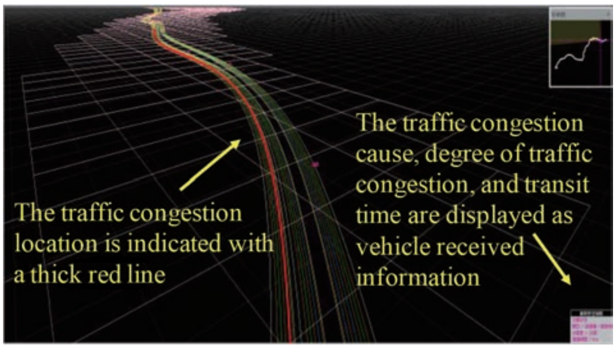


Fig. 16 Traffic congestion information

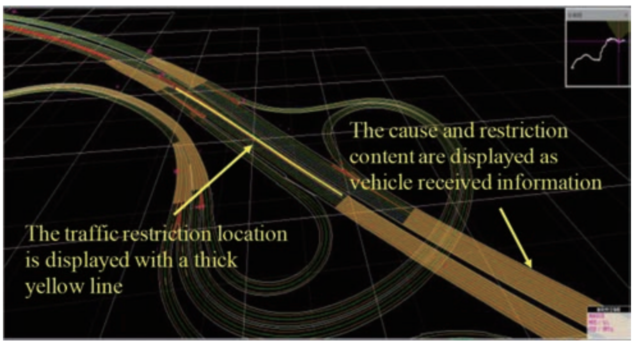


Fig. 17 Traffic restriction information

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).

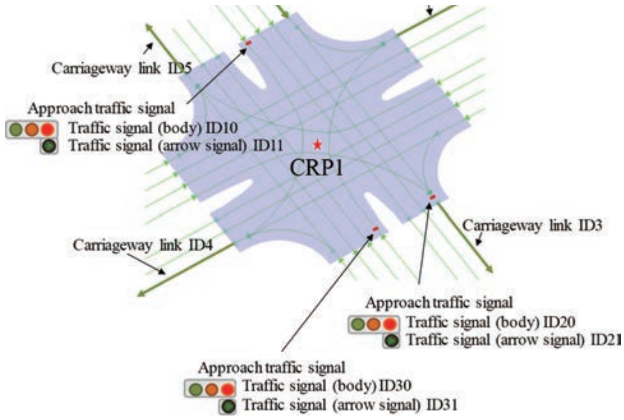


Fig. 18 Dynamic information concept

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

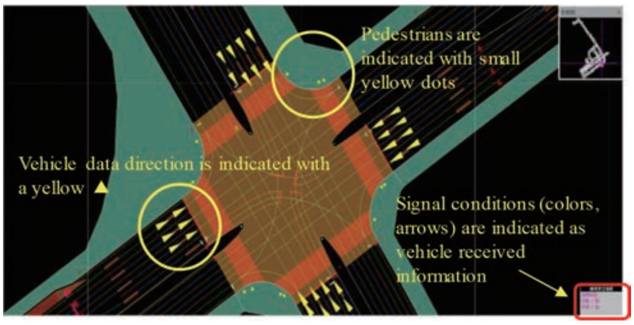
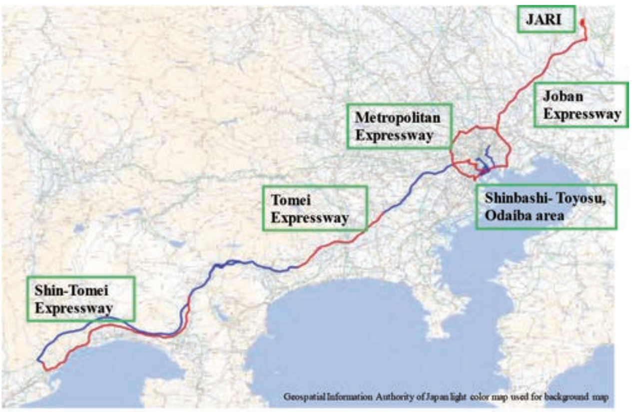


Fig. 19 Vehicle, pedestrian, and traffic signal information

3 Evaluation of Static Information

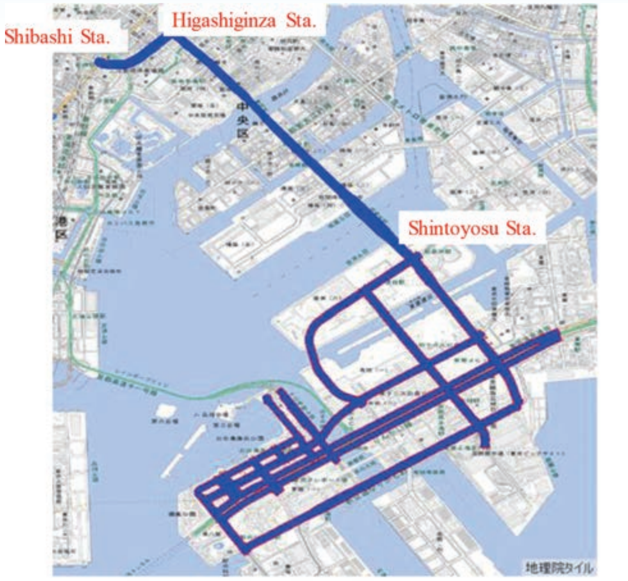
3.1. Method of Evaluating Static Information

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	

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.

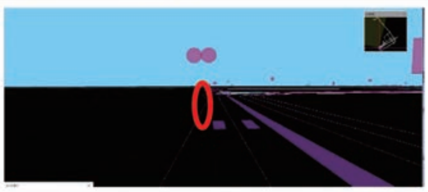
Table 14 Types and numbers of improvement requests

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)
(3) 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 (2016)
(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)

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

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.

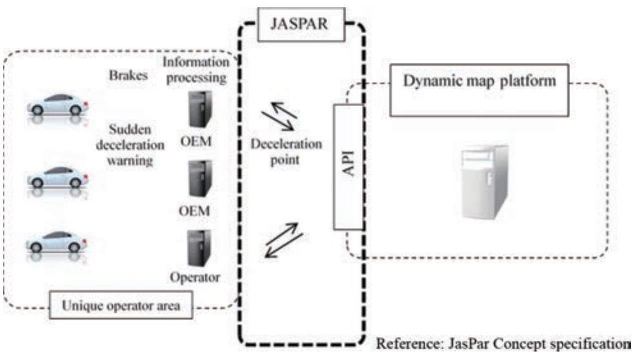


Fig. 1 Scope of Common Vehicle Information Specification

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.

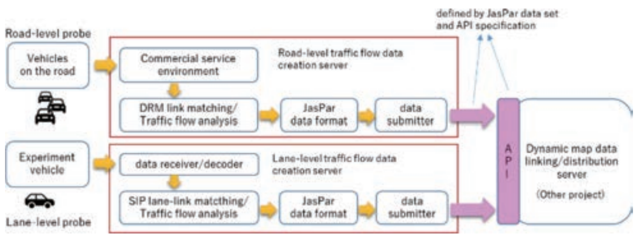


Fig. 2 Evaluation scheme

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.

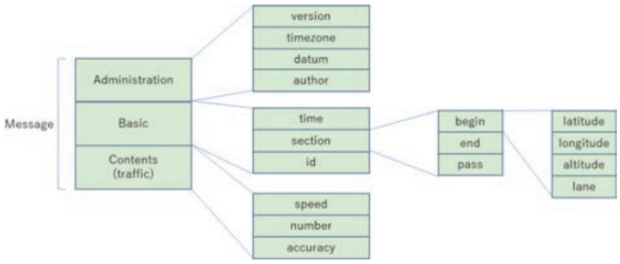


Fig. 3 Traffic flow message structure of JASPAR specification

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.

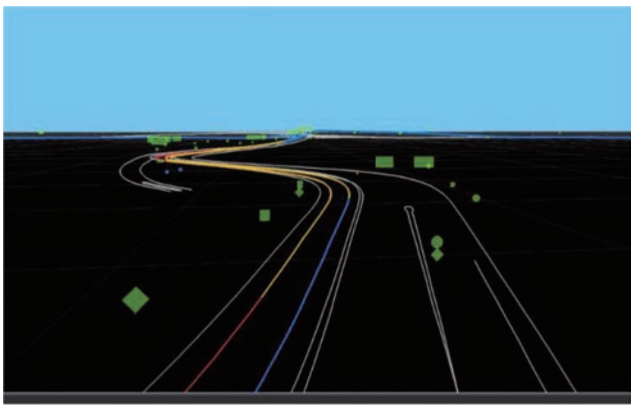


Fig. 4 Visualized image of road-level traffic flow data

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.

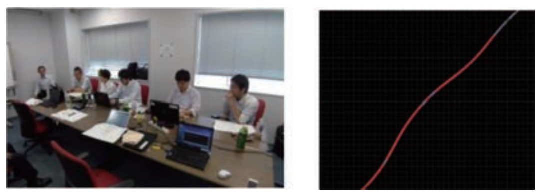


Fig. 5 Connection test with Dynamic Map FOT Consortium

① Dynamic Maps

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

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.

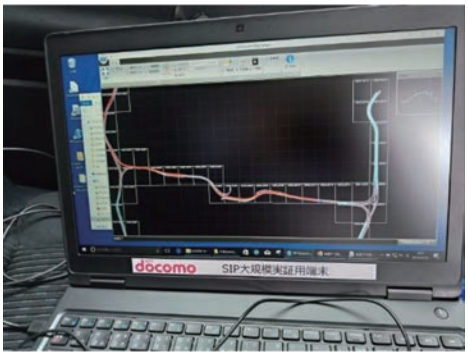


Fig. 7 Lane-level traffic flow field check using SIP Dynamic Map Viewer

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.

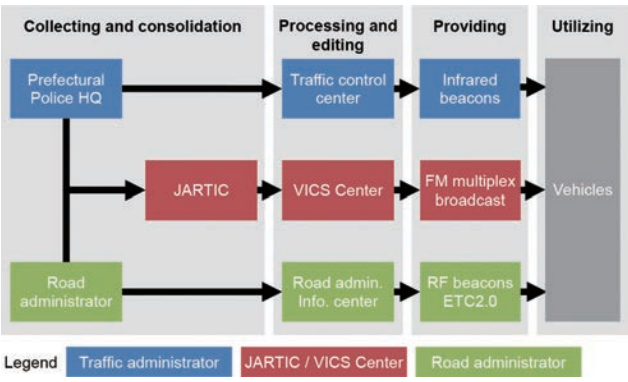


Fig. 1 Process for providing traffic information (1).

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.

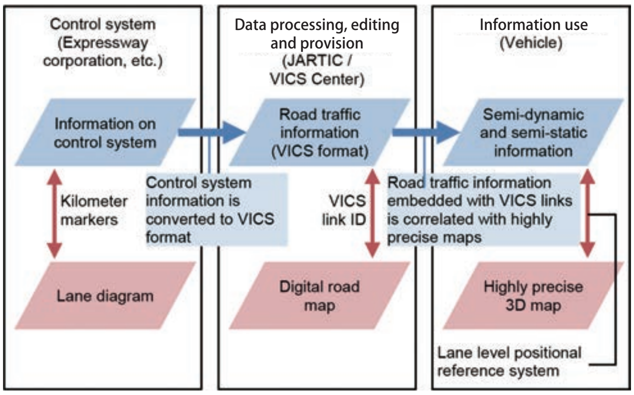


Fig. 2 Process for road traffic data format conversion.

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.

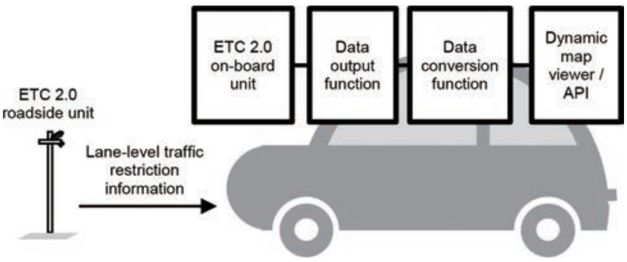


Fig. 3 Anticipated equipment configuration.

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

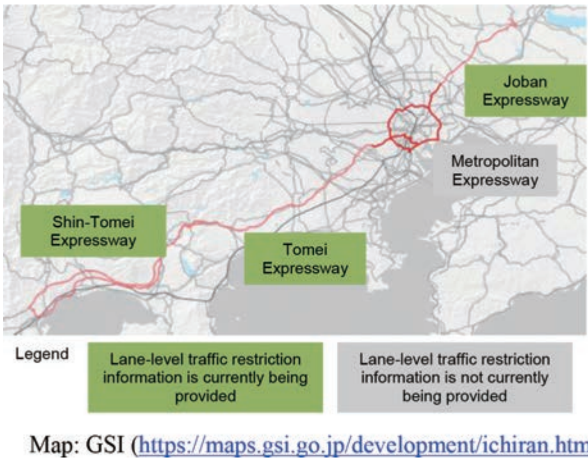


Fig. 4 Test locations and provision status of lane-level traffic restriction information.

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.

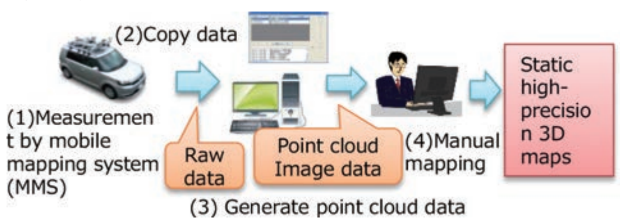


Fig. 1 An example of the flow until static high precision 3D map data is generated

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.

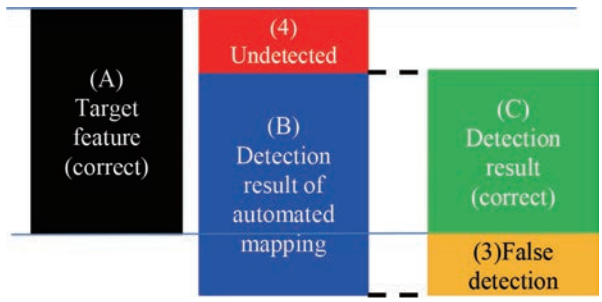


Fig. 2 Definition of evaluation index

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.

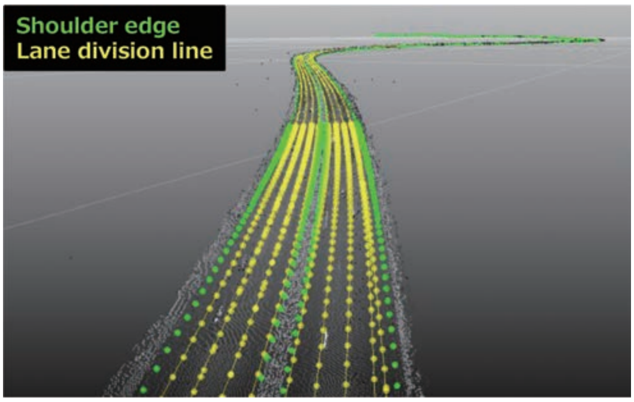


Fig. 3 A result example of the automated mapping

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

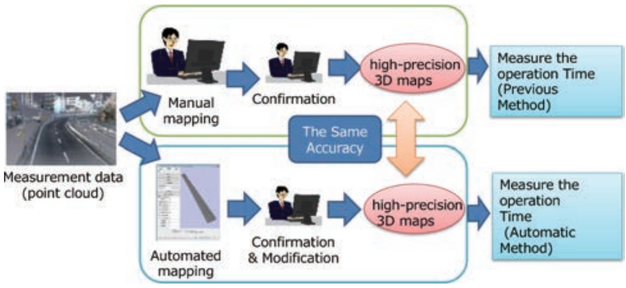


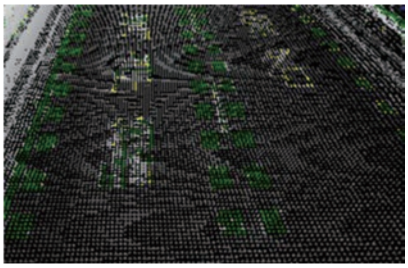
Fig. 5 Confirmation of the effectiveness of improvement by comparing map creation time

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.

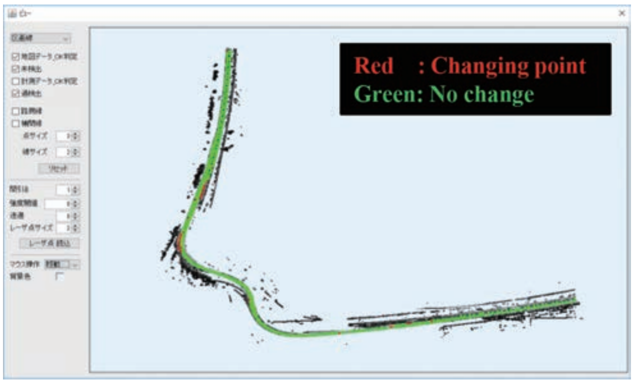


Fig. 7 Example of the dynamic maps change detection

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.

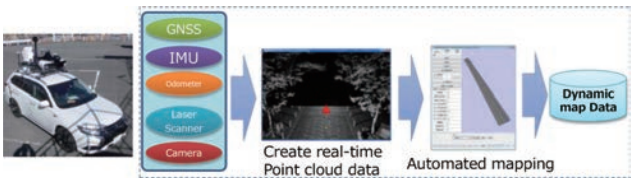


Fig. 8 Process from measurement to mapping using real-time MMS and automation technology

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.

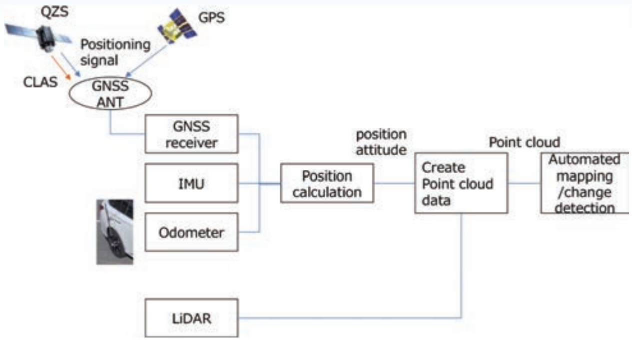


Fig. 9 Real-time MMS process with automation technology

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

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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.

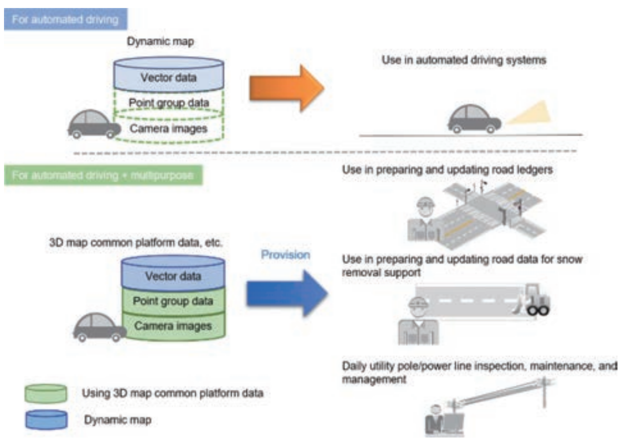

Fig. 1. Diagram of 3D map common platform data when expanding automated driving dynamic maps for multipurpose use

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.
Accuracy-related	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.

	Requirements for 3D map common platform data, etc. for automated driving	Road ledgers	Snow removal support	Utility poles/power lines
Laser	• 50 points/m² or more	25 points/m² or more	25 points/m² or more	up to 1,800 points/m²
Camera	• 5 million pixels	5 million pixels	5 million pixels	5 million pixels
Lateral	• The degree to which road shoulders are included	To public-private boundary	To edge of carriageway	Beyond public-private boundary
Vertical	• Degree of inclusion of road signs, traffic signals, etc.	None	None	Capable of acquiring entire utility poles (Roughly 20m)
	• Road shoulders, carriageway lines, rail crossings, road markings, traffic signals, road signs, carriageway links, intersection areas	Increase (Guardrails, road lights, utility poles, etc.)	Increase (Guardrails, curbs, manholes, etc.)	Increase (Utility poles, power lines, etc.)
Freshness requirements	• Once per month	Once per year	Once per year (before snowfall)	As necessary – within 3 years

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: Contents	Changes from data preparation specifications, etc., for dynamic maps aimed at automated driving: Reason for change	Impact on data quality and cost
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)
Data preparation	Road measuring	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
Data preparation	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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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.

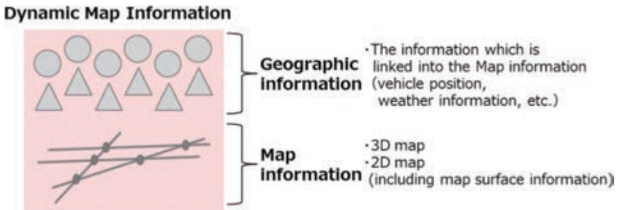


Fig. 1 Definition of the Dynamic Map

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).

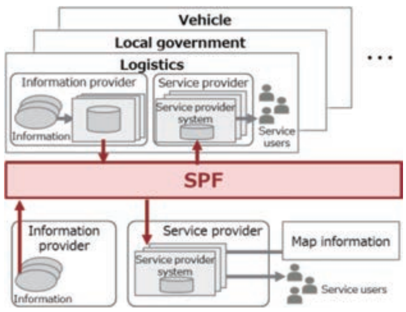


Fig. 2. Outline of the SPF

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).

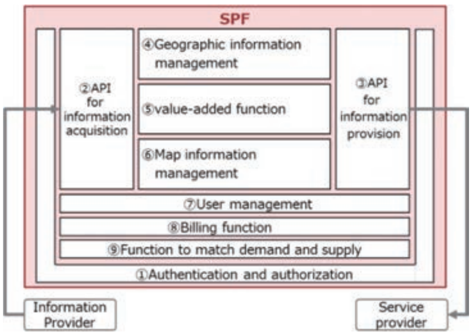


Fig. 3 Architecture of the SPF

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.

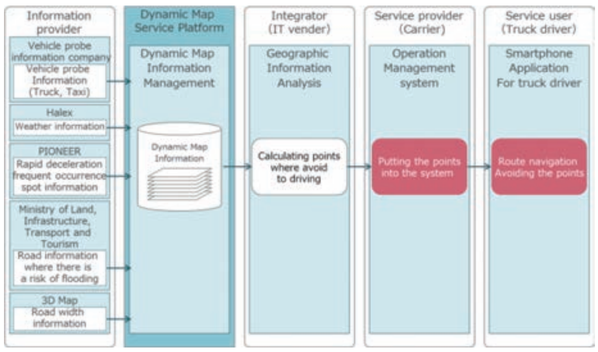


Fig. 4 Service Model for Logistics

(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.

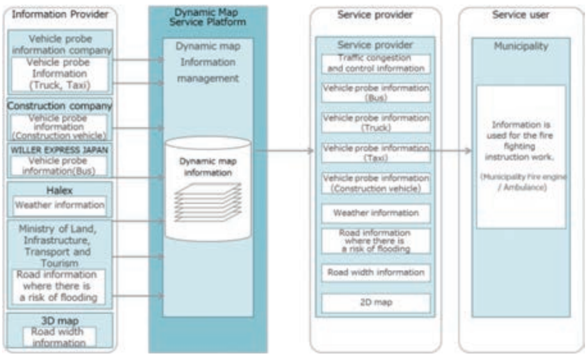


Fig. 5 Service Model for Local Government

(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.

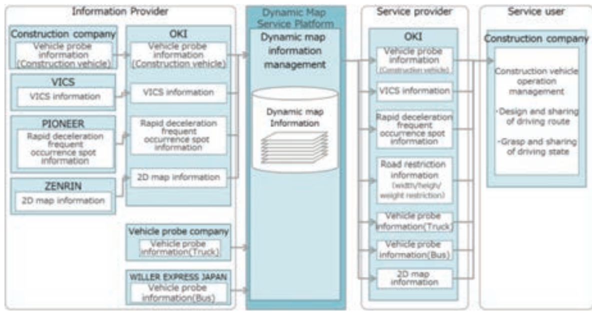


Fig. 6 Service Model for Construction

(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

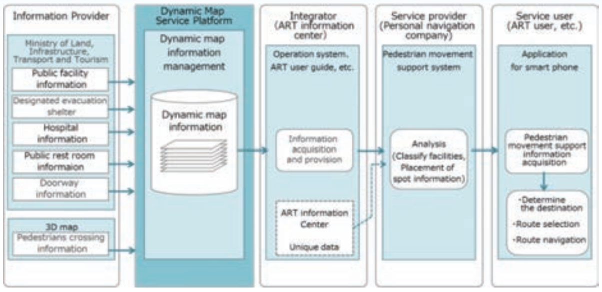


Fig. 7 Service Model for Personal Navigation

(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.

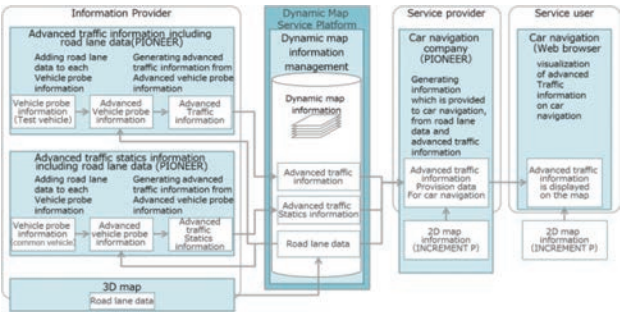


Fig. 8 Service Model for Vehicles

(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.

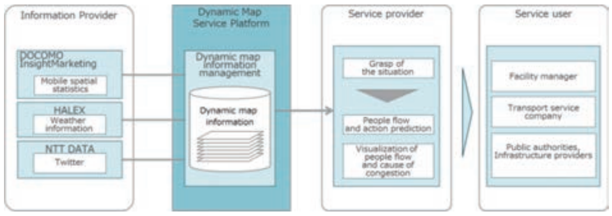


Fig. 9 Service Model for Infrastructure and Area Management

(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.

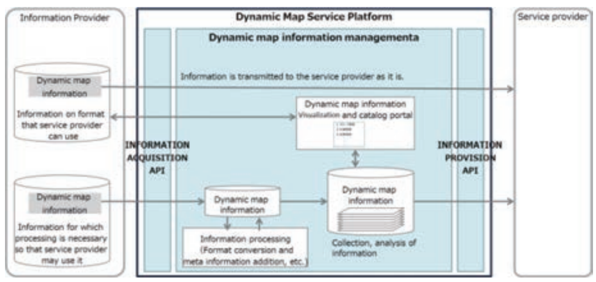


Fig. 10 Function image of the SPF

(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%.

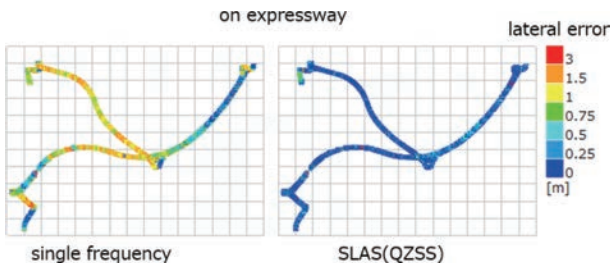


Fig. 2 Heat map of positioning accuracy

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.

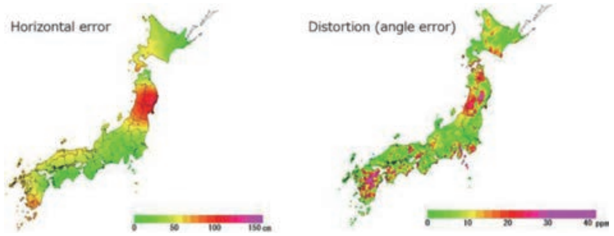


Fig. 3 Variation from 2011 to 2016

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.

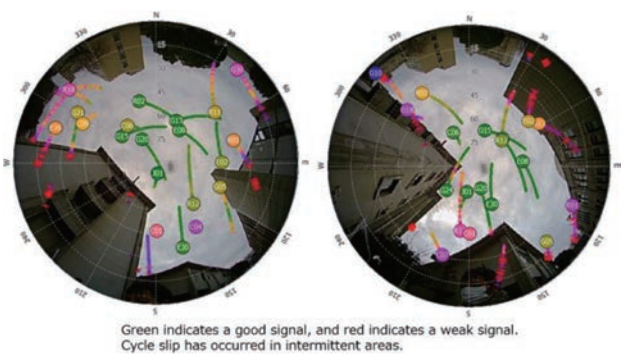


Fig. 4 Sky plot and satellite signal status

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.

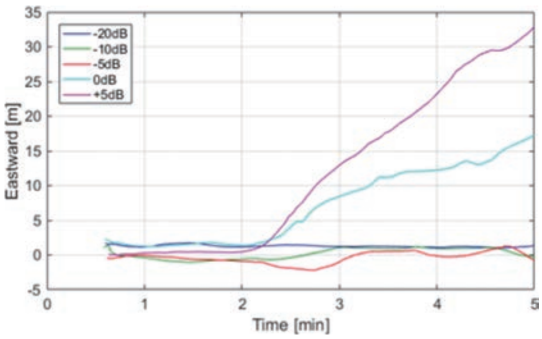


Fig. 5 Synchronized simplistic spoofing attack

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.

① Dynamic Maps

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.

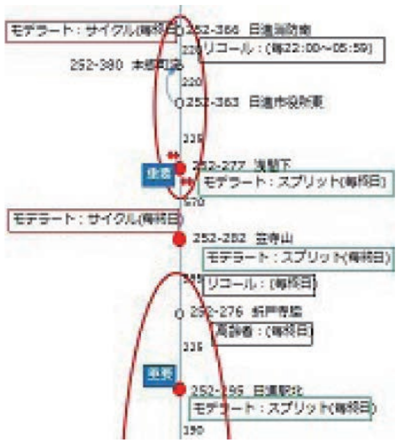


Fig. 1 Model points in Aichi Prefecture

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.

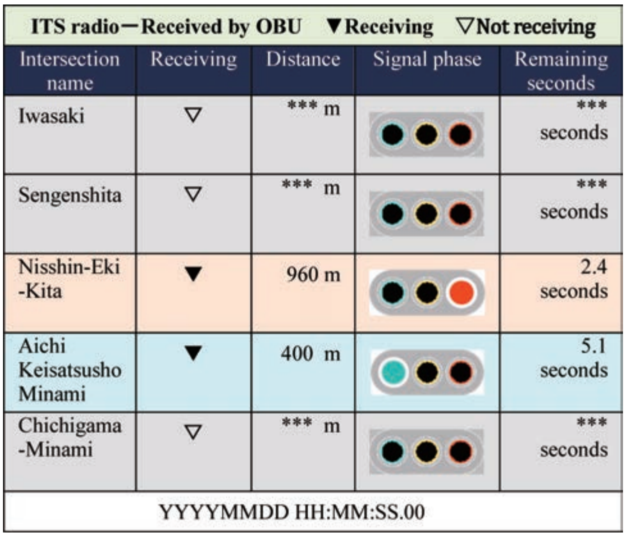


Fig. 2 Evaluation system screen (example)

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)

① Dynamic Maps

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.

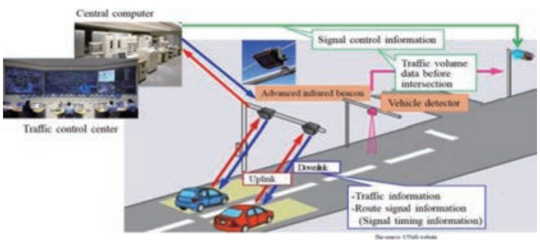


Fig. 1 Traffic Control Center signal control system

3 Services that Utilize Signal Information

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

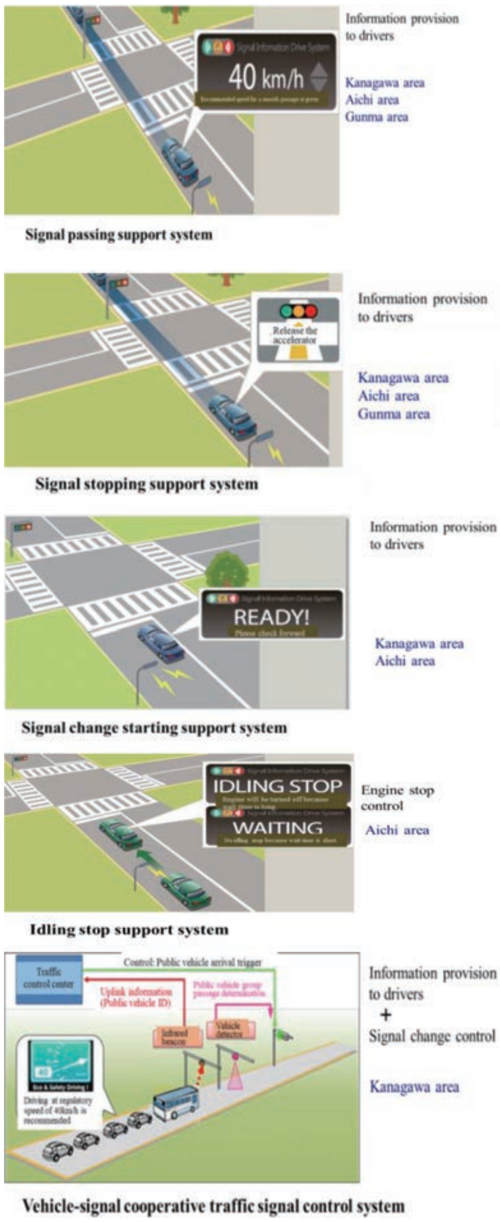


Fig. 2 Five services that utilize signal information

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.

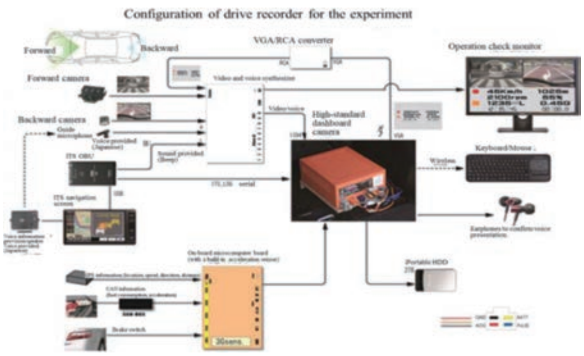


Fig. 3 On-board system configuration example 1

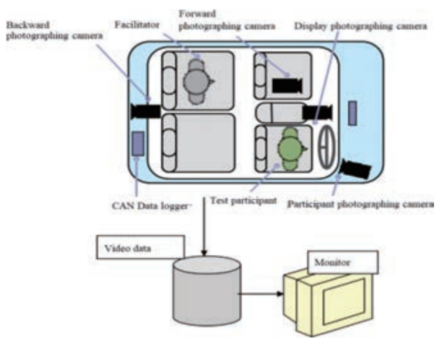


Fig. 4 On-board system configuration example 2

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.

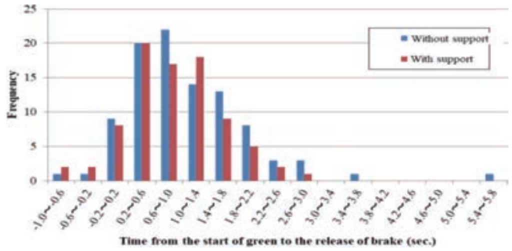


Fig. 6 Example of effect of signal change starting support system (Aichi area)

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.

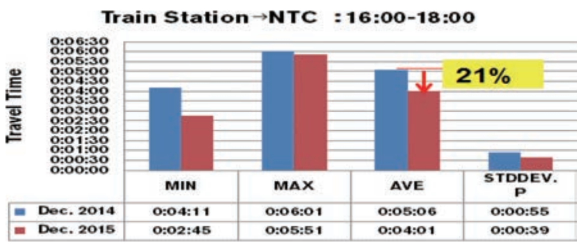


Fig. 7 Example of vehicle-signal cooperative traffic signal control (Kanagawa area)

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.

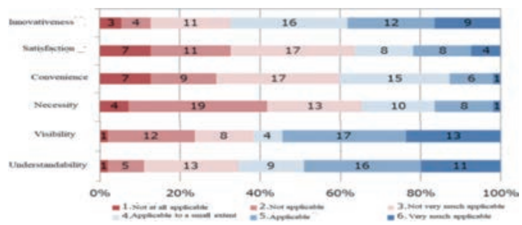


Fig. 8 Example of questionnaire results for signal passing support system (Aichi area)

① Dynamic Maps

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.

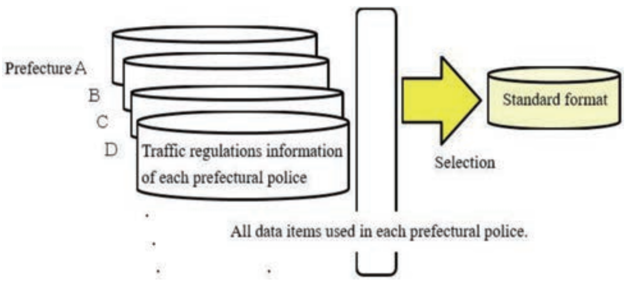


Fig. 1 Design of the standard format

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.

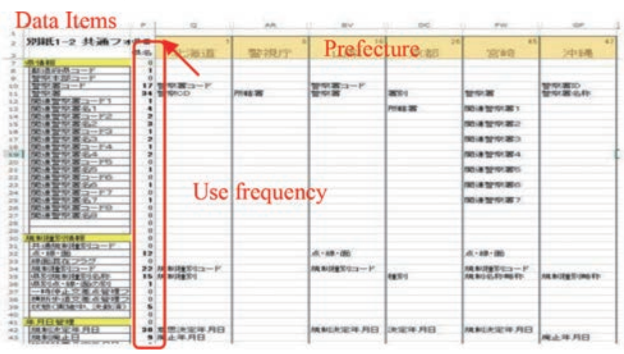


Fig. 2 Number of prefectures using each data item

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.

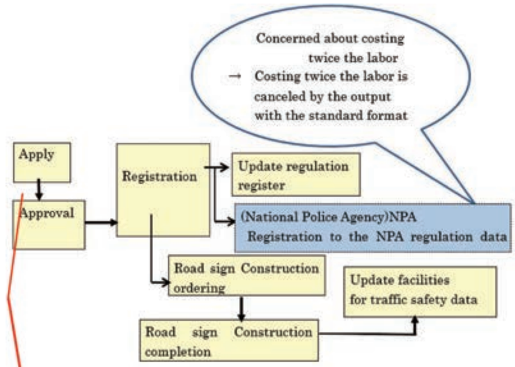


Fig. 3 Work flow of traffic regulation information and facility management

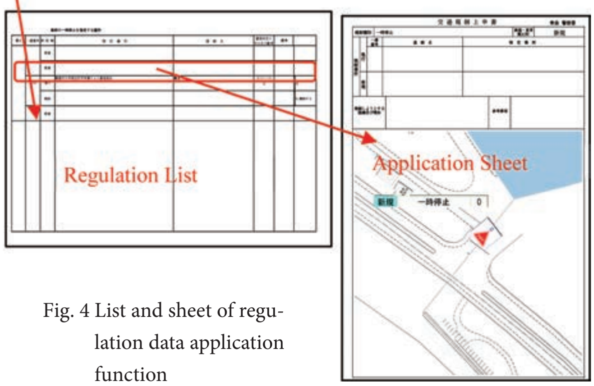


Fig. 4 List and sheet of regulation data application function

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

Manabu Sawada (DENSO CORPORATION)
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.

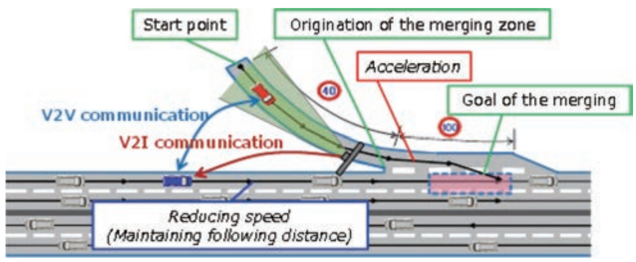


Fig. 1 Merging support model using V2V and V2I communication

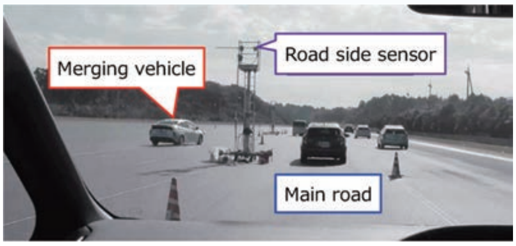


Fig. 2 Verification experiment on test course

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).

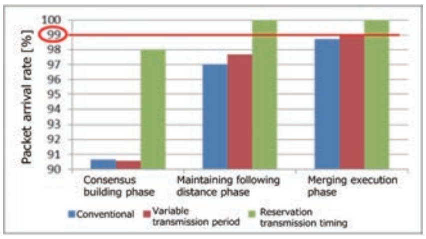
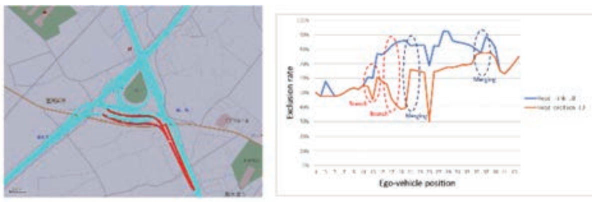


Fig. 4 Communication quality of V2V communication for merging support

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).

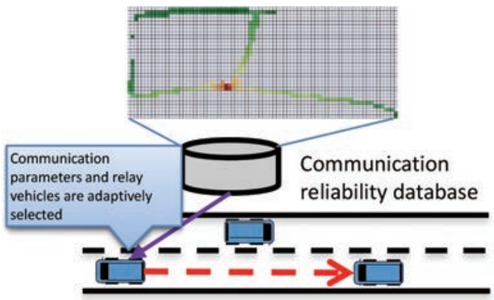


Fig. 6 Multi-vehicle cooperative relay transmission with communication reliability database

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).

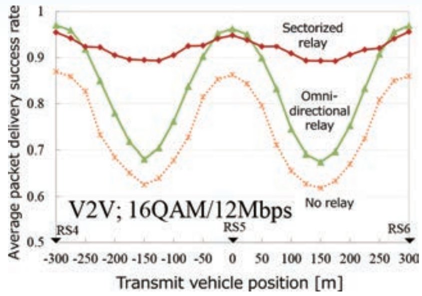


Fig. 7 Improvement effect of V2V communication quality using sectorized relay stations

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).

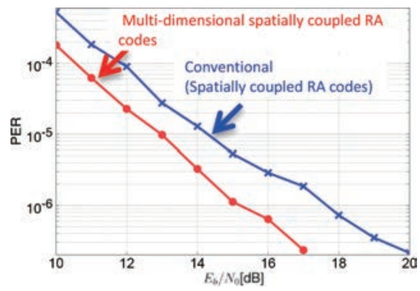


Fig. 8 Improvement effect of V2I communication quality using multi-dimensional spatially coupled RA codes

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.

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

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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

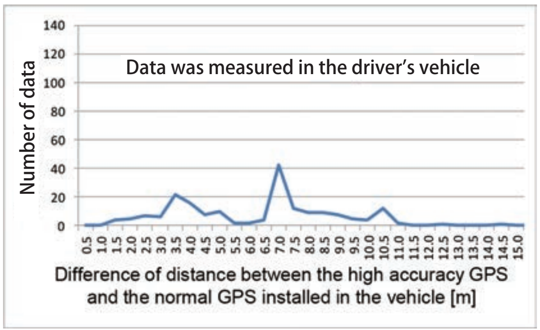


Fig. 2 Difference of distance between high-accuracy and normal GPS installed in vehicles

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

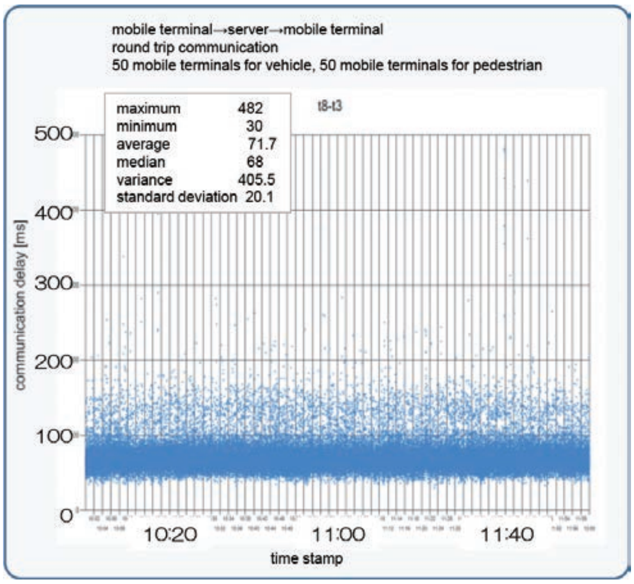


Fig. 3 Example of data of communication delay

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.

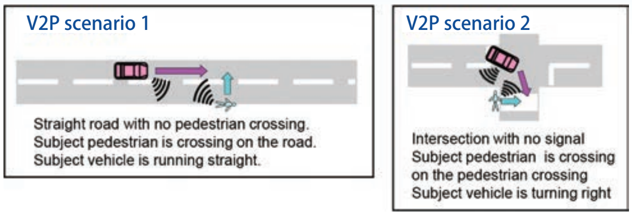


Fig. 4 Experimental test scenario for V2P communication

3.3. Test results

Figure 7 shows an example of the test results regarding

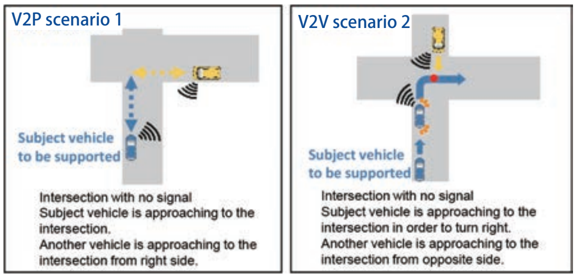


Fig. 5 Test scenario for V2V communication

Fig. 6 Test on test track

driver acceptance of the V2P communication system. In this case, "before 4.0s" is considered to be an appropriate timing for drivers.

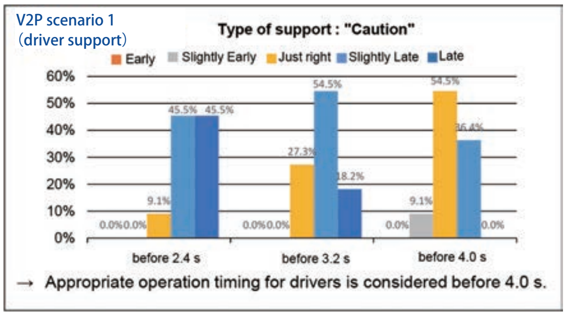


Fig. 7 Example of data of driver acceptance

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.

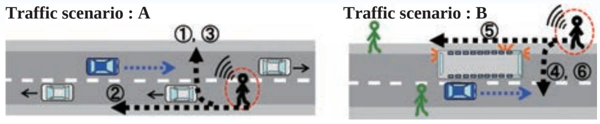


Fig. 8 Traffic scenario for test cases (V2P)

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.

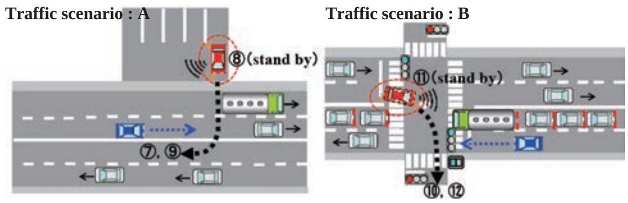


Fig. 9 Traffic scenario for test cases (V2V)

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.

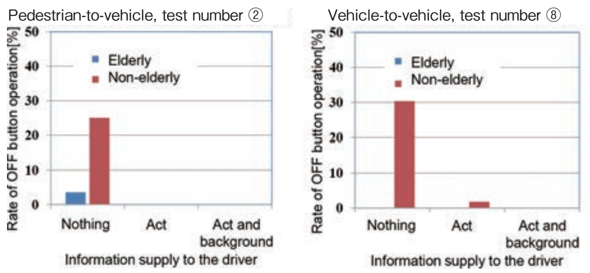


Fig. 10 Rate of OFF button operation (traffic scenario A)

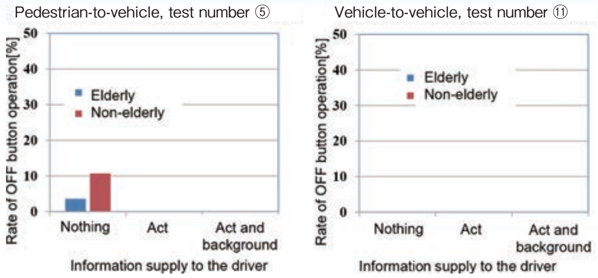


Fig. 11 Rate of OFF button operation (traffic scenario B)

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).

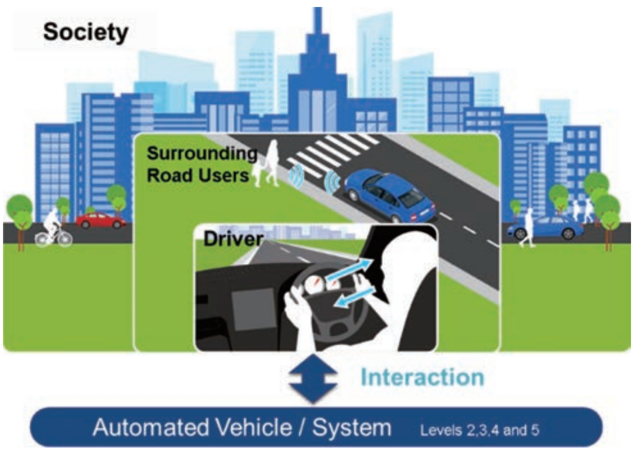
Outline of Human Machine Interface (HMI)

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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Makoto Itoh (University of Tsukuba)
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).

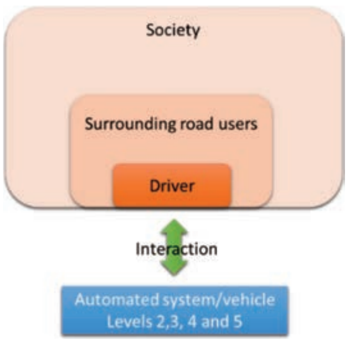

Fig. 1 The framework used to extract potential problems related to human factors in automated driving.

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.

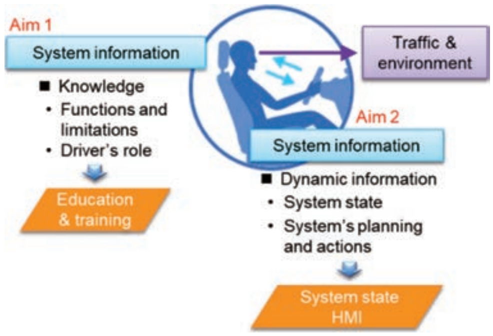

Fig. 2 Information the driver needs to have or acquire for level 2 and 3 automated driving systems.

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).

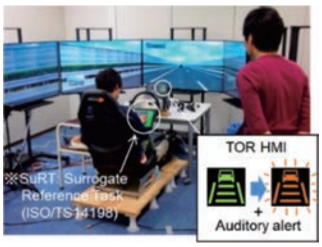

Fig. 3 The driving simulator at the University of Tsukuba used for the Task A experiments.

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).

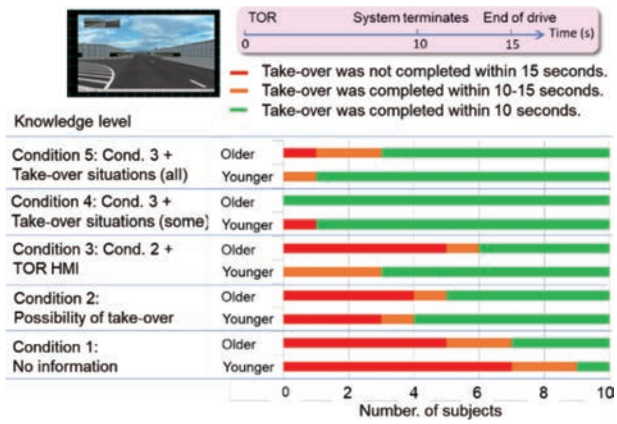

Fig. 4 Response time from TOR to initiation of steering operation.

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

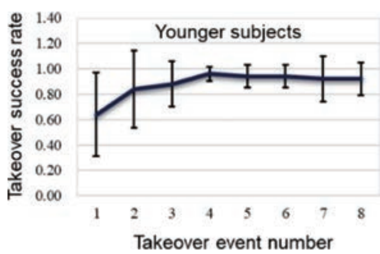

Fig. 5.1 Change in success rate of takeover of <u>younger</u> subjects over number of takeover situations.

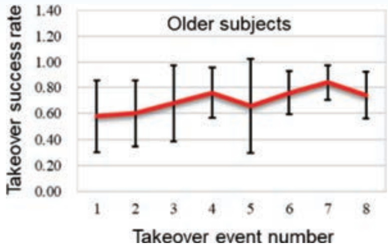

Fig. 5.2 Change in success rate of takeover of older subjects over number of takeover situations.

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.

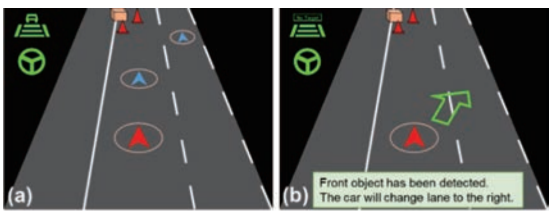

Fig. 6 (a) Information of detected objects (b) Combination of detected objects and planned action.

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.

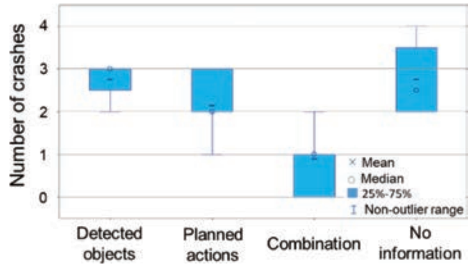

Fig. 7 Number of crashes with objects undetected by the system with provision of various system information.

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).

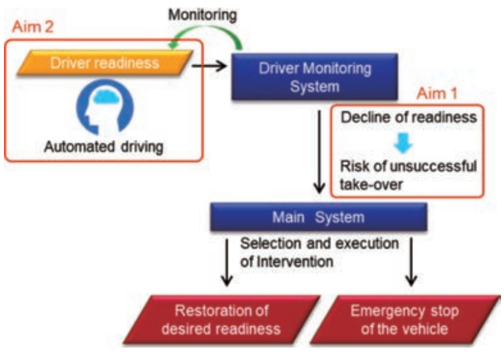

Fig. 8 Research aims of driver monitoring system and interventions.

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

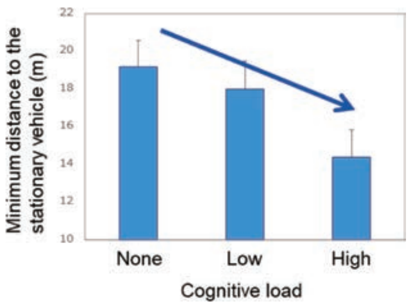

Fig. 10.1 Cognitive load applied to the driver before the TOR and takeover performance after the TOR.

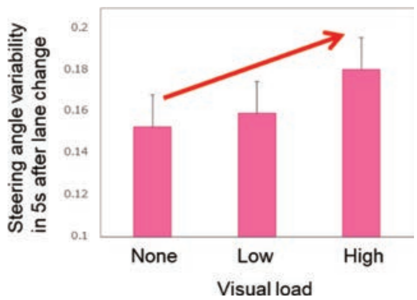

Fig. 10.2 Visual load applied to the driver before the TOR and takeover performance after the TOR.

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).

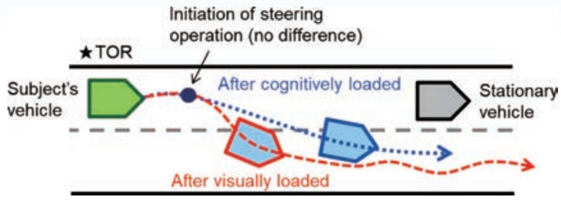

Fig. 11 Schematic expression of trajectories of the subject's vehicle after the TOR.

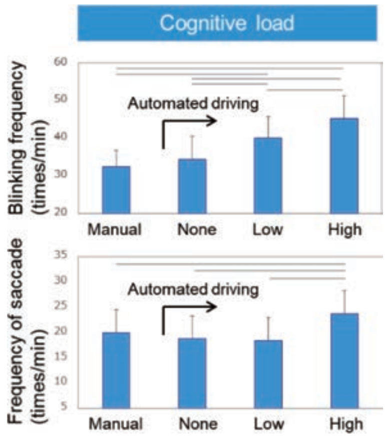

Fig. 12.1 Cognitively loaded driver state and biometrics.

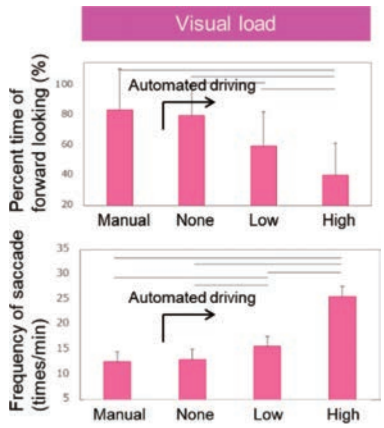

Fig. 12.2 Visually loaded driver state and biometrics.

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.

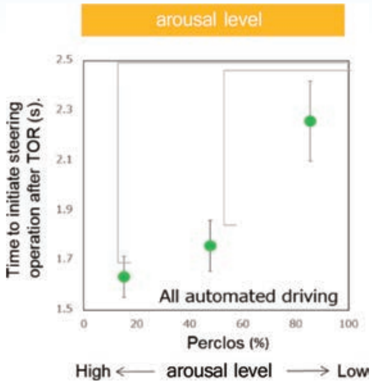

Fig. 13 "Perclos" measured before the TOR and takeover performance after the TOR.

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.

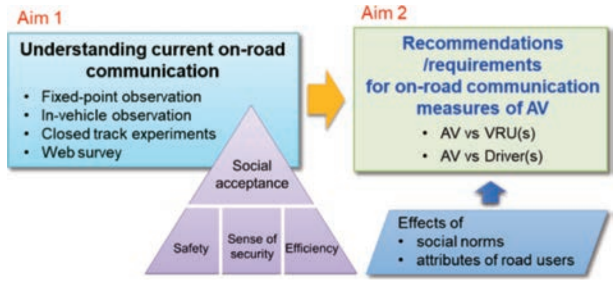

Fig. 14 Approaches to Task C

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.

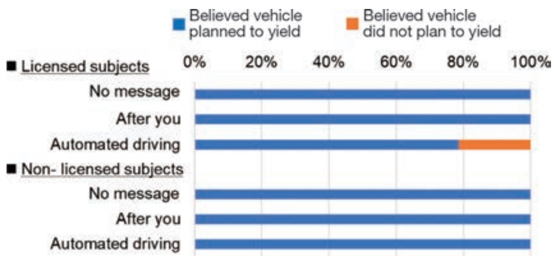

Fig. 17.1 Ratio of the subjects who believed the vehicle planned to yield for each of the written messages under the large deceleration condition.

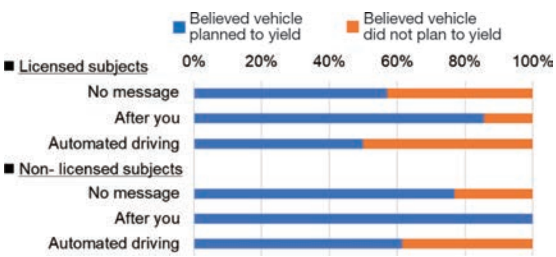

Fig. 17.2 Ratio of the subjects who believed the vehicle planned to yield for each of the written messages under the small deceleration condition.

(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.

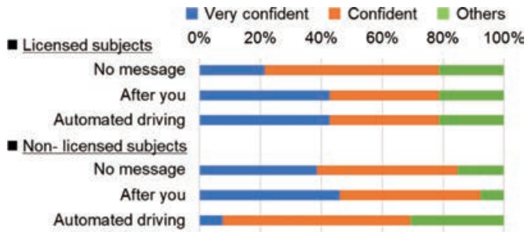

Fig. 18 Scores for the subjects' confidence in their decisions under the small deceleration condition.

(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)

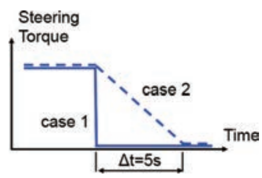

Fig. 2 Methods of reducing steering torque

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.

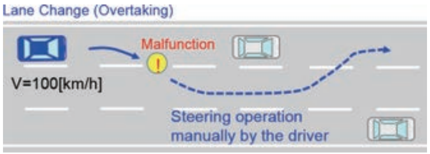

Fig. 3 Outline of experimental scenario (changing lanes)

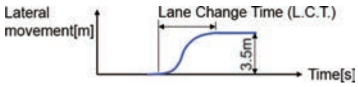

Fig.4 Definition of lane change time

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.

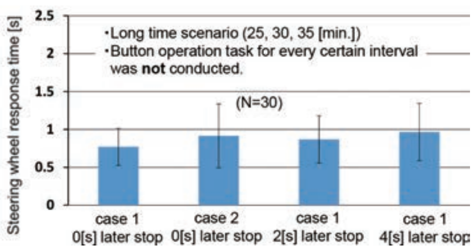

Fig. 6 Comparison of steering wheel response time

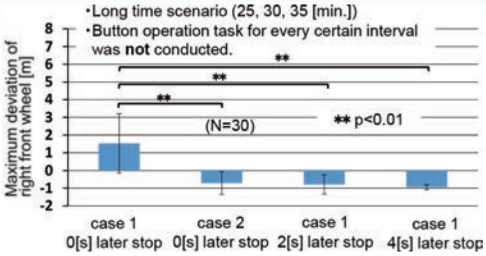

Fig. 7 Comparison of maximum deviation of right front wheel

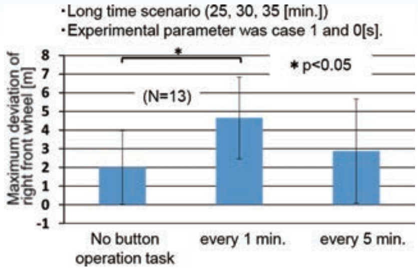

Fig. 10 Comparison of maximum deviation of right front wheel

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.

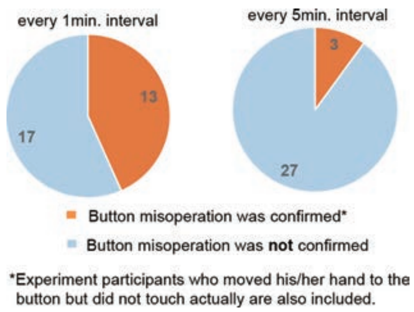

Fig. 8 Comparison of number of button misoperations

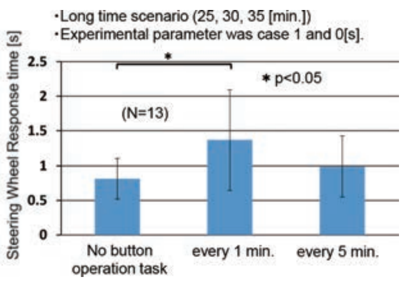

Fig. 9 Comparison of steering wheel response time

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.

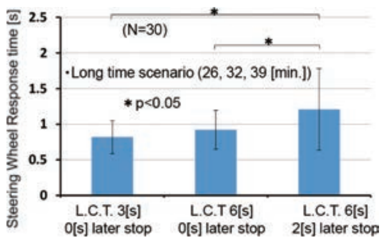

Fig. 11 Comparison of steering wheel response time

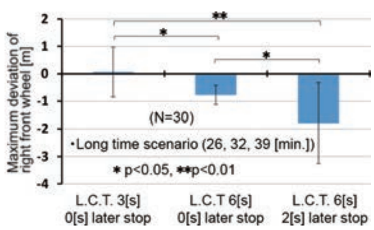

Fig. 12 Comparison of maximum deviation of right front wheel

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

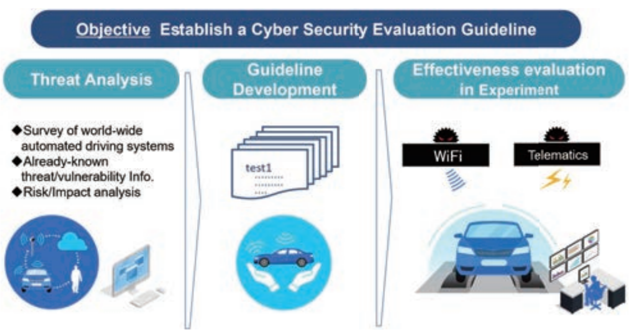

Fig. 1 Objective Establish a Cyber Security Evaluation Guideline

About the author

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

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:

③ Information Security

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

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.

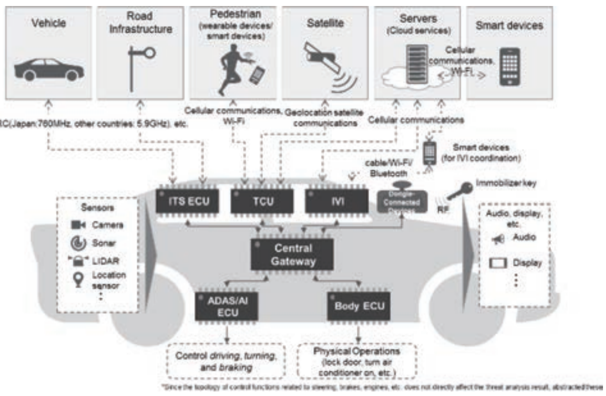

Fig. 1

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.

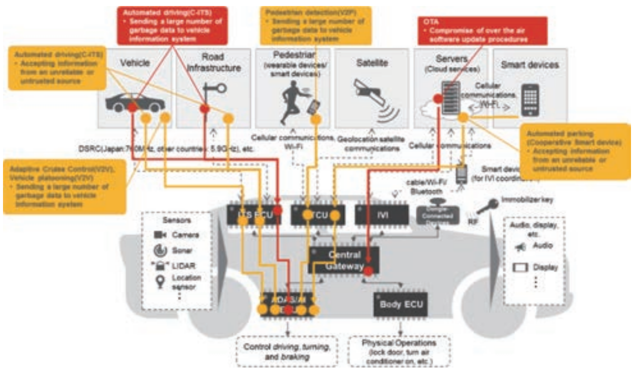

Fig. 2

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.

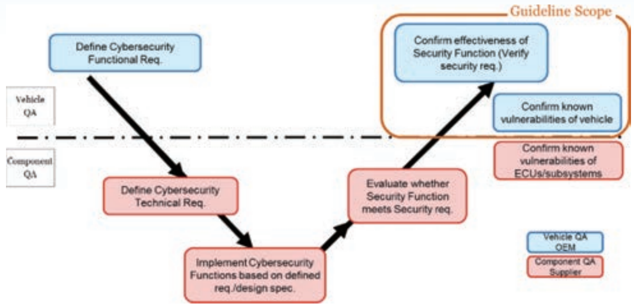

Fig. 3

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.

References

(1) Society of Automotive Engineers of Japan, Inc. (JSAE): JASO TP15002 (JP), (2015)
(2) Japan Automobile Research Institute (JARI): Research

and Development Project on Security Technology Related to Utilization of External Vehicular Information such as V2X, (2016)

(3) Hiroshi Hashimoto: JasPar's Activity towards the Standardization of CyberSecurity, (2017)

(4) Yuval Weisglass: PRACTICAL ATTACK ON CAN MESSAGE AUTHENTICATION, (2017)

(5) Dr. Frederic Stumpf: A Holistic Approach to Automotive Security with Security in the Fast Lane", (2017)

(6) Daisuke Noguchi: Security Risk of Automotive Grade Linux, (2017)

(7) National Institute of Standards and Technology (NIST): NIST SP 800-30 Revision 1, Risk Management Guide for Information Technology Systems, Recommendations of the National Institute of Standards and Technology, (2012)

(8) Information-technology Promotion Agency Japan (IPA): Automotive Information Security Practice Guide, (2013)

(9) International Organization for Standardization (ISO): ISO 26262: Road vehicles. Functional safety, (2011)

(10) National Highway Traffic Safety Administration (NHTSA): Cybersecurity Best Practices for Modern Vehicles, (2016)

(11) Shinji Sato: Hardware Security, Towards IoT Era, (2015)

(12) Randy Torrance and Dick James: The State-of-the-Art in IC Reverse Engineering, (2009)

(13) Dr. Sergei Skorobogatov, Physical Attacks on Tamper Resistance: Progress and Lessons, (2011)

(14) Bulent Yener: CSCI4974/6974 Hardware Reverse Engineering, (2014)

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

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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.

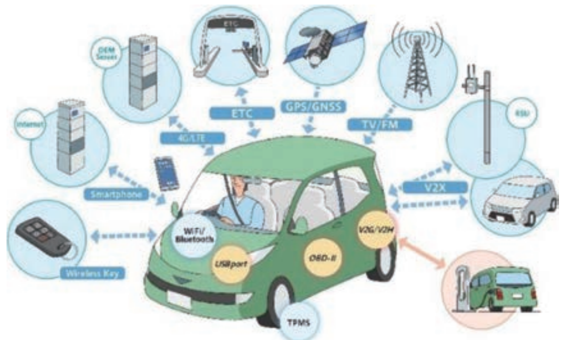

Fig. 1 Example of the External Communications in Vehicles

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.

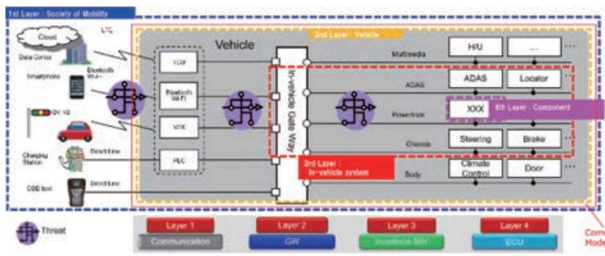

Fig. 2 Layered Structure for Automotive Cybersecurity

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.

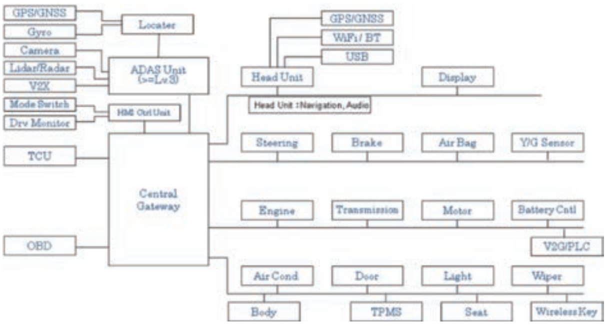

Fig. 3 Assumed In-Vehicle System Architecture

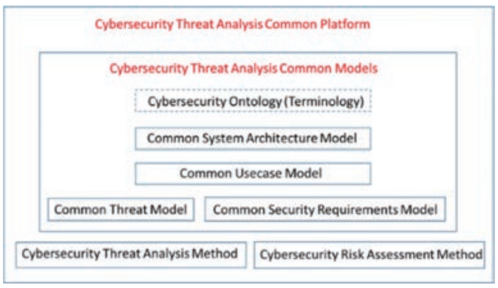

Fig. 4 Threat Analysis Platform

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.

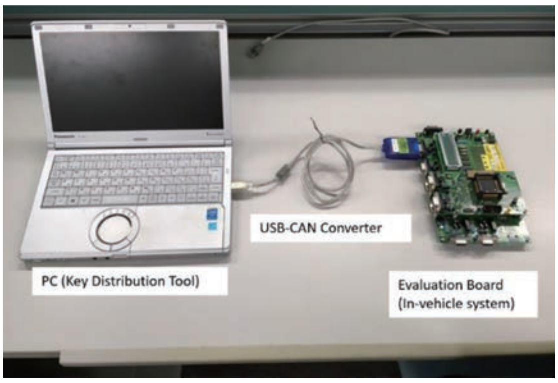

Fig. 5 Evaluation System for Component Level

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.

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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.

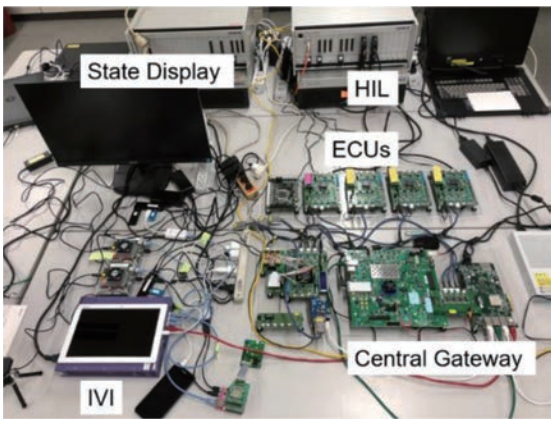

Fig. 6 Security Testbed

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.

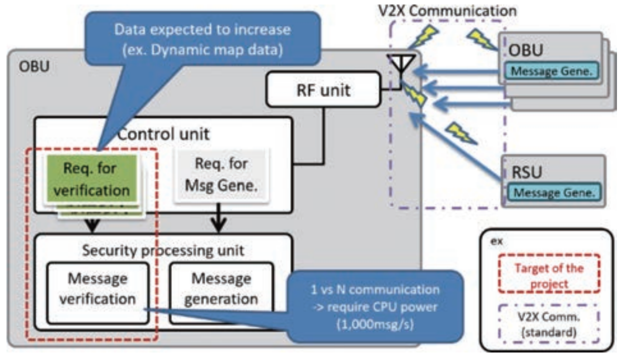

Fig. 7 Message Verification Scheme for V2X in OBU

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

(1) Koscher, K., et al.: "Experimental Security Analysis of a Modern Automobile" in *Security and Privacy (SP)*, 2010 IEEE Symposium on (pp. 447-462). IEEE (2010)

(2) Charlie Miller and Chris Valasek: *Remote Exploitation of Unaltered Passenger Vehicle*: Presentation at Black Hat (2015).