2 Building and Making Use of Traffic Environment Data

(1) Development of Technology Concerning the Generation of Traffic Environment Data

Utilization of Road Traffic Environment Data and Roadmap (Overview)

Masato Minakata (TOYOTA MOTOR CORPORATION)

Overview: Vehicles equipped with automated driving systems are required to operate safely and smoothly in various traffic environments while sharing those environments with a wide range of traffic users. To realize this objective, it is necessary to construct a cooperative infrastructure system capable of collecting and generating road traffic environment data at the roadside, as well as distributing this data in a timely fashion to vehicles. At the same time, it will also be important for the future to construct a framework for data circulation that embodies the cyber physical system defined under the so-called Society 5.0 concept, namely the generation, distribution, and re-use by vehicles of new road traffic environment data from commercial probe data collected by vehicles themselves. The SIP-adus program is working to promote practical adoption in these cooperative areas, starting from research and development related to the construction of systems for utilizing road traffic environment data and commercial probe data.

1 Utilization of Road Traffic Environment Data in Automated Driving

Human drivers operate vehicles under complex traffic environments through a repeated cycle of recognition, judgment, and operation processes. In the same way, automated driving systems must also be equipped with a wide range of on-board sensors that collect data, particularly to recognize the traffic environment surrounding the driver's vehicle. However, the extent of data that can be collected by on-board sensors alone is limited, and such systems are forced to rely on road traffic environment data obtained from external sources. Examples of such data include precise estimation of the position of the driver's vehicle on the road ("localization"), roadside structures outside the detection range of the on-board sensors, applicable traffic rules (including items that change on a periodic basis such as the color of traffic signals), and the creation of plans for driving routes that the vehicle should be controlled to follow (Fig. 1).

The SIP-adus program has investigated and categorized the requirements for various aspects of road traffic environment data that will be required to realize advanced automated driving systems.

1) Static data, i.e., road, roadside structure, and permanent traffic regulation data, as well as logical data that can be generated virtually from roads and roadside structures.

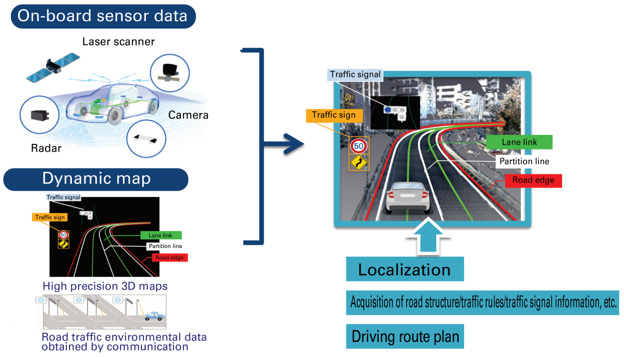

Fig. 1: Utilization of Road Traffic Environment Data in Automated Driving

2) Quasi-static data, i.e., event status data that can be planned or predicted in advance, even though the position, range, occurrence time (time zone) and attribute data of such events changes over time.

3) Quasi-dynamic data, i.e., the actual status of an event with attributes that change over time and the actual data of the applicable objects that accompany the occurrence of the event, even though the position and occurrence time (time zone) of such events may not be constant and may be generated, disappear, move, expand, and contract, or may have a constant position or constant time zone.

4) Dynamic data, i.e., data related to applicable items that move and do not have a constant position, or that have a constant position but have attributes that are updated over a short cycle, and that change position or update attributes in a unique manner to that applicable object.

SIP-adus is constructing research and development, effectiveness verification, and utilization systems related to the generation of data in various cooperative areas based on the concept of dynamic maps that utilize high precision mutually linked 3D map data consisting of location- and time-dependent static data (Fig. 2).

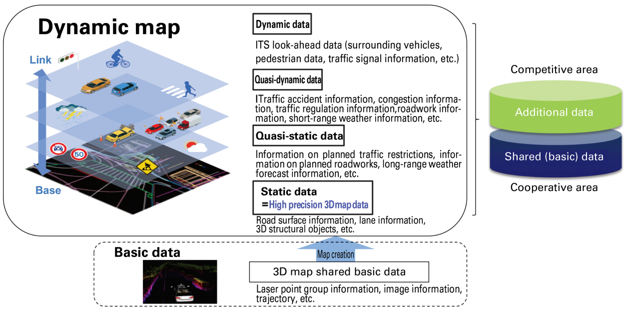

Fig. 2: Dynamic Map Concept

2 Road Traffic Environment Data Roadmap

SIP-adus is formulating a roadmap and constructing a system for the utilization of road traffic environment data, with the aim of enabling the practical adoption of advanced automated driving through cooperation with infrastructure (Fig. 3).

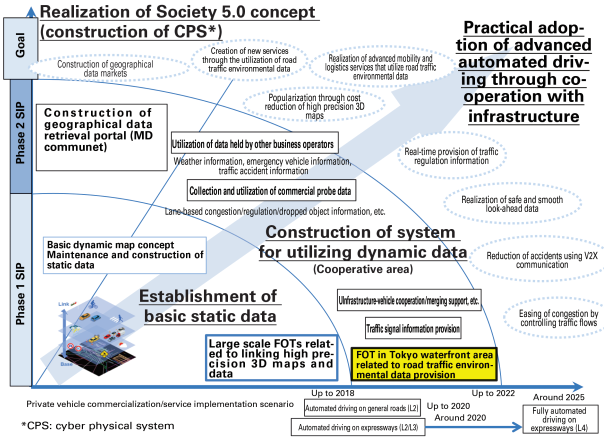

Fig. 3: Road Traffic Environment Data Roadmap

SIP phase 1 focused on establishing basic static data. Large scale field operational tests (FOTs) that attracted a wide range of participants from both inside and outside Japan were held from the standpoints of studying specifications for high precision 3D map data, prototyping, and international standardization. In these FOTs, high precision 3D map data was prepared for a total of approximately 600 km of roads covering the Tomei Expressway, Shin-Tomei Expressway, Joban Expressway, and Tokyo Metropolitan expressways. Commercialization was realized through FOTs pertaining to the effectiveness of the concept of linking to the specifications and static data of these maps and utilizing the dynamic data.

SIP phase 2 is promoting research and development to construct a utilization system that extends from the generation to the provision of each type of quasi-static, quasi-dynamic, and dynamic road traffic environment data required to expand the operational design domain (ODD) of automated vehicles. As important milestones toward social implementation, infrastructure that provides each type of road traffic environment data under the actual traffic environment of the Tokyo waterfront area has been established, and an FOT is under way that will likely extend to the end of the 2021 fiscal year. In the same way as phase 1, this FOT features a wide range of participants from both inside and outside Japan. In addition to the practical adoption of advanced automated driving through cooperation with infrastructure, SIP phase 2 is also promoting initiatives toward social implementation as expressed on the roadmap to help realize the Society 5.0 concept by encouraging the utilization of geographical data.

3 Initiatives for the Construction of Each Type of Road Traffic Environment Data

3.1. Traffic Signal Information Provision Technology for Infrastructure-Based Cooperative Automated Driving

One item of technology that will be required to expand the ODD of advanced automated vehicles onto general roads is high precision traffic signal color recognition technology. In addition to image recognition by onboard cameras, progress is also being made internationally in research and development related to the provision of traffic signal information via wireless communication to ensure redundancy of the recognition means and support color recognition reliability.

In Japan, a traffic signal information provision service for general drivers (traffic signal color information and time before the traffic signal changes color) that uses short-range wireless communication on the dedicated frequency band (760 MHz) allocated to ITS has already been practically adopted. SIP-adus is carrying out research and development toward the utilization of traffic signal information for automated vehicle control while using these assets.

The three key points of this research and development are as follows: (1) the establishment of a reliable system assuming utilization for automated driving, (2) confirmation of the accuracy of information, and (3) ensuring the availability of the system with various traffic signal control methods. For this initiative, a technology committee has been set up under the leadership of the Universal Traffic Management Society (UTMS) of Japan, which is promoting research and development in cooperation with the National Police Agency, Japan Automobile Manufacturers Association, and infrastructure manufacturers. For point (1), the following failsafe specifications have been added to traffic signal controllers and ITS wireless roadside units: traffic signal color monitoring units and functions that determine the consistency between the current and provided color information. Prototype units are currently being deployed to confirm that these specifications are functioning appropriately. For points (2) and (3), studies of the required accuracy of messages and information that must be added to communication and availability requirements are being carried out alongside experiments on test courses. In addition, since the effectiveness and benefits of information provision was verified under an actual traffic environment in the Tokyo waterfront area FOT between the 2019 and 2020 fiscal years, it is planned to reflect this information in the standards and specifications to be issued by UTMS. Furthermore, for some traffic signals with special sensing controls, countermeasure proposals and requests related to traffic signal information provision for automated vehicles are being summarized from the standpoints of functionality and operability, and studies of specifications by the technology committee are being pursued toward practical adoption.

In addition to traffic signal information provision by short-range wireless communication using the conventional ITS wireless communication frequency band (V2I), SIP-adus has also started research and development into traffic signal information provision via public networks (V2N), which is regarded as an appropriate and superior area-based approach to establishing traffic signal information provision infrastructure. An FOT using a model system was carried out in Saitama Prefecture in the 2020 fiscal year. An FOT is also planned for the Tokyo waterfront area in the second half of the 2021 fiscal year.

3.2. Development of Technology Related to Lane-Based Road Traffic Environment Data Using Probe Vehicle Data

Focusing on the underlying value of big probe data collected from the growing number of connected vehicles equipped with an onboard data communication module (DCM), SIP-adus has initiated a series of review meetings with participation from the relevant government ministries, industry organizations, and information service providers. From the standpoint of utilization in automated vehicle controls, SIP-adus is working to construct a framework to facilitate research, development, and social implementation related to lane-based road traffic environment data using probe vehicle data.

Inside Japan, existing services that provide information on traffic flows at a road-level include the Japan Road Traffic Information Center (JARTIC) and the Vehicle Information and Communication System (VICS) Center. These services are growing in popularity via onboard navigation systems. SIP-adus has been collecting probe data from private vehicles on the road and, to enable the utilization of high precision lane-based traffic flow information, traffic regulation information, and information describing the presence of objects in the road in course planning proposals for automated vehicles via statistical processing, the program carried out desktop studies related to methods of generating and providing such information in real-time. Proof-of-concept studies on actual roads were then completed by the 2020 fiscal year. In the second half of the 2021 fiscal year, to further enhance the accuracy of information, the scale and variety of the collected probe data is being expanded with plans for social implementation of a system aiming toward practical adoption running parallel to the FOT in the Tokyo waterfront area.

3.3. Updating High Precision 3D Maps Utilizing Probe Vehicle Data

Using the results of SIP phase 1, a business to provide high precision 3D map data, which is the basic static data required for dynamic maps, was started in March 2019 covering approximately 30,000 km of expressways and dedicated vehicle-only highways across the whole of Japan. The sale of vehicles equipped with advanced driver assistance systems using this high precision 3D map data has already begun. However, how to efficiently and continuously manage and maintain the accuracy and freshness of this high precision data has been raised as a new issue.

In SIP phase 2, by collecting and analyzing probe data from vehicles on the road, research is underway with the objective of identifying fast and low-cost methods of changing the road structures reflected in this high precision 3D map data. Currently, probe data that can be collected from vehicles on the road includes vehicle driving trajectories from Global Navigation Satellite System (GNSS)-based position information, driving history data such as indicator, brake, and other operations, as well as driving image data from the growing number of onboard dashcam drive recorders. By using this data in research and development related to information collection about road structures before and after changes occur and change-extraction technology, it has been confirmed that changes can be identified more accurately and in a shorter time even using driving image data from popular commercial drive recorders than conventional operator-based visual extraction techniques. Based on these research and development results, operational requirements for image collection are being organized, with practical adoption planned for the 2022 fiscal year and beyond after the necessary adjustments are made for commercialization.

【Reference】

(1)SIP-adus Workshop 2020 Outcomes Report Meeting Presentation Materials:
https://www.sip-adus.go.jp/evt/workshop2020/file/sr/SR_04J_Minakata.pdf
https://www.sip-adus.go.jp/evt/workshop2020/file/sr/SR_05J_Kobayashi.pdf
https://www.sip-adus.go.jp/evt/workshop2020/file/sr/SR_07J_Ichikawa.pdf

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2 Building and Making Use of Traffic Environment Data

(1) Development of Technology Concerning the Generation of Traffic Environment Data

Traffic Signal Information Provision Technology for Infrastructure-Based Cooperative Automated Driving

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The following three points were identified as requirements for traffic signal information from the standpoints of improving the reliability and availability of automated driving: (1) a maximum margin of error of ±300 msec between the timing of the traffic signal information and the actual traffic signal color, (2) the detection of traffic signal information errors and notification to vehicles when errors occur, and (3) the realization of traffic signal information provision with various traffic signal controls. First, focusing on the vehicle-to-infrastructure (V2I) approach, this project verified the accuracy of traffic signal information and defined failsafe specifications for roadside devices, before then validating the feasibility of functions using prototype units.To improve availability, this project organized a proposal to review the operation of traffic signal controls and carried out validation experiments for traffic signal information with special traffic signal controls on proving grounds and the like. It then expanded the scope of information provision to include emergency vehicle priority (FAST) controls, which are difficult to adopt with traffic signal information provision and pedestrian-operated button controls. Based on these validation results, technical specifications for traffic signal information provision infrastructure using V2I systems were determined. In addition, this project has also begun examining the vehicle-to-network (V2N) approach using mobile circuits as a method of providing traffic signal information without using V2I systems From the 2021 fiscal year onward, validation experiments are planned for V2N systems, with the objective of defining the appropriate provision methods based on the experiment results.

1 Objectives of the Research

The practical adoption and popularization of automated driving should help to address various social issues such as reducing traffic accidents and congestion, facilitating mobility for vulnerable road users, and improving the situation of insufficient driver numbers and high costs in the logistics and mobility service industries. From these standpoints, automated driving has the potential to help realize a society with a higher quality of life. In addition to static data such as high-precision 3D road maps, the realization of automated driving depends on highly precise and reliable recognition of the dynamic traffic environment around automated vehicles. Progress is being made in the development of a wide range of autonomous automotive sensing technologies capable of detecting pedestrians, oncoming vehicles, and other moving objects around automated vehicles, such as cameras, millimeter wave radar, lidar, and so on. By combining these technologies, it should be possible to realize the high reliability required for automated driving. In addition, before automated vehicles can be operated on arterial and general public roads, these vehicles must be capable of recognizing and safely following traffic signals at intersections. Of the current autonomous automotive sensing technologies, only cameras are capable of recognizing the status of traffic signals. However traffic signals cannot be recognized by cameras alone in some cases, such as when the signal is poorly visible on a curve or beyond the crest of a hill, when the signal is blocked by a large vehicle or the like in front of the driver's vehicle, or due to glare from sunlight on the traffic signal. Furthermore, events also occur that adversely affect the recognition accuracy of cameras. Therefore, to enable automated vehicles to accurately recognize traffic signal colors and operate safely on general roads, the provision of traffic signal information via wireless communication over vehicle-to-infrastructure (V2I) or vehicle-to-network (V2N) systems located at the roadside is regarded as essential for realizing the multiplexing of traffic signal information. The objective of this study and research project is to help realize a more sophisticated level of automated driving by identifying the issues and countermeasures related to traffic signal information provision technology for automated driving.

2 Requirements for Infrastructure-Based Traffic Signal Information in Automated Driving

This section describes the requirements for traffic signal information provided from infrastructure in automated driving. In line with the research objectives described above, the first goal of providing traffic signal information via wireless communication over roadside V2I or V2N systems is to realize reliable recognition of traffic signal colors by creating a multiplex system that uses communication information to support autonomous camera sensors. Figure 1 shows an outline of the multiplexing of traffic signal color information using communication information.

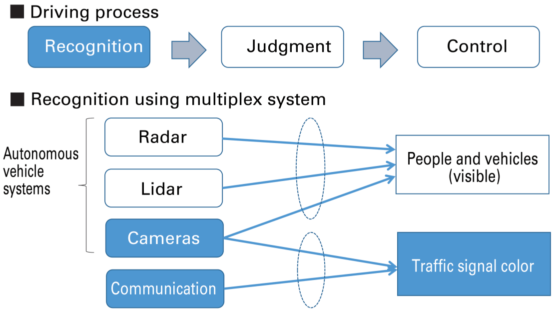


Fig. 1: Multiplexing of Traffic Signal Information Using Communication Information (Source: Japan Automobile Manufacturers Association (JAMA))

It should be noted that automated vehicles may still fall into the so-called dilemma zone even if multiplexing the traffic signal color information enables the vehicle to accurately recognize that a green signal has changed to a yellow signal. This refers to the area in front of a traffic signal in which the vehicle cannot stop at the stop line at the predetermined maximum deceleration, but also cannot pass safely through the intersection while the traffic signal remains yellow. This issue can be addressed by providing look-ahead information, such as the number of seconds remaining on a green signal, which can only be accomplished via infrastructure. This allows the vehicle to avoid entering the dilemma zone when a traffic signal is about to change, helping to reduce instances of sudden deceleration or acceleration and achieving seamless braking and stopping control. This should help to realize more sophisticated automated driving. Figure 2 outlines speed controls using traffic signal look-ahead information.

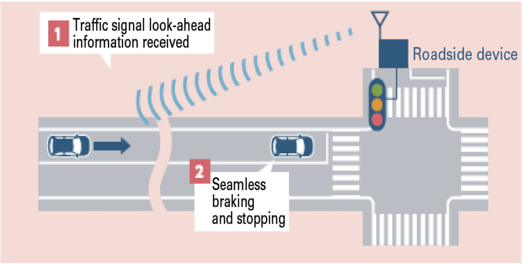


Fig. 2: Avoidance of Sudden Braking by Providing Traffic Signal Look-Ahead Information

With regard to the specific data specifications for traffic signal information covering the provision of the current traffic signal color and remaining seconds before the color changes, it was decided to comply with ISO/TS19091-Annex-F Profile-B(1), an international standard that defines the signal phase and timing (SPaT) of traffic signal information message sets in V2I communication, while maintaining compatibility with ITS Connect, a service that currently already provides traffic signal information to ordinary vehicles. In addition, as requirements for more sophisticated traffic signal information to help realize automated driving, the following three items were identified from the standpoints of improving the reliability and availability of traffic signal information, based on requirements defined by JAMA (a participant in this study and research project).

(1) A maximum margin of error of ±300 msec between the timing of the traffic signal information and the actual traffic signal color
(2) The detection of traffic signal information errors and rapid notification to vehicles when errors occur
(3) The realization of traffic signal information provision with various traffic signal controls

3 Development of More Sophisticated Traffic Signal Information Provision Technology Using V2I

3.1. Overview of ITS Wireless Communication

This section provides an overview of the studies and research into more sophisticated traffic signal information technology provision for automated driving using V2I. It was assumed that the V2I infrastructure would provide traffic signal information for automated vehicles via the ITS roadside units (RSU) used by the ITS Connect service. These ITS RSU had been installed at 93 intersections in eight prefectures and metropolitan areas (as of the end of the 2019 fiscal year) for infrastructure-cooperative driving safety support systems (DSSS) as part of the ITS Connect service(3). These ITS RSU are providing services for commercially available vehicles. The ITS RSU consist of a short-range wireless communication system using the 760 MHz band (755.5 to 764.5 MHz). The communication standards of these units comply with ARIB STD-T109(2). Figure 3 outlines the ITS RSU system and Table 1 lists the main specifications of these ITS units.

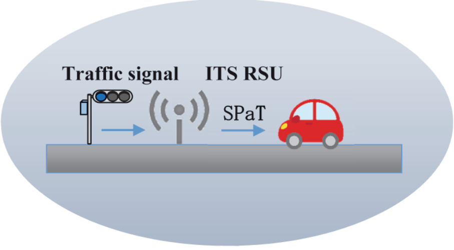


Fig. 3: Overview of V2I System

Table 1: Outline of ITS Wireless Communication Specifications

Main items	Outline of standard
Communication protocol	Broadcast communication
Frequency	760 MHz band (755.5 to 764.5 MHz)
Modulation protocols	BPSK/OFDM, QPSK/OFDM, 16QAM/OFD
Access protocols	TDMA (V2I) CSMA/CA (V2V)
Antenna power	Max. 10 mW/MHz
Transmission cycle	100 msec
Transmission timing control	Sum transmission duration of max. 10.5 msec within any 100 msec period

3.2. Overview of Development of More Sophisticated Technology for Automated Driving

This study and research project identified the following issues for satisfying the three requirements described above when providing traffic signal information via ITS RSU for automated driving. The research results are presented below for each of these issues.

(1) Margin of error in traffic signal information
(2) Enhancement of failsafe functions if a RSU malfunction occurs
(3) Countermeasures for events unrelated to the provision of traffic signal information

3.2.1. Validation of Margin of Error in Traffic Signal Information

For ITS RSU, to enable the provision of traffic signal information alongside DSSS services for vehicles that are not provided with an accurate absolute time, it was decided to provide the number of seconds remaining before the traffic signal changes color based on the time at which the traffic signal information is provided to the vehicle (such as the number of seconds that the traffic signal will remain green measured from the point of traffic signal information wireless output). In this case, the margin of error for the traffic signal information in the information provision system used by the ITS RSU is caused by the delay time from an event (such as the traffic signal changing color) to the output of traffic signal information by wireless communication. In addition, this delay time may vary due to fluctuations in the processing load of the RSU or the like. Therefore, verification experiments were carried out using test systems in plants and on proving grounds to measure the information provision delay time and its fluctuations. Figure 4 shows an image of a proving ground experiment using a test bed created at the Yokohama Works of Sumitomo Electric Industries.

Fig. 4: Image of Proving Ground Experiment

These experimental system measurement results identified a delay time of approximately 500 to 600 msec from the start of the signal operation cycle (i.e., the start of traffic signal interval 1) to the completion of wireless communication transmission from the ITS RSU.

Here, it should be noted that there are two types of traffic signal controls: normal control, in which the traffic signal intervals proceed sequentially in accordance with the command schedule (i.e., the number of seconds for each traffic signal interval) received before the start of the cycle from the traffic management center, and traffic-actuated control, in which the traffic signal intervals are determined by the traffic signal controller itself in reaction to information such as the presence of a vehicle as identified by a vehicle detector. In the case of normal control, since the number of seconds for each traffic signal color is determined in advance, compensation can be applied to the number of seconds before the traffic signal changes color by subtracting a constant and fixed delay time (500 msec). In other words, by carrying out this compensation processing, the changes in the traffic signal interval can be identified accurately with a margin of error of between 0 and 100 msec. This enables the provision of traffic signal information within the required accuracy of ±300 msec. However, in the case of traffic-actuated control, the traffic signal interval cannot be predicted in advance. Therefore, a delay in traffic signal information output cannot be avoided and a delay time equivalent to the 500 msec described above will occur as a margin of error. Due to the impact of this margin of error, the number of seconds before the traffic signal changes color might suddenly decrease, or conflicts between the color contained in the traffic signal information ("green") and the actual traffic signal color ("yellow") might occur during the delay time, adversely affecting the reliability of the traffic signal information. One possible countermeasure for these issues is an operational approach that fixes the green signal time to absorb the delay time between the applicable interval of the traffic-actuated control and the yellow signal interval. However, due to restrictions such as the upper limit on the number of traffic signal intervals and the traffic conditions, it may not be possible to introduce this fixed green time interval. In these cases, the occurrence of a margin of error due to delays in information provision is unavoidable and must be addressed by the automated vehicle driving controls. Therefore, to support these automated driving controls, it was decided to notify the automated vehicles in advance of the possible margin of error. At the same time, traffic signal operation states that require special measures in automated vehicle driving controls were analyzed, and proposals were formulated to revise the V2I message specifications. Table 2 lists the proposed additional data specifications.

Table 2: Additional V2I Message Data Specifications

Number	Special traffic signal operational state requiring notification	Event notification conditions
1	Operations in which a longer than standard delay (margin of error) is likely to occur (e.g., when the interval applicable to traffic-actuated control or yellow signal interval occur continuously).	From the start to the end of the applicable traffic-actuated interval
2	When deviation occurs from the variation range for the minimum and maximum number of seconds remaining before the traffic signal changes color that was provided at the previous timing, and an operation occurs that causes a large deviation in the number of seconds before the traffic signal changes color (e.g., emergency vehicle priority control).	Notifications for applicable intersections - When traffic-actuated control is permitted
		Event occurrence notifications - During applicable traffic-actuated operations
3	Operations that generate a traffic signal color different to the sequence of color output changes provided at the previous timing (e.g., controls that change the traffic signal sequence).	Predetermined number of seconds after the start of the change in the color sequence

3.2.2. Enhancement of Failsafe Functions

If the RSU malfunctions or another type of error occurs in the provision of traffic signal information to automated vehicles, failsafe functions must be provided that immediately detect and notify that error to the automated vehicles. Such functions are essential to ensure sufficient reliability for automated vehicle infrastructure. Therefore, the DSSS RSU specifications for the existing traffic signal information provision system that uses ITS wireless communication was analyzed to identify issues in current failsafe functions and examine the feasibility of function enhancement.

The failsafe function for traffic signal information provision adopted by roadside devices for DSSS is as follows. The lamp unit output interface (AC 100 V) of the traffic signal controller, which controls the ON/flashing outputs of the traffic signal, is incorporated into the ITS RSU. The physical ON/flashing state of the lamps can be identified by monitoring this voltage status and, if that physical state does not match the received traffic signal information for longer than a permitted set time, the system judges that an error has occurred in the traffic signal information. One issue with this failsafe function is that, due to hardware restrictions such as the size of the casing and the difficulties of installation, only a maximum of four lamps can be monitored at the same time. To ensure reliability for automated vehicles, the number of monitored lamps must be expanded to include all the lamps involved in permitting the vehicle to pass safely through an intersection (i.e., green signals, green arrow signals, and flashing yellow signals adopted at night and other timings). Therefore, with the objective of resolving the restrictions on casing size and installation and expanding the monitoring function to include all traffic signal controlled lamps (maximum of 36), the traffic signal controller lamp output interface output signal is converted to serial communication and outputted to the ITS RSU using separate communication circuits from the traffic signal information interface. Figure 5 outlines the newly added functional failsafe specifications. The ITS RSU judges that an error has occurred in the traffic signal information when the current traffic signal color information obtained from the independent communication circuits fails to match the traffic signal information for longer than a permitted set time.

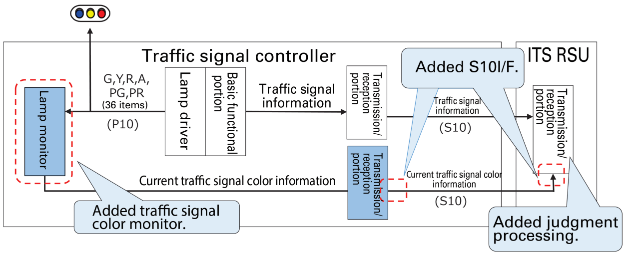


Fig. 5: Overview of Failsafe Specifications

Prototype traffic signal controllers and ITS RSU were developed to incorporate these failsafe specifications. Then, in an experimental system using these prototype units, situations (failures) were simulated in which the traffic signal information did not match the lamp color information. By connecting a logic analyzer or other instrumentation to each information input/output interface location, the transmission and reception timings of each item of information was detected. This allowed the delay from the change in the color of the traffic signal to the invalidation of the traffic signal information in the wireless communication output and the fluctuations in this delay to be measured. The main validation results are described below.

(1) Case 1

At the timing of a change from a red to a green signal, the transmission of dummy red traffic signal information was continued to simulate inconsistency. The time from the occurrence of that inconsistency to the invalidation of the traffic signal information was measured. Table 3 shows the experiment results. These results confirmed that the traffic signal information error was notified an average of approximately 350 msec (maximum: approximately 411 msec) after the failure occurred.

Table 3: Error Notification Delay Time in Case 1

Number of measurements: 60	Delay time (msec)		
	Average value	Minimum value	Maximum value
Failsafe judgment time	354.4	304.6	411.1

(2) Case 2

At night, traffic signals may flash yellow on main roads or red on secondary roads. The failsafe function was validated when a normal color sequence (green → yellow → red) involving the normal three colors was changed to flashing operation. When transitioning from a normal three-color sequence to flashing operation, all the lamps flash (duration: 0.5 sec in the experimental system) and then the red and yellow lamps turn ON alternately for 0.5 seconds in the following sequence: red → yellow. To judge the consistency of a yellow traffic signal after transitioning to flashing operation, it is necessary to confirm the flashing of the yellow lamp over several cycles in addition to measuring the flashing time of all lamps + red lamp ON time. For this reason, the failsafe judgment time under flashing operation can be assumed to be longer than for normal three-color operation. To reduce this judgment time in these validation experiments, consistency was judged by detecting the flashing time of all lamps prior to the flashing operation in combination with the traffic signal operational state information that is outputted separately by the traffic signal controller.

Although this traffic signal information indicates whether the traffic signal has transitioned to flashing operation, the following failure event was simulated as a conflict between lamp ON information and flashing operation. Using the start of the flashing time of all lamps as a reference, dummy traffic signal lamp information showing the yellow and red lamps as OFF despite reaching the flashing operation timing was applied. Table 4 shows the experiment results. These results found that the time between the failure occurring and the invalidation of the traffic signal information was less than 1 second.

However, it should be noted that the flashing time of all lamps and other parameters used in this experiment depend on the particular specifications of the experimental equipment, and these parameters will have to be standardized.

Table 4: Error Notification Delay Time in Case 2

Number of measurements:32	Delay time (msec)		
	Average value	Minimum value	Maximum value
Failsafe judgment time	836.6	742.7	939.2

3.2.3. Expansion of Traffic Signal Information Provision Functions

In some cases, it may be difficult to generate and provide traffic signal control depending on the operational state of the traffic signal controller and the details of the traffic signal control. However, to facilitate the provision of traffic signal information for automated driving, the availability of traffic signal information must be clarified and measures studied to improve this availability. Therefore, the specifications of the existing DSSS traffic signal information provision system that uses ITS wireless communication was analyzed to identify events that complicate the provision of traffic signal information. Table 5 shows the analysis results. Item 1 is an operational state that maintains the traffic signal interval so that the traffic signal operation changes non-continuously and cannot be read in advance. For this event, the current specifications (provide current traffic signal color only) were followed. Items 2 (manual operation) and 3 (failures consisting of operational states with unreliable traffic signal information) were also addressed by following the current specifications (stop information provision). In addition, from the standpoint of cost effectiveness, two items were identified as having the potential to greatly improve availability through a large number of locations and additional traffic signal information provision functions. These were items 5 (a recall function by which the pedestrian calls up a green signal by pressing a button or the like) and 6 (the FAST traffic-actuated function that prioritizes emergency vehicles). Specifications were studied to expand the traffic signal information provision function for compatibility with these items.

Then, rather than addressing items 4 (various traffic-actuated controls) and 7 (controls that change the traffic signal sequence) by adding functional specifications, countermeasures in the operation of traffic signal controls were studied. Requests and cautions for this approach were identified. The details are described below.

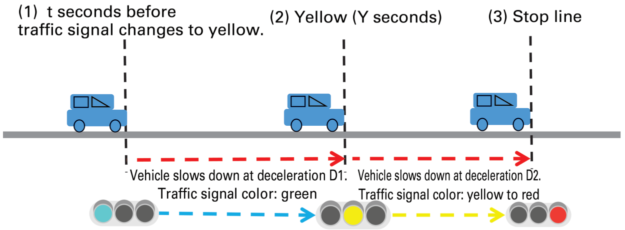
When traffic-actuated controls are implemented, the details of the traffic signal information to be provided change depending on the intervals that are applicable to traffic-actuated control and the details of the control. Therefore, depending on the conditions, this

Table 5: Events and Items that Complicate the Provision of Traffic Signal Information

Item	Traffic signal operation	Current (DSSS specifications)	Countermeasure policy
1	Maintenance of traffic signal interval	Provide current color only.	Leave specifications unchanged.
2	Manual operation	Stop traffic signal information provision.	
3	Failure operations - Security operation - Erroneous flashing	Stop traffic signal information provision.	
4	Traffic-actuated functions	Provide range in which green traffic signal duration increases or decreases (minimum and maximum number of seconds remaining) by traffic-actuated control.	Analyze operational rules.
5	Recall function (function that calls up a traffic signal color by a request signal, such as a button being pressed)	Outside scope of traffic signal information provision	Add traffic signal information provision function for main methods in large number of locations
6	FAST traffic-actuated function (priority control for emergency vehicles)	Provide current color only during FAST traffic-actuated control implementation.	Add function to provide number of seconds remaining before traffic signal changes during FAST traffic-actuated control implementation.
7	Functions that change the traffic signal sequence - Flashing control at night - Staggered time controls during certain periods (function that changes the traffic signal indication sequence)	Provide traffic signal information assuming that the same status will also continue in the next cycle.	Analyze operational rules.

might have a major impact on automated driving controls. Specifically, when traffic-actuated control is carried out, the provided traffic signal information describes the minimum and maximum number of seconds remaining before a green traffic signal changes, in accordance with the degree that the green traffic signal is lengthened or shortened. Therefore, in the event of traffic-actuated control in which the green signal start timing cannot be determined in advance (such as when the interval applicable to traffic-actuated control or yellow signal interval continues), the minimum remaining number of seconds is set to zero assuming that the green signal might end immediately. When this type of traffic signal information is provided, to prevent automated vehicles from braking suddenly to stop at a red signal, it is necessary to slow the vehicle down in advance assuming that the vehicle might have to stop at an intersection currently showing a green signal. However, if the yellow signal start timing can be provided a certain number of seconds in advance (before Δt seconds), this timing can be used as look-ahead information. The vehicle can then judge the necessity for slowing down in advance to help minimize the amount of such cautionary braking.

It should also be noted that such cautionary braking while the traffic signal ahead is green should involve only gradual deceleration to minimize the impact on trailing vehicles. Table 6 lists the provisionally calculated results for the required number of Δt seconds assuming a driving model (Fig. 6) in which gradual cautionary deceleration equivalent to engine braking is carried out only when the vehicle judges that it cannot pass through the intersection safely under the green signal at its current speed.



(1) When the vehicle cannot pass safely through the intersection at its current speed, the vehicle starts to slow down at deceleration D1 Δt seconds before the traffic signal changes to yellow.
(2) The vehicle starts to slow down at deceleration D2 after the traffic signal changes to yellow.
(3) The vehicle stops at the stop line.

Fig. 6: Example of Cautionary Deceleration Driving Model (Source: JAMA)

Table 6: Provisionally Calculated Results for Δt Seconds

Vehicle	Time to yellow	Speed limit		
		40 km/h	50 km/h	60 km/h
Ordinary vehicles	3 seconds	2.75 seconds	5.98 seconds	8.93 seconds
	4 seconds	-	1.20 seconds	4.91 seconds
Heavy-duty vehicles	3 seconds	5.67 seconds	8.84 seconds	11.90 seconds
	4 seconds	2.04 seconds	5.69 seconds	8.98 seconds

* Provisional calculation conditions:
On-board unit processing time: 0.3 seconds
Traffic signal information fluctuation: 0.3 seconds
Ordinary vehicles (D1 = 0.03G, D2 = 0.2G)
Heavy-duty vehicles (D1 = 0.03G, D2 = 0.15G)

When carrying out traffic-actuated control, it should be possible to reduce cautionary deceleration by defining operational rules for determining the yellow signal start timing in advance. However, by guaranteeing a large Δt value as shown in Table 6, the effectiveness of the traffic-actuated control might be lost and smooth traffic flows might be adversely affected. Since these two requirements have a trade-off relationship, the validity of the proposed driving model must be verified while determining an operational policy in line with traffic and other local conditions.

Another concern is that changes in the traffic signal indication sequence or the implementation of controls that change the traffic signal sequence (e.g., when the normal three-color green → yellow → red sequence changes to flashing yellow or red at night or during other times) might affect the traffic signal information provision delay. Proposed countermeasures for this concern include adopting strict operational rules not to change applicable traffic flows that have the right of way before and after the change in sequence, or disclosing the intersections and time periods affected by traffic signal sequence changes.

3.2.4. Summary of Studies and Research Related to V2I Systems

This study and research project achieved the following results.

First, it defined the three traffic signal control requirements for automated driving. Second, it identified and studied the technological issues for these requirements, manufactured prototype units, carried out operational verifications, and obtained the following results (1) to (3) about each of the defined requirements. Third, as the results of research based on these two points, proposed specifications and standards were formulated for ITS RSU and traffic signal controllers for automated vehicles.

(1) Margin of error for traffic signal color information

Current controls satisfy the requirement and can respond in less than ±100 msec. However, this delay reaches 500 msec with traffic-actuated controls that might end a green signal suddenly. Although this does not satisfy the requirement, countermeasures were proposed, such as improving the V2I message specifications and setting a system to notify the vehicle of the delay (margin of error) in advance.

(2) Failsafe functions

The operation of the failsafe functions was validated using the prototype unit and normal operation was confirmed. The delay for notifying vehicles of an error was 500 msec in the case of a three-color traffic signal color sequence and 1 second for a flashing traffic signal.

(3) Measures for special traffic signal controls

For the recall and FAST controls that are in common use and have a major impact on traffic signal information provision, the provision of traffic signal information (transmission of the minimum and maximum number of remaining seconds) was validated using the prototype unit. It was possible to notify the vehicle in advance of sudden changes in traffic signal information.

4 Development of More Sophisticated Traffic Signal Information Provision Technology Using V2N

4.1. Positioning of Development of Traffic Signal Information Provision Technology Using V2N

Traffic signal information provision systems using V2I enable high performance but are affected by high infrastructure costs. Therefore, to help reduce costs, research and development has been started into the establishment of new traffic signal information provision methods using the cloud and other network-based infrastructure.

A five-year research and development plan was inaugurated in the 2018 fiscal year and a proposed traffic signal information provision method involving prefectural and metropolitan police forces was verified using a model system in the 2020 fiscal year. From the 2021 fiscal year, studies are being carried out toward social implementation.

This report describes the research results obtained in the previous three years, starting in the 2018 fiscal year.

4.2. System Configuration and Provision Methods

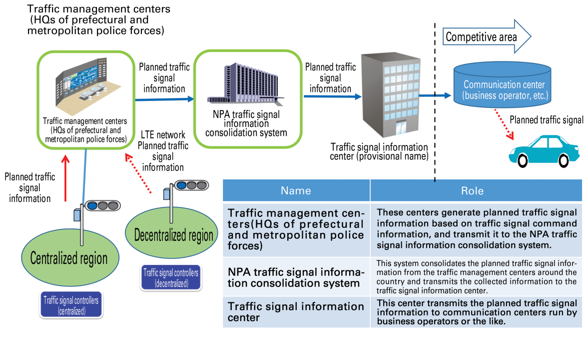
4.2.1. System Configuration

This project has been studying systems capable of providing traffic signal information using the cloud and other network-based infrastructure. Figure 7 shows the proposed system configuration.

Studies aiming at system realization in cooperative areas are currently in progress.

Table 7: Overall Research and Development Plan

2018 fiscal year (completed)	Preparatory investigations and studies of issues of most feasible methods - Preparatory investigations of methods other than V2I communication capable of providing traffic signal information - Analysis of traffic signal information provision methods other than V2I communication - Studies of countermeasures for issues to realize most feasible methods
2019 fiscal year (completed)	Verifications using simulated systems and creation of proposed specifications for model system - Definition of detailed functions and technical requirements for traffic signal information provision methods - Verification using simulated systems of three proposed traffic signal information provision methods - Creation of proposed specifications for model system to be constructed in the 2020 fiscal year
2020 fiscal year (completed)	Model system field operational test in one prefecture or metropolitan area and studies of traffic signal information consolidation system specifications - Provision and validation of model traffic signal information provision system by one prefectural or metropolitan police force - Studies of traffic signal information consolidation system* for the National Police Agency (NPA) * System that consolidates the traffic signal information transmitted from traffic management centers and traffic signal controllers. Utilization of the wide-area traffic management system of the NPA is being examined.
2021 fiscal year (planned)	Studies of configuration of traffic signal information center for social implementation - Studies of requirements of traffic signal information center - Studies related to referencing and integrating other information - Verifications for improving accuracy of traffic signal information
2022 fiscal year (planned)	Construction and validation of prefectural and metropolitan police force systems and NPA traffic signal information consolidation system - Construction of traffic signal information provision systems by prefectural and metropolitan police forces and validation of effectiveness - Construction and validation of NPA traffic signal information consolidation system



Name	Role
Traffic management centers(HQs of prefectural and metropolitan police forces)	These centers generate planned traffic signal information based on traffic signal command information, and transmit it to the NPA traffic signal information consolidation system.
NPA traffic signal information consolidation system	This system consolidates the planned traffic signal information from the traffic management centers around the country and transmits the collected information to the traffic signal information center.
Traffic signal information center	This center transmits the planned traffic signal information to communication centers run by business operators or the like.

Fig. 7: Proposed System Configuration

4.2.2. Traffic Signal Information Provision Methods

Items of traffic signal information generated by the traffic management centers and traffic signal controllers are first consolidated in the NPA traffic signal information consolidation system via an LTE network or the like. The method of providing this information to the communication centers and other points was then studied. The study and research phase in the 2019 fiscal year concluded that this could be feasibly realized by three methods (the management center, centralized, and controller methods). Figure 8 illustrates these three methods.

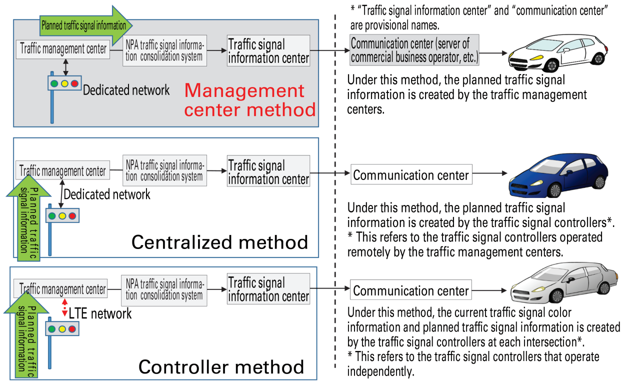


Fig. 8: Traffic Signal Information Provision Methods

It was suggested that using the management center method, which requires no infrastructure, as the main system and adopting the centralized and controller methods as supplementary systems would enable traffic signal information provision at the highest number of intersections.

4.3. Validation of Prefectural Police Force Model System

4.3.1. Construction of System for Validation

In the 2020 fiscal year, the three feasible traffic signal information provision methods (the management center, centralized, and controller methods), which had been verified in plants by the investigations in the 2019 fiscal year, were used to construct a model system in Saitama Prefecture under the cooperation of the HQ of the Saitama Prefectural police. Technical validations were then carried out of the accuracy, delay, and other aspects of the system.

The provision of traffic signal information to automated vehicles must minimize deviations between the provided information and the actual color of traffic signals. Such deviations are referred to as the margin of recognition error. The accuracy requirements defined by JAMA for this margin of error is ±300 msec. However, since V2N communication is more susceptible to delays than V2I communication, this project aimed to keep the margin of recognition error to within ±300 msec by generating planned traffic signal information with additional absolute time information under the assumption that the V2N devices could use GPS or NTP for time synchronization. Figure 9 shows the validation system constructed in the 2020 fiscal year.

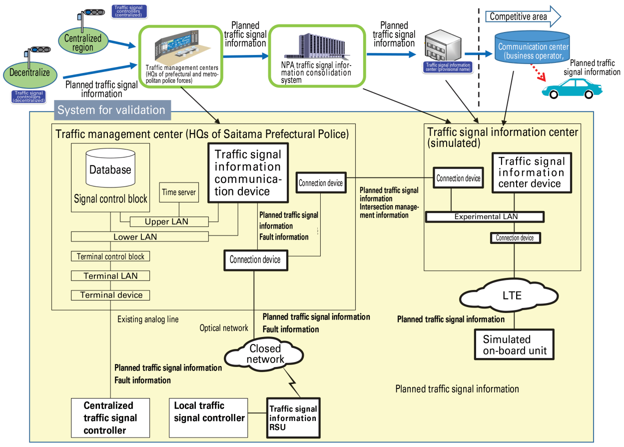


Fig. 9: System for Validation

4.3.2. Verification Results

After applying countermeasures to improve timing accuracy and the like, the system shown in Fig. 9 was verified. As shown in Fig. 10, the management center method generated a margin of recognition error in excess of 1 second. Excluding cases of traffic-actuated control and the like, the centralized method generated a margin of recognition error within ±300 msec (Fig. 11). Similarly, excluding times in which the traffic signal pattern changed, the controller method also generated a margin of recognition error within ±300 msec (Fig. 11).

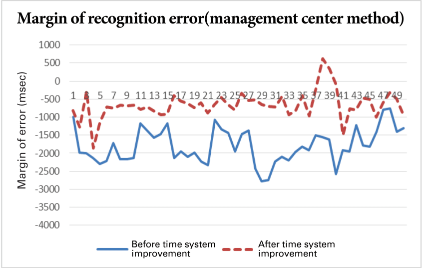


Fig. 10: Management Center Method Verification Results

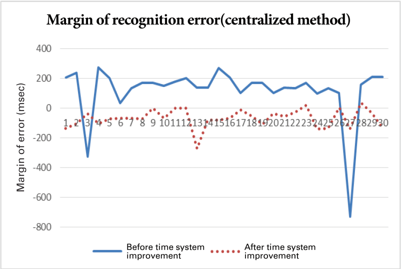


Fig. 11: Centralized Method Verification Results

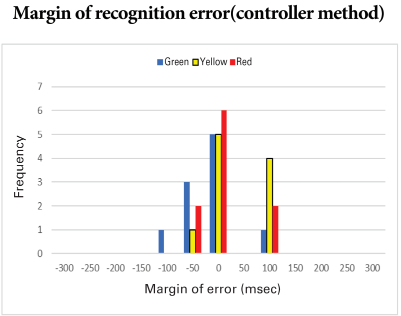


Fig. 12: Controller Method Verification Results

4.4. Studies of Traffic Signal Information Consolidation System

This project also studied the system that collects planned traffic signal information from the prefectural and municipal police traffic management centers and transmits this information to the traffic signal information center. Figure 13 shows the main systems that connect with the NPA traffic signal information consolidation system, the role of each system.

In addition to studies of the system function configuration, the functional layout, and the required screen configuration and the like for management, the project also carried out evaluations to clearly define the performance requirements, and identified the system operational requirements.

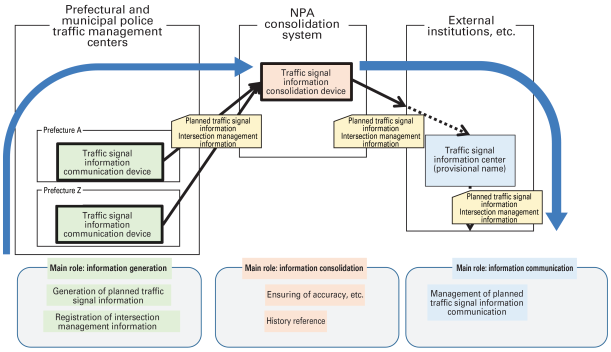


Fig. 13: Data Flow and System Roles

4.5. Results

(1) Proposed specifications for a model system for prefectures and metropolitan areas and a traffic signal information consolidation system were prepared.
(2) Proposed guidelines for reducing the impact on traffic flows at traffic-actuated and recall control intersections and traffic signal control methods to enable the provision of planned traffic signal information were prepared.
(3) Designs and operational methods for definition information (compatibility with maps) were studied to enable the utilization of planned traffic signal information.
(4) Overload tests were carried out for the traffic signal information consolidation system and basic values were obtained for future designs.

4.6. Further Actions for V2N Traffic Signal Information Provision

In the 2021 fiscal year, the following studies are planned, starting with accuracy verifications using new traffic signals based on 100 msec data management.

(1) Studies to improve accuracy

The performance of each traffic signal information provision method was identified, such as the margin of recognition error of the management center method, which reaches several seconds. One possible measure to improve accuracy is to adopt signal timings of 0.1 seconds in the traffic management center. However, as it may be difficult to realize this timing for some cases, it will be necessary to make further improvements, carry out verifications, and revise requirements in line with circumstances

(2) Studies to reduce delay times

Determining planned traffic signal information in advance is one measure for traffic-actuated controls that involve sudden changes of traffic signal colors. However, the operation of this approach must consider communication delay times. In the experiment results obtained in the 2020 fiscal year, delay times of approximately 2 seconds occurred within the management center. To reduce the impact of these delays on operations, studies are under way to reduce the delay time throughout the whole system.

(3) Studies for social implementation

To help facilitate the social implementation of traffic signal information provision using the cloud and other V2N networks, studies will be carried out into the configuration of the traffic signal information center that receives planned traffic signal information from the whole country from the NPA traffic signal information consolidation system and communicates this information to business operator servers, including from the standpoint of information security.

5 Conclusions

To help realize a more sophisticated level of automated driving, technical studies into satisfying the functional requirements of traffic signal information provision using ITS RSU (V2I) have been concluded, and some specific results have been obtained. These include the formulation of proposed specifications and standards for roadside infrastructure units such as ITS wireless RSU for automated vehicles. Points (1) to (4) below are regarded as potential approaches to facilitate the provision and popularization of V2I roadside infrastructure in the future.

(1) The formulation of an infrastructure provision plan (for the applicable roads and processes)
(2) The revision of traffic signal control operations, such as traffic-actuated controls, implementation locations, and so on
(3) The establishment of the operation and maintenance systems required by automated driving infrastructure
(4) The alleviation of the financial burden on prefectures and municipal areas to provide RSUs (such as the updating of traffic signals)

At the same time, as a method of quickly realizing a certain level of traffic signal information provision on a large scale, investigations and research are being carried out into V2N systems using the cloud, which have comparative advantages in terms of the time required to provide infrastructure and cost. Both V2I and V2N systems have respective advantages and disadvantages. In the future, it is hoped that the appropriate methods of information provision can be adopted in accordance with usage scenarios involving traffic signal control methods and the traffic signal information.

【 Reference 】

(1)ISO/TS19091:2017, Intelligent transport systems — Cooperative ITS — Using V2I and I2V communications for applications related to signalized intersections
(2)ITS FORUM. (2014). RC-013 ver1.0
(3)Masafumi Kobayashi, “DSSS (Driving Safety Support Systems), Today and the Future”, The journal of the Institute of Electronics, Information and Communication Engineers 95(8), 701-705, 2012-08-01

2 Building and Making Use of Traffic Environment Data

(1) Development of Technology Concerning the Generation of Traffic Environment Data

Development of Technology for Lane-specific Road Traffic Information Using Vehicle Probes

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Autonomous and automated vehicles drive based on information from a limited range forward of the vehicle. An accident or congestion in this range requires the vehicle to decelerate suddenly and heavy traffic flows may also prevent smooth lane changes. In these cases, if the forward traffic conditions (look-ahead information) can be identified on a lane-by-lane basis, safer and smoother automated driving may be accomplished by enabling cautionary deceleration or seamless lane changes in advance. As connected vehicles become more widespread, traffic environments that can generate such look-ahead information pertaining to traffic conditions are currently being constructed. However, there are no data formats capable of directly identifying the traffic conditions of separate lanes. This project involves the development of technology related to lane-based road traffic information to help realize safer and smoother automated driving, and the verification of the level of lane-based information that can be generated from currently available probe data. Initiatives in this project began by using data with an immediate potential for use in the future.

1 Project Overview

1.1. Purpose and Overview of Project

This project involves the development of technology to generate effective lane-based road traffic information to help realize safer and smoother automated driving on highways. In specific terms, it involves studies and verifications into the collection and integration of actual probe data from commercially available vehicles of OEMs and the like, the generation of lane-level road traffic information, as well as methods of expressing this information. In addition, as part of the large scale field operational tests (FOTs) being carried out in the Tokyo waterfront area, this project carried out an FOT involving the generation and transmission of lane-level road traffic information, particularly information on the ends of lines of traffic in each lane caused by congestion in the direction of each branch of the Metropolitan Expressway, and identified the effectiveness and issues of such information.

1.2. Necessity for and Sources of Lane-Based Road Traffic Information

As shown in Fig. 1, autonomous and automated vehicles drive based on information from a limited range forward of the vehicle. If the preceding vehicle brakes suddenly due to an accident or congestion in this range, the driver's vehicle will also have to brake suddenly, and heavy traffic flows may also prevent smooth lane changes. In these cases, measures such as obtaining road traffic information in advance for each lane ahead of the vehicle might enable seamless cautionary deceleration and lane changes (i.e., more efficient path planning). This project is studying technology with the aim of enabling the practical adoption of such measures. Lane-based road traffic information should be an effective way of realizing this objective. Probe vehicle data from the rising number of connected vehicles as well as information possessed by road and traffic management bodies are regarded as potential sources for this lane-based traffic information. In addition, more and more vehicles are being equipped with emergency notification services that contact the relevant institutions in the event of an accident or the like. This information is also regarded as a potential source for immediately identifying lane obstructions due to accidents.

Initially, this project studied information generation using probe vehicle data. The information generated from this data can also be used effectively by the driver's vehicle.

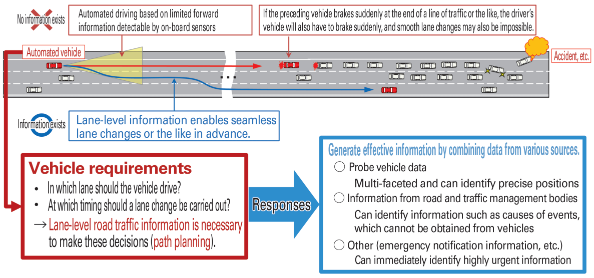


Fig. 1: Necessity for and Sources of Lane-Based Road Traffic Information

1.3. Scope of this Initiative

As shown in Fig. 2, decisions and controls carried out by automated vehicles with regard to forward road traffic events can be categorized into levels in accordance with the distance of the vehicle to the event. Although lane-based road traffic information is required for each level, the information must be provided using a range of communication means in accordance with the immediacy of the information required at each level. Under this categorization, information directly connected to vehicle controls, such as emergency avoidance maneuvers in the immediate proximity of an event, is necessary, which requires the use of vehicle-to-vehicle (V2V) or similar communication.

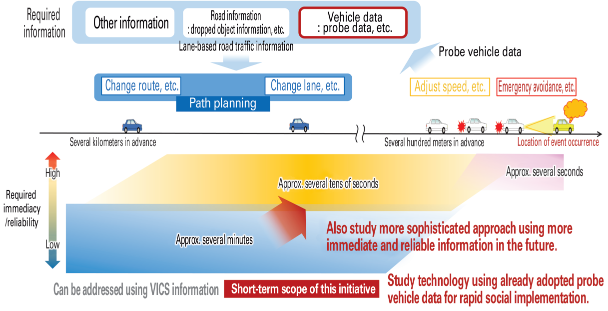


Fig. 2: Scope of this Initiative

One result of this information is likely to be changes in path planning (i.e., route or lane changes) further away from the event.

Information to support decisions and controls to make these changes will be required, which may be effectively addressed by vehicle-to-network (V2N) communication or the like. This project studied the use of generated information for path planning focusing on lane changes. The immediacy of the required information was set to approximately several minutes and it was proposed that the information could be generated from currently available probe data. Therefore, with the aim of realizing rapid social implementation of the developed technology, it was decided to use probe vehicle data that can already be obtained from commercially available vehicles to study the generation of information with the same real-time equivalency as conventional road traffic information. This decision was based on the idea that this could encourage the early realization of automated driving and the premise that the generated information could also be used effectively by the driver's vehicle.

1.4. Image of Lane-Based Road Traffic Information and Usable Probe Vehicle Data

As shown in Fig. 3, the lane-based road traffic information assumed by this project consists of information that expresses the road traffic conditions of each lane (such as decreases in speed and traffic restriction zones, as well as the ends of lines of traffic demarking these conditions). If this information can be provided, the most significant merit for automated vehicles and the like receiving the information would be the capability to select the most appropriate lane for driving. Therefore, as shown in Fig. 4, the used probe vehicle data should preferably be in a format that contains lane information from the stage that the information is collected (pattern 3 in the figure). However, this type of probe data is not currently available. Current probe data contains links to the road rather than the lane (pattern 1).

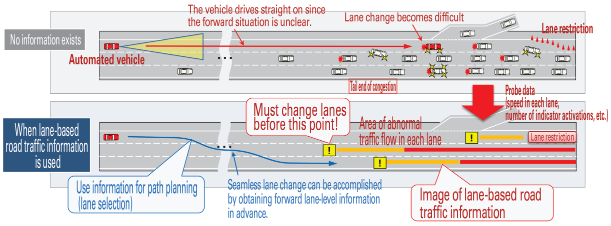
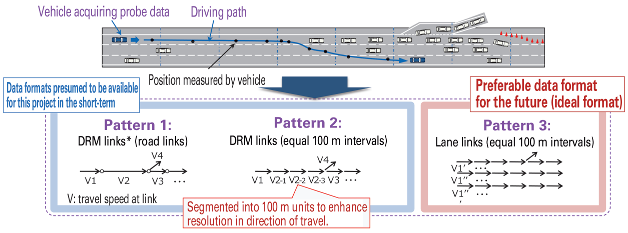


Fig. 3: Image of Lane-Based Road Traffic Information



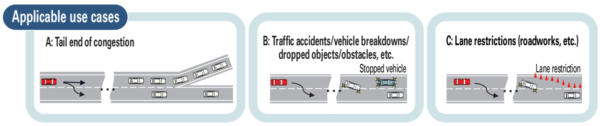
* DRM link: link format on digital road maps created by the Japan Digital Road Map Association

Fig. 4: Formats of Used Probe Vehicle Data

Therefore, this project studied methods of generating lane-level information from currently available pattern 1 probe data. However, to enable the use of this information for path planning (i.e., cautionary deceleration, lane changes, and the like), information with an equal interval resolution in the direction of travel (such as information at 100 meter intervals) was obtained from OEMs and the like (pattern 2 in the figure).

1.5. Applicable Use Cases

As shown in Fig. 5, the three applicable use cases for information provision were defined as follows: (1) the tail end of congestion (particularly congestion in each lane), which is regarded as important lane-based traffic information for lane change controls and so on, (2) the sudden occurrence of events such as traffic accidents, and (3) lane restrictions. For case (1), the tail end of congestion was detected directly from probe data. In contrast, for cases (2) and (3), although the project aimed to detect the positions of lane obstructions directly from probe data such as indicator activation and the like, since the tail end of congestion caused by such obstructions is also important, the provision of this information was also assumed.



Requirements	Applicable location	Communication	Control applications (vehicle control, information provision, etc.)	Immediacy (vehicle response after information acquired)
	Expressway	V2N	Driving plan change (change lane, adjust speed, etc.)	Not required

Note) Set with reference to Use Cases for Cooperative Driving Automation (Edition 1, September 3, 2020).

Fig. 5: Applicable Use Cases and Requirements

1.6. Future Goal and Positioning of Fiscal Year 2020 Project

As described above, this project is aiming to develop technology that can generate lane-level road traffic information from currently available road link probe data. However, as connected and automated vehicles become more widespread in the future, it is hoped that probe data containing lane-based information will become available from the information-collection stage. Therefore, assuming that the amount of available data will increase, and that it will become possible to collect and use highly fresh information without uplink delays over a shorter cycle, it is also hoped that more effective and integrated look-ahead information can be provided in combination with non-probe data. Unfortunately, since this information will not be available for the foreseeable future, this project started with the aim of realizing information provision via a logical extension of existing technology (Fig. 6).

In the 2020 fiscal year, the project verified the feasible extent of information generation using the format and volume of currently available probe data and prepared a proposal for the required technical specifications. In addition, the project also carried out real-time information generation and transmission tests on the Metropolitan Expressway as part of the large scale field operational tests in the Tokyo waterfront area using some data from OEMs and the like that is accessible online. Furthermore, the project also validated the technical specifications and evaluated the effectiveness of the generated information through test participants.

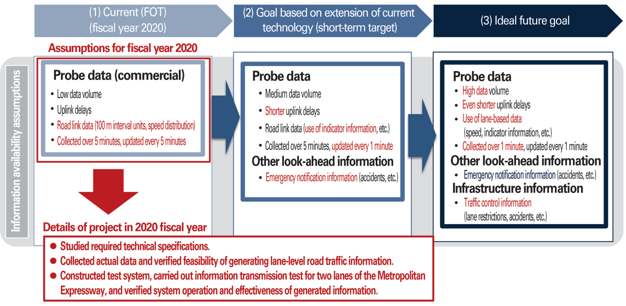


Fig. 6: Future Goal and Positioning of Fiscal Year 2020 Project

1.7. Overall Image of Fiscal Year 2020 Project

Figure 7 shows an overall image of the details of the project carried out in the 2020 fiscal year. An overall image of the information flow is as follows. It is assumed that information will be collected from OEMs and the like and that the information generated at the operational stage will then be provided to individual vehicles via the OEMs. The scope of technological development in this project consists of the following five technical elements: (1) data collection from OEMs and the like, (2) integration of data from multiple information sources, (3) generation of lane-level road traffic information, (4) conversion to data capable of expressing location, and (5) data transmission. In the studies for each technical element, first, traffic micro simulations were carried out to create simulated data assuming different levels of probe vehicle data availability. Information generation logic was constructed and the accuracy of information generation was evaluated in accordance with the proportion of available probe vehicle data. Based on these results, actual past probe data was collected from OEMs and the like, the volume of currently collected information and the extent of uplink delays were identified, and the accuracy of information generation was confirmed based on these conditions. In addition, a test system incorporating the constructed information-generation logic was built. Real-time information was then generated for probe data providers with online connection capabilities within the 2020 fiscal year, and an FOT was carried out by transmitting information to participating test vehicles via the server of the Tokyo waterfront area FOT consortium.

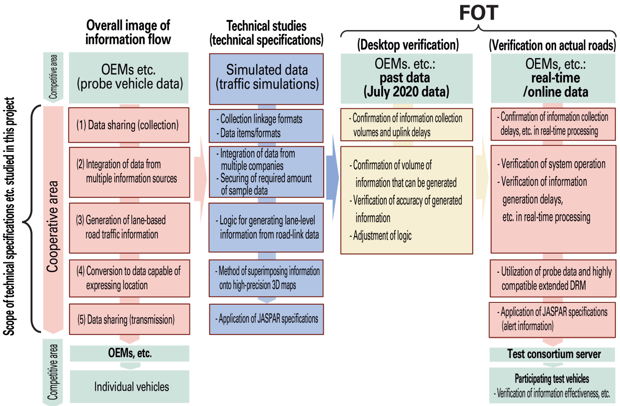


Fig. 7: Overall Image of Technical Studies and FOT for the 2020 Fiscal Year

2 Studies and Desktop Verification of each Technical Element

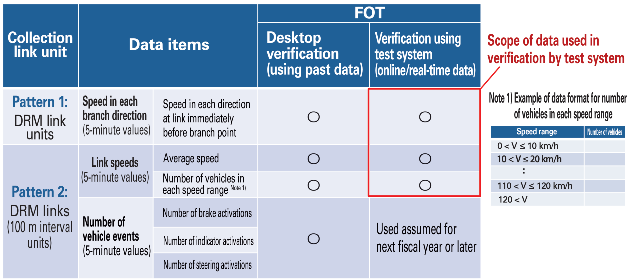
2.1. Data Sharing (Collection)

First, the specifications for sharing data with the center when collecting probe data from the servers of OEMs and the like were studied.

2.1.1. Details of Probe Data Used

Figure 8 lists the probe data obtained from the OEMs and the like. This data was used in two broad ways as follows. After receiving the past data and confirming the data volume, desktop verifications were carried out by pairing congestion and other events with lane-level information (generated as described below) and evaluating the reliability and the like of the generated information. Then, probe data providers were connected with the test system online and an FOT was carried out on actual roads by transmitting actual information to participating test vehicles using real-time data.

In addition to the link speeds, the desktop verifications used all the available data, including the speed in each branch direction and the number of vehicle events that were used to generate the lane-level information. In contrast, the actual road FOT used only the speed-related probe data (i.e., the link speeds and the speeds for each branch direction) that could be provided by probe data providers and was accessible online in the 2020 fiscal year. It should also be noted that the probe data collection period was set to five minutes based on current data collection conditions.



Collection link unit	Data items		FOT Desktop verification (using past data)	FOT Verification using test system (online/real-time data)
Pattern 1: DRM link units	Speed in each branch direction (5-minute values)	Speed in each direction at link immediately before branch point	○	○
Pattern 2: DRM links (100 m interval units)	Link speeds (5-minute values)	Average speed	○	○
		Number of vehicles in each speed range Note 1)	○	○
	Number of vehicle events (5-minute values)	Number of brake activations	○	Used assumed for next fiscal year or later
		Number of indicator activations		
		Number of steering activations		

Scope of data used in verification by test system

Note 1) Example of data format for number of vehicles in each speed range

Speed range	Number of vehicles
0 < V ≤ 10 km/h	
10 < V ≤ 20 km/h	
:	
110 < V ≤ 120 km/h	
120 < V	

Fig. 8: Probe Data Used and FOT Categories

2.1.2. Method of Handling Uplink-Delayed Data

Assuming that probe data will contain a significant proportion of uplink-delayed data, it might not be possible to obtain the required number of data samples in the data for the most recent five minutes. Therefore, considering the following two points, it was decided to use data up to 30 minutes before the current time at the data sharing (collection) stage (Fig. 9).

(1) Data is collected in five-minute units (referred to below as "levels") based on the driving time of the probe vehicle. Data is collected for up to 30 minutes in the past, including uplink-delayed data.

(2) At each level, the generation time of information that was previously obtained is collected. Level 1 refers to the data for the most recent five minutes and level 6 refers to the data collected in the five-minute period thirty minutes previously.

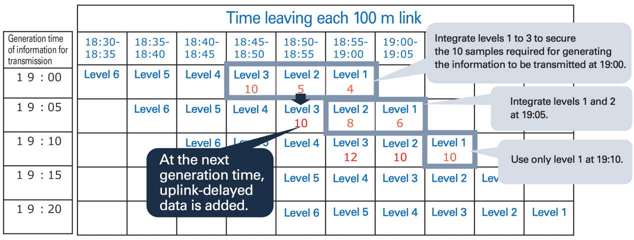


Fig. 9: Concept of Data Collection Method Considering Uplink Delays

2.1.3. Collected Information Items and Data Format

In addition to studying the information items to be collected from the OEMs and the like and the data definitions, this project specified the use of a uniform data format (the JSON format) (Table 1).

Table 1: Structure of Format Used for Data Collection

Structural information			Main information
Basic information			Geographical coordinate system, time zone, information generation time
Probe data	DRM basic information		DRM link version, secondary mesh code, link number
	Levels 1 to 6		Collect information in 5-minute increments up to 30 minutes previously (collection cut-off point)
		DRM link unit information	Average travel speed in each direction
	Levels 1 to 6		Collect information in 5-minute increments up to 30 minutes previously (collection cut-off point)
		100 m interval link unit information	Interval serial number, interval link distance Average speed information, information per speed range, other vehicle information, average travel speed in each direction

2.2. Integration of Data from Multiple Information Sources

Next, the integrated processing specifications for probe data collected from multiple information providers was studied, and the extent of information that can be collected was confirmed based on past data collection.

2.2.1. Method of Integrating Numerical Data

When integrating statistical probe data from multiple OEMs into information for a single link unit, the average data values (average travel speed and travel speed per direction) were processed by creating weighted averages based on the number of OEM data samples. In addition, the numerical values (information per speed range, other vehicle information (number of indicator activations, etc.)) were processed by creating sums of all the counted OEM values.

2.2.2. Confirmation of Probe Data Volume Required for Information Generation

The number of vehicles in each speed range is the most basic item of information for generating lane-level information. For example, it can be used to judge whether congestion has occurred in each lane by estimating the speed differential in each lane at the road links from the speed distribution. For the number of vehicles in each speed range, the proportion of probe vehicles to the total number of vehicles was calculated on the Haneda Route of the Metropolitan Expressway. During the day, this proportion was found to be around 3%, which equates to data from six vehicles per five-minutes.

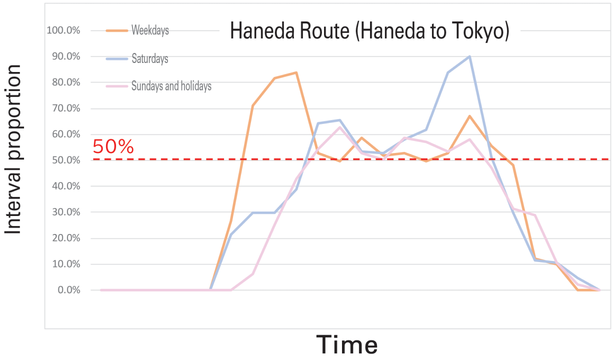


Fig. 10: Proportion of Intervals (100 m Units) in which Number of Vehicles in each Speed Range Reached Five in Five Minutes (Weekday Average between July 8 and August 7, 2020)

To estimate the average speed at a certain degree of accuracy from sample data, the margin of error can be kept down to approximately ±10 km/h (reliability: 95%) if sample data can be obtained from five vehicles. Therefore, if the target is to obtain data from five vehicles over a five-minute period, the necessary number of samples on the two routes of the Metropolitan Expressway (i.e., the FOT fields) can be obtained in approximately 50% of the two-lane section (Haneda to Tokyo, Fig. 10) and approximately 80% of the three-lane section (traveling east on the Bayshore Route). Both of these figures were calculated during the daytime. However, the five vehicles in five minutes condition was not satisfied in many time intervals during the night.

2.2.3. Effects of Uplink Delays

Although a certain volume of probe data was confirmed in the FOT fields as described above, if uplink delays result in the collection of out-of-date information, the generation of highly fresh information becomes impossible.

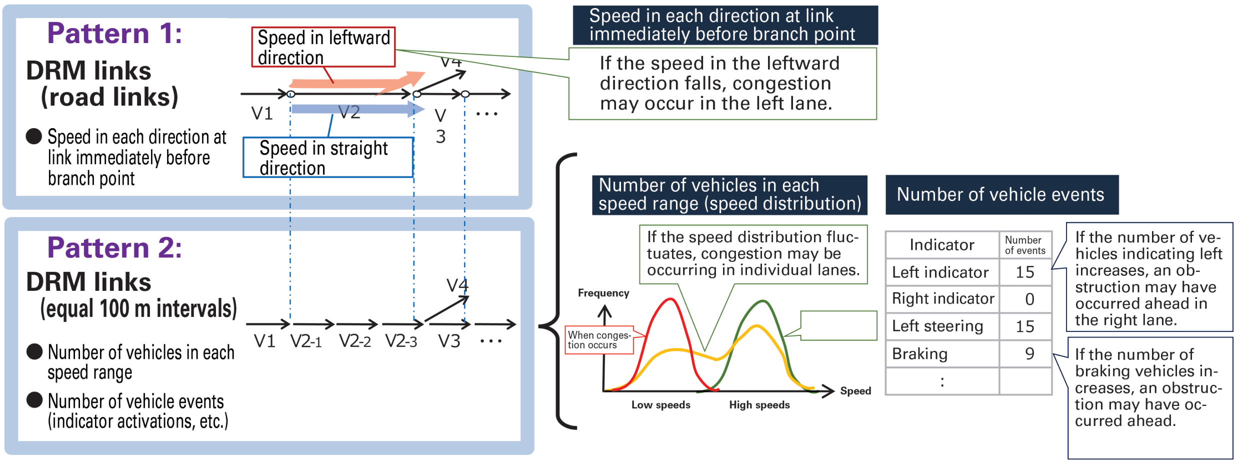
Therefore, the proportion of sections in which at least five samples can be obtained in five minutes, which is the required standard to maintain accuracy, was processed using on the previous levels. In this case, on the Haneda to Tokyo route during the daytime, level 1 (most recent five minutes) accounts for 10% of the standard, levels 1 and 2 (most recent 10 minutes) accounts for 60% of the standard, and levels 1 to 3 (most recent 15 minutes) accounts for at least 80% of the standard. This shows that, during the daytime, currently available probe data is capable of generating a certain amount of information.

2.3. Generation of Lane-Based Road Traffic Information

Next, the technical specifications for generating lane-level traffic information from the integrated lane-based probe data described above was studied.

2.3.1. Basic Reasoning behind Lane-Level Information Generation

First, locations of speed decreases in the direction of travel were identified from the information describing the number of vehicles in each speed range (speed distribution) at the 100 m link units. Congestion in one of the lanes may be assumed if the distribution of the number of vehicles in each speed range extends from low to high speeds. In this case, congestion in lanes corresponding to branching directions was determined based on the speed in each direction at the branch point (DRM link units). At other locations, the direction of an obstructed lane (left or right) was determined from indicator information (100 m link units) (Fig. 11).



If the speed in the leftward direction falls, congestion may occur in the left lane.

If the speed distribution fluctuates, congestion may be occurring in individual lanes.

Indicator	Number of events
Left indicator	15
Right indicator	0
Left steering	15
Braking	9
:	

If the number of vehicles indicating left increases, an obstruction may have occurred ahead in the right lane.

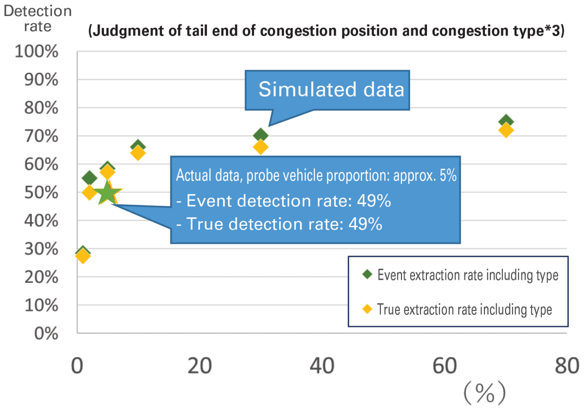
If the number of braking vehicles increases, an obstruction may have occurred ahead.

Fig. 11: Basic Reasoning behind Lane-Level Information Generation from Road Link Probe Data

It should be noted that the actual road FOT using online data in the 2020 fiscal year was only capable of utilizing speed-related probe data. Therefore, this project studied the lane-level information generation logic for the FOT system using speed-related probe input data only.

2.3.2. Verification of Accuracy of Generated Information

Using the simulated probe vehicle data created in the traffic micro simulations, the project studied the accuracy of information for the tail end of congestion generated using the number of vehicles in each speed range in accordance with the proportion of available probe vehicle data. This accuracy was examined in the area before the Hamazakibashi Junction on the Haneda to Tokyo route (Fig. 12). As a result, it was found that at a prove vehicle proportion of approximately 10%, information can be generated with an accuracy of around 70%. In addition, when the information generation accuracy was verified in the same way using the actually collected data (past probe data, probe vehicle proportion of approximately 5%), the position of the tail end of congestion could be identified with an accuracy of between 50 and 60%. If the type of congestion (such as lane-based or sectional congestion) is included, the accuracy is around 50%. These results factor in uplink delays in the actual data and are regarded as lower than the results of simulations that do not factor in uplink delays.



*1 Prove vehicle proportions: 1%, 2%, 5%, 10%, 30%, 70%
*2 True values confirmed using CCTV and dashcam video
*3 Type judgment: individual lane congestion, sectional congestion

Fig. 12: Relationship between Proportion of Probe Vehicles and Event Judgment Accuracy (Area before Hamazakibashi Junction on Haneda to Tokyo Route)

2.4. Conversion to Data Capable of Expressing Location

Next, the project studied the specifications for converting the generated lane-level road traffic information to a data format capable of expressing location, to enable superimposition onto high precision 3D maps.

This initiative collected probe data based on DRM link data from OEMs and the like, which were arranged in a 100-meter interval format. In the generation of lane-level information, lane numbers were generated for displaying the alert information upstream of the link. Therefore, the format of data collected from OEMs and the like was found to be a compatible data format for expressing location, and the extended DRB database specifications that are capable of expressing lane information were adopted. Consequently, node link maps assigned with lane numbers for each 100 m interval were created from the applicable location of the high precision 3D map. This enabled the generated alert information to be expressed at 100-meter link intervals for each lane.

2.5. Data Sharing (Transmission)

Next, the specifications for sharing data with the center when transmitting the generated information to the server that relays information to the test participants were studied.

Specifically, the specifications for expressing position that were determined in SIP phase 1 were applied to the expression of lane-based information over the 100-meter link interval units. Latitude and longitude information for the corresponding point nodes and the lane number for displaying the alert information were selected for transmission. In addition, the vehicle data sharing API specifications prepared by the Japan Automotive Software Platform and Architecture (JASPAR) were applied to the alert information transmission specifications.

3 Implementation of FOT

3.1. Overview of FOT Implementation

To evaluate the technical elements described in Section 2, an FOT system was constructed that connects to OEMs capable of online information provision in the 2020 fiscal year and transmits information processed in real-time. Information transmission tests were then carried out on two routes of the Metropolitan Expressway (Fig. 13).

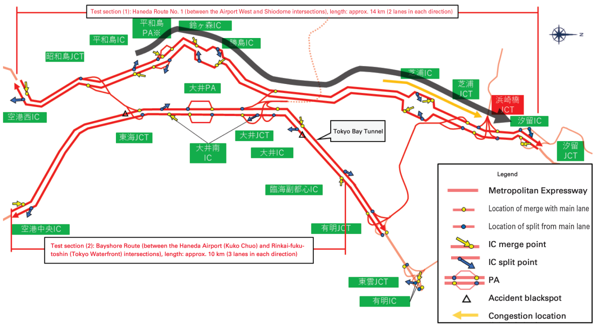


Fig. 13: FOT Routes and Sections

3.1.1. Structure of FOT System

Figure 14 shows the test system constructed for the FOT. This system transmits information to the participating test vehicles through online connections to the probe data providers and by connecting to the system of the Tokyo waterfront area FOT consortium.

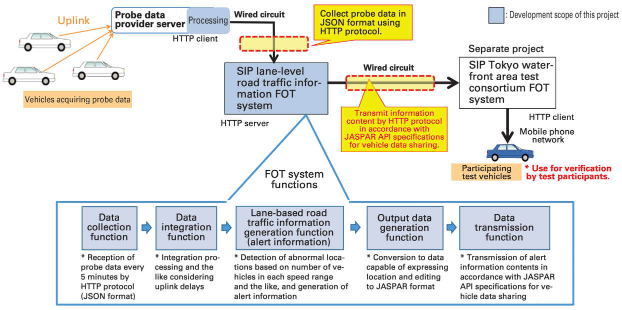


Fig. 14: Structure of FOT System

3.1.2. Details of FOT

Using the speed-related probe data available in the 2020 fiscal year, information transmission tests were carried out focusing on the primary use case of the tail end of congestion (congestion in each lane depending on the time of day), which occurs due to congestion in certain branch directions. This use case was selected because the applicable lane-level alert information can be generated. A ten-day information transmission period was set between Monday, February 15, and Friday, February 26, 2021. Participants in the Tokyo waterfront area large scale FOTs were able to receive information while driving in the applicable expressway sections during this period. The participants were asked to complete questionnaires to evaluate the effectiveness of this information.

3.1.3. Congestion Conditions in Main Verification Location and Overview of Information Transmission

Congestion constantly occurs during the day starting from the Hamazakibashi Junction on the route from Haneda to Tokyo. Since congestion occurs in the direction of Shinjuku, lines of vehicles back up into the left lane of the Haneda Route, creating congestion in certain time periods. This area was selected as the main verification location to evaluate the lane-level information. The corresponding alert information was transmitted in five-minute cycles in 100-meter units from the tail end of the congestion. If only lane No. 1 was congested, the alert information was displayed in that lane only. If both lanes were congested (sectional congestion), the alert information was displayed in both lanes (Fig. 15).

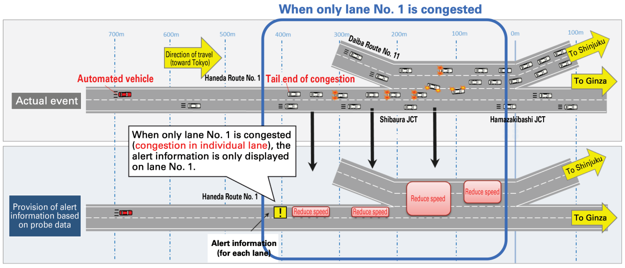


Fig. 15: Congestion Conditions in Main Verification Location and Overview of Information Transmission

3.2. Results of FOT

3.2.1. Status of Alert Information Transmission during FOT Period

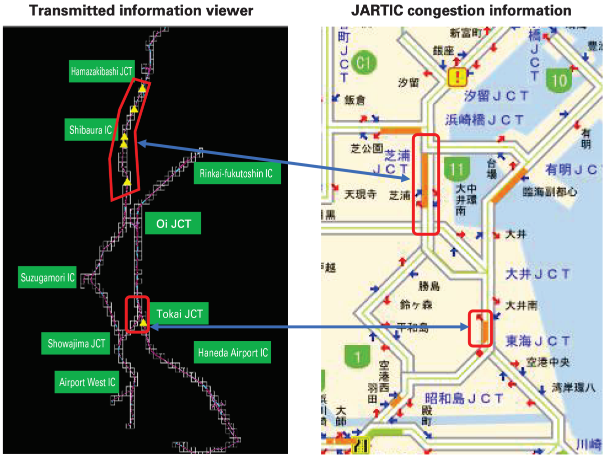
The transmitted information viewer installed in the participating test vehicles was compared with the traffic conditions provided by the Japan Road Traffic Information Center (JARTIC) during the morning rush hour (09:30). The position for the tail end of congestion in the transmitted information corresponded broadly to the traffic conditions at the same time. For example, at 09:30 on Wednesday, February 24, the viewer displayed alert information between Hamazakibashi Junction and the Shibaura Interchange on the Haneda to Tokyo route, and at the Tokai Junction in the eastern direction of the Bayshore Route, which broadly corresponds to the actual traffic conditions on the same day (Fig. 16).

Although the frequency of alert information for individual lane congestion was low, this information was mainly generated and transmitted for the area close to the Shibaura Junction merging zone. For example, at 16:30 on Wednesday, February 17, the viewer displayed alert information for the position of the tail end of congestion in lane No. 1 only on the high-precision map (at the 0.8KP position, Fig. 17).

3.2.2. Evaluation of Effectiveness by Test Participants

(1) Responses to questionnaires

Participants from 11 companies responded to the questionnaires. Of these, participants from five companies described receiving information while driving on the Metropolitan Expressway. Although the actual driving was mainly carried out on the Haneda Route, lane-specific information about the tail end of congestion was unfortunately not generated or transmitted during the times that the test participants were driving on this route.


Transmitted information viewer

JARTIC congestion information

* Source: JARTIC homepage

Fig. 16: Information Generation Status and Road Traffic Conditions in Morning Rush Hour (09:30, February 14, 2021)

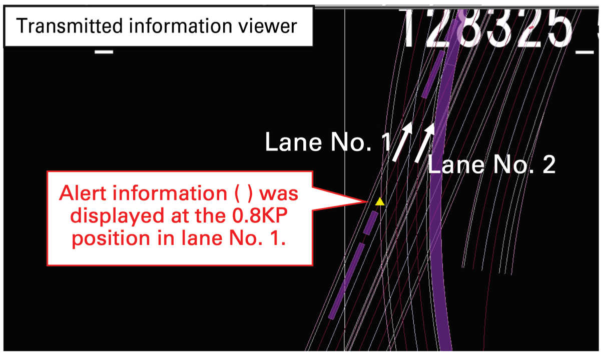


Fig. 17: Example of Viewer Display of Alert Information for Congestion in Individual Lane (16:30, February 17, 2021, Close to Merging Zone of Shibaura Junction on Haneda to Tokyo Route)

(2) Consistency between transmitted information and actual events

Of the responses, approximately 30% described the tail end of congestion information as consistent or broadly consistent with actual events. This is probably because the volume of available online probe data for this FOT was low, which meant that older (less fresh) level data was used to obtain the required number of samples for information generation. It should be possible to resolve this issue with more accurate information as the number of probe data providers and probe data volume increases in the future.

(3) Effectiveness of transmitted information

A majority of participants described the lane-level road traffic information provided in this test as effective or quite effective. Reasons given included the use of this information to enable smoother driving by changing lanes or the like in advance. In contrast, around half of responders described the information as not effective, or could not respond. In the follow up, it was found that most of the participants that selected these responses had not actually driven in conditions requiring the transmission of this information. Therefore, as the volume of probe data increases in the future and uplink delays become shorter, it is likely that more users will find this information useful.

4 Conclusions

In the 2020 fiscal year, studies and verifications were carried out into the collection and integration of actual probe data from commercially available vehicles, the generation of lane-level road traffic information, as well as methods of expressing this information. In addition, an FOT was carried out on two routes of the Metropolitan Expressway to identify the effectiveness and issues of the information. As a result, this project obtained some important results regarding the future practical adoption of information generation of speed-related probe data.

【 Reference 】

(1)JASPAR; Dynamic Vehicle Information Sharing API Specifications Ver.1.0, 2020-01-17

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Development for Updating High Precision 3D Maps Utilizing Probe Vehicle Data: Overview

Kazuhiro Nakao (Dynamic Map Platform Co., Ltd.)

This research and development project studied technology capable of identifying changes in roads using dashcam drive recorder images and probe vehicle data. These results were then applied to studies envisioning the rapid deployment of technology for identifying road changes. For the studies into technology capable of identifying changes in roads using dashcam drive recorder images, camera image data of existing sections of roads were obtained after changes were carried out. These studies then confirmed and assessed whether the changes to the road could be identified using existing technology to recognize features from the obtained camera image data, identifying those features after the road changed, and comparing the features with the state before the changes.

For the studies into technology capable of identifying changes in roads using probe vehicle data, the requirements for using probe data to update high precision 3D maps were examined on paper and then validated on a proving ground. This verification process confirmed that driving operations and vehicle behavior accompanying changes to roads can be identified using probe vehicle data in an ideal environment. Based on these results, consultations were held with OEMs about the provision of actual probe vehicle data, and the potential of using the provided real-world probe vehicle data to identify changes to roads was confirmed.

The studies envisioning the rapid deployment of technology for identifying road changes were carried out by (1) carrying out a field operational test (FOT) under a scheme envisioning the rapid deployment of technology after research and development, followed by the organization of requirements such as device specifications and the like. Then, after investigating the latest trends and so on, (2) the required conditions for starting operation on ordinary roads and globally were identified. The gap between the requirements identified at phases (1) and (2) were analyzed and summarized into a procedure for commonization.

1 Current Status of High Precision 3D Maps (Updated)

High precision 3D maps consist of a wide range of features, including demarcation (partition) lines, multiple demarcation lines, road markings, road signs, and traffic signals (Fig. 1).

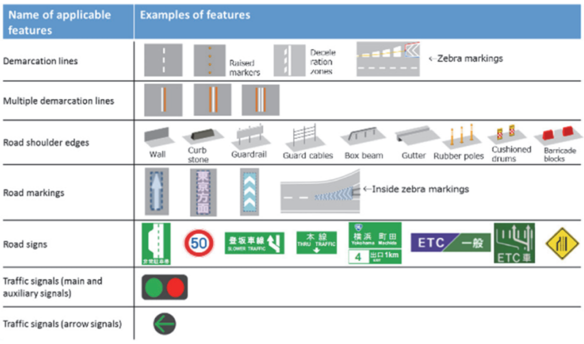
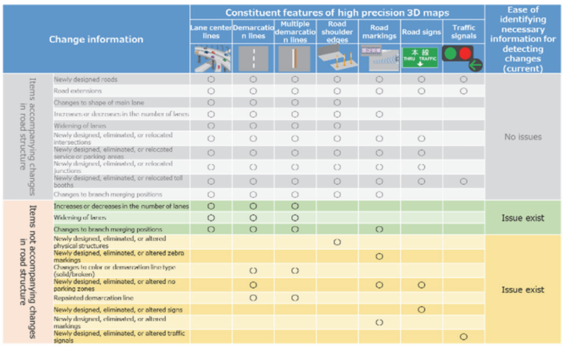


Fig. 1: Constituent Features of High Precision 3D Maps

When investigating whether features have changed, changes that accompany alterations in the road structure can be identified from public materials such as information about engineering work. In contrast, changes that do not accompany alterations in the road structure may not be identified or properly documented. As a result, it is difficult to thoroughly identify all the information required to update high precision 3D maps via current approaches (road engineering information and the like) (Table 1). Therefore, it has become necessary to develop a new system for detecting the information about changes that is necessary for updating high precision 3D maps and that does not accompany changes in road structure. This system makes use of probe vehicle driving history data, the use of which is being strongly promoted in recent years, for items that can be determined based on changes in vehicle behavior and traffic volume (the green rows in Table 1), and camera image data for items that can be determined from images of conditions before and after the change (the yellow rows in Table 1).

Table 1: Changes Affecting Roads and Current Issues of Change Detection



Change information		Constituent features of high precision 3D maps							Ease of identifying necessary information for detecting changes (current)
		Lane center lines	Demarcation lines	Multiple demarcation lines	Road shoulder edges	Road markings	Road signs	Traffic signals	
Items accompanying changes in road structure	Newly designed roads	○	○	○	○	○	○	○	No issues
	Road extensions	○	○	○	○	○	○	○	
	Changes to shape of main lane	○	○	○	○				
	Increases or decreases in the number of lanes	○	○	○	○	○			
	Widening of lanes	○	○	○	○				
	Newly designed, eliminated, or relocated intersections	○	○	○	○	○	○		
	Newly designed, eliminated, or relocated service or parking areas	○	○	○	○	○	○		
	Newly designed, eliminated, or relocated junctions	○	○	○	○	○	○		
	Newly designed, eliminated, or relocated toll booths	○	○	○	○	○	○	○	
	Changes to branch merging positions	○	○	○	○	○			
Items not accompanying changes in road structure	Increases or decreases in the number of lanes	○	○	○					Issue exist
	Widening of lanes	○	○	○					
	Changes to branch merging positions	○	○	○		○			
	Newly designed, eliminated, or altered physical structures				○				Issue exist
	Newly designed, eliminated, or altered zebra markings					○			
	Changes to color or demarcation line type (solid/broken)		○	○					
	Newly designed, eliminated, or altered no parking zones		○			○	○		
	Repainted demarcation line		○	○					
	Newly designed, eliminated, or altered signs						○		
	Newly designed, eliminated, or altered markings					○			
	Newly designed, eliminated, or altered traffic signals							○	

2 Technology for Identifying Road Changes Using Probe Vehicle Data

2.1. Selection of Information Used to Identify Road Changes

The specifications of the driving history data required to validate this research and development project were studied with the cooperation of OEMs. Table 2 lists the driving history data items identified based on these studies with the OEMs.

2.2. Technical Studies and Implementation

This driving history data consists of large volumes of data distributed densely over wide areas. To detect changes to roads from this data, the driving history data was first grouped within certain spatial and time-based ranges. The driving history data provided from the OEMs consisted of information for approximately 2 m2 ranges. This research and development project set the spatial analysis range to approximately 20 m2 for this data. The scope of

Table 2: Driving History Data Provision Specifications (Data Items)

No.	Applicable analysis parameters	Outline
1	Total data in each direction of travel (number of vehicles)	The calculated total probe vehicle data (number of vehicles) in the spatial area used for analysis within the applicable period. Analyzed in 8 directions of travel.
2	Average speed in each direction of travel	The calculated average speed of the probe vehicle data in the spatial area used for analysis within the applicable period. Analyzed in 8 directions of travel.
3	Vehicle speed distribution in each direction of travel	The calculated speed distribution of the probe vehicle data in the spatial area used for analysis within the applicable period. Analyzed in 8 directions of travel.
4	Average steering angle in each direction of travel	The calculated average steering angle of the probe vehicle data in the spatial area used for analysis within the applicable period. Analyzed in 8 directions of travel.
5	Number of vehicles turning indicator ON in each direction of travel (left)	Of the probe vehicle data in the spatial area used for analysis within the applicable period, the calculated total number of vehicles that activated the left turn indicator. Analyzed in 8 directions of travel.
6	Number of vehicles turning indicator ON in each direction of travel (right)	Of the probe vehicle data in the spatial area used for analysis within the applicable period, the calculated total number of vehicles that activated the right turn indicator. Analyzed in 8 directions of travel.

changes to the driving history data within this range was analyzed and locations with a large amount of variation were identified as road changes.

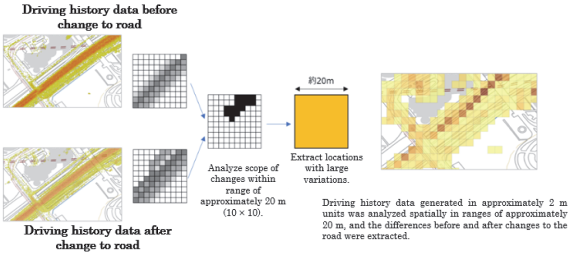


Fig. 2: Illustration of Road Change Detection Using Driving History Data

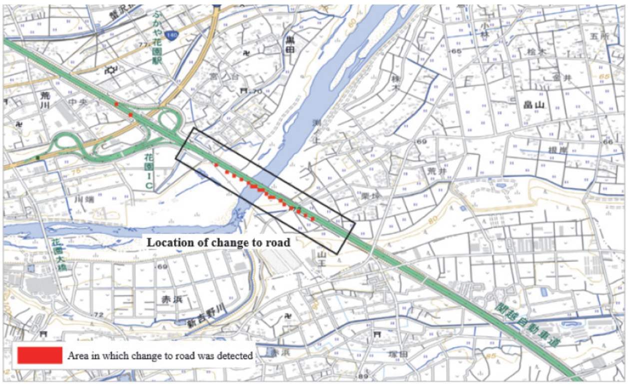


Fig. 3: Road Change Detection Result (Hanazono Interchange)

In this research and development project, four expressway locations at which actual changes to the road had been made (addition of lanes, changes to exists, etc.) were selected. The road change inspection process was then applied to these locations as a trial. The changes were detected for two locations based on the vehicle distribution pattern, but detection was not possible for the other two locations. Figure 3 shows an example in which the change was detected.

From this result, it was concluded that changes to roads could be detected using the driving history data adopted in this research and development project in areas with good position measurement performance and without the additional presence of ordinary roads. However, even based on this conclusion, the following issues remain for future practical adoption.

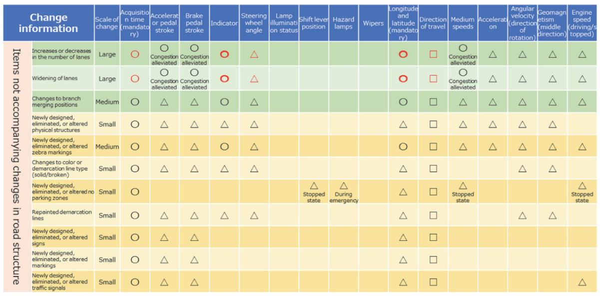
- Studies of effective driving history data items for improving detection rates
- Studies of methods to identify areas with a high detection potential using this methodology
- The automation of threshold value settings via extensive case study verifications, the automatic of cases of detection errors, and studies of methods to resolve these errors

2.3. Studies for Practical Adoption

2.3.1. Effective Driving History Data Items for Improving Detection Rates

Driving history data consists of time series data that always includes the date of acquisition and longitude/latitude in vehicle units. Based on the results obtained through consultations with the OEMs and the previous verifications, the relationship between events visible in the driving history data and driver operations and vehicle behavior in response to road changes was identified as shown in Table 3.

Table 3: Effectiveness Evaluation Matrix



Change information		Scale of change	Acquisition time (mandatory)	Accelerator pedal stroke	Brake pedal stroke	Indicator	Steering wheel angle	Lamp illumination status	Shift lever position	Hazard lamps	Wipers	Longitude and latitude (mandatory)	Direction of travel	Medium speeds	Acceleration	Angular velocity (direction of rotation)	Geomagnetism (middle direction)	Engine speed (driving/stopped)
Items not accompanying changes in road structure	Increases or decreases in the number of lanes	Large	○	○ Congestion alleviated	○ Congestion alleviated	○	△					○	□	○ Congestion alleviated	△	△	△	△
	Widening of lanes	Large	○	○ Congestion alleviated	○ Congestion alleviated	○	△					○	□	○ Congestion alleviated	△	△	△	△
	Changes to branch merging positions	Medium	○	△	△	○	△					○	□	△	△	△	△	△
	Newly designed, eliminated, or altered physical structures	Small	○	△	△	△	△					△	□	△	△	△	△	
	Newly designed, eliminated, or altered zebra markings	Medium	○	△	△	○	△					○	□	△	△	△	△	△
	Changes to color or demarcation line type (solid/broken)	Small	○	△	△	△	△					△	□			△	△	
	Newly designed, eliminated, or altered no parking zones	Small	○						△ Stopped state	△ During emergency		△	□	△ Stopped state				△ Stopped state
	Repainted demarcation lines	Small	○	△	△	△	△					△	□			△	△	
	Newly designed, eliminated, or altered signs	Small	○	△	△							△	□					
	Newly designed, eliminated, or altered markings	Small	○	△	△							△	□					
	Newly designed, eliminated, or altered traffic signals	Small	○	△	△							△	□					△

Legend
○: Items assumed to express a significant change.
△: Items that may detect a change (changes that can be confirmed quantitatively, but are frequently regarded as minor).
□: Items that may be used in processing.
Green rows: detection targets using driving history data
Yellow roads: detection targets using camera image data

2.3.2. Discussion Related to Procedure for Practical Adoption

The following scheme for adjusting driving history data was proposed. Data processed using the same specifications is procured from multiple OEMs. Finally, high precision 3D maps are provided to each company, starting with the automakers. If the quality of data procured from each OEM is uniform, data procurement can be carried out while supplementing the minimum data to satisfy the data volume required for detecting changes, thereby enhancing the completeness of the detection area. For this purpose, the quality of the data procured from each company must be assessed, trends analyzed, and the extracted results for changes compared with the confirmed results for current conditions to establish a continuous process of revision.

In addition, it is highly likely that system implementation will differ for each OEM. There are two approaches for resolving this issue. First, technical specifications can be provided by Dynamic Map Platform Co., Ltd. (DMP) to be followed by the OEMs in system implementation and development. Second, each OEM can provide the available processed data and differences in implementation can be absorbed by DMP. Actions generated related to interfaces between multiple companies are issues affecting the business of each company and affect the issue of whether the whole system can be realized. As consultations continue with each OEM about the implementation of the system, it will be necessary to define the specific details of each action item and adjust the responsibilities.

The envisioned implementation procedure is as follows. The driving history data is continually accumulated by the OEMs will be used to compare pre-change analysis results with analysis results for one-month of data in the month that a change occurred to detect the differences. If one month of processed data from OEMs and one month of statistical analysis by DMP is used, it is likely to require two to three months to detect a change in a road. This period can be shortened by reducing the extraction period in areas with high volumes of traffic while monitoring the quality analysis results. This will require measures to improve efficiency, such as formularizing the processing carried out by the OEMs and DMP.

It should be noted that the costs of data procurement from the OEMs as well as the systemization and operation costs will be reflected in the sales prices of the high precision 3D maps. For this reason, the procurement side will look to reduce total costs, and the sales side will look to improve income by increasing the frequency of updates and using the data for non-OEM applications. These will be issues for future study.

2.4. Future Prospects

Since driving history data contains various environmental factors, vehicle characteristics, and so on, the use of a statistical approach to detect changes to roads has been proposed. The results of studies indicate that this approach is suited to suburban areas with good environmental conditions. Based on this result, the following future prospects can be envisioned.

2.4.1. Greater Accuracy of Location Information

It is hoped that the reduction in price of high-precision positioning modules and the popularization of high-precision positioning technologies will help to greatly enhance the accuracy of location information in urban canyons by enabling more sophisticated multi-path elimination technologies and vehicle positioning technologies. As a result, if changes to roads in urban areas can be detected and lane-based driving behavior can be identified, it may be possible to increase the opportunities to detect medium to small changes that do not accompany changes in road structures and to use this data for multiple applications.

2.4.2. Use of Driving History Data from Controllable Commercial Vehicles

Although a statistical approach requires a certain volume of comprehensive data, the use of driving history data from controllable commercial vehicles that repeatedly travel along the same routes may enable the collection of the required volume of data on specific routes.

3 Technology for Identifying Road Changes Using Dashcam Drive Recorder Images

3.1. Technology for Identifying Road Changes Using Image Data

Technology that utilizes dashcam drive recorders is currently at the research and development phase. Studies are being carried out by collecting camera image data in areas affected by frequent road changes, applying the technology developed by different companies to the collected camera image data, and examining the requirements for probe data for updating maps, such as the capability of this technology to identify the constituent features and attributes of high precision 3D maps. Fig. 4 shows the identified characteristics of the change detection technologies developed by three companies.

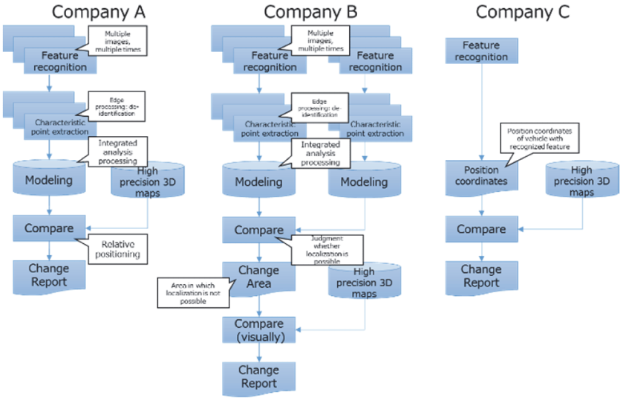


Fig. 4: Summary of Road Change Detection Technologies

The main difference between companies A and B is the capability to make direct comparisons with high precision 3D maps. Unlike the technology of company A, which can make direct comparisons between data models of current conditions with high precision 3D maps, the technology of company B makes comparisons with the high precision 3D maps based on the results of comparisons between models of the past and current conditions. Another major difference is that the technology of company A can make comparisons using features while the technology of company B makes comparisons from the standpoint of whether localization is possible.

Compared to companies A and B, the technology of company C uses a much simpler process. The technologies of companies A and B perform modeling after integrated analysis processing using multiple images. In contrast, the technology of company C judges the position information of features from single recognized images.

After pairing the summarized results of road change information from each company with the accurate data possessed by DMP, two indices (precision and recall) were calculated and used to assess whether changes on real roads could be detected accurately by the technologies of each company.

Figures 5, 6, and 7 show graphs that express the recall and precision of these technologies for demarcation lines, road signs, and road markings.

An examination of the overall results identified cases in which the characteristics of each company's technology adversely affected precision and recall.

- The technology of company A (technology that recognizes features from camera image data, extracts characteristic point groups, carries out integrated analysis processing (modeling),

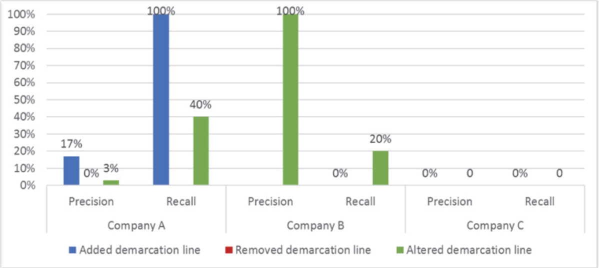


Fig. 5: Recall and Precision Results for Demarcation Lines

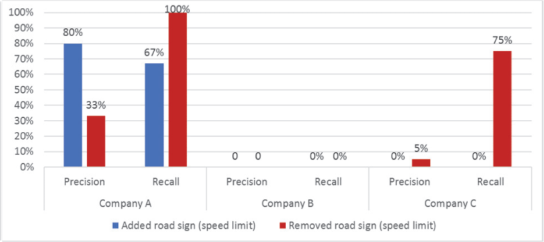


Fig. 6: Recall and Precision Results for Road Signs

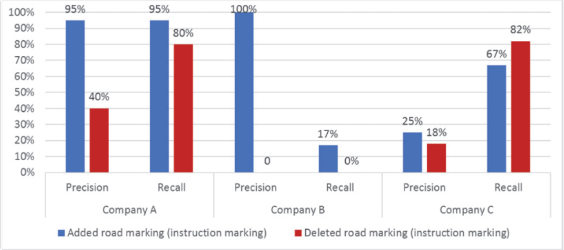


Fig. 7: Recall and Precision Results for Road Markings

and compares the results with high precision 3D maps supplied by DMP) achieved higher recall and precision than the technologies of companies B and C.

- The technology of company B had lower recall because it was incapable of detecting changes in feature units.
- The technology of company C depends strongly on the positional accuracy of the Global Navigation Satellite System (GNSS). As a result, it may generate detection errors due to the effects of the environment in which the images were obtained.
- In some cases, the target objects could not be recognized for system-based reasons (insufficient learning or detection inapplicability).
- In points containing mixtures of features, individual features cannot be detected in some cases when modeling.

Based on these study results, the requirements for road change detection technology have been defined as follows.

- This technology must be capable of recognizing features from images.
- This technology must be capable of extracting the characteristic points of features from images for modeling.
- This technology must be capable of carrying out modeling from the characteristic points of features.
- This technology must be capable of carrying out relative positioning between modeled data and high precision 3D maps.
- This technology must be capable of comparing modeled data and high precision 3D maps in feature units.

3.2. Scheme for Collecting Image Data for Road Change Detection

During the process of using the technologies from the three companies, desktop studies were carried out into the scheme for collecting actual camera image data. As a result, the following two patterns were envisioned.

Under the first scheme, camera image data obtained from dashcam drive recorders is used to extract characteristic points (information collected to identify road changes) on the edge side (vehicle), which is then transmitted and collected on the server side. In this case, it is necessary to carry out processing to reduce the data communication load and de-identify information to ensure individual anonymity on the edge side before the server accumulates the characteristic points.

Under the second scheme, camera image data from increasingly widespread dashcam drive recorders and smart phones is accumulated on the server side without processing. In this case, camera image data is collected in physical storage, but the characteristic point extraction process must be carried out on the server to ensure individual anonymity before the data is accumulated.

The road change extraction technologies using camera image data from passenger vehicles studied in this project all adopt the scheme in which characteristic point processing is carried out on the edge side before these characteristic points are collected. This study also confirmed the real-world effectiveness of systems capable of appropriately extracting changes in high precision 3D maps. However, since there are currently no systems capable of carrying out this type of processing, it will be necessary to construct an operational scheme for practical adoption.

In addition, although a wide range of collection schemes can be envisioned, it will be absolutely necessary to create a system considering standardization trends to enable the comprehensive and efficient extraction of road changes from as many business operators and vehicles as possible. To accomplish this, setting the requirements for the collection of characteristic points and camera image data, as well as defining and commonizing device specifications have been identified as major issues.

4 Technology for Identifying Road Changes Envisioning Rapid Deployment

Based on the results of studies carried out in Sections 2 and 3, the following points were confirmed with respect to the implementation of road change extraction technology using camera image and probe vehicle driving history data.

- Camera image data
  - ▸ When this technology is implemented in the future, the scheme outlined in blue in Fig. 8 would be the preferable approach. However, a system capable of appropriately extracting and processing characteristic points on the vehicle side does not exist using current technology.
  - ▸ According to the scheme outlined in red, data obtained from existing dashcam drive recorders and the like is processed on the server side. However, in this case, measures must be applied to ensure the anonymity of the data and the like.
  - ▸ When technology using data obtained from existing dashcam drive recorders was applied, detection errors were caused by the effects of GNSS positional accuracy. The results may be affected by the specifications of the devices installed in the vehicle.
  - ▸ It will be absolutely necessary to create a system considering

standardization trends and the like to enable the comprehensive and efficient extraction of road changes from as many business operators and vehicles as possible.

- Probe vehicle driving history data
  - ► Although it may be possible to use this data to identify changes such as increases and decreases in the number of lanes and the like, there are various issues related to the granularity of data that must be resolved before this data can be used in a system envisioning rapid deployment.

Based on the issues and the like related to the results described above and data acquisition, the scheme outlined in red in Fig. 8 combined with the use of camera image data collected from certain commercial fleets in consideration of anonymity may be regarded as the most appropriate approach for rapid deployment. However, with respect to the underlined issues, the results of the studies described in Section 3 show that the requirements for device specifications to prevent reductions in quality have not yet been sufficiently defined.

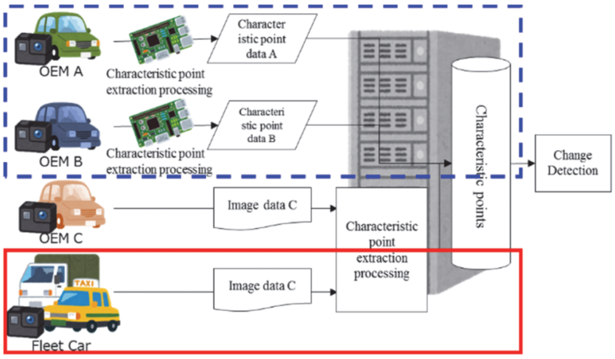


Fig. 8: Probe Image Data Collection Scheme

Therefore, based on the probe data requirements for updating maps described in Sections 2 and 3, this section investigates the requirements for devices capable of extracting road changes and that can be put into practical use rapidly. A field operational test (FOT) was carried out to examine the change extraction performance of the investigated devices and, based on the results of these tests, the device requirements are summarized in Section 4.1. In addition, with the aim of adopting the scheme outlined in blue in Fig. 8, the latest standardization trends and the like were investigated, and the issues related to characteristic points (i.e., the information collected to identify road changes) were analyzed. These are summarized in Section 4.2 alongside the procedure for realizing the commonization of characteristic points.

4.1. Studies of Requirements for Device Specifications

Based on the technical requirements for the extraction of changes in high precision 3D maps described in Section 3, desktop studies were carried out into device (cameras, inertial measurement units (IMUs), GNSS, and the like) requirements. The devices for the FOT were selected based on these results (Section 4.1.1). The FOT was then carried out using the selected devices, and the requirements for devices and the like capable of collecting camera image data using commercial fleets were defined (Section 4.1.2).

4.1.1. Desktop Studies

Table 4: Requirements for Road Change Detection Technology and Required Devices

Requirements for road change extraction technology			Devices required to satisfy requirements	Functions required to satisfy requirements
The technology must be capable of recognizing features from camera image data.	Features must exist in the images.		Camera	Angle of view
	The technology must have the resolution to recognize features.		Camera	Resolution
The technology must be capable of modeling correctly from camera image data.	The technology must be capable of estimating driving trajectories.	The technology must be capable of obtaining an absolute position.	GNSS	Coordinates
		The technology must be capable of obtaining relative positions (it must be capable of obtaining displacement amounts).	GNSS	Speed
			IMU	Angular velocity and acceleration
			Odometer	Moving distance
			Camera	Angle of view, resolution, frame rate

From the study results described in Section 3, when technology using data obtained from existing dashcam drive recorders was applied, detection errors were caused by the effects of GNSS positional accuracy. It was also realized that the results may be affected by the specifications of the devices installed in the vehicle. To avoid these issues and enable rapid deployment of these devices, the required device specifications must be defined while considering the characteristics of road change extraction technology. Therefore, first, of the technical requirements for the extraction of changes in high precision 3D maps described in Section 3, the required devices, functions, and roles to address the high likelihood that the adopted system will be affected by the devices used were studied in theory.

Next assuming use in commercial fleets, the required devices that satisfy the conditions described in Table 4 (GNSS, IMU, odometer, and camera) and the devices capable of obtaining information to supplement positional accuracy were investigated. As a result of this investigation, the existence of such devices could not be verified from publically available materials such as standard specifications. Therefore, the FOT in this research and development project were carried out using the TransLog (DN-CDR) system developed by Denso Corporation, which contains the necessary devices and functions. The required device specifications were defined based on these tests.

4.1.2. Implementation of FOT

When selecting the test routes, the engineering work that was due to be carried out during the test period (as scheduled in publically available information) was examined. However, since the outbreak of the novel coronavirus COVID-19 and other factors resulted in a reduction in the amount of work being carried out in the Tokyo metropolitan area, the routes were selected in consultation with relevant parties such as road managers and the like. It should be noted that some of the applicable roads were selected for the FOT under the assumption that temporary engineering work would result in changes to maps. With the cooperation of the road managers, camera image data was obtained using the devices selected in Section 4.1.1 for the determined routes. This camera image data was then incorporated into the technology for extracting road changes to identify changes to the roads.

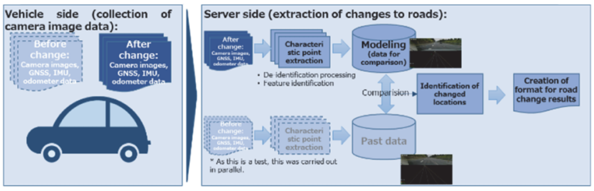


Fig. 9: Outline of Process from Camera Image Acquisition to Identification of Changed Locations

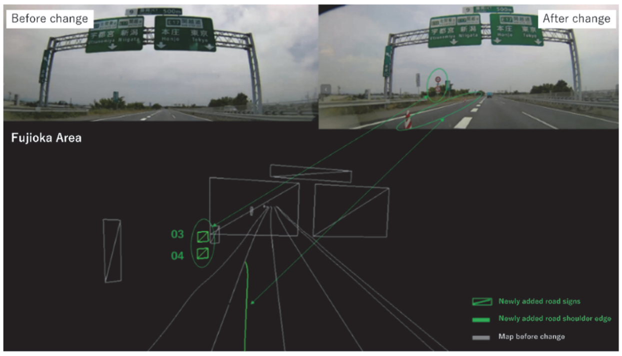


Fig. 10: Example of Road Change Extraction around the Fujioka Junction of the Joshin-etsu Expressway

To assess whether the implemented road change extraction technology was capable of correctly identifying changes to roads, the extraction results were compared with the true values (i.e., the results assessed by the party in charge of map updates (for this research and development project, DMP) using the camera image data from before and after the change).

It was confirmed that the road change extraction technology could be used to identify changes to roads with a high level of recall. However, for some results defined as "not changed" by the party in charge of map updates, the road change extraction technology reported that changes had occurred. This discrepancy might be due to an oversight by the party in charge of map updates, or because the changes to the features are not discernible to the naked eye. Therefore, more accurate extraction of changes was accomplished by adopting the road change extraction technology.

Based on the study results described above, if devices with equivalent functions and specifications to the system selected in Section 4.1.1 (TransLog) were used, it should be possible to identify changes to roads without issues. However, the commercial availability of such devices remains an issue. Therefore, to confirm the commercial availability of products capable of satisfying the recommended specifications described in Table 5, which were identified through the FOT and studies, the specifications of dashcam drive recorders and the like on the list of products (as of December 2020) compatible with the Quasi-Zenith Satellite Michibiki as disclosed by the Cabinet Office were investigated.

Twenty products were investigated, one of which satisfied the requirements established by the system used in the test (TransLog) (including TransLog, two products satisfied these requirements). In addition, seventeen out of twenty satisfied the camera specification requirements. However, it should be noted that some of the specification information for devices (GNSS, IMU, and the like) were not publically available for fifteen of the twenty products. As a result, since it was not possible to determine whether these devices satisfied the recommended specifications, it will be necessary to confirm the performance of the actual devices.

Table 5: TransLog Specifications and Recommended Specifications
Source: Communication-Capable DN-CDR Dashcam Drive Recorder (in Japanese), Leadex, Co., Ltd. https://www.leadex.co.jp/pdf/DN-CDR.pdf (Accessed October 1, 2020)

Sensor	Functions	Recommended specifications	TransLog
GNSS	Coordinates	Open sky: max. 5 m Urban areas: max. 20 m	Standalone position measurement
	Speed	2Hz	2Hz
IMU	Angular velocity and acceleration	100Hz*	100Hz
Odometer	Moving distance	50Hz*	1Hz
Camera	Angle of view	Horizontal: 118 to 135 degrees	Horizontal: 118 degrees
	Resolution	HD(1280×720)	HD(1280×720)
	Frame rate	22Hz	22Hz

As a result, even if camera image data is collected relying on the product specifications, it may not be possible to, for example, confirm the situation of far lanes, and vacancies may occur in the data during modeling. To avoid these issues, it will be necessary to collect a certain volume of camera image data and obtain data from commercial fleets via a process that prevents confirmation errors in far lanes and so on. Therefore, in the future, it will be necessary to define the range of operations that can be carried out by businesses by confirming and consulting on possible areas of cooperation with business operators and the like that use expressways.

4.2. Studies of Requirements for Characteristic Points

Section 4.1 described that it was possible to detect changes to roads by mounting dashcam drive recorders that satisfy the defined requirements in commercial fleets that drive regularly on the target roads and using these devices to collect information. However, in this process, it is necessary to construct a procedure for collecting image data from the vehicles equipped with these dashcam drive recorders, which will limit the range of applicable roads. To expand this system onto general roads and the like in the future, it will also be necessary to study the collection of data from cameras and the like installed in ordinary vehicles. Ordinary vehicles are frequently equipped with cameras, laser scanners, and other sensors to realize driving safety support systems (DSSS), automated driving support systems, and so on. Therefore, ordinary vehicles are capable of detecting objects (features) using such systems. Consequently, rather than collecting image data, the collection of information about detectable objects (characteristic points) is also a possible approach. Therefore, this section describes studies into the requirements for characteristic points to enable the detection of road changes based on Section 4.1, as well as studies into the direction of commonization and standardization for these requirements.

4.2.1. Investigation into Relevant Standards

Figure 11 shows the standards related to systems for the distribution of vehicle data. Standards and bodies related to uplinks from vehicles to centers (i.e., the cloud) include SENSORIS, ISO 20078, and Japan Automotive Software Platform and Architecture (JASPAR). However, ISO 20078 can be excluded as it deals with information for fault diagnostics.

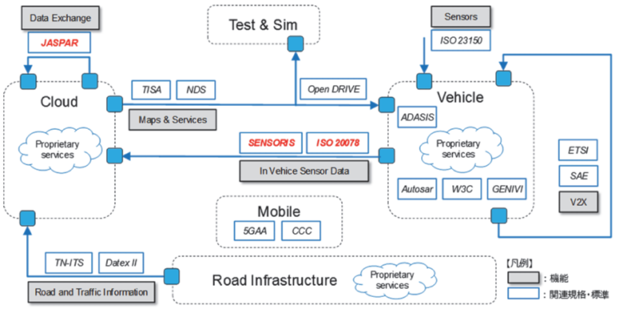


Fig. 11: Systems and Related Standards for Vehicle Data Distribution and the Like
Source: partial additions made to Prokop Jehlicka: OADF – An Introduction, SIP-adus Workshop 2018, p. 7.

4.2.2. Requirements for Characteristic Points and Study into Direction of Standardization

With reference to the FOT results and the like described in Section 4.1, desktop studies were carried out into the details of the required information when extracting characteristic points on the vehicle side, as well as the frequency (unit of acquisition) and accuracy of information collection. The results are shown in Table 6.

The gap between the existing standards and the data items required for characteristic point extraction was analyzed. The analysis results for SENSORIS and JASPAR found that SENSORIS must be adjusted to Japanese systems of road markings, road signs, and the like. For this reason, the gap to JASPAR was analyzed and identified.

The scope of JASPAR specifications differs with the specifications for sharing feature change information since the studied characteristic point requirements involve the sharing of objects (characteristic points) detected by individual vehicles, and items such as position, speed, and time data are not included in the JASPAR specifications. However, despite partial feature insufficiencies, no major differences were found in the feature data. It should be noted that, although the scope of the requirements differs from the JASPAR specifications, since road change detection processing does not have to be carried out by the OEMs, there are few technical development elements for OEMs to perform, which suggests that the distribution of information might advance more smoothly. In addition, if this information becomes more widely available, detection accuracy should improve as the range of coverage and number of samples increases. For this reason, it is necessary to also study systems of collection that lower the technological development hurdles of OEMs. Therefore, first, based on the requirements for characteristic points studied in this research and development project, it might be possible to prompt JASPAR to add specifications for exchanging characteristic point information detected by vehicles with the cloud centers at the stage before change information is extracted.

5 Conclusion

This research and development project studied technology capable of identifying changes in roads using dashcam drive recorder images and probe vehicle data. These results were then applied to studies envisioning the rapid deployment of technology for identifying road changes. In the studies into technology capable of identifying changes in roads using dashcam drive recorder images, it was confirmed that the presence of road changes can be confirmed by this technology. These studies also summarized the requirements for such road change detection technologies.

In the studies into technology capable of identifying changes in roads using probe vehicle data, the potential of using provided

Table 6: Results for Requirements Envisioning Operations on Ordinary Roads/Globally Based on Results in Section 4.1

Name	Item/details to be obtained		Acquisition unit
Feature data	Demarcation lines	- Position of external lane lines, road center lines, lane boundaries, etc. (center position)	High frequency (ref.: 0.1 sec, etc.)
		- Attributes (line type, line color, line width, multiple line information, etc.)	
	Physical structures	- Position of boundary lines and the like demarcated by continuously placed physical structures such as curbstones, walls, guard rails, poles, and the like	
	Road signs	- Center position of road sign surfaces	
		- Attributes (normal vector, size (width and height of bounding rectangle of road sign surface), type*, auxiliary sign information, etc.) * Signs that can be recognized by road sign assist (RSA) functions can be organized by identifiable category IDs. Other signs must be organized by identifiable category IDs such as shapes and the like.	
	Traffic signals	- Center position of traffic signal surfaces	
		- Attributes (normal vector, size (width and height of bounding rectangle of the traffic signal front surface), type)	
	Road markings	- Position of road markings such as stop lines, crossings, arrows on the road surface, zebra markings, etc. (center, and the bottom left and bottom right ends of the bounding rectangle)	
		- Attributes (depth from center position of bottom end of the bounding rectangle, type (stop lines, crossings, arrows on the road surface, arrow directions, etc.)	
	Reliability information	- Information that adversely affects accuracy during acquisition (acquisition on gradients, in tunnels, etc.)	
Position Speed Time Data	Position of the driver's vehicle	- GNSS position information	High frequency (ref.: 0.1 sec, etc.)
		- Position information calculated from the vehicle trajectory estimated using camera image data (including vehicle posture information such as pitch, roll, and yaw)	
	Speed	- Vehicle speed	
	Time	- Time* acquired by each device (GNSS, camera) * Since time synchronization is not carried out, the time difference is identified via a positioning process using the position of the driver's vehicle (2 types).	
Other	Camera mounting position	- Mounting position of dashcam drive recorder (origin point to calculate relative coordinates of feature data)	Low frequency (ref.: 1 hour, etc.)

real-world probe vehicle data to identify changes to roads was confirmed. These studies also summarized the operational issues for practically adopting this technology.

The studies envisioning the rapid deployment of technology for identifying road changes defined device specifications and other requirements, and confirmed that these changes can be identified by commercially available dashcam drive recorders rather than dedicated devices. These studies also identified the requirements for starting operation on ordinary roads and globally from the standpoint of future deployment of this technology, and summarized the procedure for realizing commonization.

2 Building and Making Use of Traffic Environment Data

(2) Development of Technology Concerning the Transmission of Traffic Environment Information

Study for V2X Communication for Cooperative Driving Automation

Norifumi Ogawa (Mazda Motor Corporation)

The concept of cooperative driving automation has been studied by corporations and research institutes for some time. Field operational tests (FOTs) and standardization activities for the communication protocols that will realize this functionality are also underway. In Japan, ITS wireless communication has been commercialized and is already used to support driving safety. Expanding it to automated driving can be envisioned. However, while the feasibility of its application and the communication protocols to adopt in the future, has been pursued by individual organizations, there have been no discussions for Japan as a whole. Since SIP has established a structure uniting industry, government and academia under one roof to work toward the realization of automated driving, it was decided to hold discussions under that framework. The Task Force (TF) on V2X communication for Cooperative Driving Automation was established in 2019 and initiated a 3-year plan to study future communication protocols. The TF defined use cases for assessing communication, and used them as a basis to clearly define communication requirements and study protocols that satisfy those requirements. The goal is to propose communication protocols for cooperative driving automation and formulate a roadmap that clearly indicates when they will be required.

1 Background

High expectations are placed on autonomous driving, which builds on the concept of safe and smooth advanced automated driving combined with infrastructure cooperative systems. However, the telecommunication required for that realization faces several challenges. Although ITS communication for driving safety support systems is already commercialized in Japan, questions such as "will the current frequencies and bandwidth be enough to accommodate cooperative driving automation, or will new frequencies be necessary?", or "If new frequencies have to be added, how much bandwidth will they need?", will have to be answered. Moreover, since the U.S. and Europe allocate the 5.9 GHz band of the radio spectrum to ITS communication, but Japan uses the 760 MHz and 5.8 GHz bands, prompting concerns that it will be left behind in international standards, another example of the many discussions with no resolution in sight. The SIP System Implementation Working Group (WG) tackled these issues by establishing the Task Force (TF) on V2X communication for Cooperative Driving Automation in 2019, which initiated a 3-year plan to study future communication protocols.

2 TF Objective and Achievement Plan

The objective of the TF is to "define a vision of cooperative driving automation, draw up a roadmap for its realization, and establish an optimal All-Japan communication protocol policy that takes international standards into account". The goals of its activities are to propose optimal communication protocols for cooperative driving automation and to draft a roadmap of changes in such protocols.

Envisioning the functionality and performance exhibited by cooperative driving automation is crucial to studying future communication protocols. This means it is necessary to determine specific use cases for cooperative driving automation. Compiling the communication requirements based on those uses cases and considering communication protocols that satisfy those requirements was set at the next step.

Accordingly, phase 1 of the TF activities involved clearly defining cooperative driving automation and its applicable scope, and using that as a basis to select use cases. In phase 2, the technical and communication requirements for the use cases defined in phase 1 were researched and assessed, and issues in applying them to current ITS communication were made clear. Phase 3 centered on assessing communication protocols that solve those issues and evaluating their validity. This three-phase process was established to both propose optimal communication protocols for cooperative driving automation and to formulate a future-oriented roadmap for such protocols.

The Japan Automobile Manufacturers Association (JAMA), various experts, and government agencies involved joined the TF to help draw up the use cases in phase 1. The assessment of communication protocols and other factors in phases 2 and 3 also involved the additional participation of the ITS Info-communications Forum, the Japan Electronics and Information Technology Industries Association, the Universal Traffic Management Society of Japan, the National Institute for Land and Infrastructure Management, and the Society of Automotive Engineers of Japan. The involvement of the automotive industry, communication industry, ITS-related groups, academic organizations and relevant government agencies made it possible to establish an all-Japan framework to assess future communication protocols.

3 Formulating the Use Cases

3.1. Definition of Cooperative Driving Automation

The potential scope of use cases for cooperative driving automation making use of communication can range widely from driving per se to making use of traffic environment data. This study narrowed its focus to the cases that are essential to making cooperative driving automation feasible. We made that policy clear, and prepared a definition of cooperative driving automation systems to serve as a baseline in making decisions. The next paragraph presents that definition.

"Cooperative driving automation systems are systems that enable safer and smoother automated driving control, building upon autonomous driving systems and relying on telecommunication to acquire information outside the range of on-board sensor detection, provide information possessed by the vehicle, and interact with other vehicles or the infrastructure."

The transmission of information via telecommunication is subject to uncontrollable elements such as electromagnetic interference, making it difficult to ensure 100% quality. Therefore, we chose to consider cooperative driving automation systems on the basis of autonomous driving. As a result, we determined that the final control decision would be based on on-board sensor information, with information retrieved via telecommunication used to offer safer and smoother automated driving.

Guided by the principle of telecommunication serving to acquire information that cannot be detected by on-board sensors, we incorporated the concepts of information outside the range of those sensors, as well as exchanging information or otherwise interacting with the outside world into our definition.

This definition applies to privately owned vehicles, as well as distribution and mobility service vehicles driving on public roads, namely highways and general roads.

3.2. Selection of Use Cases

3.2.1. Researching the Use Cases

As part of the Study of utilization of new communication technologies including V2X technology to automated driving system of "Cross-ministerial Strategic Innovation Promotion Program(SIP) 2nd Stage Automated Driving System (Expansion of system and service)"(1) conducted in 2018, use cases found in cooperative driving automation and driving safety support projects in Europe, the U.S., and Asia (including Japan) were investigated and collected. In Japan, the Japan Automobile Manufacturers Association (JAMA) has also been studying use cases for highways and general roads, and that information was also use as reference for our own use cases.

3.2.2. Approach to SIP Use Case Selection

The TF aims to propose future communication protocols and resources. The use cases collected in the preceding section include cases with a low possibility commercialization. This makes trying to secure the communication resources to achieve every single case potentially wasteful. We therefore decided to select the use cases presenting future commercialization potential. The selection standards are described in subsections 1 and 2 below.

1) Prerequisites for the consideration of cooperative driving automation systems
   (a) All traffic participants respect the rules of the road.
      Reason: Implementing functions to avoid accidents caused by a deliberate violation of the rules of road by another nearby traffic participant would impose an excessive cost and performance burden on cooperative driving automation systems.
   (b) Use cases achievable using autonomous driving systems are excluded.
      Reason: Cooperative driving automation systems built upon autonomous driving systems makes functions achievable only by the latter redundant and decreases the commercialization potential of the cooperative system.
2) Compatibility with the definition of cooperative driving automation systems

The three points below were established as selection criteria for SIP use cases based on the definition of cooperative driving automation systems prepared by the TF.

(a) Acquiring information outside the range of on-board sensors is required.
(b) Providing information possessed by the vehicle is required.
(c) Interaction with other vehicles or the infrastructure is required.

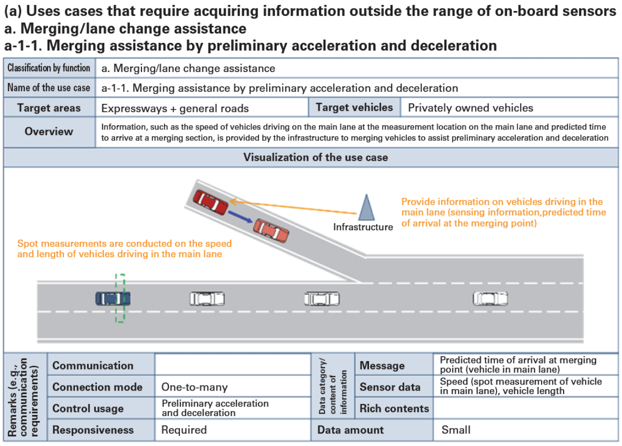
3.2.3. Results of SIP Use Case Selection

Applying our selection criteria to the results of the investigation from Section 3.2.1 left us with 25 uses cases. We classified them according to eight functions (a. merging/lane changing assistance, b. traffic signal information, c. lookahead information: collision avoidance, d. lookahead information: trajectory change, e. lookahead information: emergency vehicle notification, f. information collection/distribution by infrastructure, g. platooning/adaptive cruise control, and h. teleoperation) to provide an comprehensive overall view.

We arranged the cases according to the points of the cooperative driving automation systems definition, as shown below.

(a) Uses cases that require acquiring information outside the range of on-board sensors (14)
a. Merging/lane change assistance (2)
b. Traffic signal information (2)
c. Lookahead: collision avoidance (4)
d. Lookahead: trajectory change (5)
e. Lookahead: emergency vehicle notification (1)
(b) Use cases requiring providing information possessed by the vehicle (4)
f. Information collection/distribution by infrastructure (4)
(c) Use cases requiring interaction with other vehicles or the infrastructure (7)
a. Merging and lane changing support (4)
g. Platooning/adaptive cruise control (2)
h. Teleoperation (1)

Details of the use cases are provided in the SIP Use Cases for Cooperative Driving Automation(2) available from the SIP website. The example in Fig. 1 is case a-1-1. Merging assistance by preliminary acceleration and deceleration.



(a) Uses cases that require acquiring information outside the range of on-board sensors
a. Merging/lane change assistance
a-1-1. Merging assistance by preliminary acceleration and deceleration

Classification by function	a. Merging/lane change assistance		
Name of the use case	a-1-1. Merging assistance by preliminary acceleration and deceleration		
Target areas	Expressways + general roads	Target vehicles	Privately owned vehicles
Overview	Information, such as the speed of vehicles driving on the main lane at the measurement location on the main lane and predicted time to arrive at a merging section, is provided by the infrastructure to merging vehicles to assist preliminary acceleration and deceleration		
Visualization of the use case			

Remarks (e.g., communication requirements)	Communication		Data category/ content of information	Message	Predicted time of arrival at merging point (vehicle in main lane)
	Connection mode	One-to-many		Sensor data	Speed (spot measurement of vehicle in main lane), vehicle length
	Control usage	Preliminary acceleration and deceleration		Rich contents	
	Responsiveness	Required	Data amount		Small

Fig. 1: a-1-1. Merging assistance by preliminary acceleration and deceleration

Each of the individual 25 cases was presented in the easy-to-understand format shown in Fig. 1 that includes a simplified diagram in addition to presenting an overview and indicating the target areas and vehicles. At the same time, the remarks section was used to provide information on communication, connection mode, control usage, responsiveness and an overview of the transmitted data for use as reference in the study of communication requirements for the second phase.

There were 14 other cases that either failed to meet the prerequisites or were merged into other cases. Although they were not retained as part of the SIP use cases, they were kept on record to serve as reference for potential future revisions of the use cases.

4 Communication Requirements

The study of communication in the second phase was conducted with the cooperation of the ITS Info-communications Forum (ITS Forum), which has extensive knowledge and experience in ITS wireless communication standardization and other initiatives.

Under the ITS Forum, the use cases were reorganized from the standpoint of communication and classified into five categories. These five categories were studied concurrently by five working groups, making it possible to compile the communication requirements in a short time.

WG 1: Merging/lane change assistance (a-1-1 to 4, a-2, a-3)*
WG 2: Lookahead: collision avoidance (c-1 to 3)
WG 3: Traffic signal information & platooning/adaptive cruise control (b-1-1 and 2, g-1 and 2)
WG 4: Lookahead: trajectory change (d-1 to 5, e-1)
WG 5: Information collection/distribution by infrastructure (f-1 to 4, h-1)
*Use case number from Reference (2)

4.1. Prerequisites

Since the information presented in SIP Use Cases for Cooperative Driving Automation(2) alone is not sufficient to study communication requirements, it was necessary to assess more detailed scenarios. In addition, the availability of high precision 3D map information, communication latency, and communication quality were clearly defined as prerequisites before starting the study.

4.2. Scenario Assessment

To obtain more realistic and feasible scenarios, the assessment involved collecting necessary information by contacting research organizations carrying out technical assessments or FOTs similar to the use cases. This information was used to determine the automated driving level, time precision, maximum number of lanes on target roads, estimated vehicle distance, speed criteria, maximum acceleration and deceleration criteria, and other basic road and vehicle conditions for the assessed scenarios.

The scenario assessments for the individual use cases involved envisioning the communication area and number of target vehicles required by the use case, and then determining the actual vehicle behavior and necessary information items (messages). The exchange of messages between the sender and the receiver was also consolidated into a sending and receiving sequence. An example sending and receiving sequence is shown in Fig. 2.

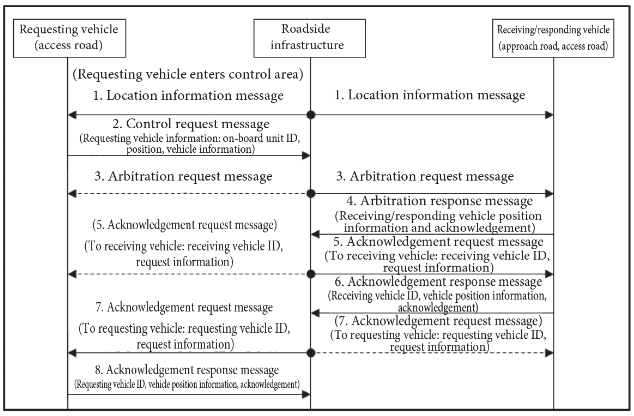


Fig. 2: Message Sending and Receiving Sequence (Example)

4.3. Messages

The amount of data constitutes an important element in the communication requirements. We defined the messages sent and received and amount of data for the above communication sequence. Examples of the contents of communication and data amount are presented below. We used this approach to estimate the data amount for each use case.

Information element		Data size*1		
		Use case a-1-1.	Use case a-1-2.	Use case a-1-3.
Shared information	Message ID	16bit	16bit	16bit
	Increment ID or information update time	32bit	32bit	32bit
	Roadside control information	8bit	8bit	8bit
	Roadside unit ID	32bit	32bit	32bit
	Merging point information	16bit	16bit	16bit
	Road number	32bit	32bit	32bit
	Number of running vehicles	8bit	8bit	8bit
Position information (varies based on the number of running vehicles)	Vehicle ID	16bit	16bit	16bit
	Vehicle position (latitude, longitude, altitude)	—	88bit	88bit
	Driving lane	8bit	8bit	8bit
	Driving speed	16bit	16bit	16bit
	Vehicle length	14 bits (+ 2 empty bits)	14 bits (+ 2 empty bits)	14 bits (+ 2 empty bits)
	Predicted time of arrival at merging point	32bit	32bit	32bit
	Sensor information acquisition time*2	32bit	32bit	32bit
	Information reliability*2	8bit	8bit	8bit

Fig. 3: Messages and Data Amount (Examples)

4.4. Communication Requirements

The communication requirements consisting of the scenario, messages and data amount, request latency, request communication quality and other requirements were summarized as shown in Fig. 4 for each use case. These summaries served as the basis for evaluating communication protocols.

5 Looking Ahead

After compiling the communication requirements for each use case, issues were identified by evaluating how they applied to existing commercialized ITS wireless (short range) and mobile (wide area) communication. Furthermore, a roadmap proposing communication protocols to solve those issues and clearly defining the necessary timeline was formulated in Phase 3. This process makes it possible to undertake future-oriented preparations to secure the necessary radio spectrum resources for cooperative driving automation.

【 Reference 】

(1)Study of utilization of new communication technologies including V2X technology to automated driving system of "Cross-ministerial Strategic Innovation Promotion Program(SIP) 2nd Stage Automated Driving System (Expansion of system and service)" (2019)
https://en.sip-adus.go.jp/rd/rddata/rd02/204s.pdf
(2)SIP Use Cases for Cooperative Driving Automation, First edition (2020)
https://en.sip-adus.go.jp/rd/rddata/usecase.pdf

Use case		a. Merging/lane change assistance						
		Merging assistance by preliminary acceleration and deceleration	Merging assistance by targeting the gap on the main lane	Cooperative merging assistance from vehicles in the main lane through roadside control				
No.		a-1-1	a-1-2	a-1-3				
Communication purpose		—	—	Provide position information	Control request	Arbitration request Acknowledgement request	Arbitration response Acknowledgement response	
Communication mode		V2I (I→V)	V2I (I→V)	V2I (I→V)	V2I (I→V)	V2I (I→V)	V2I (I→V)	
Target area (smallest range)		From 6 seconds before the merging point up to the center of that point	From 6 seconds before the merging point up to that point	From 6 seconds before the merging point up to that point	Within the scope of the control request	Within the scope of the control request	Within the scope of the control request	
Communication quality		PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	
Required communication distance		33.9 to 59.8 m (National Institute for Land and Infrastructure Management specification: 95 m)	66.7 to 116.7 m	Access road: 66.7 to 116.7 m Main lane: 111.1 to 266.7 m	(depending on the request range)	(depending on the request range)	(depending on the request range)	
Communication requirements	Data size(*1)	764 bytes (514 + 250) Envisioned number of vehicles: 31	1942 bytes (1692 + 250) Envisioned number of vehicles: 62	3616 bytes*2 (3366 + 250) Envisioned number of vehicles: 124	287 bytes*3 (37 + 250)	271 bytes*3 (21 + 250)	287 bytes (37 + 250)	
	Communication frequency	100 ms	100 ms	100 ms	Undetermined 100 ms (provisional)	Undetermined 100 ms (provisional)	Undetermined 100 ms (provisional)	
	Number of senders	1	1	1	1	1 (× number of controlled vehicles)	100*4 (Number of controlled vehicles, during congestion)	
Communication latency		Not expected	Not expected	Not expected	100 ms envisioned as the allowable latency in wireless segments	100 ms envisioned as the allowable latency in wireless segments	100 ms envisioned as the allowable latency in wireless segments	
Communication partner		Unspecified vehicle (broadcast transmission)	Unspecified vehicle (broadcast transmission)	Unspecified vehicle (broadcast transmission)	Unspecified vehicle (broadcast transmission)	Specified vehicle	Roadside infrastructure	
Driving speed		Access road: 20 to 70 km/h	Access road: 20 to 70 km/h	Access road: 20 to 70 km/h Main lane: 20 to 120 km/h	Access road: 20 to 70 km/h Main lane: 20 to 120 km/h	Access road: 20 to 70 km/h Main lane: 20 to 120 km/h	Access road: 20 to 70 km/h Main lane: 20 to 120 km/h	

Fig. 4: Communication Requirements (Examples)

2 Building and Making Use of Traffic Environment Data

(2) Development of Technology Concerning the Transmission of Traffic Environment Information

Overview of Research Concerning the Collection, Integration, and Transmission of Short and Medium Range Information

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A vast array of technologies is being deployed to realize advanced automated driving. One of those is technology that enables automated vehicles to use information obtained via V2X communication to recognize objects that are beyond the scope of on-board sensors such as camera, radar, or other sensor. Given concerns over the impact on traffic flow as automated vehicles using only on-board sensors are predicted to stop or slowly move until they can determine it is safe to proceed, that technology can be expected to mitigate such impact.

The research and development presented here focused on core technologies that effectively collect vehicle, pedestrian and other object data obtained from multiple roadside infrastructure units serving as sources of dynamic information, integrate those pieces of object data to streamline the generation of dynamic information, and efficiently transmit the processed data. This project addressed proposing parameters to integrate the object data as well as the communication protocols and common interfaces to collect and transmit the dynamic information from multiple sources to automated vehicles.

1 Scope of Research and Development

1.1. Overall Picture of Research and Development

This research and development project supports the comprehensive tracking of the position and attributes of objects that require applying control in the automated vehicle but are in on-board sensor blind spot or outside the detection range. This is achieved by collecting dynamic information from multiple sources, integrating it into real time traffic conditions, and transmitting only the necessary information in a shareable format with the automated vehicle.

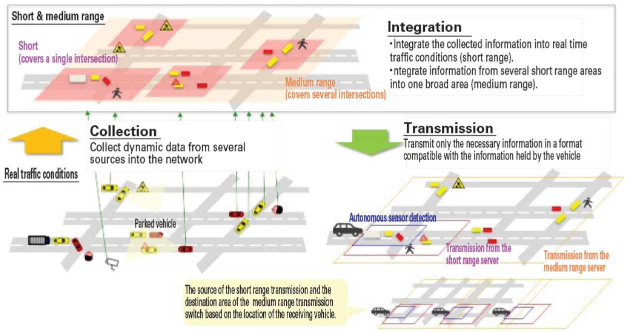


Fig. 1: Overall Picture of Research and Development

1.2. Target Research and Development Outcomes

Collecting information from multiple sources requires that those sources and the servers use common data formats and protocols. Therefore, this research and development project looked at Japanese and international standards covering IF specifications between the infrastructure and vehicles, as well as servers, to draw up a common interface. In addition, the criteria for integrating the collected information were studied and classified, and parameters for information integration were proposed.

The project also drafted a method of transmitting information to ensure compatibility with the information held by the vehicle when the network transmits the collected information.

Finally, the outcomes of this research and development project will be assessed to facilitate the preparation of guidelines on standard collection and transmission interfaces, as well as integration parameters, for the collection, integration and transmission of information from various sources in the road environment.

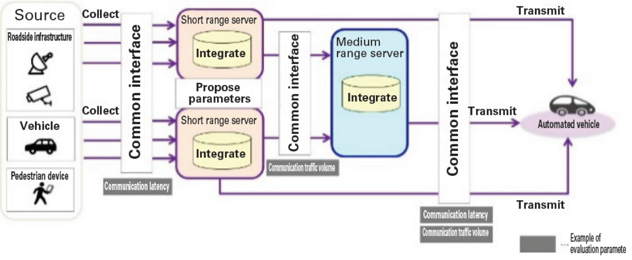


Fig. 2: Visualization of Research and Development Outcomes

2 Architecture Study and Design

2.1. System Configuration

The research targetsystem consists of a communication network that connects information sources installed in roadside infrastructure, vehicles equipped with on-board units, pedestrian devices or other sources of information, short range edge servers (short range servers) covering a short range area about the size of a typical intersection, and medium range edge servers (medium range servers) covering a medium range area about the size of a city or town with the automated vehicles which receive that information.

Automated driving in the short range area requires responding to traffic conditions around the vehicle and beyond its visibility range. Therefore, it is studied to extract information on objects (e.g., vehicles or pedestrians)in the vicinity of the intersection from multiple sources, collect it in a short range server, integrate it, and transmit that integrated information to automated vehicles.

For the medium range area, it is necessary to maintain broad ongoing recognition of conditions ahead on the route of the vehicle and respond to those conditions. Consequently, this research and development focuses on receiving the information collected and integrated by multiple short range servers into medium range servers, integrating all of that information, and transmitting the resulting integrated information.

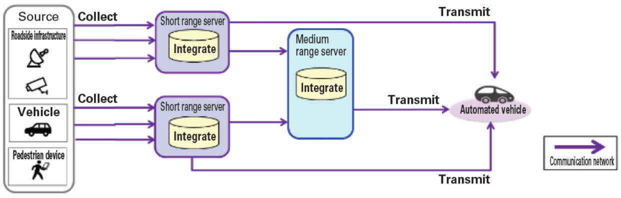


Fig. 3: Visualization of Overall System Configuration

2.2. System Configuration in Short Range Area

The roadside processing and center processing protocols were validated as both implementations of processing to extract and integrate information on objects and as communication protocols for those implementations.

2.2.1 Roadside Processing Method

This protocol extracts object information at its source and integrates it in the roadside edge server, and relies on dedicated communication (direct communication (DSRC, LTE V2X (PC5), WiGig) that does not pass through public communication stations) as a communication protocol. It is characterized by its use in short range areas to handle relatively small amounts of information such as the position vehicles or pedestrians using lightweight and inexpensive devices installed on the roadside (distributed edge servers).

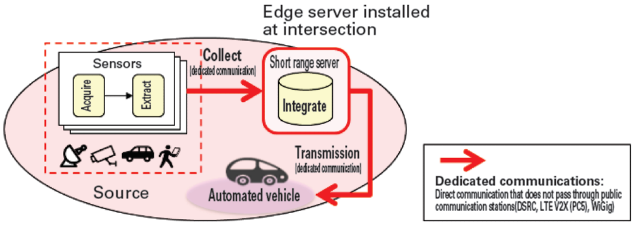


Fig. 4: Short Range System Configuration for Roadside Processing Method

2.2.2. Center Processing Protocol

This protocol sends sensor information acquired by the sources to the edge servers set in the network, and then extracts and integrates object information in the server (some sensor information is extracted in the source). It uses mobile communications (communication over a cellular network (5G + LTE)) as a communication protocol. It is characterized by its batch processing of camera images and other data with a high volume requiring advanced operations using high performance servers (edge servers) installed in the center, as well as by its economically viable support of multiple intersections (centralized edge servers).

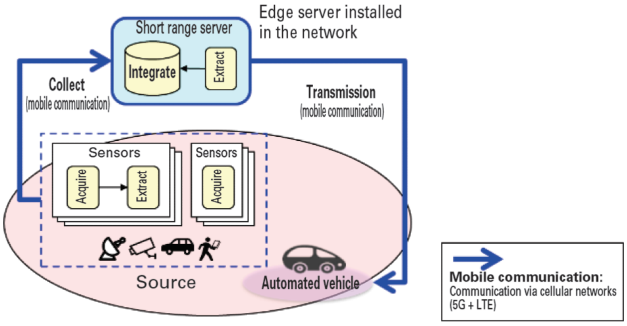


Fig. 5: Short Range System Configuration for Center Processing Protocol

2.2.3. Information Integration Method in Short Range Area

Information from multiple sensors for the same object has to be identified and integrated to prevent discrepancies with actual traffic conditions and increases in the volume of data transmitted to vehicles. It is therefore necessary to account for errors and divergences in time and position between different information sources, which led to defining measures such as the use of GNSS-based advanced time synchronization and identifying duplicate objects by correlating their relative positions and trajectories.

2.3. System Configuration in Medium Range Area

For the medium range area, it is necessary to maintain broad ongoing recognition of conditions ahead on the route of the vehicle and respond to those conditions. Therefore, mobile communication using cellular networks is used to collect information from short range servers and transmit it to automated vehicles.

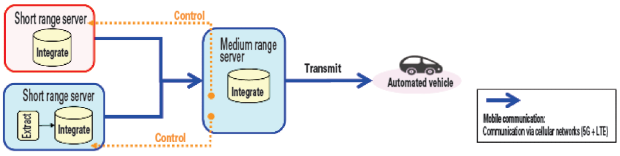


Fig. 6: Medium Range System Configuration

3 Envisioned Use Cases and KPI Achievement Targets

3.1. Envisioned Use Cases

traffic during which manual driving, driver assistance systems (levels 1 and 2), and automated driving systems (levels 3 and 4) coexist. Compatibility with the use cases assessed by the Task Force (TF) on V2X communication for Cooperative Driving Automation, as well as the coverage of both short and medium range areas specific to this project were also taken into account.

Our assessment led to defining the use cases as "relying on communication to assist automated vehicles in smoothly entering and going through intersections" for the short range, and "assistance for making lane or route changes before reaching an intersection for the medium range".

Based on the March 2017 summary analysis report on past data from the traffic accident-prone intersections map, 4x2 intersections were defined as the target size due to the following considerations.

- Over 80% of traffic accident-prone intersections consist of major road large intersections with four or more lanes.
- 4x2 intersections are common.
- They have higher levels of congestion expected to make smooth driving by automated vehicles difficult.

3.2. KPI Targets

The accuracy of extraction in the source and of integration in the short range server, communication latency when collecting and transmitting information and the traffic reduction ratio, along with the processing time for the system as a whole, were set as the evaluation parameters defining the KPIs. Table 2 presents the KPI targets and their basis. Validation for each category was carried out after breaking down the definitions and conditions for the evaluation parameters in more detail for each of the above-mentioned use cases.

Table 1: List of Use Cases (UC)

SIP cooperative driving automation UC	Detection scope		UC in this research project	Use case details
d-5	(Information collected from short range networks)		UC medium 1	Provide information on congestion due to waiting to turn right at the intersection ahead (→ assistance for changing course)
d-1	(Information collected from short range networks)		UC medium 2	Provide information on vehicles sporadically parked on the road ahead (→ assistance for changing lanes)
c-2-2	Oncoming vehicle lane Vehicle going straight	Vehicle going straight	UC short 1	Provide information on oncoming vehicles that cannot be detected by on-board sensors
c-2-2	Congestion at right turn ahead	Conditions at right turn ahead	UC short 2	Provide information on conditions at right turn ahead (e.g., empty space)
	Pedestrians	Approaching	UC short 3-1	Provide information on pedestrians or cyclists approaching the intersection
		Waiting to cross	UC short 3-2	Provided detailed attribute information on pedestrians stopped near a crossing
		Crossing	UC short 3-3	Provide information on pedestrians or cyclists crossing the road
d-5	Objects	Around the vehicle	UC short 4-1	Provide vehicle sensing information (Can also be used for UCs other than right-turn assistance)

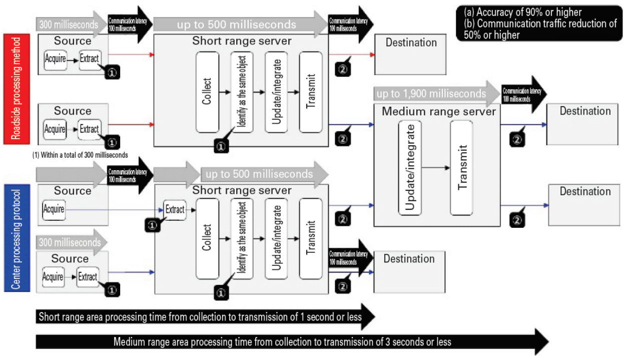


Fig. 7: Overall Visualization of KPI Targets

Table 2: List of KPIs

Research item	Achievement targets (KPIs)		
	Indicator	Expected target and basis	
Extract	Accuracy of information extracted from the source	90% or higher	Equivalent to the accuracy of typical sensors Reference criterion
Collect	Communication latency from the source of information to the short range server	Within 100 milliseconds	Equivalent to communication latency in existing V2V communication standards
Integrate	Accuracy of information integrated in the short range server	90% or higher	Integration must not cause a loss of accuracy compared to that of the extraction
	Reduction of communication traffic from the short range servers to the medium range servers	50% or more	Uniform target to secure a margin for the number of users that can be stored (e.g., number of short range areas)
Transmit	Communication latency from the short range server to the destination	Within 100 milliseconds	Equivalent to communication latency in existing V2V communication standards
	Communication traffic reduction	50% or more	Uniform target to secure a margin for the number of users that can be stored (e.g., number of destinations)
	Communication latency from the medium range server to the destination	Within 100 milliseconds	Equivalent to communication latency in existing V2V communication standards
	Communication traffic reduction	50% or more	Uniform target to secure a margin for the number of users that can be stored (e.g., number of destinations)
Overall Trends	Processing time from collection to transmission (short range)	Within 1 second	Equivalent to the dynamic data definition for dynamic maps (≤ 1 s)
	Processing time from collection to transmission (medium range)	Within 3 seconds	Set to the shortest expected medium range UC (transmission of information for the next signal ahead)

4 Field Test Details and Results

We conducted field tests for the respective short and medium range areas, as well as a comprehensive field test on actual roads (in the Odaiba area) that encompassed both the short and medium range areas.

4.1. Validation of KPIs in the Short Range Area

This section presents the results of the KPI validation and the test environments for the three protocols; the roadside processing using DSRC (roadside processing method 1), the roadside processing using WiGig (roadside processing method 2), and the center processing using 5G. The KPI validation results showed that all three short range protocols met the targets.

(1) Roadside processing method 1 (communication protocol: DSRC)

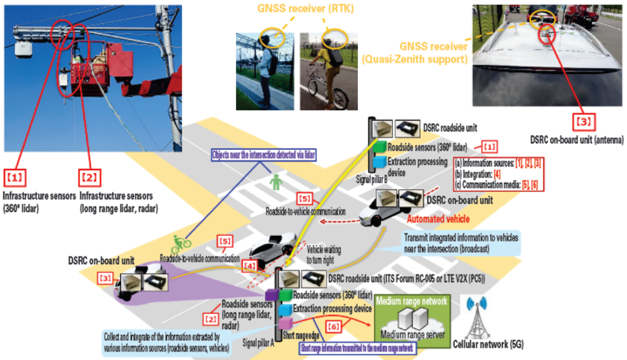


Fig. 8: Test Environment (Roadside Processing Method 1)

Table 3: KPI Validation Results (Roadside Processing Method 1)

Validation type	UC scenario	Common test	Accuracy (position)				Communication latency/ processing time		Remarks
			Extract	Pass/fail	Integrate	Pass/fail	Total	Pass/fail*2	
F validation	UC short 1-1-1		(a):100% (b):100% (c):100%	○	100%	○	(a):119ms (b):205ms (c):229ms	99% or more	• Sensors: (a) 2, (b) and (c) 1 • Extracted object: 1 • Receiving vehicle: 1
	UC short 2-1-1	○	(a):99%	○	100%	—	(a):125ms (b):207ms (c):228ms	99% or more	• Sensors: (a) 2 • Extracted object: 1 • Receiving vehicle: 1
	UC short 3-1-0	○	(a):100%	○	100%	○	(a):121ms (b):201ms (c):221ms	99% or more	• Sensors: (a) 2 • Extracted object: 1 • Receiving vehicle: 1
	UC short 4-1-1								Outside the scope of evaluation
Peak time forecast	Restricted area (b) (UC short 2 to 3)	○	—	—	—	—	(a):162ms (b):215ms (c):220ms	99% or more	• Sensors: 3 expected • Extracted objects: 32 • Receiving vehicles: 57

Sensor types: (a) lidar, (b) long range lidar, (c) radar

Communication latency/processing time: (a) average, (b) CDF 95%, (c) CDF 99%

Table 4: KPI Validation Results (Roadside Processing Method 2)

*Includes the identification cycle process wait time (250 ms)

Validation type	UC scenario	Common test	Accuracy (position)				Communication latency/ processing time*3		Remarks
			Extract	Pass/fail	Integrate	Pass/fail	Total from information source to destination	Pass/fail	
Field validation	UC short 1-1-1								Outside the scope of our evaluation
	UC short 2-1-1	○	(a): 95% or more	○	Outside the scope of integration	○	(a):218ms (b):302ms (c):330ms	99% or more	• Sensors: (a) 1 • Extracted object: 1 • Receiving vehicle: 1
	UC short 3-1-0	○	(a): 95% or more (b): 90% or more	○	95% or more	○	(a):269ms (b):454ms (c):504ms	99% or more	• Sensors: (a) 2, (b) and (c) 1 • Extracted object: 1 • Receiving vehicle: 1
	UC short 4-1-1								Outside the scope of our evaluation
Peak time forecast	Peak scenario	○					(a):518ms		• Simulation conducted • Extracted objects: 44 • Integrated objects: 12 • Receiving vehicles: 57

Extraction sensor types: (a) radar, (b) ITS communication device

Communication latency/processing time: (a) average, (b) CDF 95%, (c) CDF 99%

Table 5: KPI Validation Results (Center Processing Protocol)

Simulation evaluation results included

Validation type	UC scenario	Common test	Accuracy (position)				Communication latency/ processing time		Remarks
			Extract	Pass/fail	Integrate	Pass/fail	Total from information source to destination	Pass/fail*2	
Field validation	UC short 1-1-1		(a):99% (b):100%	○	100%	○	(a):98ms (b):134ms (c):145ms	99% or more	• Sensors: (a)1, (b) and (c) 1 • Extracted object: 1 • Receiving vehicle: 1
	UC short 2-1-1	○	(b):100%	○	—	—	(a):95ms (b):128ms (c):140ms	99% or more	• Sensors: (b) 1 • Extracted object: 1 • Receiving vehicle: 1
	UC short 3-1-0	○	(b):100% (c):99%	○	100%	○	(a):143ms (b):186ms (c):200ms	99% or more	• Sensors: (b) 1, (c) 1 • Extracted object: 1 • Receiving vehicle: 1
	UC short 4-1-1	○	(b):97%	○	—	—	(a):316ms (b):368ms (c):389ms	99% or more	• Sensors: (b) 1 • Extracted object: 1 • Receiving vehicle: 1
Peak time forecast	UC short 2 to 3	○	—	—	—	—	(a):233ms (b):319ms (c):349ms	99% or more	• Sensors: (b) 2, (c) 2 • Extracted objects: 32 • Receiving vehicles: 57

Sensor types: (a) radar, (b) lidar, (c) camera

Communication latency/processing time: (a) average, (b) CDF 95%, (c) CDF 99%
*Updated with the most recent measurement results after the emulator validation

(2) Roadside Processing 2 (Communication Protocol: WiGig)

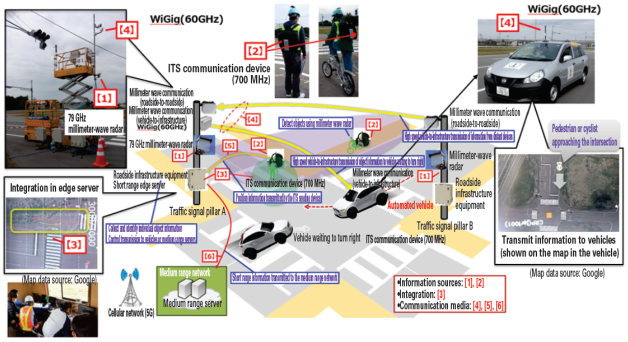


Fig. 9: Test Environment (Roadside Processing Method 2)

(3) Center processing protocol (communication protocol: 5G)

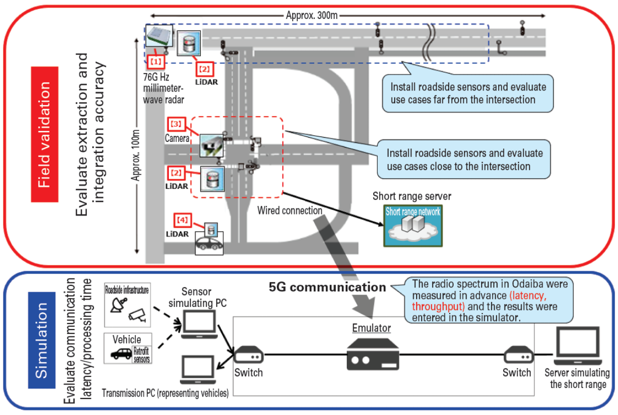


Fig. 10: Test Environment (Center Processing Protocol 1)

4.1.1 Summary of the Three Short Range Protocol Results

Table 6 presents the evaluation results for the three short range protocols. No major variation in total processing time was observed.

4.2. Comprehensive Field Test

For comprehensive field test, we prepared and validated use case scenarios involving providing the automated vehicle with assistance for changing course in the medium range area and assistance for making a right turn at an intersection in the short range area. We also checked the validity and evaluated the KPI for the overall system architecture we had assessed and built. The driving course is shown in Fig. 11.

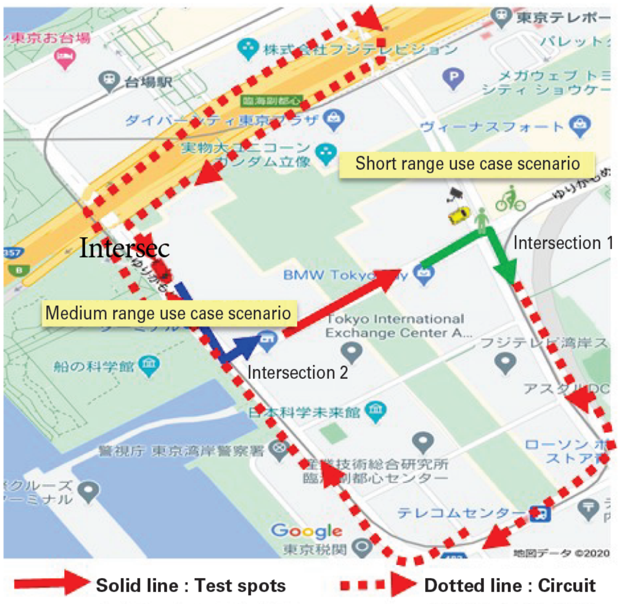


Fig. 11: Overall Scenario for the Comprehensive Field Test

4.2.1. Use Case Scenarios

For the medium range area, we defined a scenario involving providing assistance for early lane or course changes by continuously transmitting information on conditions ahead of the vehicle to realize traffic smoothing.

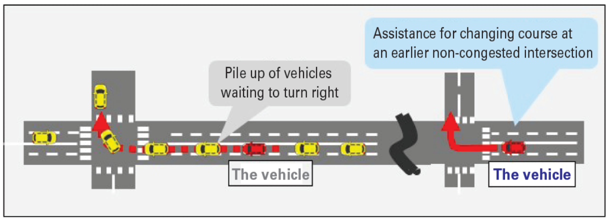


Fig. 12: Visualization of the Medium Range Use Case

For the short range area, we designed a scenario involving providing assistance for smoothly entering and going through an intersection with a complex traffic environment by ascertaining traffic conditions in and around the intersection and transmitting that information to the automated vehicle.

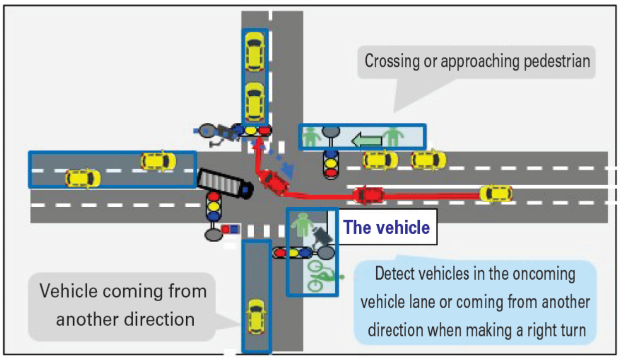


Fig. 13: Visualization of the Short Range Use Case

The above short and medium range area use cases were combined into a single driving sequence scenario as follows.

Specifically, the medium range server transmits object information (congestion information) on the vehicles staying at intersection 1 in the short range area (the yellow vehicles in Fig. 11:

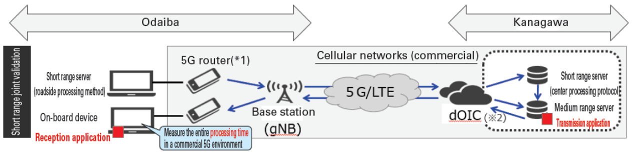
Table 6: Comparison of Short Range Systems

Processing protocol	Communication protocol (collection/transmission)	Source	Knowledge acquired	KPI evaluation results (1st row: achievement status, 2nd row: additional information)			
				Extraction accuracy	Integration accuracy	Collection/transmission communication latency	Total processing time
Roadside processing method 1 Features Suited to lightweight data such as object information (distributed processing)	DSRC Features Enables wireless communication over a broad range • Data volume: Acceptable • Communication area: Good	Object information from radar or lidar + DSRC on-vehicle unit information	✓Achievable with low-cost edge processing devices. ✓Communication is effective even when a heavy-duty vehicle is in the way.	Achieved	Achieved	Achieved	Achieved
				No problems	Improved position accuracy	Average • Collection: 13 ms • Transmission: 10 ms	Average 121 ms
Roadside processing method 2 Features Suited to lightweight data such as object information (distributed processing)	WiGig Features Enables instant transmission of information over high speed, high volume local communication • Data volume: Excellent • Communication area:Acceptable (restricted)	Object information from radar or ITS devices	✓Achievable with low-cost edge processing devices. ✓Enables direct transmission when object information increases significantly and for eventual uses such as point group information	Achieved	Achieved	Achieved	Achieved
				Dependent on the GNSS position accuracy of the ITS device	Improved position accuracy	Average • Collection: 16 ms • Transmission: 4 ms	Average 126 ms
Center processing protocol Features Enables the processing of large amounts of raw data (centralized processing)	5G Features Enables instance wide area communication using high speed, high volume cellular communication • Data volume: Excellent • Communication area: Excellent (wide area)	Object information from radar +lidar Raw data, camera image information	✓Enables detailed analysis of image or other data in high performance servers ✓Centralized processing was confirmed to reduce roadside unit installation cost and allow dynamic resource allocation	Achieved	Achieved	Achieved	Achieved
				No problems	Improved position accuracy, addition of attributes	Average • Collection: 43 ms • Transmission: 21 ms	Average 143 ms

congested intersection assumed) to the vehicle receiving assistance (the red vehicle in Fig. 11: automated vehicle assumed). The vehicle then avoids the congested area by making an early change of course (abandoning the original plan to turn left and intersection 2 in Fig. 11 and driving straight on). Next, we defined a scenario where the vehicle turns left at intersection 2 and proceeds to intersection 1 if the latter is not congested, and relies on object information from roadside sensors received from the short range server when approaching the intersection to proceed smoothly. We measured the processing time required by the entire process.

4.2.2. System Configuration

The system architecture we build is presented below. The cellular network consists of commercial 5G/LTE networks, and radars were installed as roadside sensors for the short range server.



(*1) The Wi-Fi Station SH-52A 5G router was used.
(*2) Docomo Open Innovation Cloud: cloud platform boasting MEC features that is installed within a cellular network to achieve low latency and high security.

Fig. 14: System Configuration

4.2.3. Field Test Results

As part of the use case scenarios we measure the entire processing time for the collection, integration and transmission sequence. We confirmed that the processing time met the targets in both the short and medium range areas. Table 7 below presents the validation results for the entire processing time sequence from collection to transmission in the medium range use case scenario

Table 7: Comprehensive Field Test Results (Medium Range Use Case Scenario)

Type	Use Case Scenario	Total processing time	
Roadside processing method 1	UC medium 1-1-1 (no pile up)	(a) 216.7 ms (b) 333.5 ms (c) 388.1 ms	
Roadside processing method 2	UC medium 1-1-1 (no pile up)	ITS (a) 142.0 ms (b) 265.2 ms (c) 318.9 ms	Radar (a) 153.1 ms (b) 282.2 ms (c) 338.9 ms

Legend: (a) Average, (b) CDF 95%, (c) CDF 99%

4.3. KPI Achievement

The results of the field test, including the comprehensive field test, showed that setting the entire sequence processing time targets to 1 second for the short range and 3 seconds for the medium range as KPIs to achieve smooth and comfortable driving provided sufficient response capability in the tested used cases and intersection sizes.

Similarly, for the uses cases tested, the 300 ms target set for safe and confident driving proved largely problem free and was considered valid for the system architecture studied and built in the context of this project. However, integration in the short or medium range server and the transmission cycle can sometimes exceed 300 ms, and it will be necessary to consider tuning the internal processing in the edge server or distributing the load in such cases.

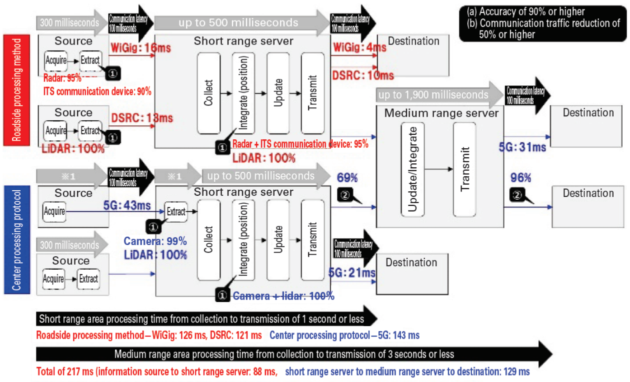


Fig. 15: KPI Achievement (for the medium 1 and short 3-1 UCs)

5 Summary of the Research and Development

5.1. Short Range Area

All KPIs were achieved for the use cases and scope of prerequisites applied in this research project, demonstrating the effectiveness of the assessed system architecture for those specific usages and conditions.

The comparison of the roadside protocols (DSRC, WiGig) and center processing protocol (5G) showed that there was no major difference in the processing time for the entire sequence. This project also provided knowledge and experience on dealing with the errors and divergences in time and position when integrating information from multiple sources during the object identification and integration in the edge server. This enabled us to provide seamless, highly accurate information without duplication to vehicles eligible for assistance, as well as to confirm both the effectiveness of measures against blocking objects and the improvements in position accuracy.

5.2. Medium Range Area

The use cases and scope of prerequisites applied in this research project imposed only a limited load on the medium range network system. We found that using the common IF and transmission control technology assessed in this research project made it possible to carry out network operations without problems when introducing a medium range network system in existing commercial cellular (5G and LTE) networks.

In contrast, the processing time required by the transmission application rose significantly as the number of receiving vehicles or the volume of data increased. Accordingly, commercializing medium range network systems while taking scalability into account will require improving the design of the system as a whole, including the applications.

5.3. Comprehensive Field Test

In the field operational test involving information collection from the short to the medium range and transmission from the medium range to the vehicles via a commercial 5G network (public roads in Odaiba, Tokyo), medium range transmission enabling a change in course at an earlier intersection base on knowing about vehicles staying at an intersection ahead, and short range transmission of intersection information allowing a smooth right turn at the intersection ahead were both achieved. We therefore confirmed the feasibility of seamless assistance for vehicles moving from a medium range area to a short range area.

6 Proposals for Social Implementation

Based on the validation results from this research project, the five points below must be considered in providing the assist system for smooth operation of autonomous self-driving vehicle. The newly complied implementation guidelines provide more details.

(a) Common IF

- Establish a common interface for collecting intersection information (short range) that accounts for the diverse sources of information at intersections (e.g., roadside & vehicle sensors, ITS devices), the short range server protocol, and differences in communication media.
- Establish common interfaces for the integration of short range information in the medium range and the transmission to the vehicle (short/medium range) that take formats stipulated by standardization bodies (such as ETSI) and position referencing protocols (CRP), to enable automated vehicles to make use of intersection (short range) and surrounding (medium range) information.

(b) Transmission Control

- Limit short range transmissions to strictly necessary information based on the position and course of the receiving vehicle to reduce the amount of processing in the automated vehicle and decrease the data volume.
- In the medium range, narrow down the scope of transmitted information according to the speed and direction of travel of the receiving vehicle.

(c) Roadside Sensors

Due to the need to enhance precision and reliability while taking advantage of the characteristics of various sensors as a way of addressing blocking objects near intersections, install several sensors on the roadside after factoring in their cost, and optimize the types and number of sensors.

(d) Edge Servers

Based on factors such as simulations of the intersections to cover, the number and types of installed detection sensors, and the required processing time, study the performance requirements of the edge servers.

(e) Communication Media

In the short and medium range validation of our system primarily focused on right turn assistance at intersections, no significant difference in processing time due to the communication medium (5G, DSRC, WiGig) was observed. However, looking ahead to the eventual enhanced resolution of images and sensors, as well as the expansion of driving assistance with greater real time applications, it is required to choose the communication medium for applications suited to its strengths when the roadside system is to be built.

7 Future Issues in Anticipation of Social Implementation

All KPIs set for the use cases and scope of prerequisites in this research project were achieved, confirming the effectiveness of the assessed system architecture for those specific usages and conditions. At the same time, an eventual social implementation will require gradually expanding the use cases and conditions based on the field tests and results of this research project. In particular, ongoing field operational tests encompassing coordination with automated vehicles and dynamic maps will be necessary.

In this research project, ordinary vehicles were used as receiving vehicles and the test was extended to the collection, integration, and transmission of intersection information. However, it will be necessary to test transmission to automated vehicles and make quantitative evaluations of how the presence or absence of roadside assistance affects smooth and safe driving based on intersection information. Potential problems with the processing load of the combined intersection information from roadside assistance and the information from the automated vehicle's own sensors, and the consistency between objects detected by roadside units and by the automated vehicle will also have to be assessed.

Assessments will have to go beyond the cooperation with automated vehicles. They will also need to consider coordination with roadside assistance and pedestrian devices contained in 5G smartphones, which are expected to become more and more widespread, as well as assistance in mixed environments that include pedestrians, cyclists, and vehicles without such a device. Similarly, current dynamic map information do not reflect dynamic data for pedestrians, cyclists and vehicles. Studying the incorporation of such dynamic data into dynamic maps and assessing its effective use will undoubtedly be necessary.

In conjunction with conducting assessments such as those outlined above, preparing for commercialization will call for further efforts. Large-scale FOTs in various fields with different conditions will be required to determine whether the proposed system is effective and whether unexpected problems arise in actual traffic environments that include greater variation in the types and numbers of traffic participants around intersections, as well as a diverse combination of behaviors and actions.

The above gives Japan a greater opportunity for nationwide propagation that can lead to an expanded market and reduced costs.