2 Establishment and Utilization of Traffic Environment Data

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

Establishment and Utilization of Traffic Environment Data and the Tokyo Waterfront Area Field Operational Tests (Overview)

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1 Need for road traffic environment data

Automated vehicles use information collected by multiple types of on-board sensors in an integrated manner to recognize, judge, and operate the vehicle on behalf of the driver. However, the information collected by such sensors is limited to a range of approximately 200 meters around the vehicle, and only real objects can be recognized as physical phenomena. Therefore, if the road traffic environment data provided by infrastructure through wireless communication, etc. can be utilized, it is possible to realize safe and smooth operation in more complex road traffic environments. (Fig.1)

Road traffic environment data includes various factors, ranging from static information such as high precision 3D map data to dynamic information such as SPaT (Signal Phase and Timing) information that changes every second. In the SIP-adus (Cross-ministerial Strategic Innovation Promotion Program (SIP) Automated Driving for Universal Services), linking rules are established according to the location, time, and unique ID of each piece of information, which is organized based on the concept of a dynamic map. (Fig.2)

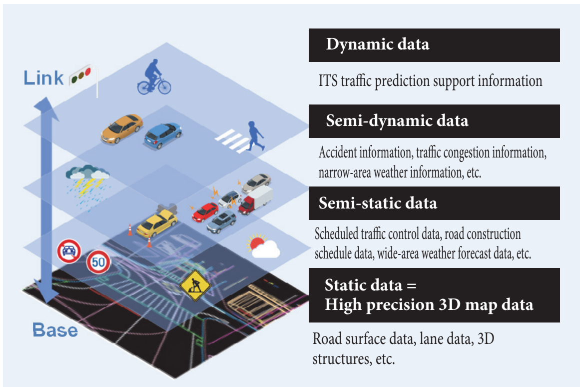


Fig.2: Concept of dynamic map

Mechanism of automated driving

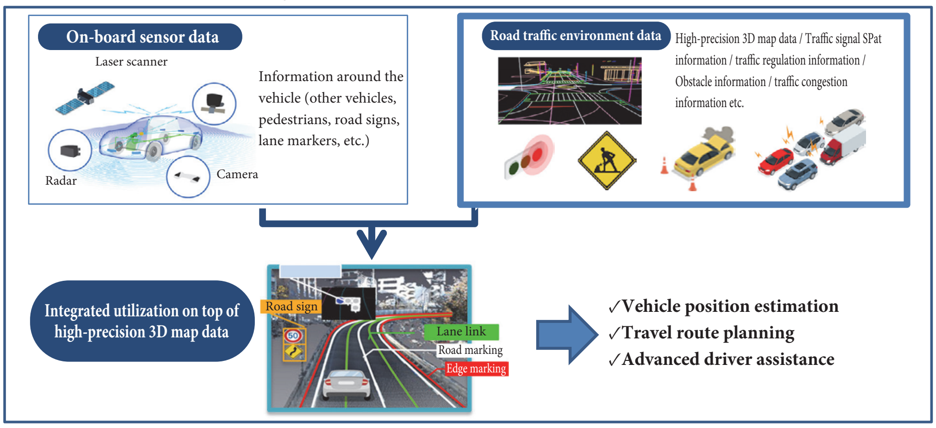


Fig.1: Utilization of road traffic environment data in automated driving

2 Activities to utilize road traffic environment data

In the first phase of SIP-adus, we worked on the establishment of a static information platform , and in 2019, based on the results of the R&D, a project to provide high precision 3D map information for approximately 30,000 km of expressways and motorways nationwide was launched, and the information was adopted by advanced driving support systems and the world's first vehicles equipped with automatic driving level 3 systems that have acquired certification. In the second phase of SIP-adus, the "Road Traffic Environment Data Roadmap" (Fig.3) was formulated to promote research and development for the establishment of a system for utilizing dynamic road traffic environment data that is linked to high precision 3D map information, and standardization and practical use were tackled through FOTs (Field Operational Tests) in the Tokyo waterfront area.

In addition, we worked on the National Police Agency's policy: Improvement of Data Accuracy of Traffic Regulation Information [See Section 2 (1) 5) for more details], and also the construction of a geographic data search portal (MD commune®) [See Section 5 (1) 1) for more detarils] to create new services by utilizing this road traffic environment data in other fields.

3 Overview of the FOTs in the Tokyo waterfront area

3.1. Positioning of the FOTs

In the development of a cooperative automatic driving system that enables safer and smoother automatic driving control by providing various road traffic environment data provided by the infrastructure through wireless communication, etc. and information owned by the vehicle, as well as the road-to-vehicle and vehicle-to-vehicle communication, it is necessary to synchronize vehicle development with infrastructure development and to integrate various technologies. For this reason, the plan was centered on FOTs under actual traffic conditions to establish a system for utilizing road traffic environment information.

(1) Determination of technical specifications and promotion of standardization in the cooperative area

(2) Accelerated development of automated vehicles and infrastructure

(3) Fostering public acceptance of automated driving through information dissemination and use in events

In collaboration with the Japan Automobile Manufacturers Association (JAMA), we worked on the development of an internationally open FOTs environment for the purpose of the items noted below:

In selecting the location, the following factors were taken into account:

(1) Moderate traffic volume and road traffic environment suitable for public road experiments

(2) Convenience of transportation for domestic and international participants in the FOTs

(3) Appeal for the technologies using the opportunity of the Tokyo 2020 Olympic and Paralympic Games.

The Tokyo Waterfront City area was selected from the viewpoint of the above reasons. Specifically, we conducted FOTs in three distinctive areas: the Tokyo Waterfront City area for automated driving on prefectural and municipal

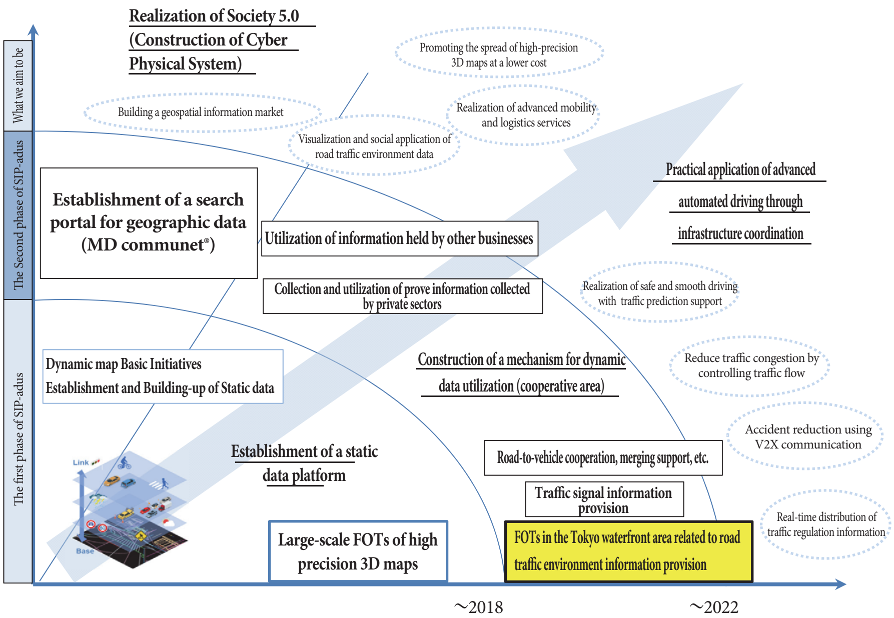


Fig.3: Road Traffic Environment Data Roadmap

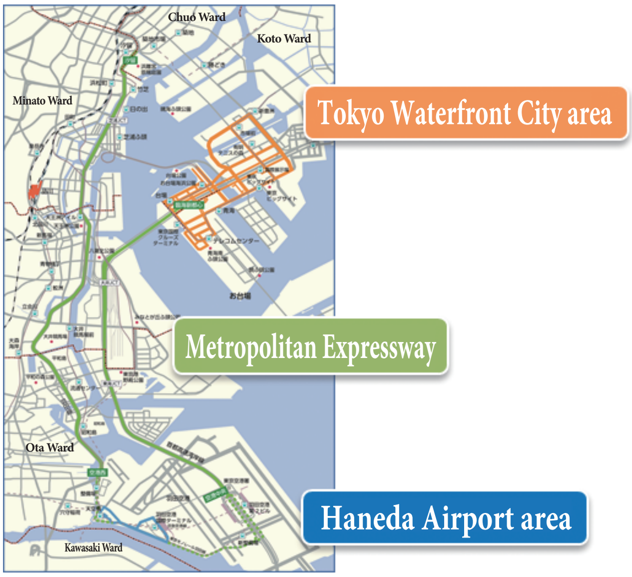


Fig.4: FOTs area (Digital Topographic Map, GSI Map)

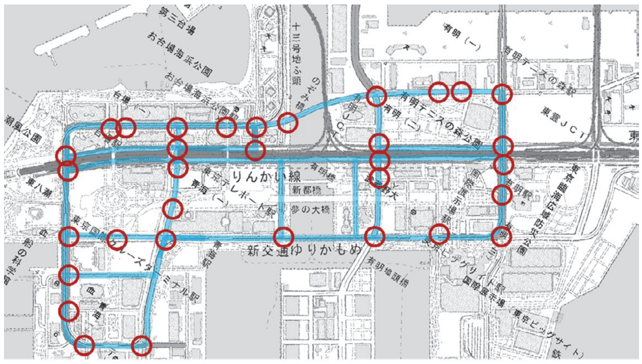
roads, the Metropolitan Expressway for automated driving on expressways, and the Haneda Airport area for automated driving services on public transportation (buses and ART) on prefectural and municipal roads. (Fig.4)

3.2. 2019-2020 FOTs

In consultation with JAMA, we decided to set a milestone of a test drive event at the Tokyo 2020 Olympic and Paralympic Games to clarify the effectiveness and technical requirements of V2I (short-range wireless communication: Vehicle to Infrastructure) SPaT information and merging lane assistance information on expressways, etc. The FOTs were conducted using the matching fund method, which aims to stimulate private-sector investment in automated driving and research and development. The SIP-adus set up and operated the road traffic environment data provision equipment and prepared the on-board equipment to receive such information, while the participants in the FOTs paid for the preparation of their test vehicles and the costs associated with the test driving, including the personnel. Participants were called globally from organizations promoting automated driving R&D. As a result, a total of 29 organizations, including domestic and foreign automakers, suppliers, venture companies, and university research institutes, participated in the FOTs. (Fig.5)

As an FOTs environment using V2I, ITS wireless roadside units were installed at 33 signalized intersections in the Odaiba area and 7 on roads around Haneda Airport, and signal data was transmitted using V2I (760 MHz band). (Fig.6)

Fig.5: FOTs participating organizations (FY2019-2020)



Source: Geospatial Information Authority of Japan map (GSI Web)

Fig.6: Intersection with ITS wireless roadside units (Odaiba)

At the Airport West IC of the Metropolitan Expressway, an ETC gate/merging lane assistance information system consisting of main line vehicle detection sensors, merging lane assistance information generation servers, and V2I (5.8 GHz band) wireless systems were installed to collect and provide information on the operation of the ETC gate and vehicles traveling on the main line. (Fig.7)

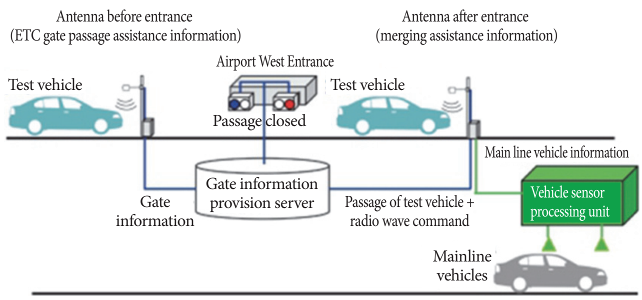


Fig.7: ETC gate/merging lane assistance information system

As previously reported in "SIP 2nd Phase: Automated Driving for Universal Services—Mid-Term Results Report (2018–2020),"(1)(2)(3) the SPaT information provision FOTs using V2I demonstrated that signal light color information can be provided stably under various environments, and the participants in the tests confirmed and agreed the effectiveness and practicality of its use in automated vehicles with specifications compliant with ISO/TS 19091 while maintaining compatibility with DSSS (Driving Safety Support System), a service that is already in practical use.

The FOTs have provided a technical prospect for the practical use of SPaT information in automated driving, but the participants commented that the priority of infrastructure installation was not determined by the locational conditions of the intersection, such as backlighting due to the westering sun, and that "providing area-covering" was essential. These results will be developed to the RoAD to the L4 project for the realization of Level 4 automated driving services and will continue to be studied for implementation. In addition, there were many requests from FOTs participants to continue to utilize the Odaiba area equipped with the whole area covering network as test environment as a development base for automated driving FOTs. In response to these requests, it was decided to utilize the area for research and development for the next step in "Construction of smart mobility platform " as the next phase of SIP.

On the other hand, as previously reported in the "SIP 2nd Phase: Automated Driving for Universal Services—Mid-Term Results Report (2018–2020),"(1) as a result of the FOTs of the merging lane assistance information provision using V2I, it was found that spot information provision is not sufficient to provide accurate merging lane assistance information even when the traffic flow changes, and a more advanced information provision system using continuous main line vehicle detection and continuous mainline vehicle detection and continuous communication technology is needed. Therefore, we conducted a simulation based on data collected from actual traffic flow observations to confirm the feasibility of a merging lane assistance information provision' system that can respond to various traffic flow fluctuations and to derive the system requirements. [See Section 2 (1) 4) for more details]

3.3. FOTs in FY2021

Due to the spread of COVID-19 starting in 2020, the Tokyo 2020 Olympic and Paralympic Games were postponed to FY2021, and the large-scale automated vehicle test-ride event that was originally planned in collaboration with the Japan Automobile Manufacturers Association was also cancelled. There was also no small impact on vehicle development for each manufacturer, who requested to extend the FOTs schedule in the Tokyo waterfront area, hence the FOTs were continued for FY2021. And reviewing the results of the FY2019-2020 FOTs, there was a high demand for the provision of road traffic environment data with network covering the whole area. That is why that, in the FY2021 FOTs, in addition to the provision of SPaT information using V2I, we also worked on the provision of road traffic environment data using V2N (public long range network (V2N)). (Fig.8)

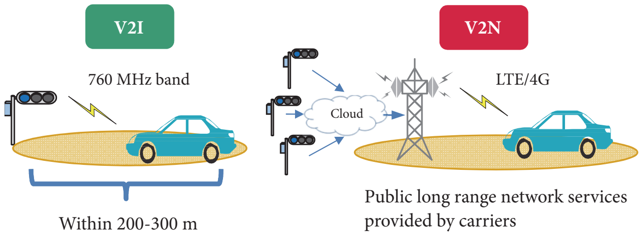


Fig.8: V2I/V2N communication system (for traffic signal information)

In addition to the need for utilization in automated driving revealed through interviews, we also considered the effectiveness of providing information to drivers, and decided to work on the generation and provision of the following four types of data as highly prioritized in road traffic environment data.

[Prefectural and municipal roads] SPaT information
[Expressways] Lane-level traffic flow information
[Common] Emergency vehicle information, rainfall information

As with the 2019-2020 FOTs, a broad call for participants resulted in the participation of 22 institutions. (Fig.9)

Fig.9: FOTs participating institutions (FY2021)

For the V2N FOTs, an information generation and provision network environment was constructed with an architecture for assumed social implementation, and information was provided to test vehicles via public long range network communications (4G/LTE). (Fig.10)

For SPaT information, a V2N information provision environment was prepared for 33 signal intersections in Odaiba where ITS Roadside Units (RSU) were installed, enabling comparative verification of V2I/V2N.

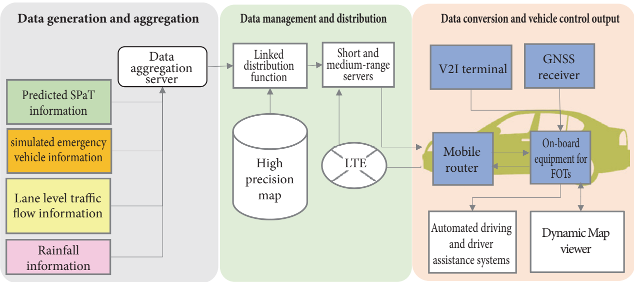


Fig.10: V2N information provision network architecture

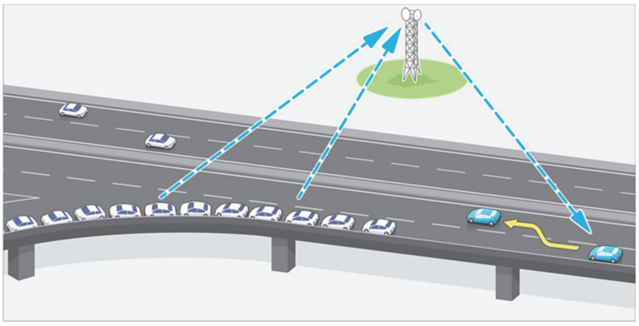


Fig.12: Lane-level Traffic flow information provision using probe information

In the utilization of V2N information, transmission delay via networks is expected to be an issue. For SPaT information, which requires particularly high temporal information accuracy, we developed technologies for generating signal cycle time schedule information for each signal control system method, studied the provision system, and verified it in the Tokyo waterfront area FOTs after confirming the functionality with a model system. (Fig.11) [See Section 2 (1) 2) for more details]

As a result of the FOTs, it was confirmed that a mechanism for efficiently distributing information on scheduled signal cycles at necessary intersections along a route from the network to each vehicle could be implemented for use in automated driving vehicles. Participants in the FOTs also commented that V2N can be expected to contribute to CO_2 reduction through optimal route planning, green wave, etc. by utilizing traffic signal information that is unique to V2N.

On the other hand, there are issues in the accuracy of the generated signal cycle time schedule information and the realization of a fail-safe feature, hence further research and development are required for practical application. Stakeholders will continue to discuss these issues in the technical committee established by the UTMS Association.

For lane-by-lane traffic flow information, we statistically processed private-sector probe data with road-way level accuracy that is now possible to be collected from moving vehicles as the spread of connected cars, and generated lane-level traffic congestion tail information. Although there is a delay in the provision of information depending on the processing interval due to the statistical processing after a certain amount of probe vehicle data is collected and accumulated, we confirmed that the system can generate and provision information that is superior to the roadway-level traffic congestion information of existing services in terms of its precision. (Fig.12) The accuracy of the generated information is expected the further spread of connected cars and the evolution of information collected from vehicles equipped with advanced driver assistance systems and automated vehicles. [See Section 2 (1) 3) for more details]

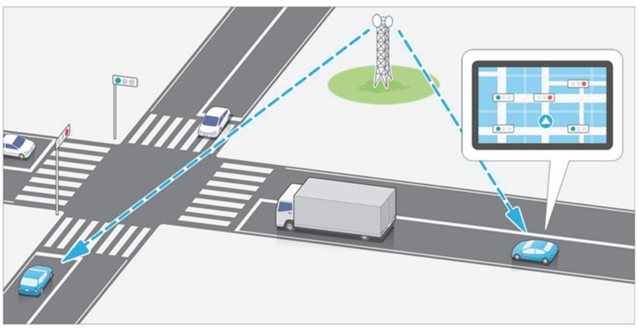


Fig.11: SPaT information provision through V2N

As for the utilization of information on emergency vehicles, a V2V alert service has been put to practical use, but it has not yet been widely adopted because it requires dedicated radio equipment to be installed in both emergency vehicles and vehicles that use the information.

In the FOTs in the Tokyo waterfront area, information on emergency vehicles was generated and provided on a simulated basis. Although there was a transmission delay of two to three seconds, participants in the FOTs noted that the system was effective in detecting the relative position and relative speed of the vehicle and in determining whether to avoid the vehicle when an emergency vehicle approached. Some participants also suggested that the system would be particularly effective for remote monitoring type automated driving. (Fig.13)

Although not the FOTs in the Tokyo waterfront area, one of the use cases of information utilization with V2N: to collect information on the approach of public transportation (buses, etc.) and emergency vehicles to traffic signal intersections, then to use this information for signal priority control, the possibility of this case was also verified. As a result of the FOTs in rural area, it was confirmed that vehicles that should be given priority can smoothly pass through signalized intersections. [See Section 2 (1) 6) for more details]

For rainfall information, the High-Resolution

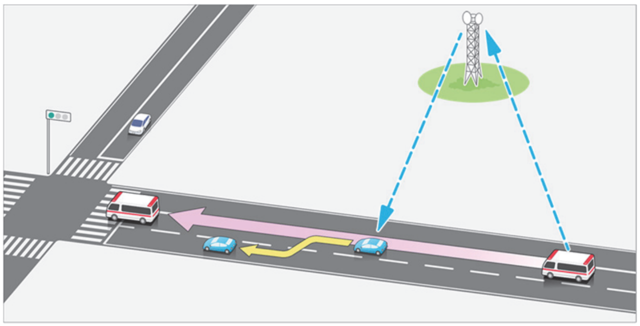


Fig.13: Emergency vehicle information provision through V2N

Precipitation Nowcast service provided by the Japan Meteorological Business Support Center was linked to a high precision 3D map and provided to the vehicles in the FOTs. The ability to select an area and utilize the information, including forecast information, was demonstrated, showing that V2N enabled to utilize a wide variety of road traffic environment data. (Fig.14)

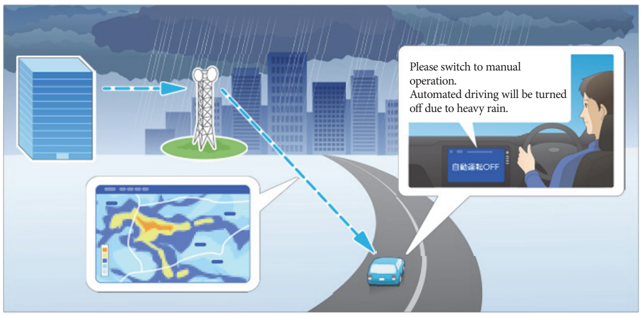


Fig.14: Provision of rainfall information via V2N

3.4. Activities for information utilization through V2N

As described above, the provision of road traffic environment data via V2N has potential for utilization of wider variety of information and is promising. On the other hand, there are many issues that need to be resolved before practical application.

In the FOTs in the Tokyo waterfront area, we specifically discussed how to use the road traffic environment data to be provided in the context of increasing communication traffic, and verified the information provision method with the participants.

Information provision methods can be broadly classified into the PULL method, which is suitable for high-volume, low-frequency updates, and the PUSH method, which is suitable for low-volume, high-frequency updates. (Fig.15) Through the provision of road traffic environment data in the FOTs, it was found that communication traffic can be reduced by properly using both methods. In addition, network and server load measurements and simulations for social implementation were conducted, and the following was identified as issues that should be taken into consideration by business entities for a large-scale social implementation before practical use.

- Realization of a system for efficient selection and use of necessary information
- Minimize information processing/transmission delays via network and check impact
- Server capacity forecast and reduction of communication data volume commensurate with the implementation of the target service scale

[See Section 2 (2) 3) for more details]

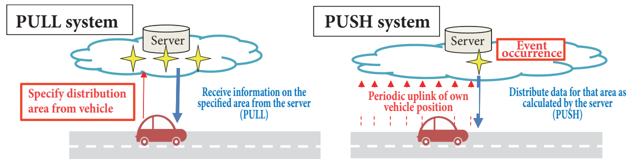


Fig.15: Information provision method via V2N

In addition to these issues, the Task Force (TF) on V2X communication for Cooperative Driving Automation has discussed to find other issues in cooperation with academic experts, relevant ministries and agencies, and members of industry organizations (automobile, electronics, etc.), and has clarified issues to be addressed, such as the formulation of cybersecurity and privacy measures. [See Section 2 (2) 1) for more details] We sincerely hope that industry, academia, and government will share the roles of research and development, and deepen cross-industry discussion and collaboration to realize the utilization of road traffic environment data via V2N in the future.

3.5. Study of the system of information utilization through V2N

The establishment of a system is also an important issue for the utilization of road traffic environment data through V2N. The European Commission has mandated the establishment of National Access Points (NAPs) in each country to collect and utilize mobility-related data through networks, as well as a system to provide data using NAPs. In Japan, it is necessary to continuously study particular cases of mobility data utilization as well as its advantages and disadvantages related to automated driving and Advanced Driving Assistance System of which the practical use will be accelerated. In the second phase of SIP-adus, we studied the ideal system for utilizing road traffic environment data via V2N in Japan through R&D and FOTs.

In the process of studies conducted through the second phase of SIP-adus, V2N SPaT information needs to be as accurate as highly required for provided information and also to be implemented with a system allowing to give nationwide service under unified interface conditions, we received such opinions and others through questionnaires and interviews with experts, related companies, and others,. We plan to examine these opinions and propose the necessity of establishing a centralized SPaT information center that will serve as the implementation entity, as well as the requirements and conditions that the organization should have. [See Section 2 (1) 2) for more details]

On the other hand, weather information, such as rainfall data, is considered as an area where the information provision business is expected to evolve and expand as a competitive area based on the needs and use cases of information utilization, including non-mobility applications, and it is desirable to develop it without establishing a unified information distribution system. Based on the results of these studies, we plan to propose a system for utilizing road traffic environment data through V2N. [See Section 2 (1) 3) for more details]

3.6. Activities in fostering public acceptance

Information on the activities of industry, academia, and government toward the realization of automated driving in the FOTs in the Tokyo waterfront area was actively disseminated through SIP-café, the Status Report Meeting, and other opportunities for public relations activities. In addition, at a test-ride event aimed at fostering public acceptance, a public road demonstration and test-ride of Level 4-equivalent automated driving test vehicles was conducted as a result of the research and development of each company through the FOTs in the Tokyo waterfront area , and publicized the current status of the research and development progress of automated driving technology and some of the results of the SIP-adus program R&D. (Fig.16) [See Section 4 (2) 3) for more details]

Fig.16: Demonstration of prototype automated vehicles

4 Conclusion

In the second phase of SIP-adus, through research and development on the utilization of road traffic environment data and the FOTs in the Tokyo waterfront area, we worked to clarify the requirements for road traffic environment data necessary for the realization of automated driving and to establish a system for information generation and provision. We have now the technical prospect of practical application of SPaT information provision through V2I, which is necessary for the introduction of automated driving on prefectural and municipal roads, and have developed this prospect to the RoAD to the L4 project aiming for the realization of Level 4 automated driving services. We will continue to study for the implementation of the system in the future. In addition, the FOTs environment in the Odaiba area will be passed on to and used for the next step of research in the next phase of SIP as the legacy we leave . In order to meet future needs for the transmission of information from area-covering network , we also conducted research, development, and FOTs on the use of various types of traffic environment information using V2N. We demonstrated the effectiveness of the system and the potential for utilizing the information provided, identified the requirements and issues for realizing the system, and made proposals for the construction of the system. We hope that the results of the efforts in the second phase of SIP-adus will be utilized to continue to promote efforts toward the practical application of the system for utilizing road traffic environment data.

[References]

(1) Masafumi Kobayashi, et al.: Traffic Signal Information Provision Technology for Infrastructure-Based Cooperative Automated Driving, SIP 2nd Phase: Automated Driving for Universal Services—Mid-Term Results Report (2018–2020), pp. 16-23, 2021.
(2) Yoshiaki Tsuda et al.: Data Analysis of the FOTs in Tokyo Waterfront City Area, SIP 2nd Phase: Automated Driving for Universal Services—Mid-Term Results Report (2018–2020), pp. 54-62, 2021.
(3) Yoshiaki Tsuda et al.: Data Analysis of the FOTs on the Metropolitan Expressway, SIP 2nd Phase: Automated Driving for Universal Services—Mid-Term Results Report (2018–2020), pp. 68-72, 2021.

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1) The Tokyo Waterfront City Area Field Operational Tests

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(Abstract) From FY2021 to FY2022, as part of the Field Operation Tests (FOTs) in the Tokyo Waterfront area, an information delivery system that uses a public long range network (V2N) was set up and used to perform verification testing for four types of traffic environment information: rainfall information, lane-specific road traffic information, mock emergency vehicle information for vehicles on emergency calls, and predictive SPaT (Signal Phase and Timing) information. A total of 22 organizations from Japan and abroad participated in these FOTs. These included motor vehicle manufacturers, suppliers, venture companies, and universities. The participants evaluated the effectiveness of delivering traffic environment information via V2N and identified the issues that were involved. PUSH and PULL methods of information delivery were set up, to be used as appropriate given the characteristics of the information to be delivered. Participants evaluated the impact of increased communications traffic volume and the impact of delays caused by the network, looking towards future practical implementation. The results of the tests were evaluated and verified by test participants in FOTs working group meetings, and information regarding the effectiveness of traffic environment information and the issues involved were summarized.

Keywords: V2N, field operation tests, rainfall information, lane-specific road traffic information, mock emergency vehicle information for vehicles on emergency calls, predictive SPaT information

1 Overview of the FOTs

1.1. Objectives of the FOTs

As part of the FOTs in the Tokyo Waterfront area, an information delivery system that uses V2N communication was set up and used to perform verification testing of rainfall information, lane-specific road traffic information, mock emergency vehicle information for vehicles on emergency calls, and predictive SPaT information with the aim of promoting greater use of traffic environment information.

1.2. FOTs area

Fig.1 shows the testing area used in the FOTs. Tests of mock emergency vehicle information for vehicles on emergency calls and predictive SPaT information were performed in the Waterfront City area (1). Lane-specific road traffic information testing was performed in the Metropolitan Expressway area (2). In order to evaluate rainfall information as long-range information, testing was performed in areas (1) and (2) and also in the Joban Expressway to Shin-Tomei Expressway area (3).

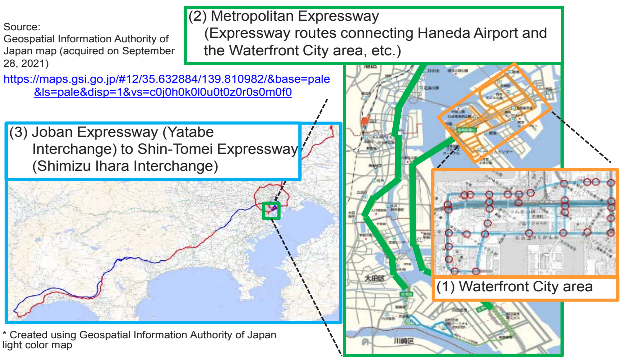
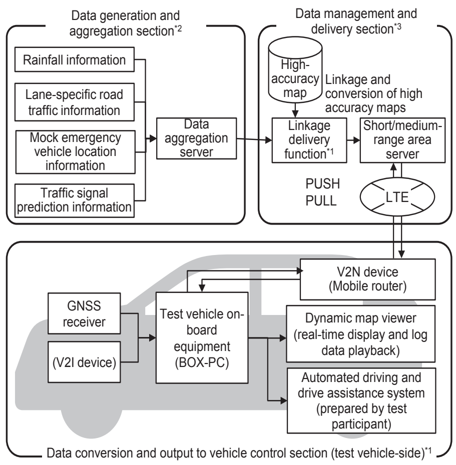


Fig.1: FOTs Area

1.3. Test system

The FOTs system was created while envisioning the architecture that might be used in future real-world deployment. In conjunction with participants to the second phase of SIP-adus (Cross-ministerial Strategic Innovation Promotion Program (SIP) Automated Driving for Universal Services) project, a test system was created, consisting of a data generation and aggregation section, a data management and delivery section, and a data conversion and vehicle control output section, as shown in Fig.2.

Each type of traffic environment information was aggregated in a data aggregation server and linked with a high-accuracy 3D map before being delivered to test vehicles via a short-range and medium-range area server and LTE communications network. On the vehicle side, the traffic environment information that was received and the vehicle location information was processed by on-board test equipment and output via a LAN or CAN interface to automated driving/driving assistant system (prepared by the test participants). Analysis software was also prepared, as was a dynamic map viewer for displaying received information in real time.



*1:Handled by "Implementation of FOTs in the Tokyo Waterfront Area" contractors (author of this report)
*2:Handled by "Examination and Evaluation of Automated Driving Control Technologies that Use Lane-specific Probes, etc." contractors
*3:Handled by "Research and Development on the Collection, Integration, and Delivery of Short-range and Medium-range Information" contractors

Fig.2: Test system structure

1.4. Testing schedule

The FOT period extends from November 15, 2021, to December 23, 2022. (Fig.3) Rainfall information and predictive SPaT information testing are being performed over the entire period. Due to information delivery period limitations, multiple, short tests are being performed for lane-specific road traffic information tests and tests of mock emergency vehicle information for vehicles on emergency calls. Test participants are holding FOTs working group meetings each month to verify test results and discuss them with other participants.

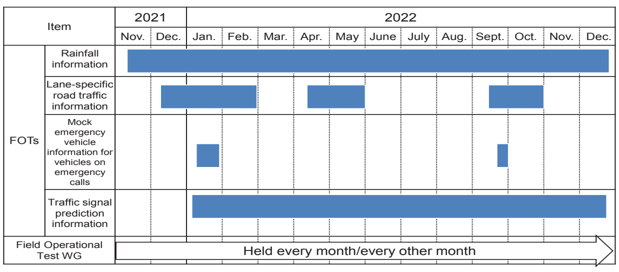


Fig.3: FOTs schedule

2 Creation and evaluation of the V2N information delivery system

Delivering traffic environment information via V2N enables the use of more diverse information over a wider area, so methods of efficiently extracting information from the cloud and delivering that information were created with an eye toward future practical implementation. The amount of communication traffic and transmission delays due to network factors are being evaluated through testing.

2.1. PUSH/PULL-based information delivery system

When delivering information via V2N, it is important to use delivery mechanisms that take into consideration data volume and transmission delay based on the characteristics of the information involved. This is why the information delivery system was designed to use two delivery methods, PUSH and PULL, as shown in Fig.4. PUSH delivery is well-suited to low volume information that is frequently updated, while PULL delivery is well-suited to high volume information that is infrequently updated. In the FOTs, the method used to deliver information was selected based on the characteristics of each type of traffic environmental information.

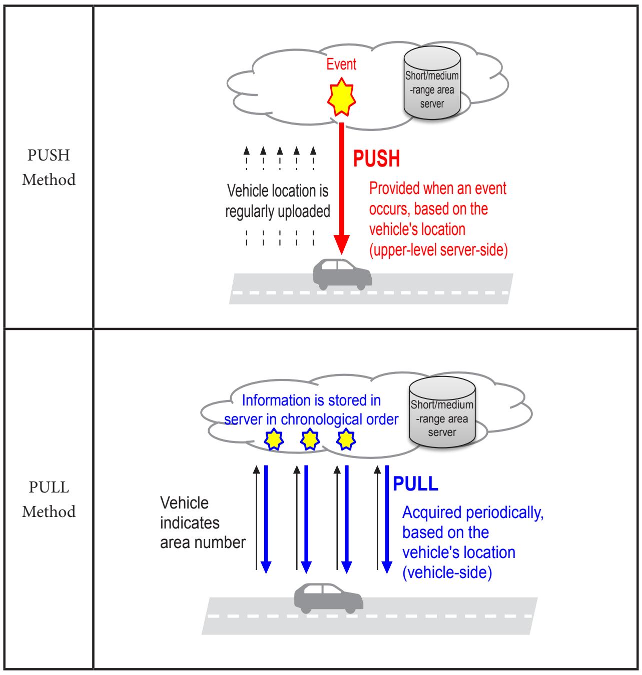


Fig.4: PUSH method and PULL method

When using the PUSH method, vehicles periodically uploaded their location to a short-range and medium-range area server in the data management and delivery section. When an event occurred, information was delivered from the short-range and medium-range area server to the vehicle based on the vehicle's location.

When using the PULL method, on the other hand, vehicles indicated the areas they wanted data for, and they periodically acquired the information from the short-range and medium-range area server in the data management and delivery section.

2.2. Traffic Traffic environmental information reception characteristics

2.2.1 Characteristics of rainfall information

Table 1 shows an overview of the rainfall information delivered during the FOTs. The High-resolution Precipitation Nowcast information provided by the Japan Meteorological Business Support Center is updated every 5 minutes, making it low frequency data, so the PULL method was used. Fig.5 shows what is displayed in the dynamic map viewer when rainfall information is received by the vehicle. Fig.6 shows a rainfall information output example (including forecast information). Rainfall information contains precipitation information for the following 30 minutes from the current time, so it can be used for handover between automated driving and manual driving and to provide caution information to the driver.

Table 1: Overview of rainfall information

Information source	Japan Meteorological Business Support Center
Provided information	"High-resolution Precipitation Nowcasts" or "High-resolution Precipitation Nowcasts" (5-minute precipitation amount) (cumulative rainfall over a 5-minute period in a grid square measuring 250 m x 250 m, current condition analysis and 30 minute forecasts issued every 5 minutes, binary data)
Provision scope	SIP Phase 1 and Phase 2 high-accuracy 3D map range (Waterfront City + Metropolitan Expressway, Joban Expressway, Tomei, Shin-Tomei)
Delivery method	PULL method

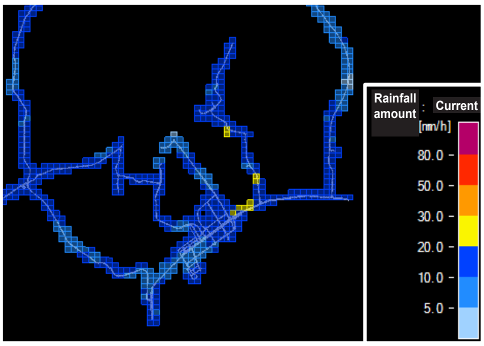


Fig.5: Dynamic map viewer screen when rainfall information is received

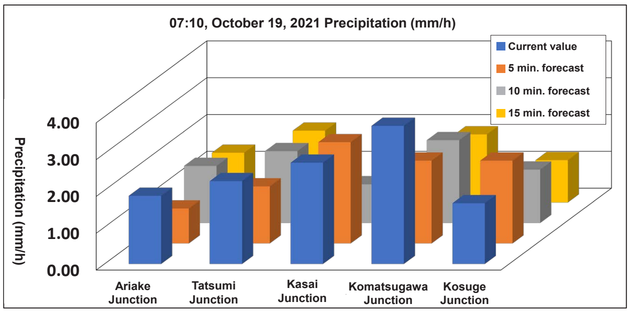


Fig.6: Rainfall information output example (including forecast information)

2.2.2. Characteristics of lane-specific road traffic information

Table 2 shows an overview of lane-specific road traffic information. Lane-specific road traffic information includes information such as coordinate and lane information regarding traffic congestion tail ends, impediments, and the like. This information is generated from probe information provided by vehicles driving on expressways and is sent to other vehicles. When this information is provided, it must be linked to the high-accuracy map data in the vehicle's own system, so the linkage delivery function, shown in Fig.2, is used to provide the vehicle with the location of the information, converted into either the distance between the information and a common reference point (CRP) on the high-accuracy map, or the coordinates of the location (in accordance with ISO17572-4). Lane-specific road traffic information is updated infrequently, once per minute, so it is delivered using the PULL method. The characteristics of received lane-specific road traffic information is shown in Fig.7.

Table 2: Overview of lane-specific road information

Information source	Probe information (OEM/car navigation equipment manufacturer)
Provided information	Traffic congestion tail end location information, impediment location information (1 minute intervals, (1) start time, (2) alleviation time, (3) occurrence location, (4) route name, (5) lane number, (6) occurrence location accuracy, (7) traffic congestion accuracy)
Provision scope	Metropolitan Expressway Haneda Route and Bayshore Route
Delivery method	PULL method

In Fig.7, a test vehicle encounters the tail end of traffic congestion affecting all lanes. As the Fig. shows, it slows down and continues driving, and then when the traffic congestion dissipates it speeds back up

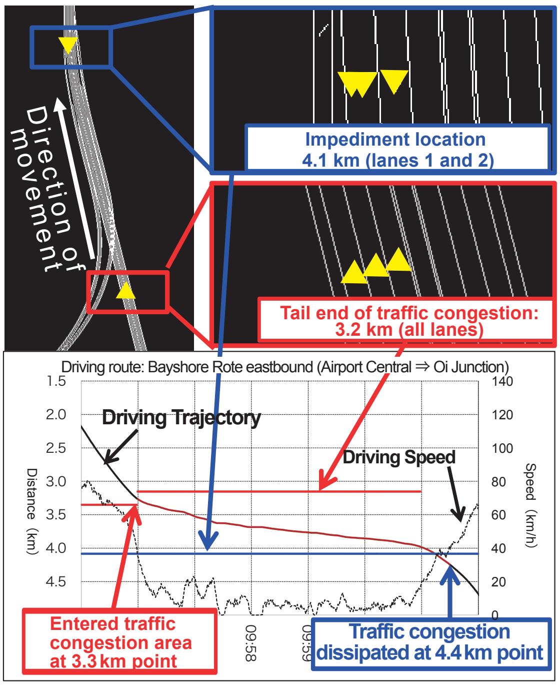


Fig.7: Reception characteristics of lane-specific road traffic information

2.2.3. Characteristics of mock emergency vehicle information for vehicles on emergency calls

Table 3 shows an overview of mock emergency vehicle information for vehicles on emergency calls and Fig.8 shows the reception characteristics of this information. The mock emergency vehicle information for vehicles on emergency calls is frequently updated, with vehicle location history information

Table 3: Overview of mock emergency vehicle information for vehicles on emergency calls

Information source	Mock emergency vehicle (rental vehicle)
Provided information	Location information for emergency vehicle updated every 100 ms, distributed every 2 seconds (1 location per 100 ms x 2 s = 20 items of GNSS information sent at a time)
Provision scope	General roads in the Waterfront City area
Delivery method	PUSH method

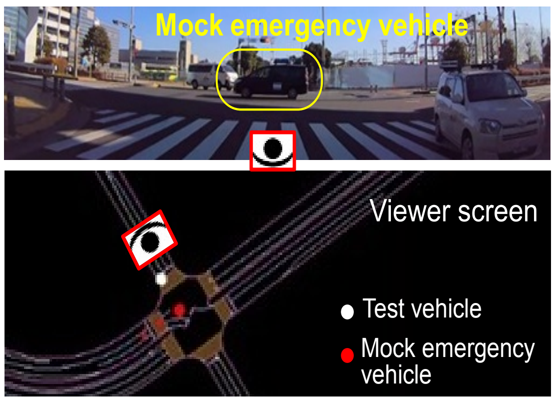


Fig.8: Front-facing image and dynamic map viewer screen when mock emergency vehicle information for vehicles on emergency calls was received

in 100 ms increments being updated every 2 seconds, so the PUSH method was used.

Fig.8 shows an image taken from the front of the vehicle when the mock emergency vehicle passed and the dynamic map viewer screen showing the relationship between the locations of the test vehicle and the mock emergency vehicle. Fig.9 shows the distance between the test vehicle and the mock emergency vehicle on an emergency call that passed each other, together with their speed characteristics. Through these tests, we were able to deliberate regarding use cases for emergency vehicle information for vehicles on emergency calls and vehicle behavior in preparation for future real-world deployment.

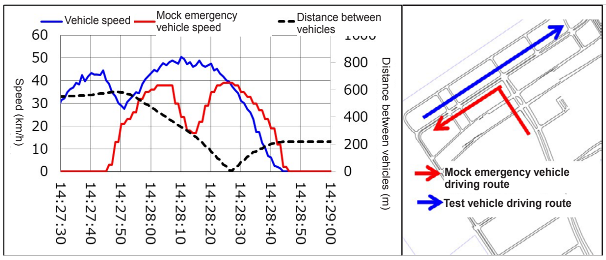


Fig.9: Speeds and location relationships of test vehicle and mock emergency vehicle

2.2.4. Characteristics of traffic signal prediction information

Traffic color information for each traffic signal was generated by the predictive SPaT generation server 3 seconds before the light turned green and provided to test vehicles via the data generation and aggregation section and the data management and delivery section. Table 4 shows an overview of predictive SPaT information.

Table 4: Overview of predictive SPaT information

Information source	Metropolitan Police Department
Provided information	Traffic signal color prediction information when traffic signal cycle is confirmed In these tests, predictive SPaT information was generated and provided 3 seconds before the start of the cycle (the time when the major road's traffic signal turned green), and the provided predictive SPaT information contained the cycle start time and light color information for two cycles for each exit direction of each entry route
Provision scope	Traffic signals in Waterfront City area
Delivery method	PUSH method, PULL method, and specified intersection PUSH method.

predictive SPaT information could be used in various ways in future real-world deployment, so we used three delivery methods, as shown in Table 5.

Table 5: predictive SPaT information delivery methods

Method	Characteristic
PUSH method	The test vehicle provided its location information to the data management and delivery section short-range and medium-range area server in 1 second intervals and received traffic signal information for int º¡ ersections in the designated radius around the vehicle's position in 1 second intervals
PULL method	SPaT information for intersections in the designated rectangular area in the direction of travel of the test vehicle was requested by and provided to the vehicle in 1 minute intervals
Specified intersection PUSH method	Traffic signal ID information requested for the intersection or intersections along driving routes was provided by the short-range and medium-range area server in the data management and delivery section in predictive SPaT information update intervals.
Output method to vehicle control output section	In the case of the PUSH method and the PULL method, among the received predictive SPaT information, the predictive SPaT information for intersections in the vehicle traveling direction is output in 100 msec intervals. In the case of the specified intersection PUSH method, the predictive SPaT information for specified intersection is output in 100 msec intervals.

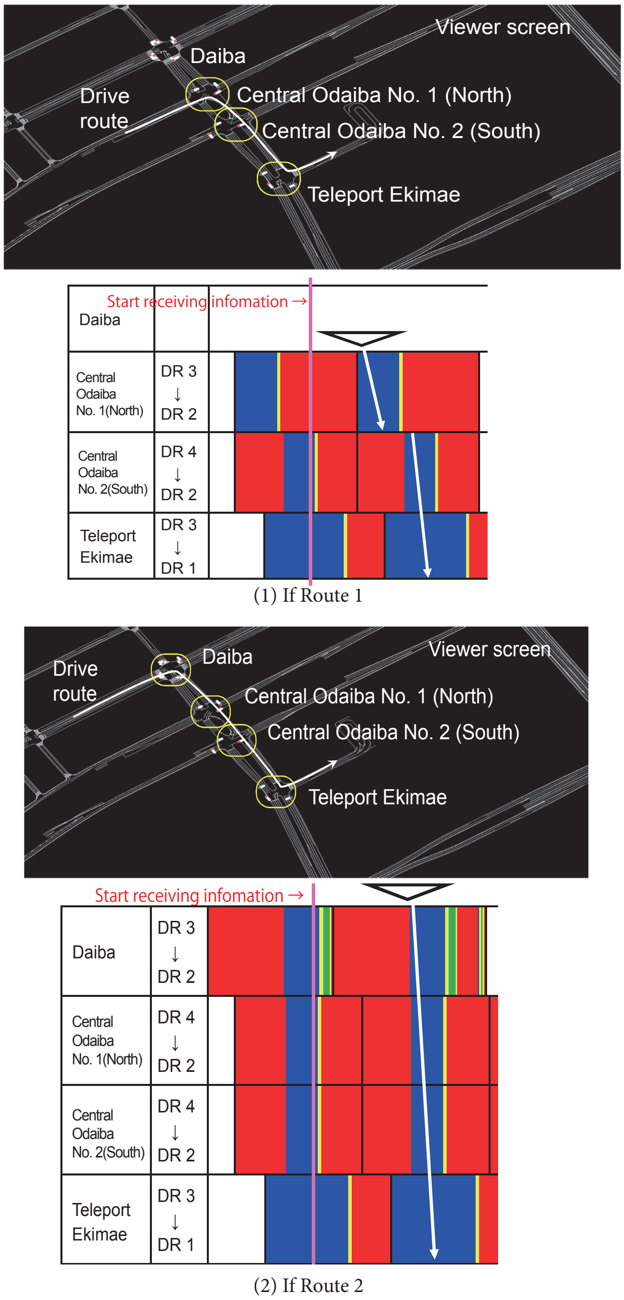


Fig.10: shows the characteristics of predictive SPaT information. This example shows the specified intersection PUSH method.

Fig.10 shows the characteristics of predictive SPaT information. This example shows the specified intersection PUSH method.

Fig.10 shows (1) predictive SPaT information requested for the three intersections in front of the Central Odaiba No. 1 (North) intersection on route 1 and (2) predictive SPaT information requested for the four intersections in front of the Daiba intersection on route 2. This shows that SPaT information for multiple intersections along the driving routes could be received at the same time, which would make it possible to avoid stopping at intersections and would be effective for selecting the optimal driving route.

2.3. Delivery system evaluation

2.3.1. Time synchronization characteristics

In order to evaluate the impact of delays resulting from network transmission, we synchronized the times of the data generation and aggregation section, the data management and delivery section, and the data conversion and vehicle control output section, as shown in Fig.2, and then evaluated the delivery system's delay times. We found that the maximum time deviation between each device could be kept to ±20 ms, and we built a test system that enabled us to evaluate network delays in the transmission of information.

2.3.2. Delivery delay characteristics

In the FOTs, information delivery methods varied depending on the information, so Fig.11[1] shows the transmission transactions and delay times for each method.

(1) Delivery delay characteristics of rainfall information

For rainfall information, we used the PULL method shown in Fig.11 There was a rainfall information delivery delay time of between 10 and 130 seconds when outputting the information from the data generation and aggregation section to the test vehicle on-board equipment (BOX-PC) in the data conversion and output to vehicle control section (test-vehicle side) as shown in Fig.2. Japan Meteorological Business Support Center data is delivered in 5 minute intervals, so this does not appear to present a problem. However, if data requests were sent in intervals of 1 minute or less, this would cause an increase in transmitted data, so it would be preferable to keep the transmission settings as they currently are.

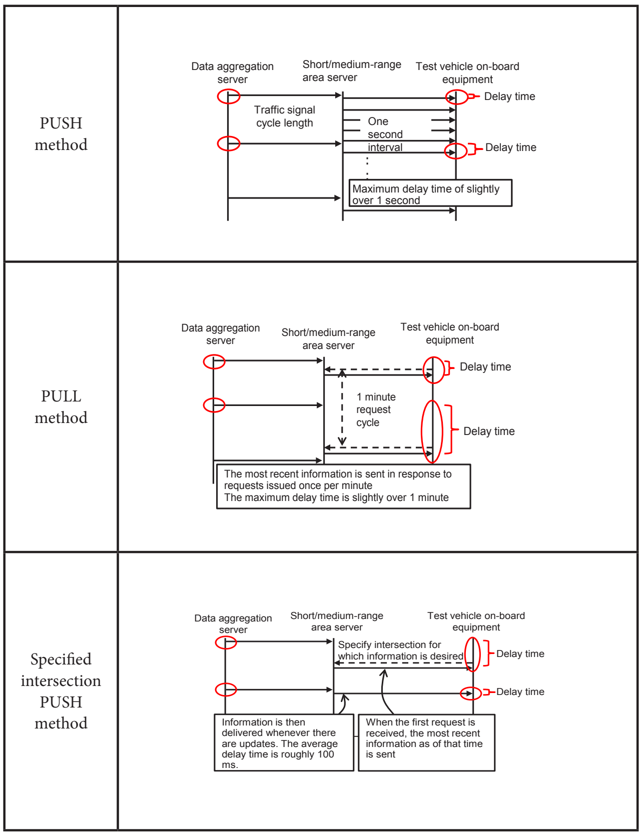


Fig.11: Transmission transactions and delay times for each method (specified distance PUSH method, PULL method, and specified intersection PUSH method)

(2) Delivery delay characteristics of lane-specific road traffic information

As with rainfall information, the PULL method was used to deliver lane-specific road traffic information, so for lane-specific road traffic information there was also a delay time of up to 66 seconds when outputting the information to the test vehicle on-board equipment (BOX-PC) in the data conversion and output to vehicle control section (test-vehicle side). This is roughly equivalent to the information source delivery cycle length, so this does not present a problem. Lane-specific road traffic information is updated infrequently, once per minute, so it would be preferable to keep the transmission settings as they currently are.

(3) Delivery delay characteristics of mock emergency vehicle information for vehicles on emergency calls

For mock emergency vehicle information for vehicles on emergency calls, we used the PUSH method shown in Fig.11 There was a delivery delay time of up to 1.3 seconds when outputting the information from the data generation and aggregation section to the test vehicle on-board equipment (BOX-PC) in the data conversion and output to vehicle control section (test-vehicle side) as shown in Fig.2. In these tests, mock emergency vehicle information for vehicles on emergency calls was supplied in 2 second cycles, so delivery times had no impact. If the cycle length of emergency vehicle information for vehicles on emergency calls is reduced 1 second in the future, it will be important to deliberate about how to reduce the delay time to 1 second or below. However, if vehicles learn in advance that an emergency vehicle is approaching, this delivery delay is not expected to have an impact. It will be important to deliberate more deeply regarding the methods of using emergency vehicle information, including these issues, and regarding potential use cases, etc.

(4) Delivery delay characteristics of predictive SPaT information

For predictive SPaT information, we measured the delay time for the three methods shown in Fig.11 when outputting the information from the short-range and medium-range area server in the data management and delivery section to the test vehicle on-board equipment (BOX-PC) in the data conversion and output to vehicle control section (test-vehicle side) as shown in Fig.2. With the PUSH method, the information was sent from the short-range and medium-range area server to the test vehicle on-board equipment in 1 second intervals, so there was a delay of roughly 1 second. With the PULL method, the test vehicle requested information from the short-range and medium-range area server in 1 minute intervals, so there was a delay of 60 seconds or longer. For the specified intersection PUSH method, on the other hand, the vehicle side issued requests for information for intersections for which it wished to receive data (using the MQTT protocol). The latest predictive SPaT information for the intersections was provided in response to these requests. This made it possible to keep the transmission load down and to keep delay times to roughly 100 ms, the shortest delay time of any of the three methods. Predictive information was finalized 3 seconds in advance, and the delay time was roughly 100 ms, so vehicles could use SPaT information sufficiently far in advance of the starts of traffic signal cycles. For predictive SPaT information, it would be best to use the specified intersection PUSH method.

3 Effectiveness of traffic environment information

Through the FOTs and deliberations in Tokyo Waterfront City FOTs working group meetings, which involved the participation of all test participants, test environment providers, the Cabinet Office, related government agencies, NEDO, and the like, we confirmed the effectiveness of the four types of traffic environment information

3.1. Effectiveness of rainfall information

The rainfall information delivered during the FOTs is envisioned for use in a wide range of applications, including switching from automated driving to manual driving, providing drivers with caution information, predicting travel times, adjusting vehicle speeds, and adjusting following distances. Also, we confirmed that when rainfall information is used by drive assist or automated driving systems, the systems would be able to respond to sudden weather changes if the amount of time taken from generating to delivering information were shortened. Rainfall information use cases should be clarified and fleshed out in preparation for practical implementation, and ongoing deliberation should be conducted regarding systems for delivering information based on these use cases.

3.2. Effectiveness of lane-specific road traffic information

Lane-specific road traffic information appears to have tremendous potential when there is traffic congestion (including traffic congestion extending from exits to side strips), when making vehicle control decisions (following/lane changes), and when providing drivers with caution information recommending making lane changes or driving route changes far in advance in the event of driving impediments (such as accidents or fallen objects). In situations such as this, the information is envisioned as being used in the issuing of requests to handover from automated driving to manual driving, in preliminary deceleration, in making lane changes, in making route changes, and more. Furthermore, with regard to the content of the messages sent in the FOTs, there were requests to add information regarding information reliability, traffic congestion likelihood based on statistical information, information regarding whether traffic congestion areas are growing longer or shorter, the average vehicle speeds at the tail ends of traffic congestion, and the linking of tail end information and start point information. We strove to share this information with the FOTs participants responsible for generating lane-specific road traffic information.

3.3. Effectiveness of mock emergency vehicle information for vehicles on emergency calls

Mock emergency vehicle location information would be effective for driving assistance and vehicle control because it would enable vehicles to learn in advance about approaching emergency vehicles. Use cases for this information would include providing sufficient advance notice to take necessary action when an emergency vehicle is approaching (such as decelerating, stopping, pulling off to the side of the road, switching from automated driving to manual driving, alerting the driver, etc.), using the information together with high-accuracy map data to confirm if an approaching emergency vehicle would directly affect one's own vehicle, and determining if an approaching emergency vehicle detected by one's own vehicle's cameras is on an emergency call or not. In preparation for real-world deployment, additional discussion is needed within the industry regarding use cases and information utilization with respect to how autonomous vehicles are to behave when an emergency vehicle is approaching.

3.4. Effectiveness of predictive SPaT information

The FOTs confirmed that traffic signal prediction information (V2N) could be used in use cases such as situations involving impediments to traffic signal color identification or deviations in traversal decision-making,[2] for which short range communication (V2I) was also effective. Information can be received not only for the area immediately surrounding a vehicle, but also for a large area, so it could be applied to driving route plans to reduce the number of vehicle stops and shorten the amount of time required, thereby contributing to the achievement of carbon neutrality. Even in suburban and rural areas where traffic signals are far apart, the information could assist in setting cruising speeds and providing driving assistance, so laterally expanding the area for which V2N predictive SPaT information is provided has the potential to assist with the expansion of areas where automated driving is possible. Ongoing deliberation is recommended in preparation for real-world deployment.

4 Conclusion

An information transmission system that used a public long range network (V2N) was set up in the Waterfront City area. Information delivery testing was performed for rainfall information, lane-specific road traffic information, mock emergency vehicle information for vehicles on emergency calls vehicle information, predictive SPaT information, and the like. The results of these tests were discussed in FOTs working group meetings, and we evaluated the delivery system and how the information could be used. We organized information regarding the issues involved in this utilization, and verified the effectiveness of the information. Based on the issues identified through these FOTs and the results of the effectiveness evaluation, use cases should be clarified, discussions should be held regarding situations where delivered traffic environmental information can be utilized, and progress should be made in the real-world deployment of this information.

[Reference]

(1) FOTs in the Tokyo Waterfront Area Consortium: FY2021 "Cross-ministerial Strategic Innovation Promotion Program (SIP) Phase Two - Automated Driving (Expansion of Systems and Services)/Implementation of FOTs in the Tokyo Waterfront Area" Results Report, March 2022, pp.42-73, (2021)

(2) Yoshiaki Tsuda, et al: "Data Analysis of the FOTs in Tokyo Waterfront City Area, SIP 2nd Phase : Automated Driving for Universal Services —Mid-Term Results Report (2018–2020), pp.54-62, (2021)

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2) Technological Development to Provide Traffic Signal Information to Automated Vehicles Connected to Infrastructures (V2N)

Yukiko Hatazaki (NIPPON SIGNAL CO., LTD.), Yuichi Takayanagi (Panasonic Connect Co., Ltd.), Toru Mabuchi (OMRON Social Solutions Co., Ltd.), Shunichi Kawabe (UTMS Society of Japan)

(Abstract) From the viewpoint of improving reliability and availability, three requirements for SPaT (Signal Phase and Timing) information for automated driving were identified: (1) the error between SPaT information and actual light color should be less than ±300ms, (2) errors in SPaT information should be detected and the vehicle should be notified of the errors, and (3) the provision of SPaT information in various signal control systems should be achieved. First, for the V2I system, the technical specifications for SPaT information provision infrastructure using V2I were decided on by FY2020. Next, from the viewpoint of reducing maintenance costs, etc., we started studying the V2N system using mobile lines in FY2019, and by FY2021, through FOTs (Field Operational Tests) in Saitama Prefecture, we worked on the establishment of SPaT information provision technology using the V2N method. We also studied the social functional requirements of the SPaT Information Center, which constitutes the core of the social implementation model envisioned in the study of the V2N method. Based on these studies, in FY2022, we conducted FOTs integrating a series of components from SPaTs at 17 locations to simulated on-board devices, and verified the effectiveness of the three SPaT information provision methods and of the overall system configuration.

Keywords: V2N, SPaT information provision, SPaT Information Center, MQTT

1 Purpose of the Study

Automated vehicles recognize SPaT light colors using on-board cameras, but there are some issues, such as the inability to recognize signal light colors with a single camera, and reduced recognition accuracy due to backlighting. As a measure to address these, there is a need to provide SPaT information from the infrastructure. V2I systems have already been developed, but there have been issues in terms of maintenance costs. Therefore, research and development was begun in FY2018 to establish a new SPaT information provision method that utilizes cloud computing and other means with the aim of reducing costs. (Table 1)

Table 1: Overall research and development plan

FY 2018	Case study and examination of issues with highly feasible methods ・Case study of methods other than V2I communication to provide SPaT information ・Sorting out of SPaT information provision methods other than V2I communication ・Study of measures to address issues with a view to realization of methods with high feasibility
FY 2019	Verification using a simulated system and preparation of draft specifications for a model system ・Detailed functional and technical requirements for traffic signal information provision methods ・Verification of three SPaT provision method proposals with a simulated system ・Draft specifications for the model system to be built in the FY2020 project
FY 2020	Model system test in a single prefecture and specification study of a SPaT information aggregation system ・Development and verification of a model system for provision of SPaT information by individual prefectural police forces ・Study of specifications for the Police Agency's SPaT information aggregation system
FY 2021	Study of the SPaT Information Center for social implementation ・Study of SPaT Information Center requirements ・Study on coordination and integration with other information ・Verification to improve the accuracy of SPaT information
FY 2022	Construction and verification of the prefectural police system and the National Police Agency SPaT information aggregation system ・Establishment and effectiveness verification of a SPaT information provision system at prefectural police departments ・Establishment of a SPaT information aggregation system for the National Police Agency ・Verification of effectiveness

The method of providing SPaT information is based on a system configuration in which SPaT information generated at traffic control centers and SPaT controllers (hereinafter referred to as "signal controllers") is first aggregated in the National Police Agency's SPaT information aggregation system via LTE and other lines, and then sent to a distribution center. We determined that the control center-based method, the centralized control-based method, and the controller-based method would be the most applicable methods. Fig.1 shows the three methods.

2 Study of the socio-functional requirements of the SPaT Information Center

The social implementation model studied in this project is shown in Fig.2. In this model, in addition to the direct users of SPaT information, companies promoting automated driving, local governments operating automated driving buses, and others, they bear the cost in course of the service operation.

We asked the opinions of experts, related companies, and others through interviews and questionnaires about the SPaT

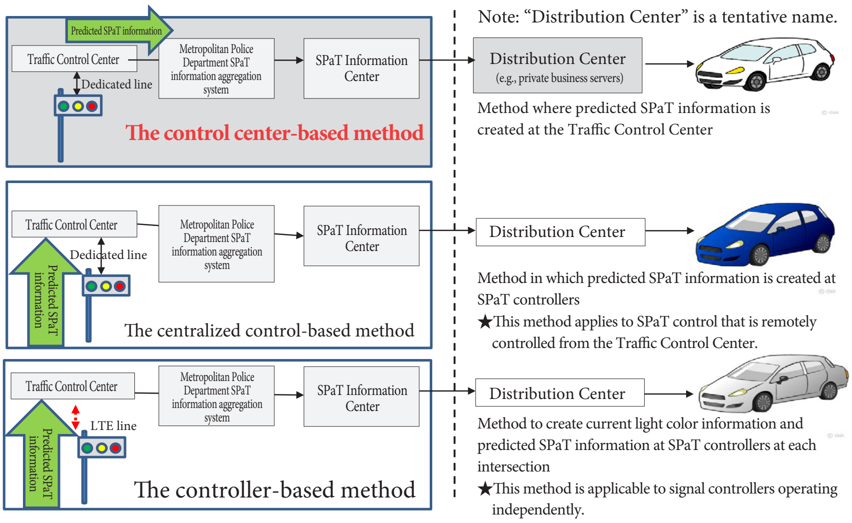

Fig.1: SPaT information provision methods

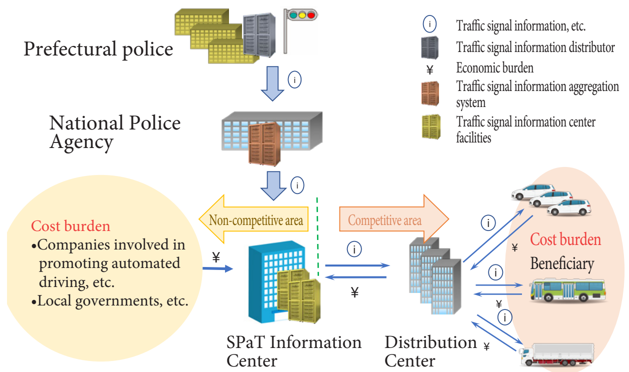

Fig.2: Schematic of a social implementation model

Information Center, which exists between the non-competitive areas (police area + cooperative area) and the competitive areas on the route from the prefectural police that manages SPaTs to vehicles, because it plays a decisive role in the success or failure of social implementation.

Table 2: Necessary social functional requirements

Item	Necessary social requirements	Issues
Operation of organizational bodies	·Management planning functions ·Functions to secure financing	·Securing human resources (finance experience, including experience securing beneficiary contributions) ·Facilitation of communication with relevant agencies
Relaying SPaT information	·Relay-related operational functions ·Recovery functions in case of an event	·Securing human resources (operations experience) ·Experience in similar work
Development, maintenance and management of SPaT Information Center facilities	·SPaT Information Center Facility planning, design and related ordering functions ·Cybersecurity management functions ·Routine fault handling ·Customer support	·Human resources (field engineering functions) ·Experience in similar work
Technical connections to customers	·Installation of equipment for connections, etc. (including construction work on SPaT Information Center facilities) and other implementation functions	·Securing human resources (technical management abilities) ·Experience in similar work
Procedural connections to customers	·Receipt (confirmation of conditions) functions ·Cost (beneficiary's portion) collection functions	·Securing human resources (customer service experience) ·Experience in similar work
Technical support to customers	·Technical support to confirm specifications, standards, etc.	·Securing human resources (knowledge of newly developed SPaT information provision technology)

* Red font shows personnel who must be secured by the SPaT Information Center. Operations and facilities can be externally dependent.

The results of the study included a variety of issues, such as the need to accurately identify needs, consideration of local needs, the utilization of the human resources and expertise of agencies that have been providing transportation information, and the need for careful consideration of the initial and maintenance cost burden. Table 2 shows the necessary social functional requirements. There were several comments on the need for various types of human resources. There were also opinions that it is necessary to provide the same level of service under nationally standardized interface conditions and to ensure a nationwide system that can operate 24 hours a day.

The conditions for the implementing entities are shown in Fig.3.

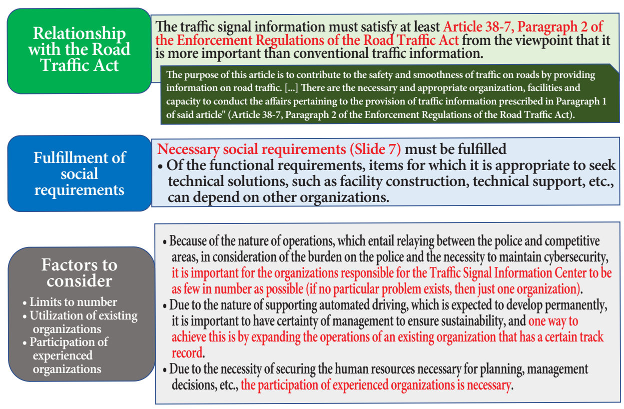

Fig.3: Conditions for Implementing Entities

3 Methods of providing SPaT Information

3.1. Overview of the Control Center-based Method

The control center-based method is a method in which SPaT information is generated by a SPaT information distributor installed in the Traffic Control Center for centrally controlled SPaT controllers.

Centralized control is control in which the Traffic Control

Center determines signal control parameters, such as cycle length, split, and offset, using sensor information, etc., and dictates them to the signal controller before the signal cycle begins. SPaT information may differ from cycle to cycle.

With the control center-based method, SPaT information is predicted using the control history of the previous cycle of the signal controller and the signal control parameters dictated to the signal controller. With this method, the accuracy of the time stamp added to the control history is important.

In the FOTs in Saitama Prefecture (FY2020), the target SPaT information accuracy was not achieved due to the low time accuracy of the signal controller at that time. Therefore, in FY2021, we tested the latest specification of the signal controller with the addition of time synchronization by GPS, and verified that the target performance could be achieved through in-factory verification.

In the course of the study in FY2021, it was recognized that, as a new issue, although signal controllers have a function to determine the split when tracking offsets, the method of processing fractions of seconds of less than 100 milliseconds differs from manufacturer to manufacturer, resulting in a maximum error of about 200 milliseconds. Among the companies contracted for this project, we verified that no error occurred with the SPaT controller of one company as it generates SPaT information in accordance with the method for processing fractions. (Fig.4) We are investigating possible countermeasures for signal controllers manufactured by other companies.

The main functions of the SPaT information distributor are shown in Table 3. In addition to SPaT information generation, distribution, and data storage functions, the system has

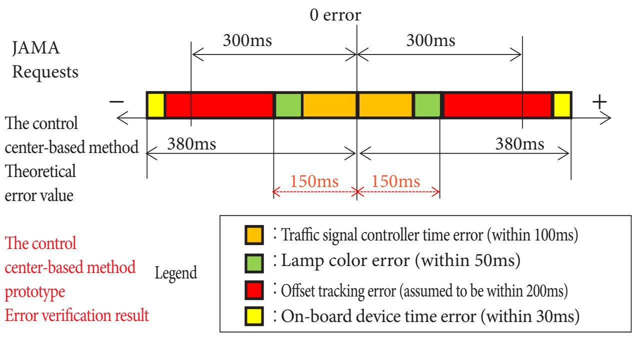

Fig.4: Error model and validation results of the control center-based method

Table 3: Main functions of SPaT information distributors

Function name	Function overview
Information gathering	Information used for SPaT information generation is collected from the signal controller via the terminal control block.
SPaT information generation and distribution	SPaT information of the control system is generated and distributed via MQTT brokers.
SPaT information conversion and distribution	Converts the SPaT information from the Centralized method and distributes it via MQTT brokers.
Data accumulation	Various information updated by the MQTT broker is stored in the database.
SPaT information monitoring	Monitors whether the distribution of SPaT information has been stopped.
SPaT information verification	Verifies the accuracy of the SPaT information from the control method.
MQTT broker	Receives connections from SPaT information aggregation systems, SPaT information roadside units, etc., and distributes information.

functions for intersection management information for managing SPaT information, a predicted SPaT information verification function for constantly monitoring the accuracy of SPaT information, and other functions. The device also has an MQTT broker function and uses the MQTT protocol to communicate with external devices such as SPaT information aggregation systems and SPaT information roadside units.

The MQTT protocol is used because it is advantageous in distributing SPaT information with low latency since new information can be sent in a push fashion. Communication messages are created based on a common draft standard that is referenced by each device that generates or uses signaling information.

3.2. Overview of the Centralized Control-based Method

The centralized control-based method, like the control center-based method, is applicable to centralized controllers. Unlike the control center-based method, SPaT information is generated on the signal controller side, enabling immediate processing, such as sensitivity control, which cannot be achieved with the control center-based method.

In the SIP project, formally titled "Research and Development of Advanced SPaT Information Provision Technologies for Automated Driving" (completed in FY2020), a SPaT information generation method for SPaT controllers had already been established, so in realizing the centralized control-based method, compliance with that method was a prerequisite.

3.3. Outline of the Controller-based Method

The controller-based method is for non-centrally controlled SPaT controllers that do not have communication functions. Two methods were considered: one was to add SPaT information roadside units to the currently operated signal controllers (roadside device method), and the other was to add signal controllers capable of generating SPaT information and wireless devices.

In the roadside device method, SPaT information is generated by detecting the on/off of light signals with a CT sensor. Since SPaTs are controlled according to the day of the week and time of day in non-centrally controlled SPaTs, the SPaT information can be easily predicted. However, because offset tracking is performed when the signal pattern changes, it is difficult to predict with an error of 300 milliseconds or less, and during a FOT in Saitama Prefecture in FY2020, a decline in accuracy was observed. As a result, in FY2021, measures were taken to address this by learning the offset tracking behavior in 100 millisecond increments.

4 Verification by Prefectural Police Model System

4.1. Outline of the Prefectural Police Model System

Fig.5 shows an overview of the prefectural police model system configuration.

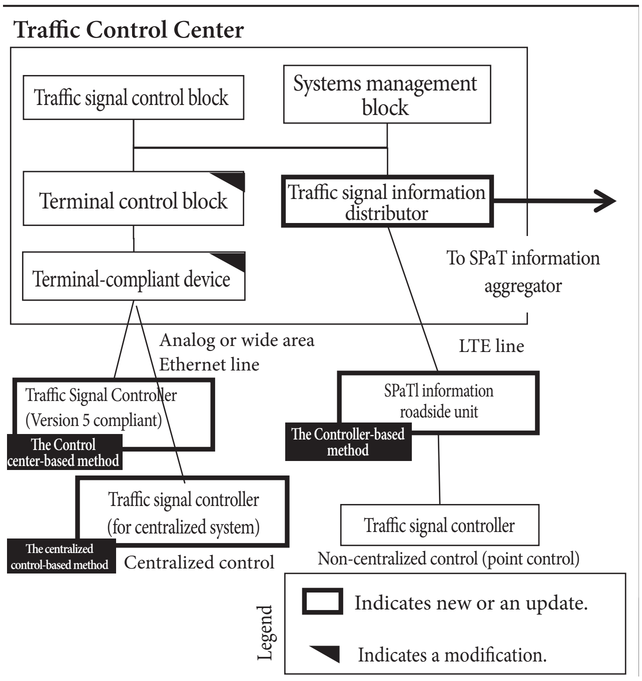

Fig.5: Overview of the system configuration of the prefectural police model system

4.2. Purpose of Verification

The purpose of this verification is to demonstrate that SPaT information at a wide variety of intersections can be provided accurately and in a cost-effective manner using equipment in operation. To this end, the verification was conducted at the intersections shown in Table 4.

Table 4: Verified intersections and signal control status by method

Item / Methods	Number of intersections	Number of recall controls	Number of right-turn sensitive controls	System Number of controls	Nighttime Number of flashes
The control center-based method	9 Note	6	0	9	0
Centralized method	6 Note	3	3	4	0
Controller-based method	5	1	0	4	4

Note: Both the Controller-based method and Centralized method are implemented at three intersections.

4.3. Verification items

Table 5 shows the main verification items using the prefectural police model system.

Table 5: Main verification items using the prefectural police model system

Perspective	Verification items
Verification of SPaT information generation	Improvement of accuracy of Controller-based method and Controller-based method Confirmation of compliance with each signal control such as recalls and right turn sensitivities
Verification of SPaT information distribution	Verification of communication interface standardization Verification of intersection definition information Verification of communication delay time Verification of Δt acquisition in a simulated on-board unit
Verification focusing on actual environment and operations	Verification of connection to SPaT information aggregation system Verification of the effects of actual line performance, GPS reception environment, etc. on the accuracy of SPaT information Verification of the long-term operation of SPaT information provision Verification of monitoring of SPaT information provision status

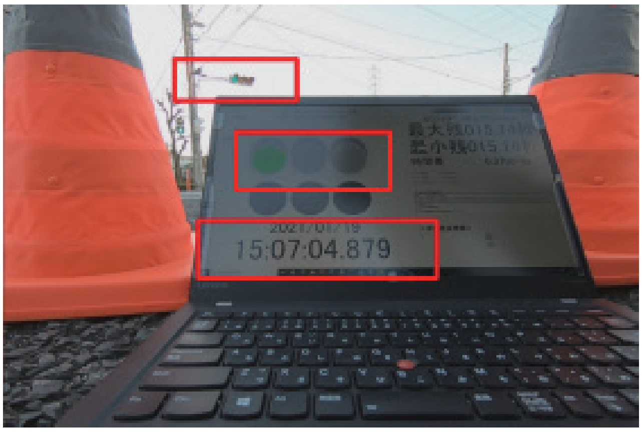

Fig.6: Capturing of video

4.4. Verification Method

As in the Saitama FOTs in FY2020, the accuracy of the SPaT information was verified by taking video of the signal lights and the simulated in-vehicle devices and by calculating the error in the number of remaining seconds of the SPaT information when the signal light color changes. Fig.6 shows the verification from the Saitama FOTs in FY2020. In addition to capturing video, the information stored in each device was compared to calculate the delay time and verify the consistency between the data.

5 SPaT Information Aggregation Systems and SPaT Information Centers

5.1. Overview of Functions

A schematic diagram of the SPaT information provision service is shown in Fig.7.

The SPaT information aggregation system collects and consolidates SPaT information from SPaT information distributors installed in the 47 prefectures. The collected SPaT information is in the same format and can be handled in the same way regardless of the method used. At the same time, the SPaT Information Center distributes the received SPaT information to each private SPaT Information Distribution Center. In order to realize social functions, the SPaT Information Center also manages the distribution history, aggregates operational results, and provides operational support functions such as format verification of SPaT information.

Traffic control systems in prefectural police departments generate predicted SPaT information using either the controller-based method, the centralized control-based method, or the controller-based method, and distribute it via SPaT information distributors. Next, the SPaT information aggregation system installed in the National Police Agency aggregates the predicted SPaT information distributed by the SPaT information distributors nationwide and distributes it to the SPaT Information Center. Finally, the SPaT Information Center distributes the predicted SPaT information to distribution centers operated by private operators. Ultimately, the predicted SPaT information is distributed to automated vehicles via the distribution

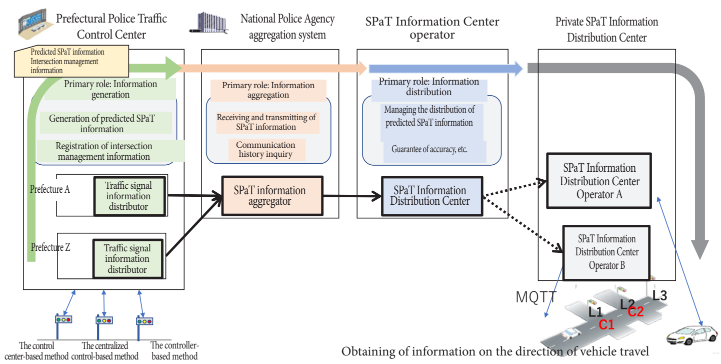

Fig.7: Overview of functions of SPaT information aggregation systems

centers.

Considering the social requirements of the SPaT Information Center, the functions of each system were examined from the standpoint of the SPaT information aggregation system and the SPaT Information Center, and the functions were organized so that the SPaT Information Center would ensure the consistency of SPaT information rules and manage the information provided, while the aggregation system would only amalgamate routes and monitor communications.

5.2. Evaluation of Communication Time Up to SPaT Information Reception in an Integrated Environment

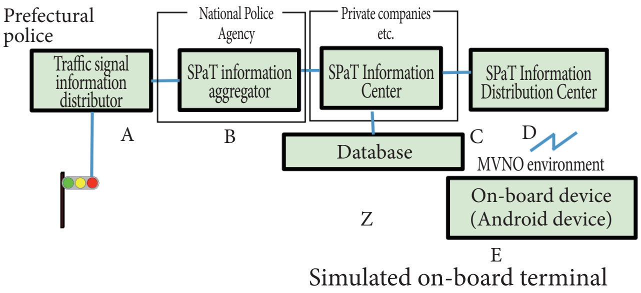

Fig.8: Streamlined test environment

The SPaT Information Center distributes SPaT information for more than several thousand intersections nationwide and is also considering a data storage function, but there is concern that the processing delay time will increase. The system configuration shown in Fig.8 was constructed by utilizing the MQTT protocol as a common platform to create a communication load verification environment where SPaT information is streamlined from simulated signal controllers to simulated on-board devices.

The performance of the SPaT Information Center system was measured and examinations were conducted for faster SPaT information transmission. However, the area from the SPaT Information Center to the on-board device is a competitive area, and this is only a reference example of implementation.

SPaT information must reach the on-board device Δt seconds before the light color turns yellow (Δt is about 5 seconds). Therefore, a simple simulation system was constructed and the communication delay time was measured.

A low bandwidth (12.5 Mbps) environment was established between the SPaT information aggregator and the SPaT Information Distribution Center by designing on paper the required bandwidth at 2,048 intersections (four-prefecture connection). (The bandwidth between A and B in Fig.8) In addition, between the SPaT Information Distribution Center and the simulated on-board device a permanent communication call was established via one-second interval MQTT-PING communication.

Fig.9 shows the average daily results of delay time including communication time for each section in Fig.8.

The predicted SPaT information was measured using 585 bytes of data, assuming a complex intersection.

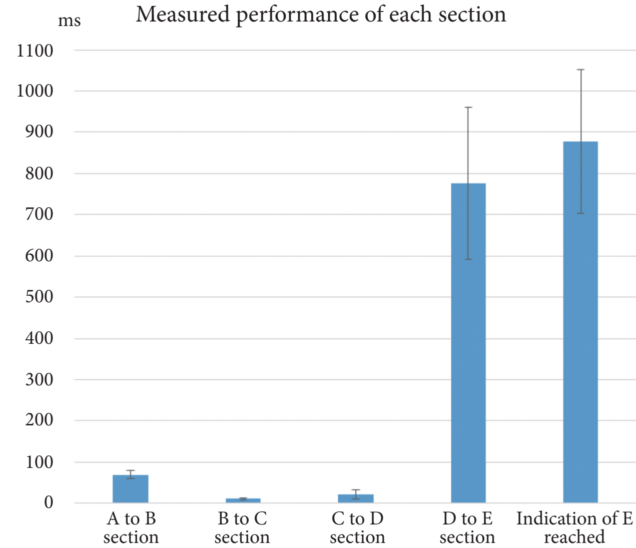

Fig.9: Communication processing time for each section

We were able to demonstrate that data transmission from a roadside SPaT to a simulated on-board device is possible in about one second. Although it was under limited conditions in a simulated environment, it is very significant that we were able to demonstrate that this service can be established via devices that are equivalent to those in the real environment.

5.3. FY2022 Verification Environment

In FY2022, the prefectural governments and the National Police Agency prepared a verification environment consisting of a SPaT information distributor and a SPaT information

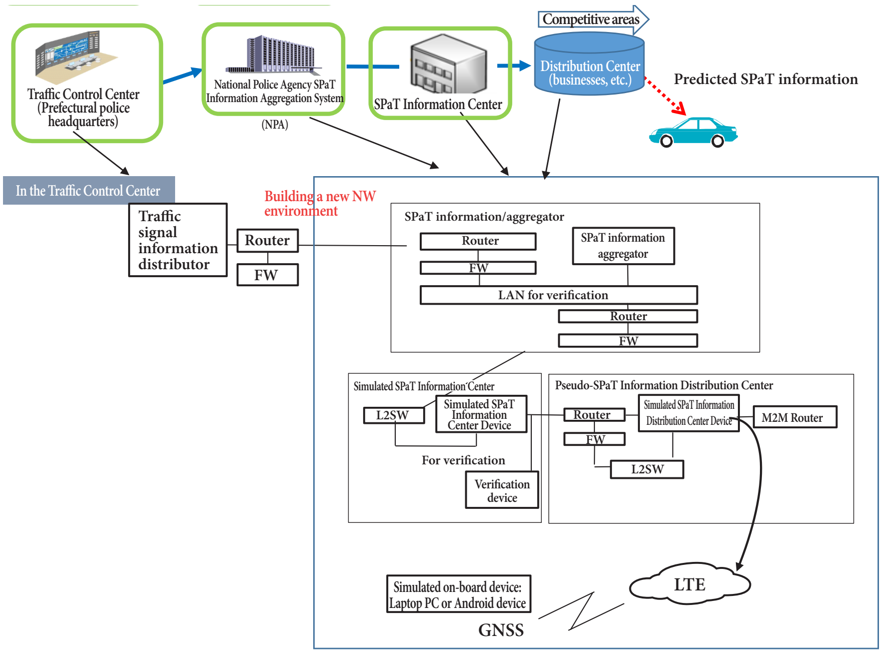

Fig.10: Testing environment for FY2022

aggregation system developed based on the specifications, as well as simulated devices set up from the SPaT Information Center to the on-board devices, and conducted verification. (Fig.10)

As for the circuit network, the evaluation was conducted on a closed network in line with other SIP-adus FOTs environments.

The purpose of the verification environment using simulated devices from the SPaT Information Center to the on-board devices is to provide an environment that is assumed to be more similar to that of social implementation.

6 Examination of the Linkage Between SPaT Information and High Precision 3D Maps

In the FOTs in the Tokyo waterfront area conducted from FY2019 to FY2020 as part of the second phase of SIP-adus project, SPaT information linked with a high precision 3D map is provided, utilizing the results of the "Research and Development of Advanced SPaT Information Provision Technologies for Automated Driving". We conducted a survey on the method and summarized the information necessary for linking SPaT information and high precision 3D maps as follows.

- Intersection information: Intersection ID and intersection location
- Information to identify which intersection is pointed to on the map
- Signal light information: Light ID and location information
- Travel route: Combination of in-flow and out-flow routes
- Reference light information: Reference lights for each travel route
- Stop line information: Location information
- Information that links lights on the map with the direction of SPaT information

As for information necessary to link with high precision 3D maps, Table 6 shows a proposed functional arrangement for providing SPaT information by V2N.

Table 6: Proposed layout of functions linked to high precision 3D map

Prefectural and Metropolitan Police (including National Police Agency)	Cooperative areas in providing SPaT information (SPaT information centers, map vendors, etc.)	Competitive area (automakers, automated driving business operators, etc.)
Provides the following information ・Intersection ID to identify information and location information to identify the location on the map ・Direction ID and information to identify the location on the map	・Management of SPaT information correspondence table to link SPaT information (intersection ID, direction) with high precision 3D maps (stop line [direction], lights) ・Linking high precision 3D maps and SPaT information	Distribution of SPaT information to vehicles

In the FOTs in the Tokyo waterfront area, the SPaT information correspondence table was managed by the simulated on-board devices, but for social implementation, this information should not be managed by each operator but by the cooperative area.

7 Conclusion

7.1. Outcomes of the Project

The introduction of absolute time and new specifications for SPaTs (e.g., synchronization of time by GPS and a change from control in 1-second increments to control in 0.1-second increments) have enabled the V2N SPaT information technology to meet the technical requirements for providing SPaT information required for automated driving, including an error margin of ±300ms or less between SPaT information and actual light colors. This is a significant step forward in terms of satisfying the technical requirements for the provision of SPaT information required for automated driving.

At the same time, regarding the technical functional requirements for the SPaT Information Center, which occupies the core position of the social implementation model assumed in this research and development, we proposed 58 functions, 14 screens and 5 forms. Based on the functional requirements of the proposed SPaT Information Center, we also studied the functions that can be reduced from the proposed specifications of the SPaT information aggregation system studied in FY2020.

For cybersecurity, we proposed 15 countermeasure requirements from the perspective of availability, continuity, and scalability.

7.2. Future Technical Issues and Responses

Technical issues remain, such as fail-safe operations, offset tracking, and the delay in the notification of anomalies due to the communication time. Therefore, it will be necessary to continue technical examinations.

In FY2022, we implemented a SPaT information distributor for prefectural police and a SPaT information aggregation system for the National Police Agency. We also constructed a verification environment consisting of a simulated SPaT information center and distribution center, and conducted various verifications using the MQTT protocol. This enabled us to identify phenomena that could not be experienced in the simulated verification environment available until FY2021, and which would occur only in a real environment.

The remaining issues mentioned above and those identified in FY2022 will continue to be studied in FY2023 and beyond as part of independent research.

7.3. Differentiating Methods

For the V2N method, we studied the control center-based method, the centralized control-based method, and controller-based method, but the control center-based method, which we particularly focused on, is an especially promising technology to promote the process of social implementation because it can utilize existing traffic safety facilities. However, it is undeniable that the V2N method is not as good as the V2I method in terms of delay, fail-safe operations, and other technical aspects. In addition, methods other than the control center-based method studied for the V2N method have their own technical merits. Therefore, it is necessary to differentiate among the methods according to the traffic conditions at each intersection, the characteristics of signal control, the details of use cases, and other factors.

7.4. Efforts at Social Implementation

In addition, we will continue to study issues other than technical aspects that are necessary for social implementation, such as commercialization, and will continue our activities toward the realization of social implementation of automated driving at Level 4 or higher.

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3) Technological Development for Lane-level Road Traffic Information Using Probes Vehicle Data

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(Abstract) Autonomous automated vehicles operate based on a limited range of information. If there is an accident or other traffic congestion ahead then they may need to decelerate suddenly, and if there is heavy traffic then they may be unable to change lanes smoothly. At such times, allowing the traffic situation ahead to be known in advance for each lane (anticipatory information) would make it possible for automated vehicles to drive more safely and smoothly; for example, by decelerating earlier or changing lanes in a more prepared and relaxed way. With the spread of connected vehicles, a data acquisition environment for generating such anticipatory information is becoming available, but not in a format that enables direct lane-by-lane understanding of traffic conditions. This project aims to develop technology for lane-level traffic information, which would be considered highly useful for the safe and smooth driving of automated vehicles. As an element of this goal, the project established an FOT (Field Operational Tests) environment to confirm the level of lane-by-land data that can be generated from the probe information from vehicles currently on the market and then offer centralized aggregation and distribution of the generated data together with other road traffic environment data.

Keywords: probe vehicle data, Lane level road traffic information, traffic congestion tail, traffic congestion tail, turn signal information, FOTs

1 Purpose and Outline

In order to realize completely automated driving and a higher level of safe driving support, various types of road traffic environment data, including lane-level road traffic data, are expected to be utilized to anticipate conditions that lie beyond the range of on-board sensors. As roadside sensors can only make fixed-point observations, it is therefore necessary to develop a system to generate and provide road traffic data using probe vehicle data, allowing for monitoring of road traffic conditions of surrounding areas.

The creation of just such a system is the purpose of this project. We formed a study group of public and private stakeholders to develop a system for providing road traffic data from probe vehicle data. During the FOTs in the Tokyo waterfront area, probe data obtained from cars on the market was collected from probe operators and used in FOTs to create and distribute road traffic data, such as lane-level traffic congestion tail information for the Tokyo Metropolitan Expressway, proving the effectiveness of this data while also helping to highlight further issues.

2 Our Future Visions

2.1. The requirement for lane-level road traffic information

As shown in Fig.1, the on-board sensors in an automated vehicle can only collect information in a limited frontal area. If obstructions such as traffic congestion at the lane-level could be anticipated in advance, safer and smoother automated driving would become possible. Such information would also be beneficial for human drivers.

One possible source of such data is probe vehicle data obtained from increasingly popular connected vehicles. In

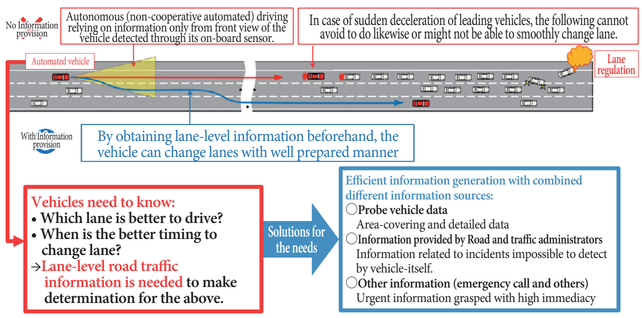


Fig.1: Requirement for lane-level road traffic information and its sources

addition, vehicles with emergency notification services in the event of an accident are becoming increasingly widespread; such information can also be expected to help immediately determine the location of obstructions caused by accidents.

2.2. Scope of project

As shown in Fig.2, the decision-making and operations performed by an automated vehicle in response to a road traffic event in front of it vary in accordance with the distance from the event. This project targets the use of this information in path planning, focusing on lane changes. The immediacy of the required information can be as short as a few minutes, meaning there is potential for generating the required information even from currently available probe data.

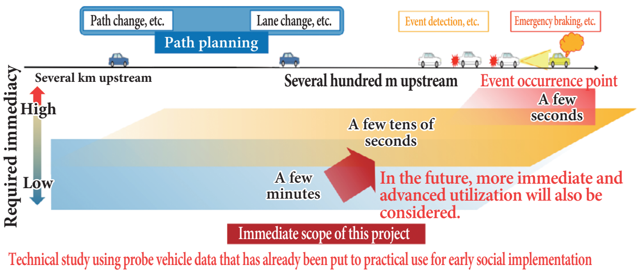


Fig.2: Scope of project

3 Study of each component technology

The overall flow of the provision of lane-level road traffic information is assumed to be the collection of data from probe operators, followed by the provision of the generated information to individual vehicles via the same probe operators. (Fig.3)

Therefore, the component technologies that need to be considered for the cooperative area of lane-level road traffic information generation can be broadly classified into the following five areas: (1) data aggregation from probe operators, (2) integration of data from multiple information sources, (3) generation of lane-level road traffic information, (4) conversion to data capable of representing a location, and (5) data distribution.

3.1. Study of data sharing (aggregation) functions

Here, we examined the data sharing specifications between centers when aggregating probe data from probe operator servers. The probe data obtained from probe operators is shown in Table 1. The aggregation time unit of the probe data was set to 5 minutes, based on such considerations as the current state of data collection.

Table 1: Used probe data

Aggregate link unit	Data item	
DRM link unit	Speed by direction at junction (5 min)	Speed by direction at link prior to junction
DRM link 100m division unit	Link speed (5 min)	Average speed
		Number of vehicles by speed classification Note 1)
	Number of vehicle events (5 min)	Number of braking occurrences
		Number of turn signal occurrences
		Number of steering occurrences

Note 1) Image of data format for number of vehicles by speed classification

Speed Classification	Number of vehicles
0＜V≦10km/h	
10＜V≦20km/h	
:	
110＜V≦120km/h	
120 < V	

In addition, it is assumed that a certain percentage of probe data is uplinked from the vehicle to the probe data provider center's server with a delay, and that the number of samples may not be sufficient by taking only the most recent 5 minutes of data. Therefore, in the data sharing (aggregation) phase, we considered the following points (1) and (2), and made it possible to use up to 30 minutes old data retroactively. (Fig.4)

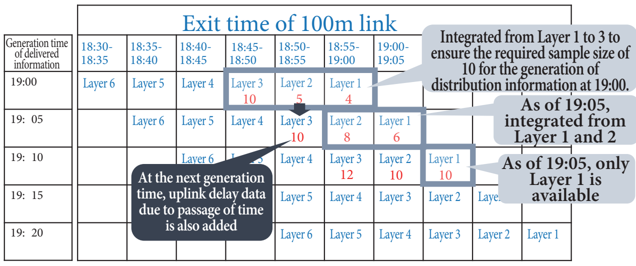


Fig.4: Data collection method giving consideration to uplink delay

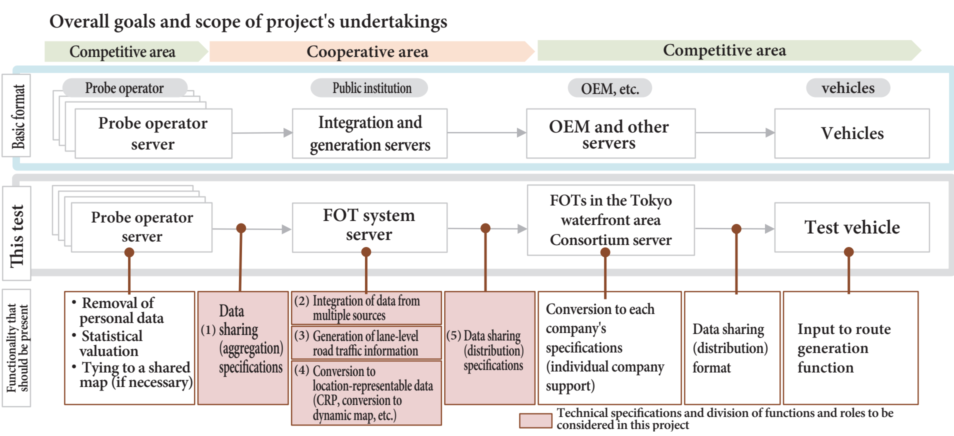


Fig.3: Scope of this study

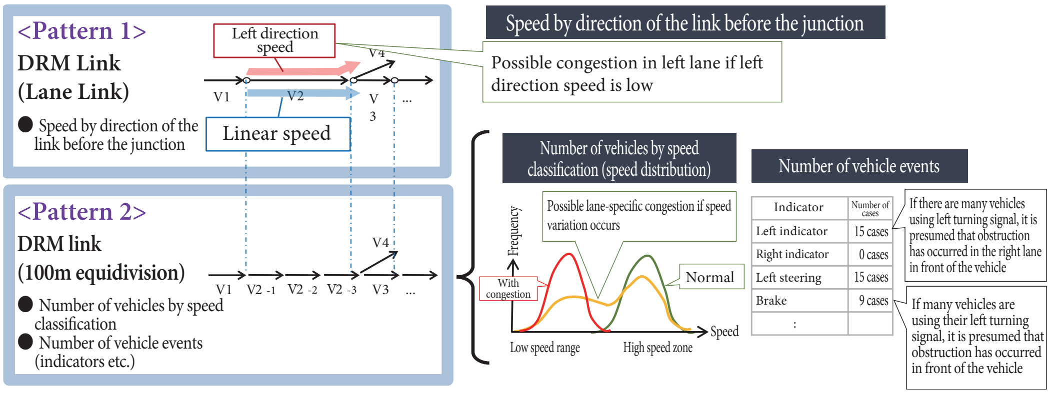


Fig.5: Basic concept of generating lane-level information from probe information tied to road links

(1) The data is collected in 5-minute increments (called "layers"), based on the travel time of the probe vehicle and including uplinked data that comes in late, with data collecting going back a maximum of 30 minutes in the past.

(2) Each segment also aggregates data from the previous information generation time collected up to that point. Layer 1 aggregates the most recent 5-minute data, while Layer 6 aggregates all levels of 5-minute data from the previous 30 minutes.

When estimating average speed with a certain accuracy from sample data, an error of ±10 km/h (95% confidence level) is considered to be acceptable when 5 or more vehicles are acquired, and so the base level for minimum number of samples was set at 6.

We also studied data items and data definitions collected from probe operators and subsequently defined a unified data format (JSON format). Using this format, we collected probe information from probe operators and conducted the FOTs (field operational tests) as reported in Section 4.

3.2. Study of functions to integrate data from multiple sources

Here, we examined the specifications for processing the integration of probe data collected from multiple providers. When integrating probe statistics from multiple probe providers into single link unit data, the travel speed and travel speed by direction took the form of averages weighted by the number of samples from each probe provider. In addition, quantitative data such as speed tier data and other vehicle information (number of activation of turn indicator, etc.) used the sum of the values counted by each probe operator.

3.3. Study of function for generating lane-level road traffic information

Here, we examined the technical specifications for generating lane-level road traffic information from the lane-specific probe data as integrated in the previous section. First, the location seeing a speed reduction in the direction of travel are identified based on the number of vehicles by speed classification (speed distribution) in 100-meter link units. If the distribution of the number of vehicles by speed layer straddles the line between low speed and high speed, it is assumed that some lanes are congested. In this case, at the junction, the lane corresponding to the direction of the junction is determined to be congested based on the speed by direction (in DRM link units); in other locations, the direction of the obstructed lane (left/right) is determined based on turn signal information (in 100m link units). (Fig.5)

3.4. Study of function for conversion to representable data

Here, we examined the specifications for converting lane-level traffic information generated on the Metropolitan Expressway into a location-representable data format for superimposition onto a high precision 3D map. In this project, the probe data is collected from the probe operators in link format, with the DRM links divided into 100-meter segments to improve the resolution of the direction of travel, and during the creation of lane-level information lane numbers were generated to display alert information at the upstream end of the link. For the lane representable data format we adopted an expanded DRM-DB specification[(1)], which is compatible with the data collected from sources such as OEMs. Use of a high precision 3D map then allows for the creation of a node-link map expressing the number of lanes in each 100-meter section, and makes it possible to represent warning information for each lane.

3.5. Study of data sharing (distribution) functions

Here, we examined the required data sharing specifications between centers when distributing the generated information to servers that relay the information to participants in the testing. Specifically, the representation of the lane-by-lane information for each 100-meter link segment by sending the latitude and longitude information of the node in question and the lane number in which the alert information is displayed. The distribution specifications were based on the Vehicle Information Shared API Specifications from[(2)] Japan Automotive

Software Platform and Architecture (JASPAR), with alert information content used to distribute the information.

4 Outline of Lane-Level Road Traffic Information Distribution Field Operational Tests

In order to evaluate each component technology, we constructed a FOT system for two routes on the Metropolitan Expressway. The system was connected online with probe information providers and capable of delivering information processed in real time.

4.1. Overall schedule

The first FOT was conducted in the winter of FY2020. A total of four FOTs were ultimately conducted, seeking to improve information accuracy while implementing various enhancements based on the PDCA cycle. (Fig.6)

4.2. Overall configuration of the field operational tests

The test system constructed for the FOTs was as shown in Fig.7. The system was connected online to probe providers and the own system of the Consortium for the FOTs in the Tokyo waterfront area, enabling the distribution of information to vehicles participating in the tests. In addition, starting with FOTs in FY2021, various types of road traffic environment data (rainfall information, V2N traffic signal information, etc.) that could be used for appropriate decision-making and control of automated vehicles was collated with lane-level road traffic information and distributed to vehicles participating in the tests.

Here, collection of road traffic environment data was performed according to the distribution specifications of the information source. On the other hand, the information was distributed to the OEM data center or equivalent in accordance with specifications based on the characteristics of the information. The data format for distribution was based on JASPAR (Dynamic vehicle information sharing specification), but when high real time performance was required, the data format of the information source was used without modification, taking into consideration the data volume after conversion with JASPAR specification (Table 2).

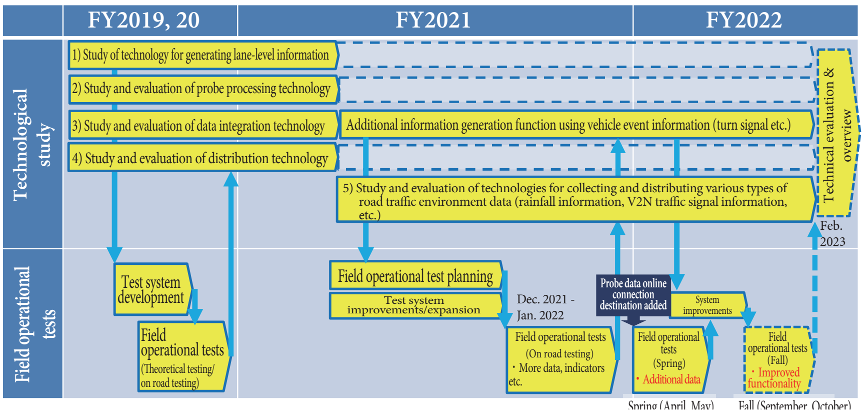


Fig.6: Overall schedule for FOTs

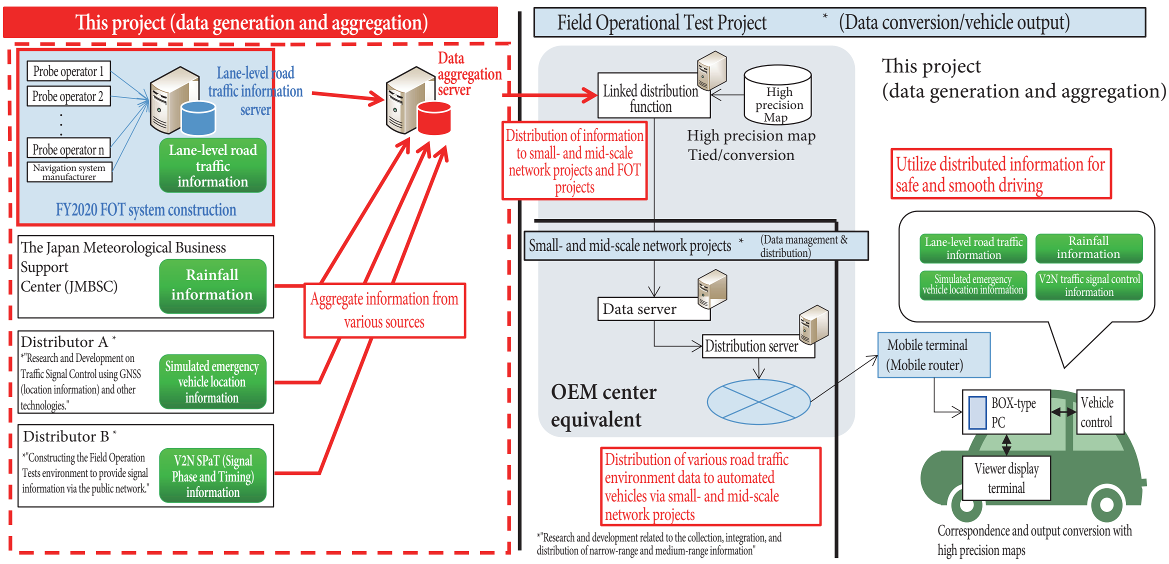


Fig.7: Overall structure of the FOT environment

Table 2: Collection and distribution methods for various types of road traffic environment data

By information type	Gathering information from sources				Information distribution to OEM center		
	Information source	Data representation format	Communication system	Collection cycle	Data representation format	Communication system	Distribution cycle
(1) Lane-level road traffic information	Lane-level road traffic information server	JASPAR: JSON format Content：attention	HTTP	1 minute cycle	JASPAR: JSON format Content：attention	HTTP	1 minute cycle
(2) Rainfall information	The Japan Meteorological Business Support Center (JMBSC)	GRIB2 *1	SFTP	5-minute cycle	JASPAR: JSON format Content: Environment	HTTP	1 minute cycle
(3) Simulated emergency vehicle location information	Distributor A	Proprietary binary format	UDP	As required	Proprietary binary format	Web Socket	As required
(4) Traffic signal schedule information	Distributor B	Proprietary binary format	UDP	As required	Proprietary binary format	Web Socket	As required

*1 GRIB2 format: WMO Maual on Code I.2 FM92 GRIB General regularly distributed information in binary form

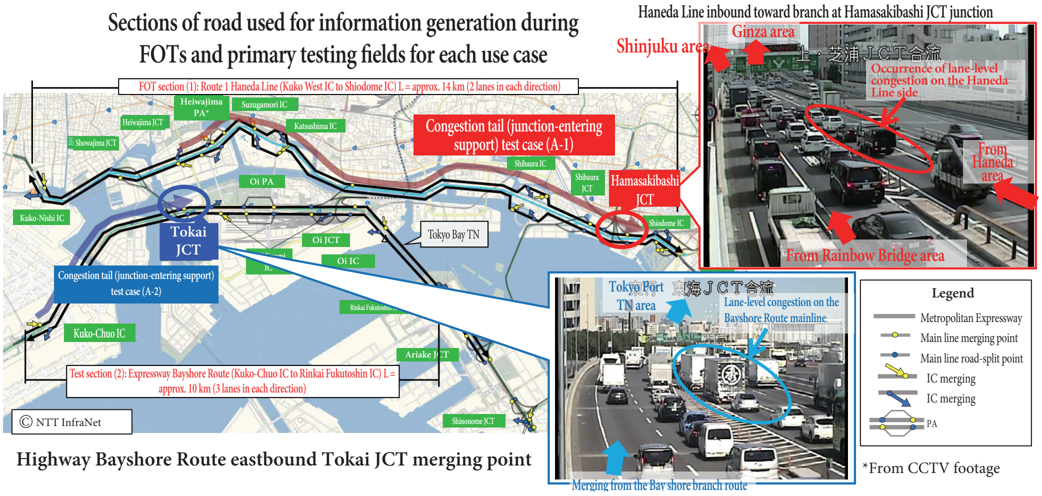


Fig.8: Sections of road used for information generation during FOTs

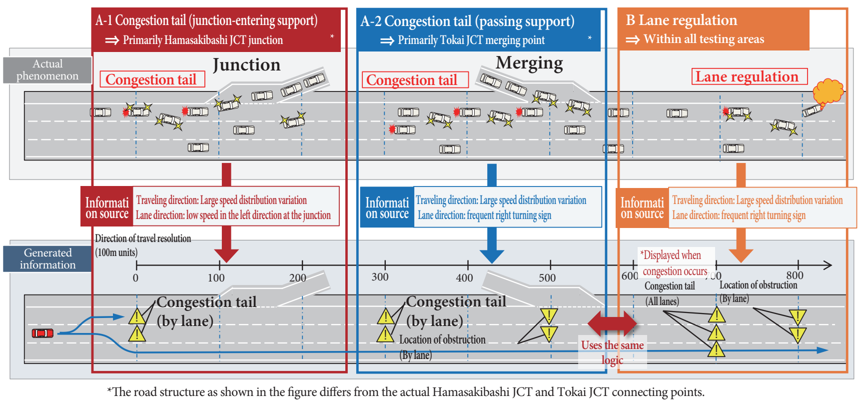


Fig.9: Overview of information generation in the target use cases

4.3. Sections of road used for information generation and primary testing points

During the FOTs, information distribution was conducted for two Metropolitan Expressway routes. (Fig.8) On the inbound Haneda Line, traffic congestion is a regular occurrence during mornings and evenings on weekdays, leading from the Hamasakibashi JCT. With congestion in the direction of Shinjuku overflowing into the left lane of the Haneda Line, causing lane-specific congestion depending on the time of day, we positioned this as the primary testing point for evaluating lane-level information. The eastbound Bayshore Route also has a high probability of encountering congestion on weekday mornings and evenings, starting from the Tokai JCT and caused by vehicles merging from the Bayshore Branch Route, and so this was also positioned as a primary testing site.

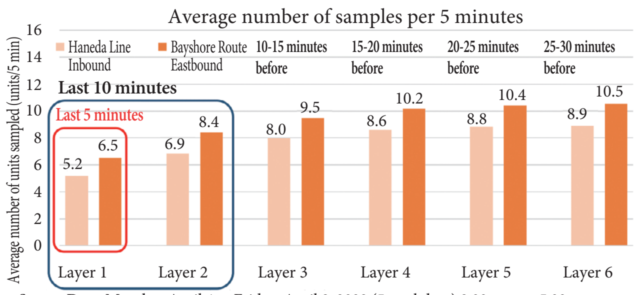
4.4. Overview of information generation in the target use cases

[A-1: Congestion tail (junction-entering support)] is intended to be provided at a branch. In the case of a lane-by-lane congestion, the system estimates the congested lanes based on the speed information in each direction at the junction and provides information on the congestion tail. [A-2: Congestion tail (passing support)] is intended to be provided at a merging point. In the case of lane-by-lane congestions, the system estimates the congested lane based on turn signal information and provides information on the congestion tail. Furthermore, at the head of the congestion, the system uses turn signal information to estimate the lane of the obstruction and provides information on the location of the obstruction. [B: Accidents, falling objects, etc.] is intended to be provided for all segments.

The information generation and provision logic is the same as that of [A-1: Congestion tail (passing support)], but when there is little information and congestion does not occur, the system uses turn signal information to estimate the lane of the obstruction and provides information as the location of the obstruction. Furthermore, the position of the congestion tail (obstruction) is distributed in 100-meter section and five-minute cycles as alert information. If the congestion is estimated to be in the left lane only, the alert information is displayed in all lanes except the rightmost lane, and if all lanes are congested (cross-sectional congestion), the alert information is displayed in all lanes. (Fig.9)

4.5. Status of acquisition of probe information

The number of sample vehicles collected online from the four probe service providers during the FOT period (spring FY2022) averaged 5.2 vehicles per 5 minutes in Layer 1 (the most recent 5 minutes) across the Metropolitan Expressway Haneda Line (Kuko West IC to Shiodome IC) FOT information generation section. (Fig.10) In addition, looking at the actual distribution of the number of vehicles sampled (Fig.11), only 40% of the sections and time periods in Layer 1 were able to obtain six or more vehicles, and for the remaining 60% of the sections and time periods, information was generated using samples from Layer 2 (last 5 to 10 minutes) or other levels.



Survey Date: Monday, April 4 to Friday, April 8, 2022 (5 weekdays) 9:00 a.m. to 5:00 p.m.

Fig.10: Average number of probe vehicle samples per 5 minutes

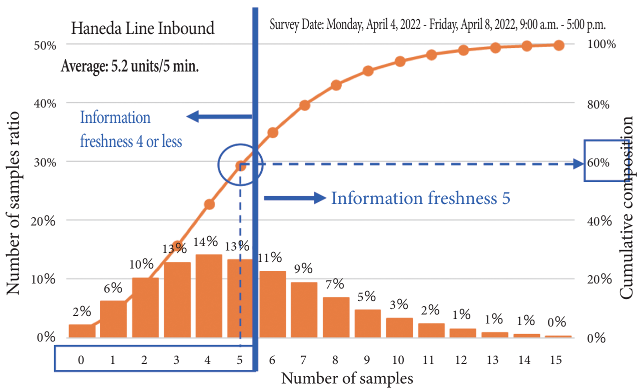
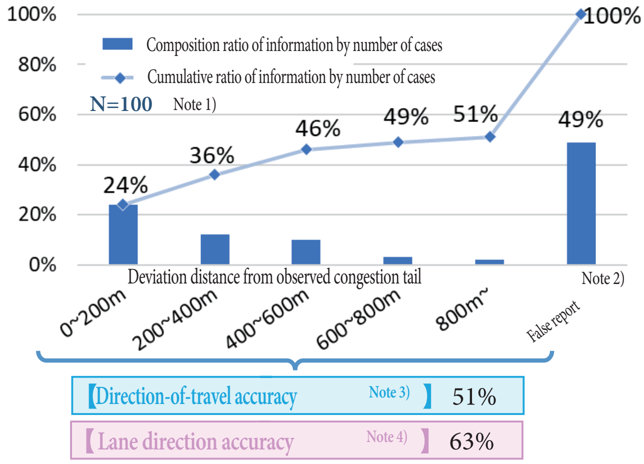


Fig.11: Probe vehicle sample volume distribution
(Level 1: most recent 5 min)



Note 1) Period for the spring testing (May 2022): 2022/5/10 - 5/31
Note 2) False report: When congestion tail information was displayed but the corresponding congestion tail was not observed, such as the test vehicle failing to encounter congestion.
Note 3) Direction-of-travel accuracy: Percentage of cases in which congestion actually occurred after the provision of information on a congestion tail.
Note 4) Lane direction accuracy: Percentage of the information on the congestion tail that is correct for the direction of travel and correct for the direction of the lane in which the congestion occurs.

Fig.12: Distribution of deviation distances from the observed congestion tail position

4.6. Verification of accuracy of generated information

Fig.12 shows the distribution of the number of information items by distance for the deviation distance between the congestion tail information provided during the FOT (spring FY2022) and the actual congestion tail position observed by the test vehicles. According to the results, 24% of the information items were provided within 200m of the actual congestion tail location, and 36% were provided within 400m of the actual congestion tail location. The directional accuracy rate--the percentage of cases where congestion was actually observed--topped out at only 51% of the total number of provided information on congestion. In those cases in which the direction was accurate, the lane directional accuracy rate--the percentage of cases where the direction of the congested lane was correct--was 63%. Some of these factors require medium-term improvement, such as shortening the current 5-minute cycle and increasing the amount of acquired turn signal information. On the other hand, FOTs will be conducted in the fall of FY2022 to confirm the improvements that can be made using current methods of determination, with those that prove effective being reflected in the technical specifications.

5 Future Direction and Issues

In the second phase of SIP-adus, we have been working to clarify the business structure and establish a business model in parallel with technical studies for the generation and provision of lane-level road traffic information through technical testing. Issues to be considered for practical application include clarification of the division of functions and roles, establishment of a sustainable operating system, establishment of a data infrastructure development and maintenance system, and clarification of a roadmap for service expansion.

6 Conclusion

We actually collected real probe information from multiple probe operators via cars on the market, and examined and tested the generation of lane-level road traffic information and methods for its representation. Although the amount of probe data was limited, we conducted FOTs on two Metropolitan Expressway routes to investigate the usefulness of the information and to identify any further issues. As a result, we were able to obtain results regarding the amount of information that can be collected and the possibility of generating lane-level road traffic information using probe data, with a view toward practical application.

[References]

(1) Japan Digital Road Map Association, "Draft Data Standard for Expanded DRMDB (Outline and UML Class Diagram)" and "Data Standard for Expanded DRM-DB (Record Format)" (Version 12/11/2019)

(2) JASPAR, ST-VI-1 Dynamic Vehicle Information Sharing API Specifications Ver.1.0, Dynamic Vehicle Information Sharing Study WG, 2020.1.17

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4) Technological Development and Establishment of Simulation Environment for Lane Merging Assistance

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(Abstract) Merging on expressways is one particular use case in which automated vehicle controls are difficult to achieve, as the vehicle must merge by selecting and moving into a space between other vehicles that are being driven at high speeds on the main lane. In particular, expressways in urban areas, including the Tokyo Metropolitan Expressway, provide little distance to merge. As such, vehicles must merge into gaps between other vehicles on the main lane after accelerating to their speed in just a short merging area. We believed that smooth merging in this area could be realized by using a vehicle to infrastructure (V2I) communication system to share vehicle location information with automated vehicles to assist with their automated driving. In this study, we built concepts and evaluated system feasibility by using a simulator to test a "lane merging assistance system," assisting merging using a V2I communication system. Specifically, we acquired tracking data for actual traffic patterns based on the outbound Higashi Ikebukuro Entrance of the Metropolitan Expressway Route No. 5 Ikebukuro Line, and then developed a traffic flow simulator that recreated it. Using this simulator, we compared and analyzed the impact of changing merging assistance system factors such as communication and sensing area on the main lane traffic flow and merging vehicle behavior, both with and without assistance.

Keywords: Merging assistance, service feasibility, merging assistance system to select and enter inter-vehicle gap on the main lane (Day 2 system), cooperative assistance system for main lane vehicles (Day 3 system)

1 Background and Purpose of the study

To realize automated driving on expressways, merging points are one location that require sophisticated driving maneuvers. The merging vehicle must merge into a gap between other vehicles on the main lane after accelerating to the target speed. On the expressways in urban arears, many roads with shorter merging lanes, where it is also hard to scan the main lane for merging beforehand, make driving maneuvers more difficult.

We believe smooth merging of vehicles would be possible by providing information on vehicles in the main lane to the merging vehicle via a merging assistance system and providing navigation for cooperative action to the main lane vehicles on the expressway.

1.1. Concept of Merging Assistance System

From the perspective of technological feasibility, the Japan Automobile Manufacturers Association, Inc (hereinafter called "JAMA") defines four steps as Day 1 to Day 4 systems for merging assistance systems. (Fig.1)

Day 1 and Day 2 systems presume scenarios from free traffic flow to slightly tight traffic. The Day 1 system delivers a traffic forecast based on sensing from a main lane traffic cross-section, (merging assistance to adjust speed on merging lane). Then the system assists in merging at the same speed as the main lane traffic, in the case that the traffic is less busy, after assessing the necessity for handover based on main lane conditions. The Day 2 system performs entire-area sensing and communicates information continuously (merging assistance to select and enter inter-vehicle gap on the main lane). Knowing the traffic flow on the main lane beforehand from continuously delivered information allows a vehicle to smoothly enter the flow with speed being suitably adjusted beforehand when targeting an inter-vehicle gap on the main lane.

In the Day 3 system, based in a scenario in which more than 30% of traffic is automated and equipped with on-board equipment, and when additionally the traffic is tightly packed, merging assistance navigation to main lane vehicles provided by roadside infrastructure is added to the Day 2 system (cooperative assistance for main lane vehicles with roadside infrastructure). This assistance seeks to control the speed of merging vehicles by

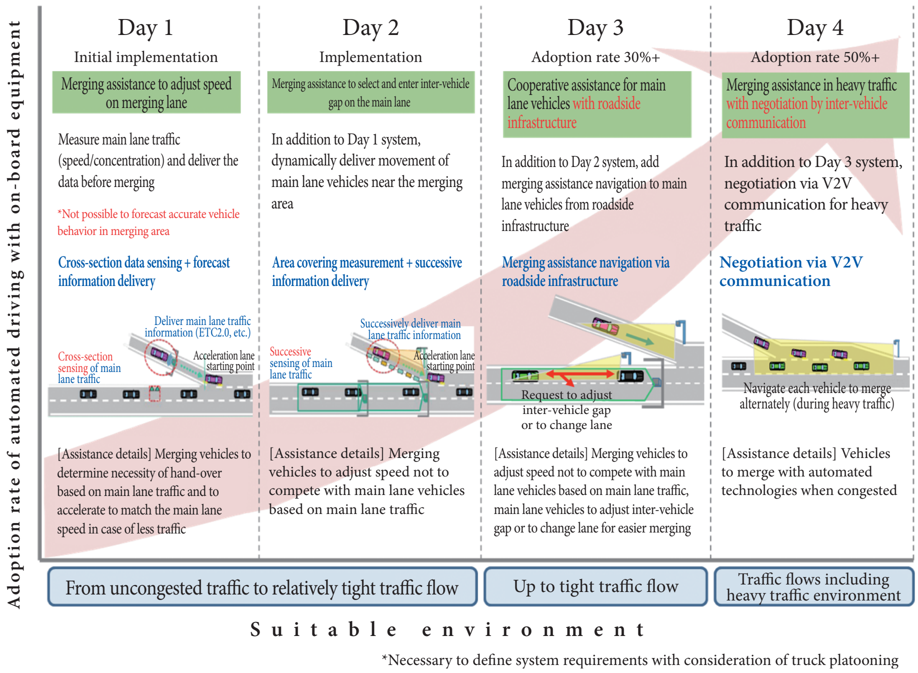

Fig.1: Merging Assistance Step-by-Step Development Process[1]

watching main lane traffic so as not to compete with main lane vehicles, and also to adjust the inter-vehicle gap of main lane vehicles or to change lanes to allow for easier merging.

In the Day 4 system, assistance scenarios consider heavy traffic patterns in which 50% or more of vehicles are automated driving with on-board equipment. Based on the Day 3 system, the further system aims to provide automated merging assistance by negotiations via vehicle to vehicle (V2V) communication during heavy traffic (merging assistance in heavy traffic with negotiation by inter-vehicle communication).

1.2. Purpose of the Study

The SIP-adus (Cross-ministerial Strategic Innovation Promotion Program (SIP) Automated Driving for Universal Services) aims to achieve early realization of a lane merging assistance system. As the first step, a system which can be promptly implemented, the Day 1 system, was considered by combining existing technologies. For the second step, we are now studying a system which will be realized in the future, the Day 2 system.

During the SIP-adus, we applied the Day 1 system at the Airport West IC on the Haneda Line of the Metropolitan Expressway during FY 2019 and 2020 as part of the FOTs in the Tokyo Waterfront area, in order to conduct test driving and evaluate the system. As a result, despite comments from drivers of the Human Machine Interface evaluation test that the system has potential, the Day 1 system using the method to estimate merging timing by cross-section sensing was unable to provide sufficient accuracy in heavy traffic. Therefore, we concluded that the Day 2 system using entire-area sensing and providing the data for the main lane is more suitable. Expecting the prompt realization of the merging assistance system, in order to clarify issues for service availability and social implementation, we decided to test the Day 2 and Day 3 systems via simulation during our FY 2021 and 2022 activities.

We therefore carried out during this study simulation tests for the Day 2 system, based on which proceeded the detailed study for Day 2 and discussed concepts for the Day 3 system while studying its feasibility.

2 Selection of Area for the Simulation

In order to select an area for the simulation, we investigated alignment of roadways around merging areas of the interchanges on the Metropolitan Expressway, then clarified the length of the merging lanes as well as traffic volume of each area.

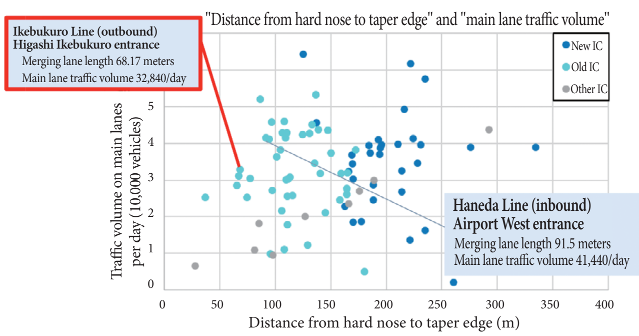

Fig.2: "Distance between hard nose and taper edge" and "main lane traffic volume" in the Metropolitan Expressway merging area

Fig.2 shows that the outbound Higashi Ikebukuro entrance on the Ikebukuro Line has a merging area with extremely short merging lane length. We also found that there were two peaks in the distribution of the Metropolitan Expressway merging lane lengths, one for ICs using the old

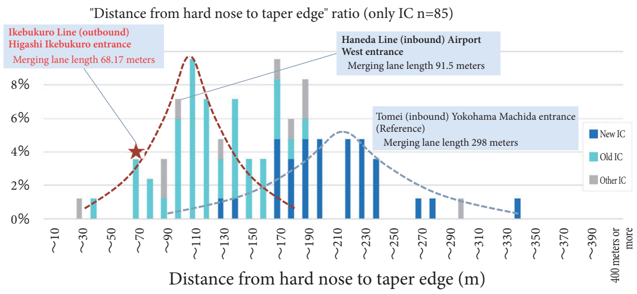

Fig.3: Percentage of "Hard nose-Taper edge length" in whole merging area

standard and the other for those using the new. (Fig.3)

Areas with short merging lane lengths (old standard), including the Higashi Ikebukuro entrance, provide little time between starting and completing the merge. This means there are many potential cases in which merging assistance could be helpful. Areas with comparatively long merging lane lengths (new standard) make it possible to merge via autonomous driving: that is automated driving without human assistance.

On the other hand, the Ministry of Economy, Trade and Industry's SAKURA Project (Safety Assurance KUdos for Reliable Autonomous vehicles) prepared vehicle tracking data for the Higashi Ikebukuro entrance. JAMA also has a simulation that recreates merging behavior at the Higashi Ikebukuro entrance. Therefore, for the FY 2021 and 2022 initiatives, we decided to carry out a simulation using the outbound Higashi Ikebukuro entrance on the Metropolitan Expressway Route No.5 Ikebukuro Line.

3 Study of Day 2 System Feasibility

3.1. Definition of Merging Quality

In order to test the feasibility of merging assistance systems, it is necessary to evaluate the degree of improvement in merging behavior via the service by first defining what is better or worse regarding merging.

As an indicator to determine the quality of merging behavior, we defined and introduced evaluation scores calculated using inter-vehicle time and relative speed. The vehicle subject to calculation of the score is the vehicle in the main lane nearest to the merging vehicle while merging.

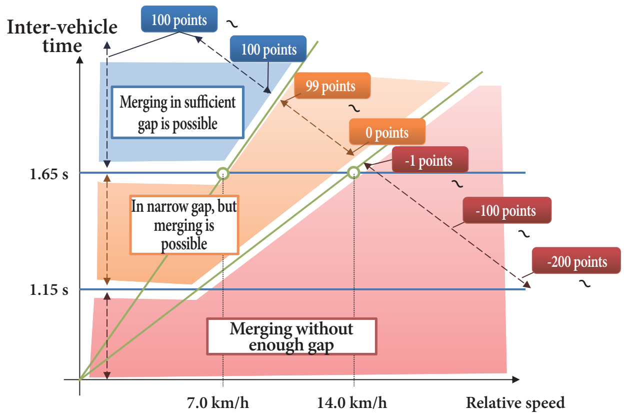

Fig.4: Merging evaluation score map (tentative)

The relationship between the score used in this analysis and inter-vehicle time/relative speed is shown in Fig.4. Smaller relative speed and larger inter-vehicle time gaps showed safer and more efficient merging with higher scores. Considering the danger of collisions, areas where easier merging is possible were evaluated with 100 points. The father away from that area, the lower the evaluation score, and area with less than 0 points were defined as those with no margin and unsuitable for merging.

3.2. Simulation Environment Construction

As the basis for the simulation environment, we used a simulation model that recreated the merging behavior at the Higashi Ikebukuro entrance to Metropolitan Expressway No 5. (hereafter called the "Higashi Ikebukuro Model"). The simulation model is owned by Kozo Keikaku Engineering. The traffic flow data applied in the Higashi Ikebukuro Model is the real traffic data acquired by the SAKURA Project excluding data during traffic congestion.

In order to conduct effectiveness verification simulations of the Day 2 system, we added a function to simulate the Day 2 system, as well as behavior rules for merging vehicles assisted by the Day 2 system to the Higashi Ikebukuro Model. The former is to consecutively deliver data of main lane vehicles acquired from main lanes sensing areas toward merging vehicles in the communication area. The latter is merging vehicles to accelerate and decelerate so as improve the merging evaluation scores.

The following parameters were introduced into the simulation as physical conditions of this system in order to test requirements of the Day 2 system. (Fig.5)

- Length of sensing area
- Length of communication area
- Information delivery delay by vehicle detection sensor
- Positioning error for delivered information by vehicle detection sensors
- Velocity error for delivered information by vehicle detection sensors

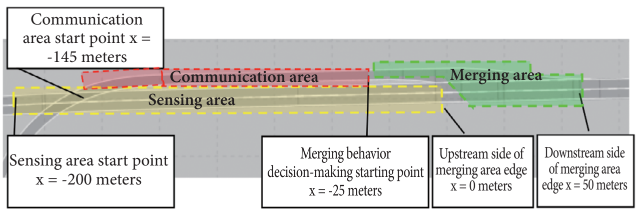

Fig.5: Road alignment for the simulation

3.3. Verification of the Day 2 System's Effectiveness

We conducted simulations for scenarios with and without the Day 2 system's assistance and compared the scores for each. The ideal physical conditions for the Day 2 system were that the sensing area and communication area were sufficiently long and that there was no information delivery delay or transmission information errors. Specifically, the parameters were set as follows: the length of sensing area at a maximum of 200 meters, starting from the point where the merging is possible toward direction of upper flow of traffic; the communication area is 120 meters from the point where a driver makes a merging decision toward the direction of the upper flow.

The results of comparing the scores in scenarios with and without assistance with 20% of automated vehicles in traffic are shown in Fig.6. Considering the decrease of the number of merging vehicles with less than 0 points, applying the Day 2 system could increase the number of merging with sufficient gaps or decrease the number of merging without enough gaps, thereby improving the overall evaluation score. Overall, the system improved the scores. As a result, under ideal physical conditions in the Day 2 system, we concluded that the Day 2 system is effective in achieving better and safer merging.

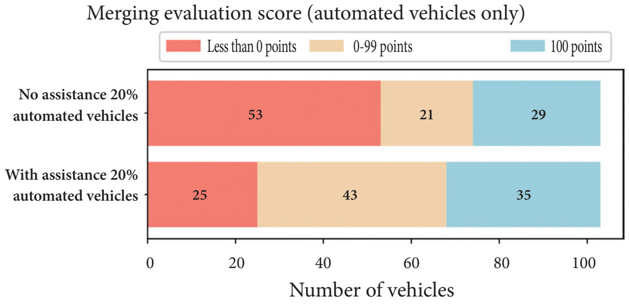

Fig.6: Distribution of the scores for each scenario

For the vehicles that scored less than 0 points, meaning they were not in a situation suitable for merging even in the scenario with assistance, we checked the simulation videos to clarify the cause. This verification revealed that when the main lane is busy the inter-vehicle gap on the lane cannot be sufficiently secured for effective assistance by the Day 2 system. Under such circumstances, we believe it necessary to consider assistance via the Day 3 system or beyond, including assistance vehicles on the main lane, to improve merging maneuvers.

Furthermore, we tested the impact upon surrounding traffic flow by merging assistance, but no impact was confirmed.

3.4. Verification of the Day 2 System's Physical Conditions

We conducted a simulation changing the Day 2 system's physical conditions as a parameter and verified the impact of condition changes on assistance effectiveness. The impact of each physical condition is shown in Table 1. The verification scope for the sensing and communication areas was calculated from the driving distance necessary to adjust speed of the vehicle receiving the Day 2 system's assistance. The verification scope of information delivery delay, error (location) of vehicle detection sensor and error (speed) were decided by referencing existing research.[(2)(3)]

Table 1: Day 2 system physical conditions parameters verification scope and impact on assistance effectiveness

Physical conditions parameters	Verification scope of parameters	Impact on assistance effect
Length of sensing area	Maximum 200m-Minimum 140m to the upper flow direction from the point where the merging is possible	Mostly no impact
Length of communication area	Maximum 120m-minimum 40m from the start point of decision-making for merging behavior toward the upper flow direction	The shorter the length, the greater the negative impact
Information delivery delay	Mean value of 0-1.3 seconds, normal distribution of 0.2 seconds standard deviation	Larger the latency, the more the negative impact
Delivered information positioning error	Uniform distribution of -1m to +1m	Mostly no impact
Delivered information velocity error	-6km/h to 6km/h, -12km/h to +12km/h, Normal distribution with -12km/h to 0km/h in 95% percentile	Negative impact only when speed error distribution is overly negative

4 Detailed Verification of the Day 2 System

In section 3, we verified the effectiveness of the Day 2 system. In this section, we further developed this, estimating the effectiveness of the Day 2 system over combinations of various physical condition parameters in order to verify the Day 2 system requirements.

Changes in traffic volume are also expected to greatly impact assistance effectiveness, especially during congestion on the main lane. Therefore, in this section, we will evaluate the impact of traffic volume on the Day 2 system assistance effectiveness, allowing us to further test the Day 2 system.

4.1. Improvement of Simulation Environment

We identified three issues in the simulation environment used in Section 3 and earlier, and therefore revamped the simulation environment prior to this detailed verification to address each of them. The issues and their solutions are as shown below.

(1) Revision of the evaluation score map

When using the evaluation score map for analysis in Section 3, we found a non-negligible amount of cases in which scores were not directly linked to the behavior of vehicles in the simulation. For the detailed study in this section, we revised the map to realize an evaluation more closely based in reality. With the applied formula to calculate boundaries, it is possible to evaluate based on the inter-vehicle gap while accounting for the response delay of trailing vehicle maneuvers. Table 2 shows the formula for boundaries calculation at scores of 0 and 100 in the evaluation score map.

A merging and a main lane vehicle getting closer together, and the two same vehicles moving apart create two situations that are almost completely different in terms of the difficult of the merging maneuver. As such, in order to correctly distinguish these situations to evaluate, the scores for the relative velocity in negative field are also revised. The final version of the relative score map is shown in Fig.7.

Table 2: Formula for 0 and 100 point threshold in the evaluation score map

Item	0 points	100 points
(1) Inter-vehicle gap after decelerating Time margin [m]	15	25
(2) Reaction delay Time [seconds]	1.0	1.5
(3) Deceleration speed [G]	0.3	0.2
A (x: Relative speed)	$\frac{x^2}{0.6G}+1.0x+15$	$\frac{x^2}{0.4G}+1.5x+25$

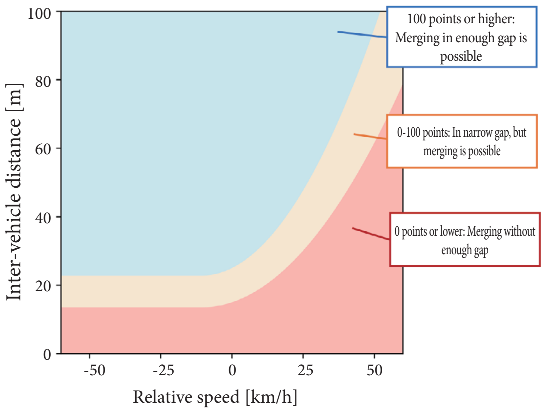

Fig.7: Final version of the evaluation score map

(2) Construction of main lane vehicle behavior model prior to entering the merging area

As we did not have the real trajectory data of main lane vehicles prior to entering the merging area during testing, uniform linear velocity was applied to the vehicles. Therefore, lane changes, speed changes, and others maneuvers were not correctly reflected in the model. We recognized this as a remaining issue.

Vehicle behavior, such as lane changes and speed changes in the sensing area, is considered to be a factor that changes the main lane situation and is expected to greatly impact on the effectiveness of the Day 2 system assistance. Therefore, for further evaluation of the Day 2 system, we plan to construct the behavior model of main lane vehicles in the upper stream traffic flow, improving the simulation in the sensing area. We intend to acquire additional data of real trajectory of vehicles in the main lane upper stream for these purposes.

(3) Revision of automated vehicle behavior model

In the Higashi Ikebukuro Model, the non-automated vehicles (hereafter called "standard vehicles") are programmed to keep the desired gap according to the distribution of the inter-vehicle gap captured from real trajectories. The standard vehicles keep the desired gap as programmed for traffic flow, and there are not a few vehicles that have a time between vehicles of less than 1 sec. On the other hand, it is more common to recognize that an automated vehicle keeps the gap longer. Hence the automated vehicles are programmed to basically keep the inter-vehicle time gap at 2 seconds.

4.2. Verification of the Day 2 System Requirements

The simulation is carried out changing the Day 2 system physical conditions as parameters to evaluate the impact on the assistance effectiveness by this parameter change. It is expected that assistance effectiveness will be enhanced when the simulation area is larger and the delay and errors are smaller. The system requirements will be verified by investigating physical conditions that make assistance more effective compared with circumstances without said assistance.

4.3. Evaluation of Impact of Changing Traffic Volume on Day 2 System Assistance Effectiveness

If there is light traffic volume in the main lane, it is possible to merge smoothly even without merging assistance. On the other hand, if there is heavy traffic volume, it is difficult to merge smoothly even using Day 2 system assistance because the gap between vehicles in the main lane is narrow. The assistance effectiveness of Day 2 systems differs based on the changes in main lane traffic volume. The system is most effective under the conditions when the main lane traffic volume is at optimal levels, and below maximum traffic capacity of the road.

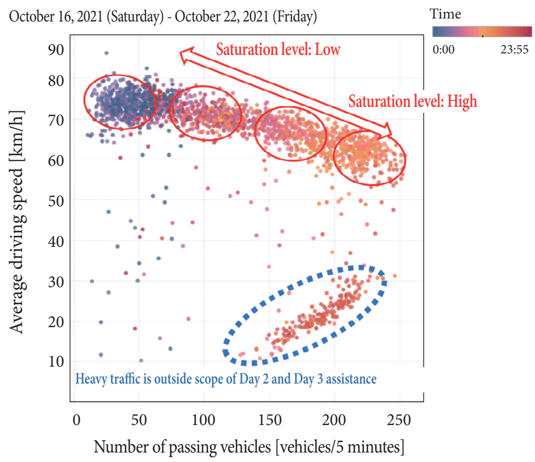

Fig.8: Categories of traffic volume and QV chart based on traffic counter data measured in simulated area

In order to evaluate the impact of main lane traffic volume, we estimated the effectiveness of Day 2 system assistance in the four traffic volume areas shown in Fig.8, using the simulation. The traffic counter data in the simulated area was provided by Metropolitan Expressway Company Limited. By comparing the assistance effectiveness in the four traffic volume areas, we investigated the traffic volume that is more effective for Day 2 system assistance and less for Day 3.

In the case of congestion, V2V communication and cooperation in the merging area are necessary. As long as the situation is out of scope of Day 2 and Day 3 systems, we excluded the case from this study.

5 Concept Planning and Feasibility Verification of the Day 3 System

5.1. Concept Planning of the Day 3 System

The Day 3 system gives merging assistance for both the merging vehicle and the main lane vehicle. However, if the main lane vehicle is not an automated vehicle but rather a standard vehicle, the system cannot provide it with merging assistance. Furthermore, if the gap between the trailing car and the leading car in the main lane is sufficiently wide, then the merging vehicle can merge smoothly without assistance for the vehicles in the main lane. Hence what is provided by Day 3 system assistance must differ depending on types of situation of vehicles around the merging point during the maneuver. This program was therefore designed to determine whether to assist the merging vehicle and main lane vehicles based on two factors: whether the three main lane vehicles (a vehicle considered as leading by the merging vehicle, its trailing vehicle, and another following vehicle) are automated vehicles or not, and as second, the inter-vehicle time between each main lane vehicle.

5.2. Verification of Day 3 System's Effectiveness

It can be expected that assistance effectiveness would be improved by implementing the Day 3 system in situations when the effectiveness of Day 2 system assistance fell due to high traffic volume. In planning the concept for the Day 3 system and verify effectiveness, we apply traffic volume in which assistance effectiveness was lower during the detailed verification of the Day 2 system. The traffic flow volume for the verification will also be estimated by simulation. The physical conditions for the Day 3 system are equivalent to the ideal physical conditions and the Day 2 system requirements.

6 Expectations of Technological Outcomes in Fiscal 2022

In FY 2022, we plan to construct the vehicle behavior model for the main lane traffic stream and revise the automated vehicle behavior model. Further, we will analyze the effects of Day 2 system assistance, systems requirements, and Day 3 system effectiveness. The following are expected as results.

- Day 2 system effectiveness and system requirements using simulations where vehicle behavior reproducibility is improved in the sensing area
- Evaluation results on impact of traffic volume on Day 2 system
- Day 3 system assistance effectiveness in traffic flow where Day 2 system assistance effectiveness is reduced
- Estimated one-day assistance effectiveness of Day 2 system and Day 3

7 Conclusion

7.1. Considerations for this Study

The study of this project was carried out in a limited model, applied to the Higashi Ikebukuro entrance and using standardized vehicles (non-large-sized) alone.

7.2. Recommendations for Future Development and Analysis

In this project, we built a simulation environment to evaluate the assistance effectiveness of Day 2 and Day 3 systems, and evaluated these around the Higashi Ikebukuro entrance. Based on the results of this project, we are conducting discussions with related parties participating in the meetings about merging assistance systems simulations to continue discussions after the conclusion of the second phase of SIP-adus, hopefully leading to the realization of merging assistance systems.

As noted in 7.1, this study is limited in terms of road alignment and type of vehicles. The assistance effectiveness and system requirements for Day 2 and Day 3 systems are thought to differ based on the road alignment in the merging area. Therefore, using the simulation built for this project, it would be preferable to also evaluate the assistance effectiveness of Day2 and Day 3 systems in merging areas besides the Higashi Ikebukuro entrance.

In addition, it is possible to consider further development of the previously mentioned simulation environment for large-size vehicles as a future expectation. When doing so, it will be necessary to take into account for the acceleration and deceleration range of the vehicle, which is smaller than standard-sized cars.

[References]

(1) NEDO: FY2021 Briefing materials for open call to the second phase of SIP-adus/ Construction and analysis of the Simulation Environment fot the Merging Assistance Systems (targeting Main lane inter-vehicle gap) Verification, https://www.nedo.go.jp/content/100936118.pdf (Reference 09/01/2022)

(2) Toshimasa Nakagawa, et. all: "Verification of Merging Support Information Provision System (DAY 1 system) through Field Operational Test in the Tokyo Waterfront Area" JSTE Journal of Traffic Engineering, Vol. 8, No. 1 pp. 39-48, 01/2021.

(3) Toshimasa Nakagawa, et. all: "Basic Study on Measurement Accuracy of Vehicle Detection Sensor of Merging Support Information Provision System (DAY 2 System)" JSTE Journal of Traffic Engineering, Vol. 8, No. 1 pp. 49-58, 01/2021.

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5) Improvement of Data Accuracy of Traffic Regulation Information

Moto Baba (JARTIC), Makoto Maeda (TOSCO CORPORATION), Ryo Sakaguchi (Dawn Corporation)

(Abstract) Held over three years from fiscal year 2020, this research aims to improve the precision of traffic regulation information data managed by the police department that is required to establish a traffic environment in which automated vehicles are able to drive safely and securely. In order to enhance traffic regulation information precision, we deliberated issues and improvement plans for the standard format of existing traffic regulation information and prepared a new expanded standard format and its manual. Through the FOTs (Field Operational Tests), based on the model system requirements definition (proposal) prepared in fiscal 2020, we developed and tested a model system to confirm consistency between the traffic regulation information and the information conveyed with traffic signs and marks and to link these information, and also the image recognition technology was evaluated, In fiscal 2022, we used the technology and expanded standard format developed the previous year to construct a prototype system, conduct FOTs related to improving traffic regulation information data precision and effects verification, and organized a requirement definition (proposal) for the system implementation.

Keywords: Traffic regulation information, traffic signs and road markings information, image recognition technology, data precision improvement, expanded standard format, high-precision 3D map

1 Purpose and Overview of Research

A vehicle can capture high-precise data of road signs and markings on the road with on-board camera and mobile mapping system (MMS). However, it is difficult to produce traffic regulation information from this data. Therefore, we conducted research related to improving traffic regulation information data precision for the utilization of safe driving support information in order for automated vehicles to drive safely and in accordance with traffic regulations by improving precision of data derived from traffic regulation information that is held and released by the police department.

1.1. Techniques to Improve Traffic Regulation Information Data Precision

We aimed to improve traffic regulation information data precision by comparing road signs and markings on the road against the traffic regulation information held by the police department. We used two methods for collecting road signs/ markings data. As Method-1, we extracted and collected road signs/ markings data using image recognition technology from imagery data of an onboard dashboard cameras. As Method-2, we collected road signs/ marking data using smartphone web applications (the field-research application).

The collected road signs and markings data were registered into the road signs/marking position prediction system used in FOT, in which the data was automatically compared with the traffic regulation information, then this was followed by a consistency check in which it was categorized as matching or not matching, aiming for improving the precision of the traffic regulation information. For signs and markings recognized as unmatched without consistency, a field research was conducted as Method-2 to verify again the consistency of data, then we verified improvement of the data precision, as well as worked to find an optimal method which can improve the traffic regulation information precision.

As for the image recognition system, we studied how to support production of traffic regulation information from collected road signs and markings.

Additionally, the standard format of the traffic regulation information we had used contained structural issues. Therefore we prepared a new version as the expanded standard format (proposal) that can unify the management of traffic regulation information for the purpose of solving the issues and improving the data precision of traffic regulation information, along with a user manual.

1.2. Outline of the FOTs

In fiscal 2020, we prepared a requirements definition (proposal) for model system development. In fiscal 2021, we constructed a model system (the field-research application and the road sign position prediction system) and conducted FOTs in the target area of Kanagawa Prefecture.

In order to improve the precision of data effectively, we conducted a study to automatically recognize road signs and markings data recorded by a dashboard cameras using image recognition technology. In fiscal 2022, we constructed a prototype system using technology developed in fiscal 2021 and the expanded standard format, conducted FOTs and effect verification, and prepared a systems requirement definition (proposal) to add functions into the traffic regulation information management systems of the National Police Agency and prefectural police.

2 Construction of Model System

2.1. The field-research application

The field-research app supports field research of road signs and marking with smartphones. The application has the function to collect road signs and markings data and to display traffic regulation information.

The field-research application is used in a web browser on a smartphone device. It compares traffic regulation data displayed on the smartphone with road signs placed on the road and can record or revise data if there are any insufficiencies or errors. Information that can be recorded include road sign administrative information, road sign board types, state of deterioration, and photo images. It is possible to link pieces of information manually as with the road sign position prediction system.

By using this, it is possible to tentatively link signs that could not be automatically linked to traffic regulation information with road sign position prediction system.

2.2. Road Sign Position Prediction System

The road sign position prediction system is a system that supports linking of data to verify consistency of traffic regulation data and road sign data, as well as identifying erroneously recorded data in the system. First, importing traffic regulation data controlled by the prefectural polices, the system predicts position of road sign corresponding to each regulation data, then check if targeted road sign exists inside predicted area to automatically make tentative linkage of the regulation data with the sign data. The results of the automatic tentative linking were confirmed on the road sign position prediction system map screen and list screen. For data that could not be linked, the operator can manually link data on the prediction system. For the position prediction, we applied a best candidate method for each traffic regulation type out of multiple prediction methods. Also, we created a system that can adjust parameters because registration of coordinate data and linking of traffic regulation data with traffic signs data, these are conducted with various ways in each prefectural police.

2.3. FOTs with the Model System

The fiscal 2021 FOTs were conducted for regional traffic regulation information covering district held by some police departments in Kanagawa prefecture.

The procedures for these tests were as follows. (Fig.1)

·The standard format data and road sign data of the target area are registered in the road sign position prediction system, then are made tentative linkage.

·Following verification of the tentative linkage result, field research is carried out for areas of low precision using the field research app, then pieces of the data are linked again as tentative.

·The tentative linkage is compared with the traffic regulation linkage data which has been made in the prefectural police system, then verified eventual linkage.

·The position prediction methods are reconsidered based on the result of linkage to find more optimal one, which is tested then used to make another tentative linkage.

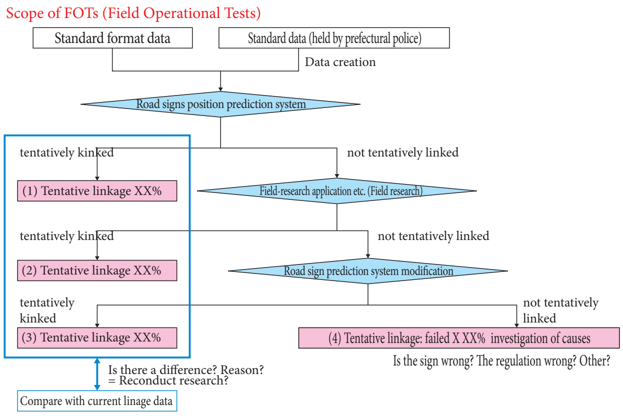


Fig.1: FOTs flow chart

As for verification of effectiveness, we calculated "tentative linkage rate" and "precision" of the collected traffic regulation data in accordance with the flow chart in Fig.2. As a result of 5 times of revising position prediction method, the tentative linkage rate was 91.5% and the precision was 93.5%.

The 27 items of traffic regulation data that could not be linked were all able to be linked through the field research with the application.

[Tentative linkage rate] The percentage of the number of tentatively linked traffic regulation data against the number of traffic regulation data subject to the testing

[Precision] The percentage of the number of correctly linked regulation data against the number of data of tentatively linked regulations which are also made linkage in the prefectural police system

2.4. Study and Evaluation of Image Recognition Technology

As for the image recognition technology, we studied method to collect and extract with easier way information such as road signs and marking location from image data collected through the prefectural polices' duties including installation and inspection of such road signage, in the flow as

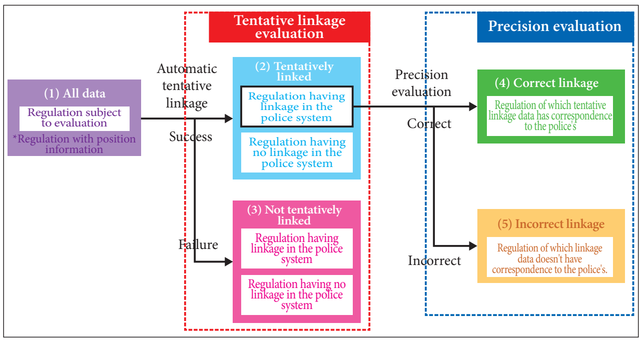


Fig.2: Evaluation flow in FOTs

shown Fig.3.

2.4.1. Research and Evaluation of the Technology

We performed studies from perspectives shown in Table 1 for the technologies of extraction, recognition, and position estimation required to construct the systems.

For the technological evaluation, methods for extraction and recognition are categorized into two types, one is the template matching based and another is the machine learning based. The template matching based can be realized by creating specialized matching algorithms, but requires massive amount of development to catch irregular cases. In contrast, the machine learning based does not require all patterns to develop. Collecting necessary data to additionally learn then securing time to learn this data, it is possible to handle irregular cases.

Therefore, we developed a prototype of evaluation software using machine learning method and performed evaluations.

(a) Extraction

As for evaluation of extraction method, we used 200 images including images of poor conditions such as rainy weather and deteriorated sign boards (containing 297 of road signs, 131 of supplementary signs as target), and 34 minutes of driving video (containing 219 road signs and 112 supplementary signs as target). As a result shown in Table 2, each of the outputs indicated more than 95% extraction.

We also conducted evaluation of stop lines, crossing sidewalks, direction arrows, and speed limits on road marks and confirmed results in 95% on average.

Table 2: Extraction results

Road sign type, etc.	Number of signs	Number of extractions	Extraction rate
Still images of principal signs	297	281	95%
Still images of supplementary signs	131	129	98%
Video of principal signs	219	214	98%
Video of supplementary signs	112	111	99%
Road markings	261	248	95%

(b) Recognition

As for evaluation of the recognition method, we used 297 images of extracted road signs.

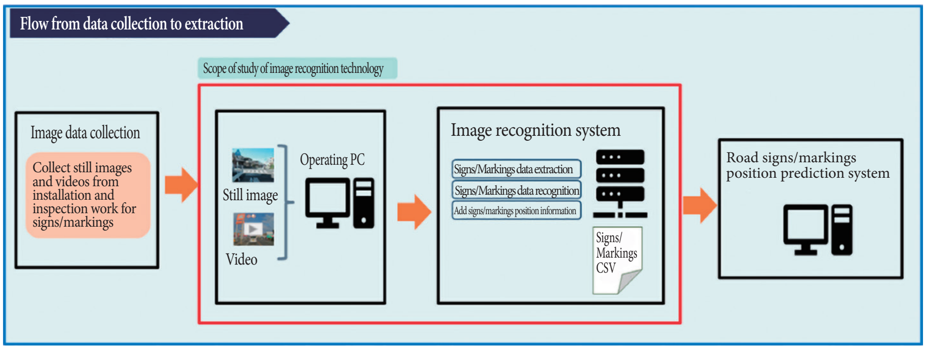
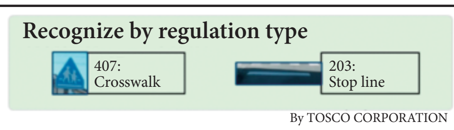
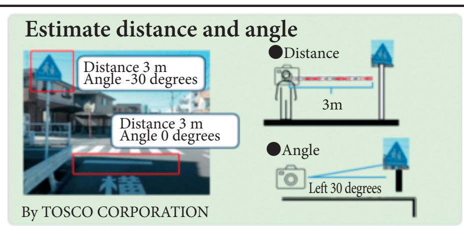


Fig.3: Flow from data collection to extraction

Table 1: Planned process

Process	Explanation	Illustration of Process
Extraction	Process to detect area containing sign or marking in still image or video, then to extract image from the area	
Recognition	Process to determine whether the detected signs or markings is correct or not in the extracted area image, then to identify the type of regulation.	
Position estimates	Process to calculate latitude and longitude using distance and angle estimated from data of position where objects (signs or markings) contained in video and still image are recorded	

As a result, there were cases in which the designated direction only signs lane usage signs (Fig.4) were falsely recognized as the one-way street signs. (Fig.5) Though, the recognition rate could be by relearning the learning data of the designated direction only signs. Recognition results are as in Table 3.

Fig.4: Designated direction only sign

Fig.5: One-way street sign

Table 3: Recognition results

Class	Number of signs	Number of extractions	Extraction rate
Parking prohibited	106	106	100%
Maximum speed 40km	15	15	100%
Crosswalk/bicycle crossing	14	14	100%
Designated direction only	13	13	100%
Direction specific lane usage *Result after relearning shown in ( )	11	3 (11)	27% (100%)
Maximum speed 50km	11	11	100%
(Omitted)			
Total	297	274	92.3%

(c) Position Estimation

As for evaluation of the position estimation, we used 1,600 images with distance data between 2m to 10m measured beforehand, and applied the depth estimation algorithm and the regression model.

As a result, among 1,600 images, approximately 96% can be used for position estimation with error of within 2 meters. (Table 4)

Table 4: Distance measurement results
(error between actual distance and estimated distance)

Error range	Number of images (1,600 images)	Percentage
2 meters or less	1,539	96.2%
More than 2 meters - within 4 meters	59	3.7%
More than 4 meters	2	0.1%

2.5. Expanded standard format

The current standard format was a data format about the traffic regulation information, which had been organized through research study related to a project "advancement of driving support by utilizing traffic regulation information", as part of SIP, the Cross-ministerial Strategic Innovation Promotion Program. But in order to address issues clarified in this research study, we deliberated and created the expanded standard format.

2.5.1. Expanded standard format

In order to enhance traffic regulation information data precision, we prepared an expanded standard format complying with traffic regulation standards, which are standards that prefectural police departments apply to traffic regulations. This expanded standard format aims to reduce the input work by the prefectural police by covering insufficient codes needed to accurately display regulations and difference updates, eliminating similar items, and clarifying input definitions. This format can centrally manage three types of information: traffic regulation information, corresponding traffic signs information, and road markings information.

The overall structure of the expanded standard format is shown in Fig.6.

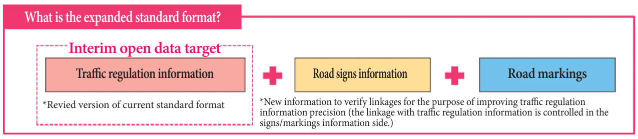


Fig.6: Structure of expanded standard format

3 Prototype System

3.1. The road signs/marks/display position prediction system and the field research application

In order to confirm the relationship between road signs actually on the ground and traffic regulations determined by the prefectural police, we built up a new prototype system (Fig.7) with additional functions as below, based on the system that had been established and used for the FOTs in 2021 for making linkage between the traffic regulation data and the road signs data.

- Input/output of the expanded standard format (traffic regulation data, Road signs/marks data, linking)
- Prediction of road marking position from traffic regulation data
- Prediction of traffic regulation position from road signs
- Registration of supplementary signs
- Loading of image files

Further, we added the function as below to the field research application (Fig.8) prepared for supporting the road signs and markings position prediction system and linking the traffic regulation data and road signs/ marks data.

- Input/output of the expanded standard format (traffic

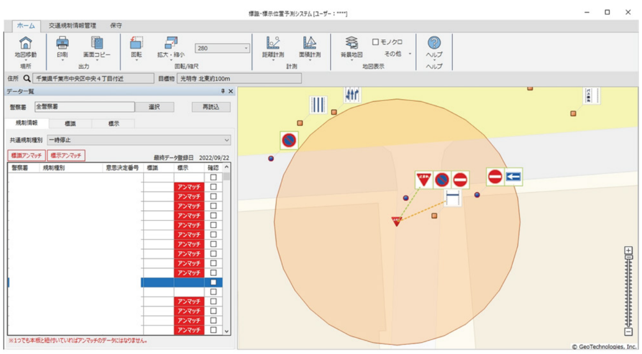


Fig.7: Road signs/markings position prediction system sample screen

regulation data, Road signs/marks data, linking)
- Registration of supplementary signs
- Registration of road signs/ marking board direction

Fig.8: Image of registering road signs/markings on smartphone device

3.2. Image recognition system

As for the data recognition system which aimed for comprehensive collection of road signs/markings information on wide area and effective data organization, we established a prototype system. (Fig.9) This prototype system has the functions, extracting the road signs/markings information such as regulation type, position information and direction, transporting the extraction output to the prediction system.

3.3. FOTs and evaluation of effectiveness using the prototype system

In fiscal 2022 FOTs, we used regional traffic regulation data and road signs/markings data held by some police departments in Chiba prefecture. We improved the precision of traffic regulation data by loading road signs/markings data acquired by using the field research application and the image recognition system into the road signs/markings position prediction system.

As for the image recognition system, we studied to acquire information such as signs/marking position, regulation type, direction of photographing the sign, using image data acquired by the field research app as well as by

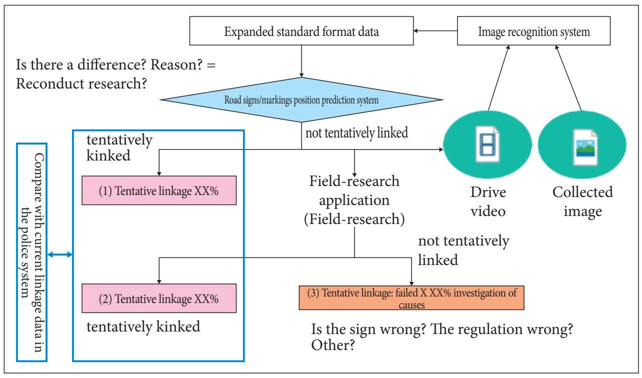


Fig.10: FOTs flow chart of prototype system

dashboard cameras and others. This was associated with the study to acquire data of supplementary road signs.

For the effectiveness evaluation of the prototype system, we sought the tentative linkage rate and the precision like in fiscal 2021. In fiscal 2021, we used the standard format data and the road sign data for the evaluation. In fiscal 2022, it is the expanded standard format including traffic regulation data and road signs/markings data in accordance with the evaluation flow shown in Fig.11 to calculate the tentative linkage rate and the precision.

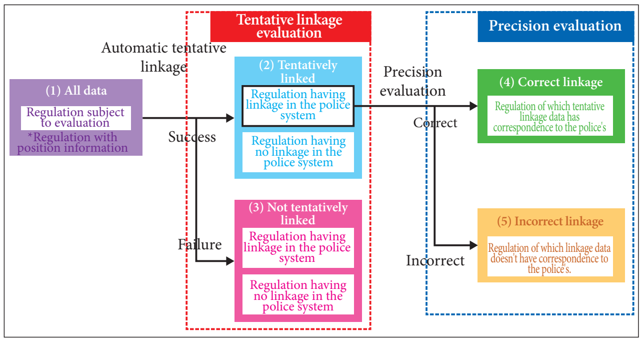


Fig.11: Evaluation flow of the prototype system

The detailed procedures are as follows. First, we carry out prediction of road signs/markings position with the position prediction system for the expanded standard format data, checking position of traffic regulation data and categories of regulation, then tentatively link the road sighs/markings data which is inside the predicted position area. This is followed by

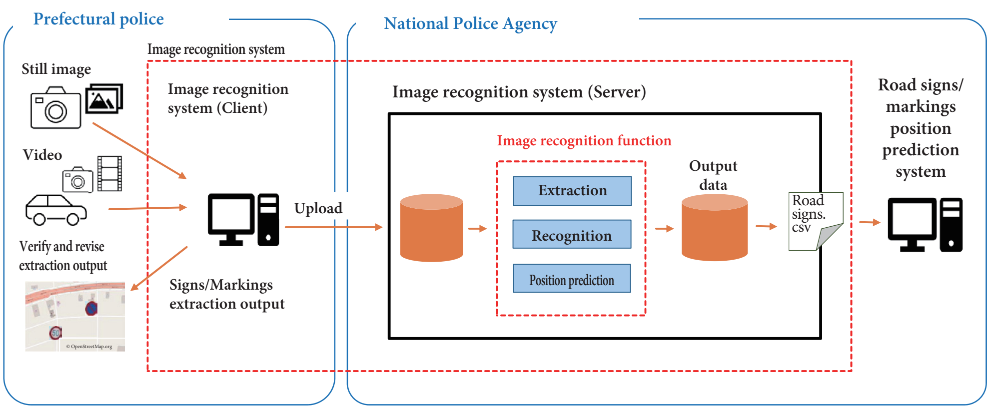


Fig.9: Image recognition system configuration

adjustment of the predicted position area based on the tentative linkage output to find out optimal position as prediction. The regulation data unable to be linked is recognized as unmatched data at the end of the process. For this unmatched data, we collect the road signs/markings data actually on the road using the field research app and the image recognition system. The collected data is subjected to the prediction again through the prediction system for another tentative linkage to seek the final tentative linkage rate and precision. If there is traffic regulation data of which the linkage is impossible or false, causes are analyzed to improve the data precision.

3.4. Preparation of expanded standard format manual

Based on results of hearings of prefectural police, FOTs carried out with the expanded standard format, and expert meetings, we narrowed down the regulation categories to 74 items for the expanded standard format (proposal) studied in fiscal 2021. We also reviewed 224 traffic regulation information categories in the proposal format. In particular, the traffic regulation information was defined basically with categories consisting of "regulation type", "regulation location", "regulation target", and "date related to the regulation" based on the traffic regulation standards, then verified data to eliminate similar categories. Further, in order for registrants to register the traffic regulation data correctly in the expanded format, also for users to understand the format, we prepared a manual.

The manual is comprised of the main manual and supplementary documents. We included data overviews and file specifications in the main manual, and format, code list, as well as input definition and registration examples for each regulation category in the supplementary documents.

3.5. System operation manual

In order to improve data precision of traffic regulation information, we prepared a system operation manual for the prototype system constructed taking into account the future social implementation. The system operation manual is comprised of the main volume describing the purpose and overall structure, the operating manual for each tool (road signs/markings position prediction system, the field research application, the image recognition system), and the operating volume that includes operation techniques.

4 Cooperation with high precision 3D map

As utilization of the high-precision 3D map (Fig.12) is expected for automated driving on public road, we carried out as below:

- Research on High precision 3D map data
- Study of traffic regulation information provision methods
- Organizing issues related to traffic regulation information provision

The traffic regulation information generated through this study and the road signs/markings information made from the high precision 3D measurement with the mobile matching system (MMS), both are utilized to verify technology to incorporate such data into the high precision 3D map.

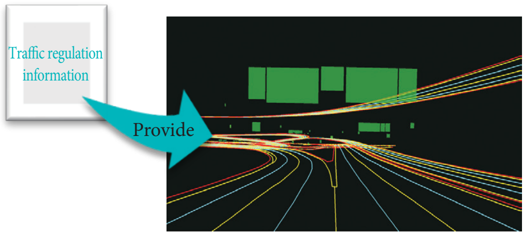


Fig.12: Image of high precision 3D map
(Source) Dynamic Map Platform Co., Ltd.

5 Conclusion

5.1. Concept of future operation

We are considering implementing the expanded standard format into traffic regulation information management systems of the prefectural police in accordance with Fig.13.

The National Police Agency must be able to receive data in both the standard format and the expanded standard format until the prefectural police can support the expanded standard format. Operations related to improving traffic regulation

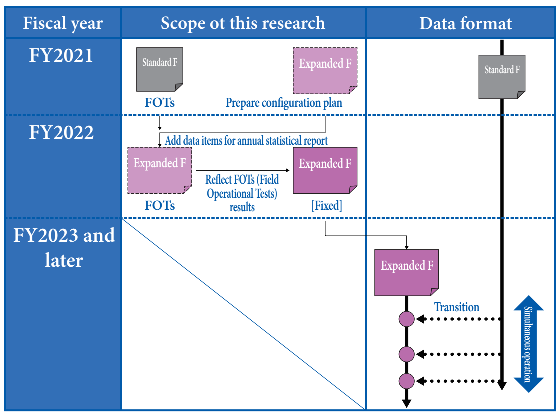


Fig.13: Concept of future operation

information data must be handled in the prefectural police. Therefore, it is preferred that operations are conducted with lesser workload.

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6) Technological Development for Traffic Signal Control and Emergency Vehicles Information Using GNSS (Location Information) and Other Technologies

Kenji Sumi (KOITO ELECTRIC INDUSTRIES, LTD.)

(Abstract) Currently, traffic signal priority control for public transit buses and emergency vehicles is mainly provided by a system using optical beacons installed on the roadside, however we have developed a system using GNSS (location information) and mobile phone communication networks. The GNSS enables the service to be provided even in locations where optical beacons are not installed. In FOTs (Field Operational Tests) of traffic signal priority control, it was demonstrated that the non-passage rate of buses during extended green signal periods was reduced by 88.9% compared to that of optical beacons by continuously obtaining location information and travel speed using GNSS, and that finer traffic signal priority control was possible. In addition, FOTs were conducted in the Tokyo waterfront area using the mechanism developed in this technology development to distribute information on emergency vehicles (simulated) to automated vehicles. By providing the location information of emergency vehicles such as ambulances to the automated vehicle, it is possible to recognize their presence from a greater distance. We expect that the results of this technological development will be implemented in society as soon as possible with the goal of realizing "practical application of advanced automated driving with infrastructure cooperative system" as indicated in the SIP Roadmap of V2X Communication Methods for Cooperative Driving Automation.

Keywords: GNSS, signal control, location information, emergency vehicles, public transportation

1 Overview of Research and Development

1.1. Background

Among the new traffic management systems (UTMS: Universal Traffic Management Systems) currently in wide usage, there are two subsystems that implement traffic signal priority control for road traffic signals: Public Transportation Priority Systems (PTPS) (since 1995) for route buses, and the Field Ambulance Support System (FAST) (since 2003) for emergency vehicle operation.[(1)]

These systems use near-infrared light to communicate with optical beacons installed on the road to detect approaching vehicles and determine whether or not they are operating in an emergency, and then implement traffic signal priority control (extended green signal time, shortened red signal time) for necessary vehicles.

As shown in Fig.1, the conventional traffic signal priority control system uses optical beacons installed in front of intersections to detect the approach of public vehicles (buses) and emergency vehicles (fire trucks, police cars, etc.) in order

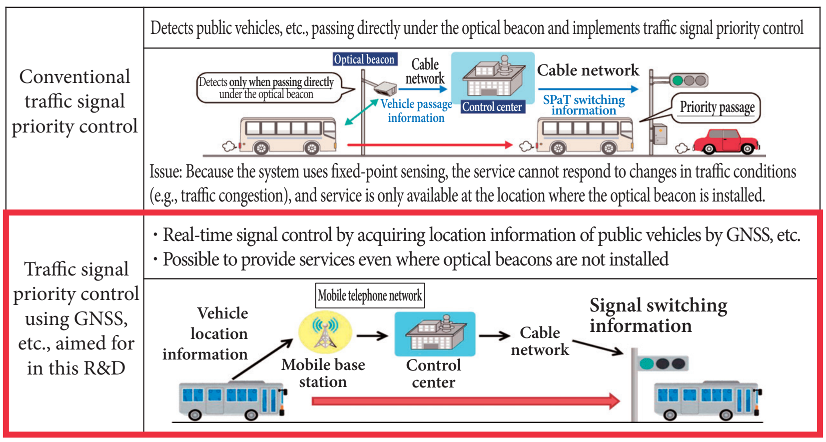

Fig.1: Comparison of conventional and GNSS traffic signal priority control

to determine their locations, and the cost of installing optical beacons has been an issue.

In addition, because the optical beacon is a fixed-point sensor, it cannot respond to changes in the traffic environment (e.g., traffic congestion before an intersection) after the optical beacon has been passed, causing stopping at red lights, which would result in wasted green signal time for traffic in the crossing direction.

The location information that is being considered for use in this technology development to determine the location of vehicles is based on GPS (Global Positioning System: a satellite positioning system operated by the United States of America), a type of GNSS (Global Navigation Satellite System) which has been widely used as a satellite-based positioning system in Japan, but generally has a position error of 10 to 20 meters.

To solve this problem, Japan's own GNSS, QZSS (Quasi-Zenith Satellite System (MICHIBIKI)), began operating four satellites in November 2018 to complement GPS. RTK and DGPS positioning methods have improved positional errors and are expected to provide more accurate positioning.

1.2. Purpose

The purpose of traffic signal priority control in the technology development for traffic signal control and emergency vehicle information using GNSS (location information), etc. (hereinafter referred to as "this technology development") is to enable service deployment even where optical beacons are not installed by changing the means of determining the location of buses and other vehicles from optical beacons to the more common GNSS. The purpose is to reduce the error in the estimated arrival time at intersections by continuously obtaining the location information of buses and other vehicles closer to intersections compared to optical beacons, in other words, to improve the effectiveness of priority signaling control.

1.3. Overview

This technology development was carried out in cooperation with UTMS Society of Japan after deliberations by the National Police Agency, prefectural police, vehicle manufacturers, traffic infrastructure manufacturers, and experts with GNSS knowledge.

In addition, the system for collecting location information on emergency vehicle operation was used to generate and provide simulated emergency vehicle information in the FOTs in the Tokyo waterfront area.

In the specification development phase, the draft specifications (1) through (6) shown in Fig.2 were developed. In the effectiveness verification phase, traffic signal priority control FOTs were conducted in Shizuoka City, Shizuoka Prefecture, based on the draft specifications and verification plan.

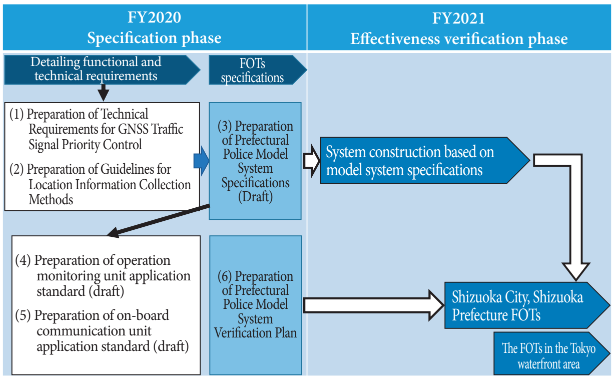

Fig.2: Technological development overall process

2 Traffic signal priority control in this technology development

2.1. Current traffic signal priority control

As shown in Fig.3, the current traffic signal priority control system uses an optical beacon (fixed point) installed in front of the intersection to detect an approaching bus and extend the green light time or shorten the red light time for the number of seconds it takes the bus to reach the intersection at a predetermined, fixed, calculated speed, and is effective when the calculated speed and actual speed are almost the same.

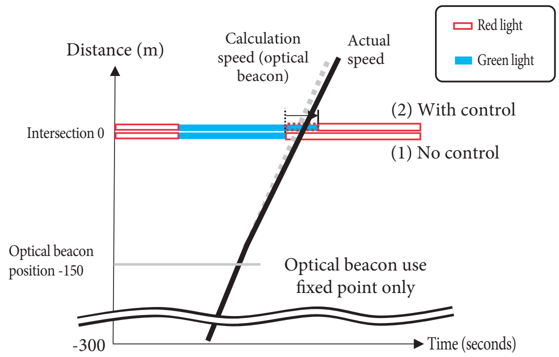

Fig.3: Comparison of conventional method with and without traffic signal priority control

2.2. Current issues

When there is a change in traffic conditions, such as traffic congestion before an intersection, the difference between calculated and actual speeds increases, as shown in Fig.4, and there are cases where drivers may not be able to pass through an intersection with a green light.

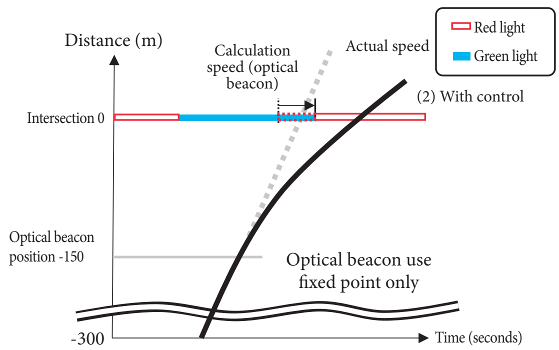

Fig.4: Conventional traffic signal priority control issues

2.3. Traffic signal priority control in this technological development

In this technological development, the final location-determination point is set closer to the intersection than the optical beacon using GNSS, as shown in Fig.5. By determining the arrival time based on the actual speed at the final location-determination point, the error in the intersection arrival time can be minimized.

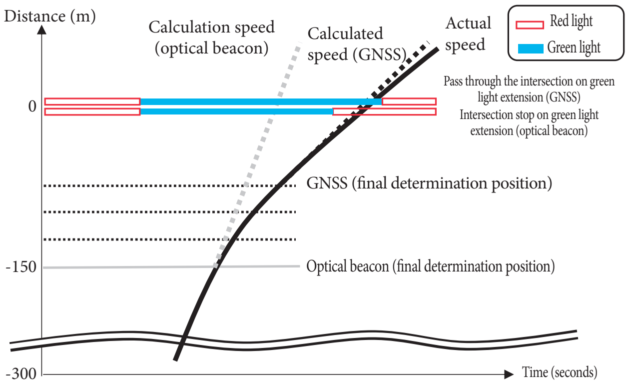

Fig.5: Traffic signal priority control based on this technology development

3 Detailing functional and technical requirements

Using location information, etc., we detailed functional and technical requirements to improve the accuracy of estimated arrival times at intersections for buses and other vehicles.

3.1. Position error target performance

The position error was assumed for a driving speed of 50 km/h. Because the time setting of the signal controller shortening/extending time is in units of 1 second, it is desirable to set the position error so that the expected arrival time error at the intersection is less than 1 second. Therefore, the performance requirement for the position error was set to 10 m or less, which results in an arrival time error of 0.8 seconds at a travel speed of 50 km/h.

3.2. Measurement cycle target performance

The measurement cycle was set to 2 seconds, taking into account the expected communication delay of several hundred milliseconds to 1 second, including fluctuations caused by the cellular phone network, the processing load of the operation monitoring unit, and the volume of data communication.

3.3. Positioning method

For the positioning method, RTK, which uses a reference station and its correction information via a cellular phone network, or DGPS, which increases positioning accuracy by receiving reinforcement signals delivered from a satellite with a GNSS receiver, shall be adopted from among widely used methods, depending on the external environment of the operation route. One or more of the two methods can coexist in the same system.

3.4. Position correction method

The position correction method when GNSS positioning accuracy degrades was optional in consideration of the introduction of new technology in the future.

4 Traffic signal priority control FOTs

4.1. FOTs outline

Verification of the operation and control effectiveness of GNSS traffic signal priority control was conducted based on the Prefectural Police Model System Verification Plan. An outline of the FOTs is shown in Table 1.

Table 1: FOTs outline

Item	Contents	
Verification area	Shizuoka City, Shizuoka Prefecture	
Implementation policy	Verify the operation and control effects of GNSS traffic signal priority control in a model system. The verification route shall be an existing route in order to compare with the existing traffic signal priority control (PTPS and FAST) using optical beacons. Because verification is conducted by connecting to existing routes (public roads) and existing control systems, sufficient consideration should be given to ensuring safety, and the configuration should be designed to minimize the impact on existing systems. From the Prefectural Police Model System Verification Plan.	
	PTPS	FAST
Target intersection	2 directions, 4 intersections (including 1 new intersection) Inbound: Kagoue, Zaimokucho, Abecho, Nakacho (new) Outbound: Abecho	11 intersections (including 2 new intersections) Yuzuki, Gokoku Jinja Minami, Gokoku Jinja Iriguchi, Tokiwacho 2-chome, Kuroganecho Nishi, Aikawa Koen Kita, Aikawa Koen Minami, Ikama Jinja Kita, Ikama Jinja Nishi, Egawacho (new), Nakacho (new)
Verification period	Optical beacon: November 29 - December 3, January 18 - 21: 9 days (The period is adjusted to the number of days for GNSS control verification (9 days))	Optical beacon: November 27 - December 3, January 17 - 21: 12 days
	GNSS: December 15 - 21, January 11 - 14: 9 days (Not including weekends or national holidays)	GNSS: December 15 - 21, January 10 - 14: 12 days (including weekends and national holidays)
Verification day time slot	Monday - Friday (weekdays) 9:00 a.m. - 4:00 p.m. (The project is conducted during daytime hours when there is less impact on area traffic.)	24 hours including weekends and national holidays
Number of vehicles verified	Buses: 3 + FOTs vehicle: 1	Ambulances: 3

The FOTs routes were selected from the existing routes shown in Fig.6 to compare with the existing optical beacon-based traffic signal priority control (PTPS and FAST) in Shizuoka City, Shizuoka Prefecture.

Because verification was conducted by connecting to the existing route (public road) and existing control system, it was conducted in a configuration that minimized impact on the existing control system.

Specifically, as shown in Fig.7, the system configuration consists of a control system with operation monitoring unit, etc., and buses and ambulances with newly installed

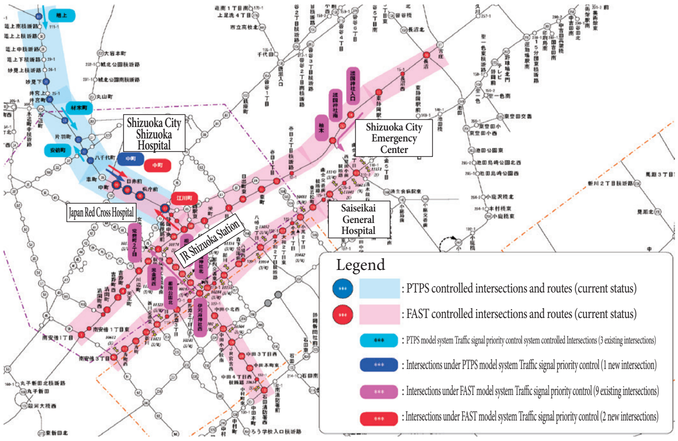

Fig.6 FOTs routes and intersections

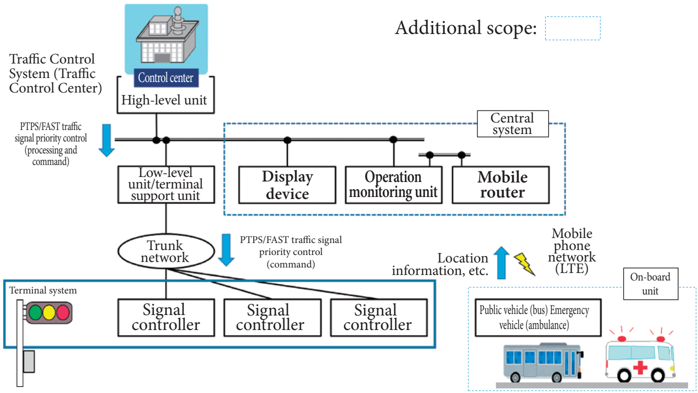

Fig.7: FOTs system configuration

(additional) on-board GNSS-compatible instrumentation.

The existing control system was notified at the timing determined by the operation monitoring unit, and traffic signal priority control of traffic signals was executed (operated) by existing equipment. For comparison, the number of seconds for setting the PTPS and FAST devices using optical beacons and the position of the optical beacons were implemented under the condition that the existing system was not changed.

PTPS evaluation was conducted from 9:00 a.m. to 4:00 p.m. outside morning and evening rush hour times while the system was in operation so as not to affect current traffic. This was done to confirm that the results of PTPS and FAST using optical beacons are equivalent to or better than the standard.

The validation period was one month long, and the optical beacon traffic signal priority control and GNSS traffic signal priority control were conducted alternately twice each week in order to minimize the difference in traffic volume during the validation period and to average the effects of each day of the week.

For the PTPS, only weekdays were used for the FOTs in accordance with the current operational status.

4.2. FOTs results

The basic operation, position error, delay time, etc. were confirmed, and the control effect was confirmed to be equivalent or superior to that of optical beacon control, as shown in Table 2.

The following table shows each verification item, its purpose, evaluation values, and results. For details, please refer to the report[2].

GNSS accuracy was confirmed to meet the target position error of 10 m or less within the PTPS verification route as shown in Table 3.

Table 2: Verification items and results

No.	Verification items	Objective/evaluation	Results
1	Priority control operation	Confirmation of basic operations: green light time extension and red light time shortening	Priority control (green light time extension and red light time shortening) Reduction of differences in passing through stop lines Average -74.7 sec. Reduction of non-passage rate during green light time extension -88.9%
		Basic operation: Equivalent to or better than optical beacon control	
2	Control effects	Confirmation of travel time reduction effect in priority control implementation Impact on cross-directional traffic Confirmation	Intersection vehicle passenger time reduction Average 2.1 sec. Reduced route travel time Average 8.1 sec. Reduction of wasteful green light extension time Average 2.1 seconds
		Control effectiveness: Equivalent to or better than optical beacon control	
3	GNSS accuracy	Confirmation of position error for selected routes	Shizuoka City: 10 m or less Tokyo waterfront area: 10 m or more in multipath propagation environment in some cases
		Position error: 10 m or less	
4	Extension time	Validation against the measurement cycle	281 ms (max. 960 ms)
		Communication and processing delay time from on-board unit to traffic signals: less than 1 second	
5	Bus priority control operation when multiple buses pass	Operation confirmation on continuous bus approach	Maximum deceleration at bus stop $0.83\ m/s^2$ (0.09 G)
		Deceleration at stop: $1.96\ m/s^2$ (0.2 G) or less	
6	Priority control conditions	Operation confirmation at time of crossing direction congestion extension to a bus route	Priority control release is executed when the set value is exceeded (Release is confirmed at 100 m or more compared to the set value of 100 m)
		Priority control is released when the congestion length in the crossing direction exceeds the set value	

Table 3: Position error verification results within the verification route

Unit: m

Evaluation site	Abecho	Kagoue	Zaimokucho	Nakacho
Mean value	1.58	2.74	2.39	2.49
Maximum value	4.95	5.12	4.84	4.89
Minimum value	0.16	0.99	0.63	0.63

Table 4: Position error verification results outside the verification route

Unit: m

Evaluation site	In front of the Japan Red Cross Hospital	From Japan Red Cross Hospital to Egawacho	Egawacho
Mean value	2.59	3.19	3.23
Maximum value	9.71	11.57	20.00
Minimum value	0.42	1.44	0.50

The area near Shizuoka Station was excluded from the validation route because of multipath propagation (reflected radio waves from buildings, etc.). As a reference, Table 4 shows the results of position error verification outside the validation route.

The results of function verification specific to this technology development are shown below.

(1) Additional operating functions for traffic signal priority control

The current optical beacon system detects the location of a bus only when it passes directly under an optical beacon installed on the roadside, so the location of the bus is indeterminate after it passes the optical beacon.

For example, if there is a bus stop after passing the optical beacon and the bus stops, it may not be possible to pass even if the green light time is extended.

On the other hand, the GNSS-based traffic signal priority control system can continuously monitor the bus position so that even when a bus stops at a bus stop triggering a red light, the system can implement additional traffic signal priority control to shorten the red light time. Fig.8 shows an example of how this function allows a bus to pass through an intersection quickly.

(2) Traffic signal priority control release operation function

With the current optical beacon system, the position of the emergency vehicle after it passes the beacon is indeterminate, as is the case with buses. The GNSS-based traffic signal priority control system can continuously determine the position of the emergency vehicle, allowing the traffic signal priority control system to be released immediately after it passes through an intersection.

Fig.9 shows a case in which traffic signal priority control using GNSS reduced the amount of wasted green light time, whereas a conventional optical beacon would have continued to extend the green light time even after an emergency

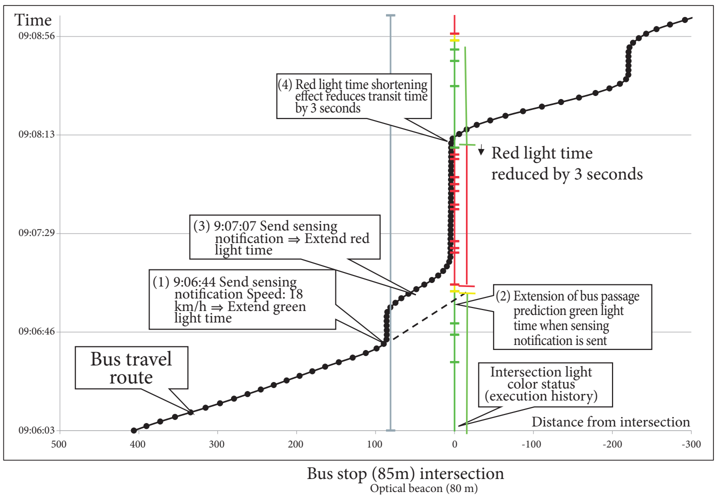

Fig.8: Example of a function unique to this technological development (addition of priority control)

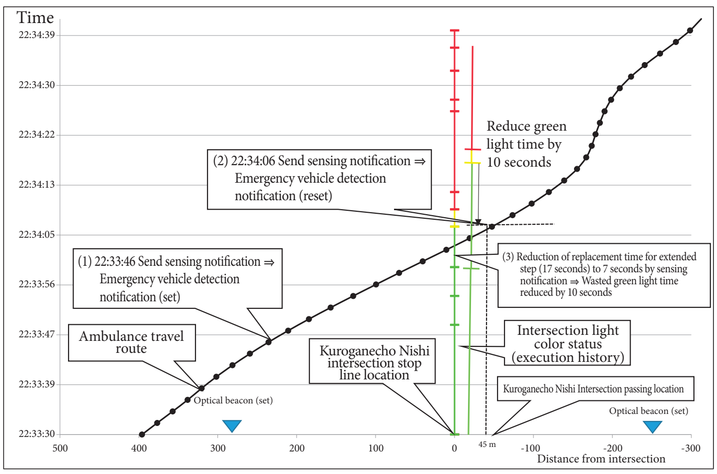

Fig.9: Example of a function unique to this technological development (cancellation of priority control)

vehicle passed through the intersection.

By reducing wasted green light time, the impact on the flow of traffic in the crossing direction can be reduced.

5 Simulated emergency vehicle information transmission FOTs

5.1. FOTs outline

We conducted emergency vehicle information (simulation) distribution and GNSS position error FOTs using an on-board device with simple and minimum performance requirements, which was developed for GNSS traffic signal priority control in this technology development, for 10 days from January 10 to 14 and 17 to 21, 2022, from 10:00 a.m. to 4:00 p.m.

A mechanism has been developed in which location information from an on-board unit is controlled by the operation monitoring system and utilized for traffic signal priority control. Functionality has been added for sending location information to the operation management system in the form of an information collection and distribution server.

Location information was collected from the on-board unit installed in the simulated emergency vehicle via the cellular phone network LTE (closed network) and was distributed through other servers via the business Ethernet (closed network) to the automated vehicles participating in the FOTs in the Tokyo waterfront area.

Fig.10 shows the FOTs configuration and Table 5 shows the distributed information specifications.

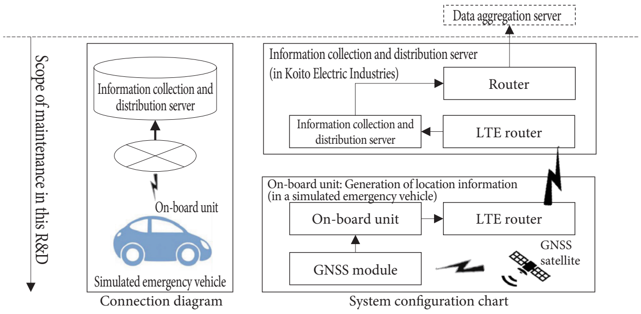

Fig.10: Test configuration in the FOTs in the Tokyo waterfront area

Table 5 Distribution information specifications

Item	Standard
Communication control procedure	UDP
Transmission cycle	Every 2 seconds
Number of GNSS information units stored	Max. 20 (100 ms)

In the FOTs, two passenger cars simulating emergency vehicles were prepared, and stickers were attached to the cars bodies to serve as identification markers so that the participants could check them with drive recorders, etc. A colored box was mounted on the roof rack.

Fig.11 shows the appearance of the simulated emergency vehicle that was actually driven in the Tokyo waterfront area for location information distribution testing, and Fig.12 shows the five different routes it traveled.

Fig.11: Simulated emergency vehicle

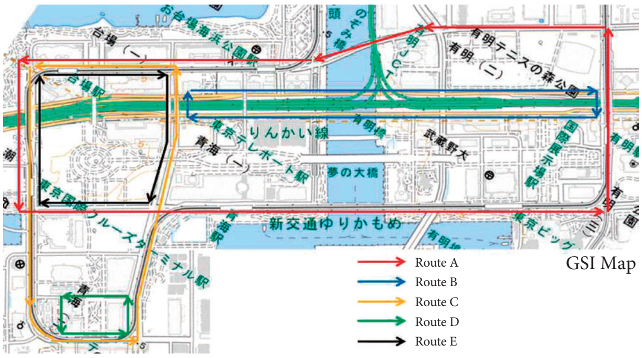

Fig.12: Travel route

5.2. FOTs results

The fact that the location information was distributed to and utilized on the participants' automated vehicles was checked on a confirmation screen (Dynamic Map viewer) associated with a high precision 3D map installed in the automated vehicles.

Position error was calculated by installing 2 cameras on the simulated emergency vehicle, obtaining the evaluation site passing time from 19 locations in images from the front rear, and above, then comparing the true value with the position information (latitude and longitude) obtained from the GNSS receiver at the same time.

The evaluation sites in the Tokyo waterfront area are shown in Fig.13.

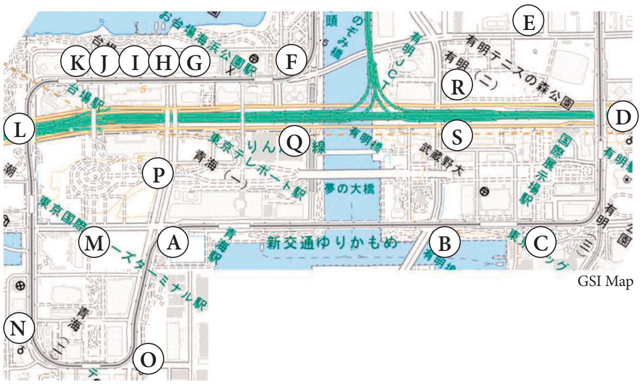

Fig.13: Evaluation sites

The results of the position error evaluation are shown in Table 6.

The PTPS FOTs verification route measured during the traffic signal priority control FOTs was in an open sky environment, and as expected, the maximum position error was less than 10 m at 5.12 m.

On the other hand, in the Tokyo waterfront area, there are many environments where radio waves from satellites are blocked, such as at points where multipath propagation is a concern due to adjacent buildings and under the Yurikamome Line elevated railway tracks.

Although the average value was less than 10 m, the maximum value exceeded 10 m in some cases, and there were many locations where there was a significant difference between the minimum and maximum values.

Table 6: Evaluation results (Part 1)

Unit: m

Evaluation site	A	B	C	D	E
Mean value	2.41	2.07	2.49	2.90	1.98
Maximum value	4.73	3.51	3.87	5.30	4.67
Minimum value	0.59	0.57	0.38	0.97	0.16

Evaluation results (Part 2)

Unit: m

Evaluation site	F	G	H	I	J
Mean value	2.14	3.22	5.29	8.37	5.09
Maximum value	4.60	5.27	9.92	17.67	14.10
Minimum value	0.16	0.19	1.41	1.12	0.92

Evaluation results (Part 3)

Unit: m

Evaluation site	K	L	M	N	O
Mean value	2.35	1.27	2.18	3.20	2.41
Maximum value	5.23	2.19	3.62	20.81	5.36
Minimum value	0.82	0.34	0.50	0.45	0.70

Evaluation results (Part 4)

Unit: m

Evaluation site	P	Q	R	S
Mean value	2.55	2.23	2.56	1.92
Maximum value	8.28	3.47	3.79	2.19
Minimum value	0.25	0.39	0.13	1.56

In addition, because two simulated emergency vehicles were used to distribute location information, the error evaluation of the on-board unit was conducted in the L-S section where the two vehicles traveled the same route.

The evaluation results for Vehicle 1 and Vehicle 2 are shown in Tables 7 and 8, respectively.

A significant difference occurred only at evaluation site N, but the analysis revealed that it was due to the effect of position error fluctuations during vehicle stops.

No significant errors were found in the results.

Table 7: Evaluation results by vehicle: Vehicle 1 (Part 1)

Unit: m

Evaluation site	L	M	N	O
Mean value	1.13	2.32	1.90	2.75
Maximum value	1.96	3.56	2.97	5.36
Minimum value	0.63	1.56	0.85	0.70

Evaluation results by vehicle: Vehicle 1 (Part 2)

Unit: m

Evaluation site	P	Q	R	S
Mean value	2.39	3.47	3.79	1.91
Maximum value	6.97	3.47	3.79	1.91
Minimum value	0.28	3.47	3.79	1.91

Table 8: Evaluation results by vehicle: Vehicle 2 (Part 1)

Unit: m

Evaluation site	L	M	N	O
Mean value	1.41	2.04	4.47	1.99
Maximum value	2.19	3.62	20.81	4.89
Minimum value	0.34	0.50	0.45	0.77

Evaluation results by vehicle: Vehicle 2 (Part 2)

Unit: m

Evaluation site	P	Q	R	S
Mean value	2.79	0.99	1.33	1.94
Maximum value	8.28	2.08	2.19	2.19
Minimum value	0.25	0.39	0.13	1.56

6 Conclusion

In this technology development, the impact on the current control system was minimized and a configuration was used that can be implemented in society at an early stage. The results of the two-year project are as follows.

In FY2020, the functional and technical requirements were detailed, and the following 6 specifications (drafts) and other documents were developed.

(1) GNSS Traffic signal priority control Technical Requirements Document
(2) Location Information Collection Method Guidelines
(3) Operation Monitoring unit Communication Application Standard (Draft)
(4) On-board unit Communication Application Standard (Draft)
(5) Prefectural Police Model System Specifications (Draft)
(6) Prefectural Police Model System Verification Plan

In FY2021, traffic signal priority control FOTs were conducted in Shizuoka City. We confirmed that the effectiveness of traffic signal priority control has been improved compared with conventional optical beacons.

In addition, with the realization of practical application of advanced automated driving with infrastructure cooperative system in mind, we conducted FOTs of simulated emergency vehicle information distribution in the Tokyo waterfront area, and confirmed that the information distributed from the infrastructure was effective.

We will promote standardization as social infrastructure equipment for early social implementation.

[References]

(1) UTMS Society of Japan History of Traffic Signals in Japan: The Next 40 Years, p.54
(2) New Energy and Industrial Technology Development Organization (NEDO): FY2020-2021 Progress Report: The second phase of SIP-Automated Driving for Universal Services/Research and Development on Traffic Signal Control using GNSS (location information) and other technologies, (2022)

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2 Establishment and Utilization of Traffic Environment Data

(2) Technological Development Concerning the Transmission of Traffic Environment Data

Research for V2X Communication for Cooperative Driving Automation (Overview)

Hideaki Suganuma (TOYOTA MOTOR CORPORATION)

1 Introduction

As various efforts are being made by industry, government, and academia to develop the technology and legislation to realize an automated driving society, expectation is being placed upon "cooperative automated driving," in which vehicles and road traffic infrastructure cooperate with each other in order to realize safer and more comfortable automated driving. However, there is yet to be a unified view on the communication method required for the adoption of cooperative automated driving.

In Japan, ARIB-STD T109[1] (hereinafter referred to as "700 MHz Band ITS"), which utilizes radio waves in the 700 MHz band, has been specified as an ITS radio to support safe driving, and the service is already in actual use. Therefore, it is thought that the expansion of the 700 MHz Band ITS will contribute most to the early adoption of communications for cooperative automated driving. On the other hand, there are concerns that the bandwidth will not be sufficient with only the frequencies that are currently allocated, and that Japan, which uses the 700 MHz band, will fall behind the global standard when compared to Europe and the United States, where the 5.9 GHz band has been allocated.

A conclusion has not come into sight because there are also opinions that, although from a global perspective many regions and countries have allocated the 5.9 GHz band as a frequency for ITS, the radio waves in the 5 GHz band, including the 5.9 GHz band, have strong linearity and may not be suitable for ITS, which needs to detect conditions beyond the visible range. There are also opinions that the applications and locations may be limited due to it causing interference with ETC and other systems and suffering interference from wireless LAN frequency extension, and most of all, that it might not be appropriate for the situation of Japan's frequency use since the 5.9 GHz band is still being used by broadcasters as FPUs (Field Pickup Units), and frequency migration work across industries will be necessary.

As industry, academia, and the government have established a system to work together toward the adoption of automated driving in SIP, in light of this background the "Task Force (TF) on V2X communication for Cooperative Driving Automation" (hereinafter the "TF") was established in FY2019 to study future communication methods under a three-year plan. The following sections describe the efforts of the TF.

2 Outline of Activities

2.1. Definition, Purpose, and Goals of Cooperative Automated Driving

The activities of the TF started with defining the cooperative automated driving system that the TF would handle and setting its goals. Clarifying this is very important to facilitate the TF's discussions.

The TF defined cooperative automated driving as "a system that is based on an autonomous automated driving system and which enables safer and smoother automated driving control by obtaining information from outside the detection range of on-board sensors, providing information which the vehicle possesses, and vehicle-to-vehicle and vehicle-to-infrastructure mutual communication."

The purpose of establishing the TF was "to draw a roadmap towards the adoption of the ideal cooperative automated driving, and to establish a policy for the optimal communication system for 'all-Japan', while taking into account international standards." In order to achieve this purpose, the goals were to (1) propose an appropriate communication system for cooperative automated driving, and (2) establish a roadmap that specifies the communication system required for cooperative automated driving and the timing when that communication system will be required.

2.2. Phases of the Study

In order to achieve the goals stated in section 2.1, the TF conducted the study by dividing the tasks to be performed into three phases.

Phase I: Sorting the use cases to be used as the basis of the study

Phase II: Clarify the communication requirements for each use case

Phase III: Study communication schemes that meet the communication requirements and develop the roadmap

In addition, the structure of the study was enhanced by the participation of ITS-related ministries and agencies in the capacity of committee members who proactively promoted the study, and by the broad participation in the study by people with knowledge of communications from Phase II onwards.

These activities are described in Section 3. The members of the TF and the overall schedule are shown in Fig.1.

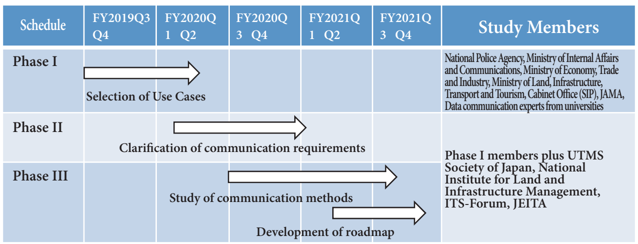


Fig.1: TF Study Members and Overall Schedule

3 Study of communication methods

3.1. Selection of Use Cases

Many use cases have been proposed for the utilization of communications for cooperative automated driving, both in Japan and overseas. However, there are many use cases in which communication is clearly the objective, such as using communication instead of on-board sensors, or that appear difficult to realize only through the application of communication due to significant issues with the elemental technologies other than communication being visible at this point in time. The TF considered it unrealistic to implement all of these use cases, so it decided to define use cases that are expected to be realized in the future. However, the TF did not consider all of the use cases anew, but adopted a method of collating and sorting use cases that have been proposed around the world and selecting the use cases that should be dealt with the TF. For the actual use cases, proposals from the Japan Automobile Manufacturers Association (JAMA) and the results of the "Study of utilization of new communication technologies including V2X technology to automated driving system",[2] a research study conducted in FY2018 as SIP-adus project. JAMA's proposals were use cases that are considered essential for automated vehicles to be able to drive, such as the distribution of SPaT information, merging assistance, and emergency vehicle notification. In addition, the FY 2018 research study collected the use cases used in cooperative automated driving and driving safety support projects in Europe, the U.S., and Asia, including Japan.

The TF selected use cases based on the above, with focus placed upon the following three points during the selection process.

(1) All traffic participants basically comply with the law

(2) It is not feasible by autonomous automated driving system.

(3) Compatibility with the use cases defined in the definition of a cooperative automated driving system for the purposes of (1) obtaining information beyond the detection of on-board sensors, (2) providing information possessed by the vehicle, and (3) vehicle-to-vehicle/ vehicle-to-infrastructure communication

Through this, the use cases that have been proposed globally were sorted and 25 use cases to be handled by the TF (hereafter referred to as "SIP-UC") were selected. The details of SIP-UC were published in September 2020.[3] Fig.2 shows, as an example of a use case, a use case of cooperative merging assistance for mainline vehicles via roadside infrastructure network.

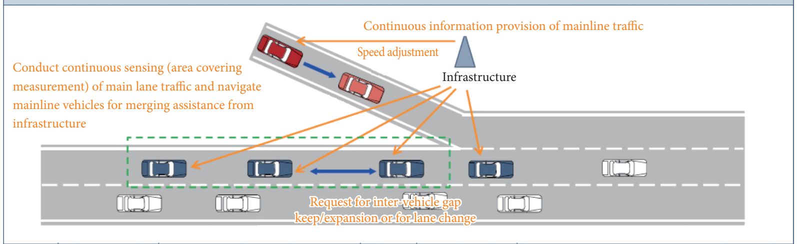
3.2. Clarification of Communication Requirements

In Phase II, with the cooperation of the ITS Info-communications Forum (hereinafter referred to as the "ITS Forum"), which has abundant knowledge and experience in the standards and standardization of ITS wireless communications, the communication requirements were sorted under the lead by the ITS Forum. In addition, because it is necessary to specify the details of each service in order to define the communication requirements, interviews were also conducted with research groups that are conducting technical studies and field operational tests) similar to those for SIP-UC. Table 1 shows the communication requirements for the cooperative merging assistance for mainline vehicles via roadside infrastructure network, as an example of the communication requirements that were defined by the ITS Forum based on the information collected from various organizations.[4]

Research for V2X Communication for Cooperative Driving Automation (Overview)

Functional classification	a. Merging/lane change assistance		
Name of the use case	a-1-3. Cooperative merging assistance for mainline vehicles with roadside infrastructure network		
Target areas	Expressways + prefectural and municipal roads	Target vehicles	Privately owned vehicles
Overview	Providing merging vehicles with area-covering information including mainline vehicles location and speeds through infrastructure, the system navigates mainline vehicles to adjust inter-vehicle gap as merging assistance.		

Image of the use case



Remarks (communication requirements, etc.)			Data category / content of information		
	Communication	V2I		Message	Arrival time at the merge point (main line vehicle), request for adjustment of inter-vehicle gap
	Topology	One-to-many		Sensor data	Speed, position
	Control Usage	Speed adjustment, vehicle distance adjustment		Rich content	-
	Responsiveness	Required	Data amount		Small

Fig.2: Use case example: merging assistance

Table 1: Example of communication requirements

Functional classification	a. Merging/lane change assistance			
Use cases	Cooperative merging assistance for mainline vehicles with roadside infrastructure network			
No.	a-1-3			
Message name	Location information	Control request	Negotiation request Update request	Negotiation response Update response
Communication method	V2I (I to V)	V2I (V to I)	V2I (I to V)	V2I (V to I)
Message destination	Non-specific vehicles	Roadside infrastructure	Specific vehicle	Specific vehicle
Target area (minimum range)	From 6 seconds before the start of merging until the merging point	Within the control request range	Within the control request range	Within the control request range
Number of transmission vehicles per area	1 vehicle	1 vehicle	1 vehicle (x number of controlled vehicles)	48 vehicles (number of control vehicles, during congestion)
Required communication distance	Connecting road: 66.7 - 116.7 m Main line: 111.1 - 266.7 m	66.7 - 116.7 m	Connecting road: 66.7 - 116.7 m Main line: 111.1 - 266.7 m	Connecting road: 66.7 - 116.7 m Main line: 111.1 - 266.7 m
Maximum relative velocity	Connecting road: 20 - 70 km/h Main line: 20 - 120 km/h	Connecting road: 20 - 70 km/h Main line: 20 - 120 km/h	Connecting road: 20 - 70 km/h Main line: 20 - 120 km/h	Connecting road: 20 - 70 km/h Main line: 20 - 120 km/h
Maximum data size	5,236 bytes (4,986 + 250) Estimated number of vehicles: 184	287 bytes (2)	273 bytes (2)	287 bytes (2)
Periodic/ Aperiodic	Periodic	Aperiodic	Aperiodic	Aperiodic
Transmission interval	100ms	not specified		
PAR per packet	PAR ≥ 99% (tentative)	PAR ≥ 99% (tentative)	PAR ≥ 99% (tentative)	PAR ≥ 99% (tentative)
Maximum acceptable delay in radio area	Not specified	Assumed 100ms	Assumed 100ms	Assumed 100ms

3.3. Technical Testing of Communication Systems

The feasibility of the use cases were evaluated from the perspective of the feasibility of communication by applying the communication requirements defined in Section 3.2 to the SIP-UC selected in Section 3.1. In the evaluation, the applicability of the following two communication methods to twenty of the SIP-UC use cases was studied, excluding the five use cases for which information distribution over a wide area by V2N (Vehicle to Network) communication is clearly suitable.

(1) Expansion of 700 MHz Band ITS

(2) Application of C-V2X(*) as an example of a new \ communication method

*Adopted as an example of utilization of the 5.9 GHz band frequency

C-V2X (Cellular V2X: X stands for 'everything')

The actual evaluation was conducted by Kyocera Corporation (hereinafter referred to as "Kyocera") and NEC Corporation (hereinafter referred to as "NEC"), who were entrusted with this task. Of these, Kyocera was responsible for the evaluation of the 700 MHz Band ITS, while NEC was responsible for the evaluation, roadmap development, and overall summary of the new method based on C-V2X.

Regarding these evaluations conducted by Kyocera and NEC, please refer to the details in Section 2 (2) 1) "Research on Communication Methods to Realize Cooperative Automated Driving Use Cases" that follows this section. This section briefly describes the results of the testing.

In the evaluation of 700 MHz Band ITS, Kyocera evaluated the feasibility of adding all twenty SIP-UC to the existing ITS services that support safe driving. As a result, among the V2I (Vehicle to Infrastructure) communications between vehicles and the roadside infrastructure, information distribution from the roadside infrastructure to vehicles was feasible in all cases. On the other hand, some of the requirements for information distribution from vehicles to the roadside infrastructure could not be met. As for V2V (Vehicle to Vehicle) communication, eight of the eleven use cases in SIP-UC that assumed V2V communication could not meet the requirements.

The use cases that failed to meet the requirements were characterized by the need for a function (called "negotiation") in which the vehicle that is the source of information identifies the vehicle to be communicated with and exchanges individual information with it. The negotiation function is a mechanism that does not exist in the 700 MHz Band ITS, which is based on broadcasting, and this evaluation confirmed that a new communication method, as well as a new communication bandwidth in some instances, are required to realize such use cases.

On the other hand, NEC's evaluation using C-V2X focused on the evaluation of packet arrival rate (PAR), reception level, and the impact of shadowing, based on merging assistance through negotiation and services around intersections, which could not be realized in the evaluation of the 700 MHz Band ITS. As a result, it was confirmed that there were cases in which the requirements could not be met, such as sudden deterioration of communication conditions due to shadowing and a drop in packet arrival rate due to road reflection and other effects.

The results of the technical testing are summarized below.

- For infrastructure-to-vehicle communications under V2I, all use cases can be met by expanding the 700 MHz Band ITS.
- Some of the vehicle-to-infrastructure communication use cases under V2I and all of the V2V communication use cases did not meet the requirements
- A review of the detailed conditions for each individual use case scenario and the application of new communication methods are necessary
- For use cases that require advanced communication, such as negotiation between vehicles, the requirements were not met even in the C-V2X evaluation.

From these results, it was found that it will be difficult to realize all of the SIP-UC simply by adding new methods, and it was concluded that "further study is needed".

4 Development of roadmap

The SIP-UC defined by the TF are classified into two categories: those that are essential for driving automated vehicles and those that support safer and more comfortable driving. The timing of their realization varies, including those that can be realized through the extension of safe driving support, those that require advanced mechanisms, and those that have already been positioned as national policies by ITS-related ministries and the national government. Therefore, in Phase III, the deployment timeframe for each of the SIP-UC use cases was arranged and defined using a timespan of approximately five years, based on information from the various related parties. In addition, because the realization of the use cases requires a wide range of issues to be solved, not only technological but also including the legal system, business models, and clarification of the roles and responsibilities among service providers, at the same time the TF identified the necessary issues to realize the SIP-UC and included them in the deployment plan.

In the deployment plan, the use cases that can be extended from safe driving support to automated driving and the use cases that are essential for the driving of automated vehicles are expected to be realized around 2025, and the 700 MHz Band ITS can be utilized. The use cases for safer and more comfortable automated driving, which are expected to be realized from 2030 onwards, will require advanced communications such as the negotiation that is described above, and will require the introduction of new communication methods and the securing of frequency bandwidth. Based on these considerations, the TF developed the roadmap shown in Fig.3 and reached the following conclusions.

- It is assumed that new communication methods for negotiation, etc. will be required around 2040
- If we anticipate, for example, 30% adoption of cooperative automated vehicles around 2040, introduction of the new communication methods will be required from around 2030
- The 700 MHz Band ITS can be utilized for use cases that will commence earlier, before 2030

Further, in order to realize each use case, it is very important to have timelines to address the many other issues, not only the results of the TF's study of communication methods.

Regarding the deployment plan and roadmap, please refer to the details in Section 2 (2) 1) "Research on Communication Methods to Realize Cooperative Automated Driving Use Cases" that follows this section.

5 Conclusion

The TF defined 25 use cases to realize cooperative automated driving that utilizes communication. It then conducted a study of the communication methods that should be applied to these use cases and compiled them together with the timeframe for realization of each use case and issues that need to be solved in a roadmap.

In order for the early adoption of automated driving, it is necessary to continuously study the application of use cases that utilize the 700 MHz Band ITS and the new communication methods needed to realize the use cases that require advanced communication in the future.

We hope that the study will be progressed steadily in the future according to the roadmap that has been defined on this occasion.

[References]

(1) ARIB-STD T109 700 MHz Band Intelligent Transport Systems, https://www.arib.or.jp/english/std_tr/telecommunications/desc/std-t109.html, (accessed 25th October 2022)

(2) Study of utilization of new communication technologies including V2X technology to automated driving system, 2019, https://en.sip-adus.go.jp/rd/rddata/rd02/204s.pdf, (accessed on 25th October 2022)

(3) SIP Use Cases for Cooperative Driving Automation-Activity Report of Task Force on V2X Communication for Cooperative Driving Automation in FY2019-, First edition, 2020, https://www.sip-adus.go.

(2) Technological Development Concerning the Transmission of Traffic Environment Data

Research for V2X Communication for Cooperative Driving Automation (Overview)

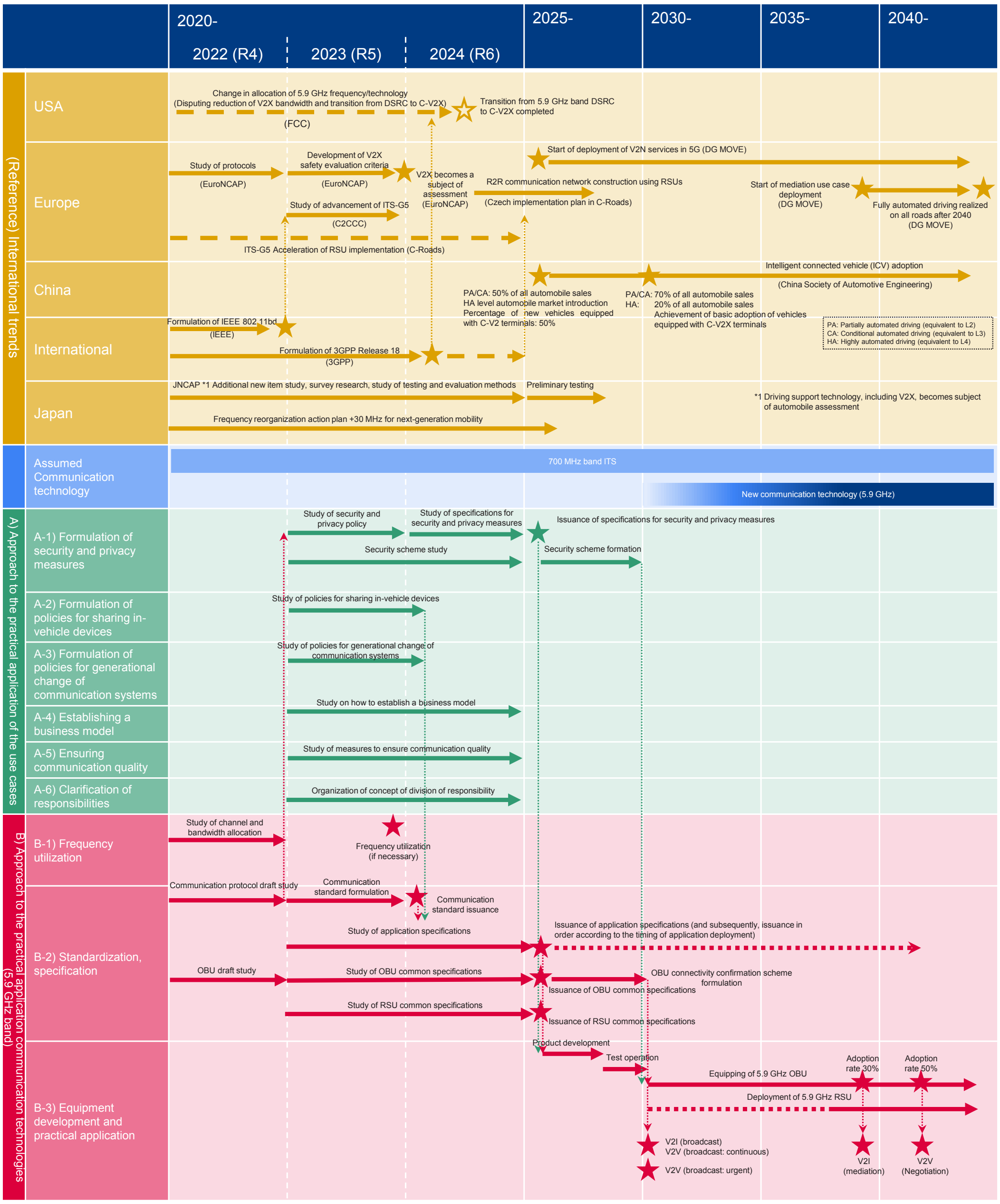


Fig.3: Roadmap for V2X Communication for Cooperative Driving Automation

jp/rd/rddata/usecase.pdf, (accessed on 25th October 2022)

(4) ITS Forum RC-017: Study report on communication scenarios and requirements for "SIP Use Cases for Cooperative Driving Automation", 2022, https://itsforum.gr.jp/Public/E3Schedule/p40/ITS_FORUM_RC-017eng_v10s.pdf, (accessed on 25th October 2022)

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1) Research on Communication Methods to Realize Cooperative Automated Driving Use-cases

Satoshi Kimura, Takeshi Nunomoto (NEC Corporation), Masato Ogawa, Tomoaki Konishi (KYOCERA Corporation)

(Abstract) This project was conducted to formulate the roadmap for the timing of social implementation of communication technologies necessary for the realization of an automated driving society, based on the study, verification, and field tests of the technical feasibility of wireless communication, including specific requirements for wireless communication technologies, for the use-cases for cooperative driving automation utilizing the V2X as formulated by the Task Force on V2X communication for cooperative driving automation, system implementation working group. Specifically, we examined the communication requirements for use-cases; verified whether the wireless communication cellular V2X system could be used, formulated measures to solve any problems that arose, and then verified their effectiveness; verified whether the existing wireless 700 MHz band Intelligent Transport Systems could be used, formulated measures to solve any problems that arose, and verified their effectiveness; and developed the roadmap of communication requirements for cooperative automated driving as necessary for the realization of an automated driving society.

Keywords: cooperative automated driving, V2X, cellular V2X (C-V2X), 700 MHz band ITS

1 A Study on V2X communication for achieving use-cases of cooperative driving automation (cellular V2X system)

1.1. Overview

Based on the SIP use-cases for cooperative driving automation (hereafter "SIP-UC")[1] formulated by the Task Force on V2X communication for cooperative driving automation (hereafter "TF"), the technical and communication requirements for SIP-UC were studied jointly with Radio System Technology Task Group of advanced ITS info-communication system committee in ITS Info-communication Forum (hereafter "TG"). We verified the suitability of the cellular V2X system, one of the available wireless communication systems, to meet with these communication requirements, formulated measures to solve any problems that arose, and verified their effectiveness. (V2X: Vehicle to X, V2I: Vehicle to Infrastructure, V2V: Vehicle to Vehicle, V2N: Vehicle to Network)

1.2. Study of communication requirements

Through discussions with the TG and organizations and companies involved in each SIP-UC, the technical requirements (function sharing between road and vehicles, communication functions, etc.) and communication requirements (communication sequences, message content, communication performance, etc.) required to realize the use case were defined for

Table 1: Examples of communication requirements

Functional classification	a. Merging/lane change assistance					
Use-cases	Merging assistance by preliminary acceleration and deceleration	Merging assistance by targeting the gap on the main lane	Cooperative merging assistance with vehicles on the main lane by roadside control			
No.	a-1-1	a-1-2	a-1-3			
Message name	Location information	Location information	Location information	Control request	Negotiation request/update request	Negotiation response/update response
Communication method	V2I (I → V)	V2I (I → V)	V2I (I → V)	V2I (V → I)	V2I (I → V)	V2I (V → I)
Message destination	Non-specific vehicles	Non-specific vehicles	Non-specific vehicles	Roadside infrastructure	Specific vehicle	Specific vehicle
Target area (minimum range)	From 6 seconds before the merging point to the center between the 6 seconds before the merging point and the merging point	From 6 seconds before the start of merging until the merging point	From 6 seconds before the start of merging until the merging point	Within the control request range	Within the control request range	Within the control request range
Number of transmission vehicles per area	1 vehicle	1 vehicle	1 vehicle	1 vehicle	1 vehicle (xnumber of controls)	48 vehicles (number of control vehicles, during congestion)
Required communication distance	33.9 to 59.3 m (National Research Institute Specifications: 95 m)	67.8 to 118.6m	Connecting road: 67.8 to 118.6 m Main lane: 112.5 to 270.0 m	67.8 to 118.6m	Connecting road: 67.8 to 118.6 m Main lane: 112.5 to 270.0 m	Connecting road: 67.8 to 118.6 m Main lane: 112.5 to 270.0 m
Maximum relative velocity	Connecting road: 20 to 70 km/h	Connecting road: 20 to 70 km/h	Connecting road: 20 to 70 km/h Main lane: 20 to 120 km/h	Connecting road: 20 to 70 km/h Main lane: 20 to 120 km/h	Connecting road: 20 to 70 km/h Main lane: 20 to 120 km/h	Connecting road: 20 to 70 km/h Main lane: 20 to 120 km/h
Maximum data size	1510byte estimate: 46 vehicles	2752byte estimate: 92 vehicles	5236byte estimate: 184 vehicles	287byte	369bytes	287byte
Periodic/Aperiodic	Periodic	Periodic	Periodic	Aperiodic	Aperiodic	Aperiodic
Transmission interval	100ms	100ms	100ms	not specified		
PAR per packet	PAR ≥ 99% (tentative)	PAR ≥ 99% (tentative)	PAR ≥ 99% (tentative)	PAR ≥ 99% (tentative)	PAR ≥ 99% (tentative)	PAR ≥ 99% (tentative)
Maximum acceptable delay in radio area	Not specified	Not specified	Not specified	Assumed 100ms	Assumed 100ms	Assumed 100ms

PAR: Packet Arrival Rate

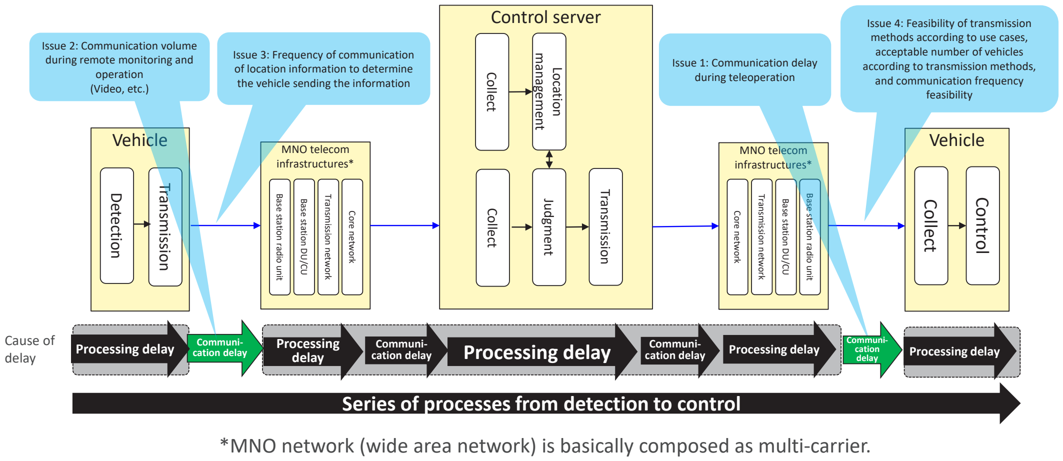

Fig.1: Issues in realizing communication requirements

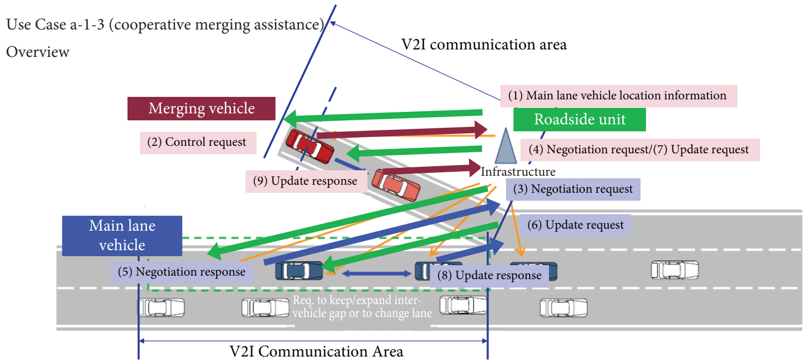

Fig.2: Communication model for merging assistance

SIP-UC in cooperation with the TG. Examples of communication requirements for use-cases related to merging and lane change support are shown in Table 1.

The results of the study were developed by the TG as a Study report on communication scenarios and requirements for "SIP Use-cases for Cooperative Driving Automation".[(2)]

1.3. Consideration of wide area network

For each SIP-UC using a wide-area network (d. Lookahead information: trajectory change, f. information collection/distribution by infrastructure, etc.), we organized the issues facing the realization of communication requirements and theoretically studied measures to deal with these issues. Fig. 1 shows the issues in realizing the communication requirements, and Table 2 shows proposed countermeasures for each issue.

Table 2: Proposed measures to address each issue

Issues	Item to study	Policy Outline
Issue 1: Communication delay during teleoperation	—Reduced communication delay (V ⇔ N)	—Priority control of wireless communications —Securing of dedicated frequency bandwidth —Securing of end-to-end dedicated bandwidth (e.g. slicing)
Issue 2: Communication volume during remote monitoring and operation (Peripheral Images, etc.)	—Reduced communication delay (V to N)	—Priority control of wireless communications —Securing uplink (V to N) communication capacity —Securing of dedicated frequency bandwidth —Securing of end-to-end dedicated bandwidth (e.g. slicing)
Issue 3: Frequency of communication of location information to determine the vehicle sending the information	—Reduction of communication frequency (V to N)	—Feasibility study for each transmission method (Unicast, multicast, broadcast)
Issue 4: Feasibility of transmission schemes according to use-cases, acceptable number of vehicles according to transmission schemes, and communication frequency feasibility	—Reduction of communication volume (N to V)	

V: Vehicle, N: Network

1.4. Study of Short range communication

For each use case that utilizes short range (road-to-vehicle and vehicle-to-vehicle) communication, we identified issues in realizing communication requirements, verified communication performance through cellular V2X communication simulations (5.9GHz band and 10 MHz bandwidths), and proposed theoretical measures to address these issues. Two major use-cases (1) cooperative merging assistance and (2) intersection area were taken up for testing. Fig.2 shows an example of the communication model used in the simulation of cooperative merging assistance communication.

Through communication simulations, issues in achieving the communication requirements were clarified, and are-assessment including countermeasures was then conducted.

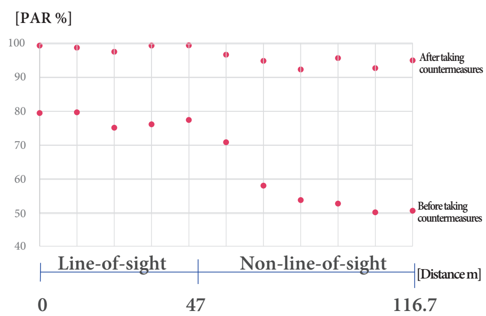

Fig.3: Example of communication simulation results

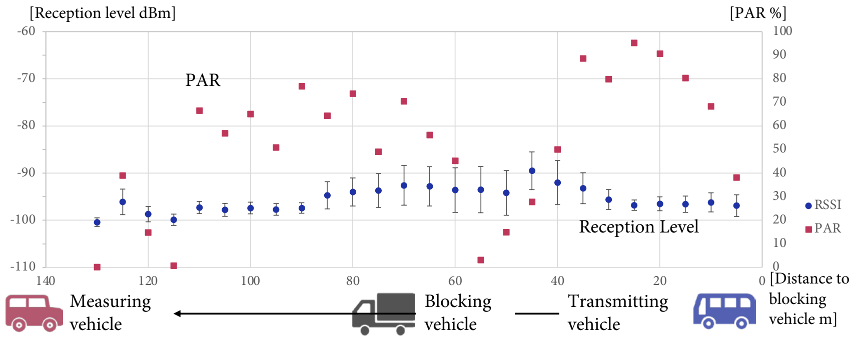

Fig.4: Example of test results on shadowing impact by a vehicle

Fig.3 shows, as an example, the results of the initial simulation (packet arrival rate (PAR) depending on the distance) and that of the simulation after taking countermeasures (to aggregate messages to be transmitted, to reduce impact of shadowing loss due to vehicles) against assumed factors causing declining of packet arrival rate, such as reception error on roadside unit by conflict of transmission/reception timing, as well as packet conflict at timing of data transmission to vehicle due to hidden node.

In addition, we conducted a communication performance evaluation test using vehicles and cellular V2X communicators on a test course to verify the effects of elements such as shadowing and communication congestion, which require verification in the field for wireless communication. From the perspective of communication performance, we evaluated (1) the impact of shadowing by vehicles and (2) the impact of communication congestion depending on the communication volume. Fig.4 shows the result the field operational tests (FOTs) of the impact of shadowing by a vehicle, as an example.

As a study of short range communication, the following were confirmed from the results of communication simulations and FOTs.

1) In order to realize a single use case, communications with various requirements are mixed and mutual influence occurs.
2) In order to realize multiple use-cases in the same location, communications with various requirements are mixed and mutual influence occurs.

In actual operation, the wireless communication environment (shadowing, multipath, etc.) and the driving environment (number of vehicles, inter-vehicle gap, etc.) cannot be uniquely specified or limited. Communication taking place in an unexpected environment can lead to communication congestion and subsequent communication delay or failure. It is therefore necessary to consider measures to prevent such problems. Specifically, the following measures should be considered: 1) reducing the impact of communication congestion by controlling communication congestion at not only the communication layer but also the application level, in accordance with the wireless communication environment and the driving environment; 2) reducing the impact of communication congestion by allocating communication channels according to the communication area (by lanes, by direction of traffic, etc.) and the content of communication.

2 A Study on V2X communication for achieving use-cases of cooperative driving automation (700MHz band ITS)

2.1. Overview

As in Section 1, among the SIP-UC formulated by the TF, 20 use-cases (see Table 3, with specific use-cases hereafter referred to by those designations), targeting V2I and V2V were considered. Based on study report on communication scenarios and requirements for "SIP Use-cases for Cooperative Driving Automation",[2] we verified whether the use-cases can be supported by 700 MHz band Intelligent Transport Systems (hereafter "700 MHz band ITS") and developed countermeasures to solve relevant issues through desk study and simulations.

2.2. Desk study

Desk study evaluated communication quality from the perspective of linked budgets, transmission time constraints, roadside unit installation constraints, and message sets.

In the evaluation of communication quality and transmission time constraints, SIP-UC a-1-3, a-1-4, a-2, and a-3, in which interaction is required, did not meet the transmission time constraint due to the number of transmitting vehicles per area. In the use case of unmanned platooning of following vehicles by electronic towbar (g-1), the communication requirement specifies a transmission cycle of 20 ms in the case of emergency, but the 700 MHz band ITS standard ARIB STD-T109 specifies a communication cycle of 100 ms, so the communication requirement was not met. In other use-cases, the transmission requirement was met.

In the roadside unit installation constraint evaluation, we examined the allocation of wireless transmission slots (hereafter "slot") for roadside units, and found possible to allocate the four slots required for SIP-UC. We therefore confirmed that the slot allocation for roadside-vehicle communication and inter-roadside communication is feasible even if SIP-UC is added to the 700 MHz band ITS service.

In the message set evaluation, we examined the possibility of adding SIP-UC message sets to 700 MHz band ITS messages, and confirmed that SIP-UC onboard unit message sets can be added by utilizing the free field (optional area) of ITS Connect TD-001.(3)

2.3. Simulations

To confirm whether SIP-UC is compatible with the 700 MHz band ITS, we constructed a simulation environment in which radio waves transmitted from multiple roadside units and onboard units interfere with each other. Fig.5 shows the SIP-UC study model. The road model is a 300m-plane layout, which has the highest density of roadside units in the existing model simulation(4), and includes the main lane and connecting routes of the expressway. Table 3 shows the simulation results.

SIP-UC infrastructure-vehicle communication (a-1-1, a-1-2, a-1-3, b-1-1, c-2-2, d-1 to d-5) and some SIP-UC vehicle-infrastructure communication (d-1 to d-4, f-2) were met the communication requirements of the TG. SIP-UC inter vehicle communication (a-1-4, a-2, a-3, c-1, c-2-1, c-3, e-1, g-1, g-2) and some SIP-UC vehicle-infrastructure communication (a-1-3) could not be met the communication requirements of the TG. The reason for this is considered that under CSMA/CA, the radio system for 700 MHz band ITS, when onboard unit A and B are located outside the carrier sense range and do not know each other's transmission timing, if both transmit at the same timing, their messages will collide at the position where each transmission arrives (hidden terminal problem).

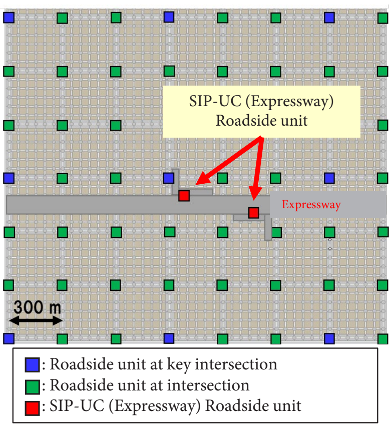

Fig.5: SIP-UC study model

Table 3: Simulation results

SIP-UC Name	Compatible or not with 700 MHz band ITS
a-1-1. Merging assistance for accelerating/decelerating on merging lane	✓
a-1-2. Merging assistance for aiming inter-vehicle gap on main lane	✓
b-1-1. Driving assistance by providing SPaT information (V2I)	✓
c-1. Collision avoidance assistance for sudden stop or sudden deceleration in front	–
c-2-1. Driving assistance by providing intersection information (V2V)	–
c-2-2. Driving assistance by providing intersection information (V2I)	✓
c-3. Collision avoidance assistance by providing hazard warning information	–
d-1. Driving assistance by providing notification of abnormal vehicles	✓
d-2. Driving assistance by providing notification of wrong-way driving	✓
d-3. Driving assistance by providing congestion information	✓
d-4. Assistance for congestion at highway junction and exit point	✓
d-5. Driving assistance by providing hazard warning information	✓
e-1. Driving assistance by providing information on emergency vehicles	–
f-2. Information collection for traffic flow optimization	✓
a-1-3. Cooperative merging assistance for mainline vehicles with roadside infrastructure network	– (V2I is ✓)
a-1-4. Merging assistance with inter-vehicle negotiation	–
a-2. Lane change assistance during congestion	–
a-3. Assistance for entering to priority road from non-priority roads during congestion	–
g-1. Electrified platoon without drivers	–
g-2. Adaptive cruise control (ACC) driving and platoon with driver using vehicles equipped with ACC	–

2.4. Issues and future actions

Based on the results of Sections 2.2 and 2.3, we identified issues and proposed future actions for the use-cases that did not meet the communication requirements of the TG.

The communication requirements of the TG are more stringent than the service requirements because the details of the service requirements have not yet been finalized. This shows that in confirming these communication requirements in detail, it will be necessary to further organize the service requirements for automated driving, such as the applicable scenarios and means of collecting information for each SIP-UC. One future action is to work with related organizations that have studied each use case to further specify the service requirements and define practical and optimal communication requirements.

For SIP-UC a-1-3, a-1-4, a-2, a-3 that require interaction, since the current 700 MHz band ITS specification is a broadcast protocol, supporting interaction is difficult. We therefore propose the following possible two countermeasures.

Proposal 1: New communication method only

A new communication method will be used that includes recognition of the surrounding situation (e.g., position and speed information). In such cases, it is necessary to study bandwidth and transmission (propagation). In addition, relationships with existing safe driving support services need to be considered (in the case of coexistence, the impact of cost and installation is significant. Deployment and dissemination of vehicles and quality assurance are issues when transitioning to a new system).

Proposal 2: 700 MHz band ITS + new communication method

This proposal is for the concept of "Basic Message (BM) + Advanced Message," in which basic recognition of the surrounding situation (position, speed information, etc.) is performed by the 700 MHz band ITS, and the subsequent interactive sequence is performed by new communication methods.

The above requires further discussion in the future.

The challenges for practical application of the system include standardization of message sets, slot allocation placement rules, and cybersecurity requirements. Future actions to address this issue include formulating guidelines and promoting standardization in consultation with related organizations.

In the use case g-1, the issue is the 20 ms cycle transmission during emergency braking. As a future action, the ARIB STD-T109 standard should be revised, or the requirements should be modified by further digging down into use case requirements.

2.5. Future prospects

2.5.1. Promote verification testing and social implementation of 700 MHz band ITS, which can be utilized over the long term

In this R&D project, we verified the applicability of SIP-UC to the 700 MHz band ITS through theoretical studies and simulations. Excepting SIP-UC a-1-3, a-1-4, a-2, and a-3, which require interaction, most of the use-cases handle the same basic information—such as vehicle position, speed, and direction—as the 700 MHz band ITS services currently in use. In addition, the 700 MHz band wave ability to reach far and travel around obstacles is said to be very advantageous for Japanese road conditions, which face issues such as poor visibility, and for vehicle antenna design. It is therefore important to maximize the use of the 700 MHz band ITS for cooperative automated driving, while taking into account international trends. For this purpose, it is important to define more detailed service requirements and communication requirements for each SIP-UC, taking into account various conditions such as road conditions; to prioritize essential services for driving automated vehicles according to the use case roadmap; and to steadily implement these services in society. In addition, more advanced communication is also required.

2.5.2. Consideration of a new communication method, assuming the period for realization of SIP-UC that requires mutual communication

SIP-UC a-1-3, a-1-4, a-2, and a-3, which require mutual communication, are difficult to support using a broadcast system designed for information distribution such as the 700 MHz band ITS. A new communication method that enables bidirectional communication will be necessary for such communication. However, further study is needed to investigate the communication requirements and new communication methods. As we continue to study this issue, it is important to discuss new communication methods, including a proposal that incorporates the concept of "basic message + advanced message."

3 Establish a roadmap for the timing of social implementation of communication technologies necessary for the realization of an automated driving society

3.1. Overview

In developing the roadmap, based on the plans already developed by the relevant ministries, agencies, and organizations, as well as case studies of their efforts, we established a timeline for the realization of each SIP-UC, and organized a use case deployment plan that lists the realization timeline in chronological order. Then, considering the issues in realizing the communication requirements of the use-cases described in Sections 1 and 2, we organized the items necessary for the realization of the deployment plan. Based on the above, we have compiled a roadmap in chronological order of the items to be implemented to realize the deployment plan.

3.2. Considerations of use case deployment plans

In considering the use case deployment plan, the communication methods (V2I, V2V, and V2N) applicable to each use case were assumed and studied through the TF discussions. Fundamentally, the use-cases are to be realized as cooperative automated driving, but since some of them may be initially used first for driving safety support, they are divided into cooperative automated driving and driving safety support in the deployment plan. Based on the above, we have established a timeline for the realization of each use case and organized a use case deployment plan that lists the realization timeline in chronological order, based on plans already established by related government agencies and organizations, as well as examples of initiatives being taken by various organizations. Fig.6-8 show the use case deployment plans for each communication method.

3.3. Implementation items for realization of use case deployment plans

Based on the issues in realizing the communication requirements of the use-cases described in Sections 1 and 2, we have organized the items necessary to realize the deployment plans. In realizing the use case deployment plans, we have organized the items to be implemented into the following two categories.

(A) Clarification of the direction of various issues through examination and discussion among the entities concerned (details shown in Fig.9).

(B) Practical application of new communication methods (e.g., application of 5.9GHz band) (details shown in Fig.10)

For the compilation of A), Issue Survey Report of Advanced ITS and Automated Driving Using Cellular Communications Technologies by ITS Info-communications Forum Cellular System the TG[5] were referred to.

3.4. Development of the roadmap

Based upon study results up to this point, we can conclude that in order to realize all 25 SIP-UC: new communication methods for V2I and V2V are needed around 2040; new communication methods need to be in place around 2030 (when the automated driving begin to be adopted) so as to be installed in 30% of cooperative automated vehicles by the assumed plan target of 2040; and the 700 MHz band ITS, an existing ITS wireless communication system, is expected to be utilized for the use-cases that are starting relatively sooner. Taking these points into account, the items required for the realization of the plan to expand the use-cases were broken down and a roadmap of communication requirements for cooperative automated driving necessary for the realization of an automated driving society was developed. The roadmap is shown in Fig.11.

Deployment of each use case and expected communication requirements for each communication method: V2I

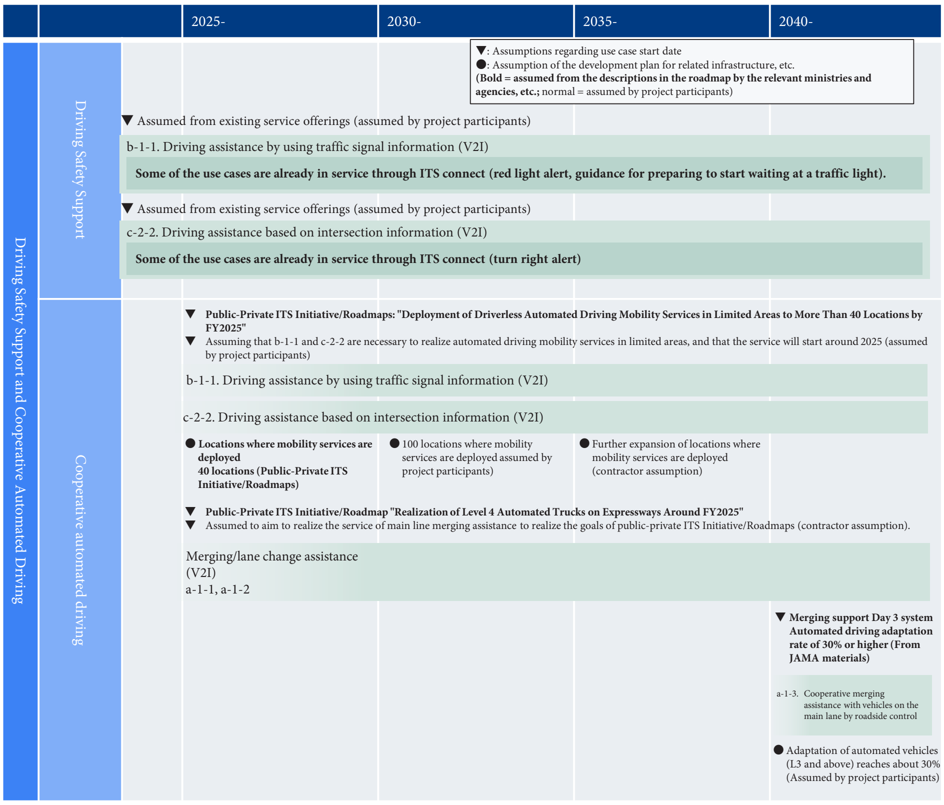

Fig.6: Use case deployment plan (V2I)

Deployment of each use case and expected communication requirements for each communication method: V2V

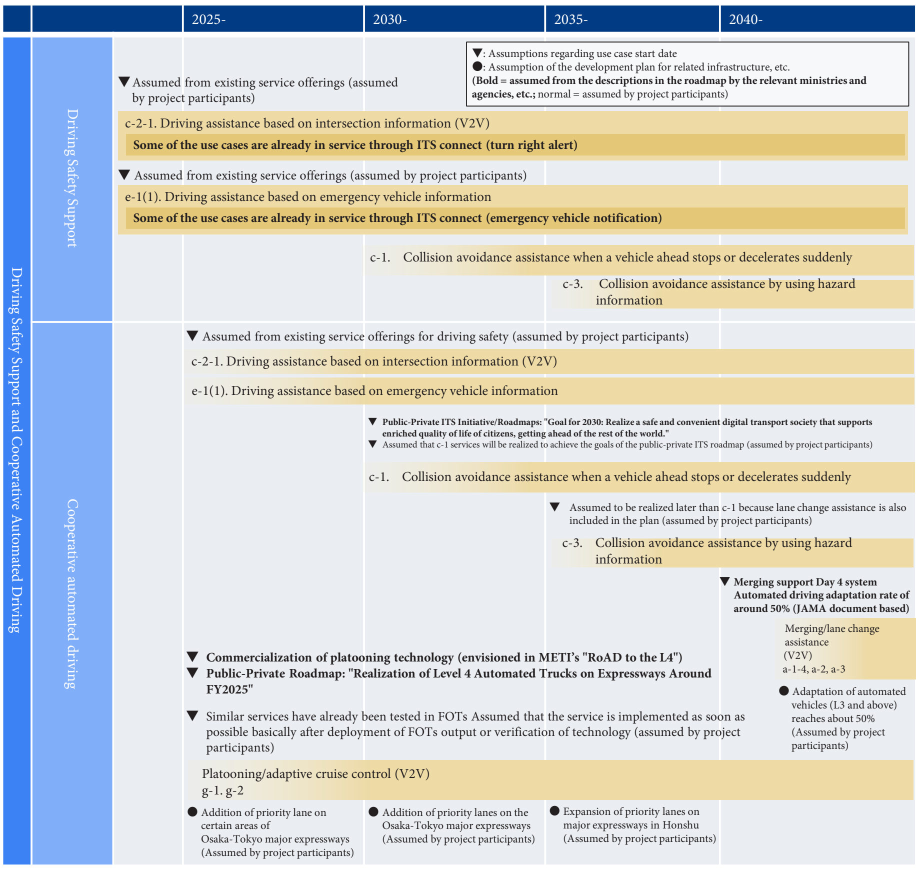

Fig.7: Use case deployment plan (V2V)

Deployment of each use case and expected communication requirements for each communication method: V2N

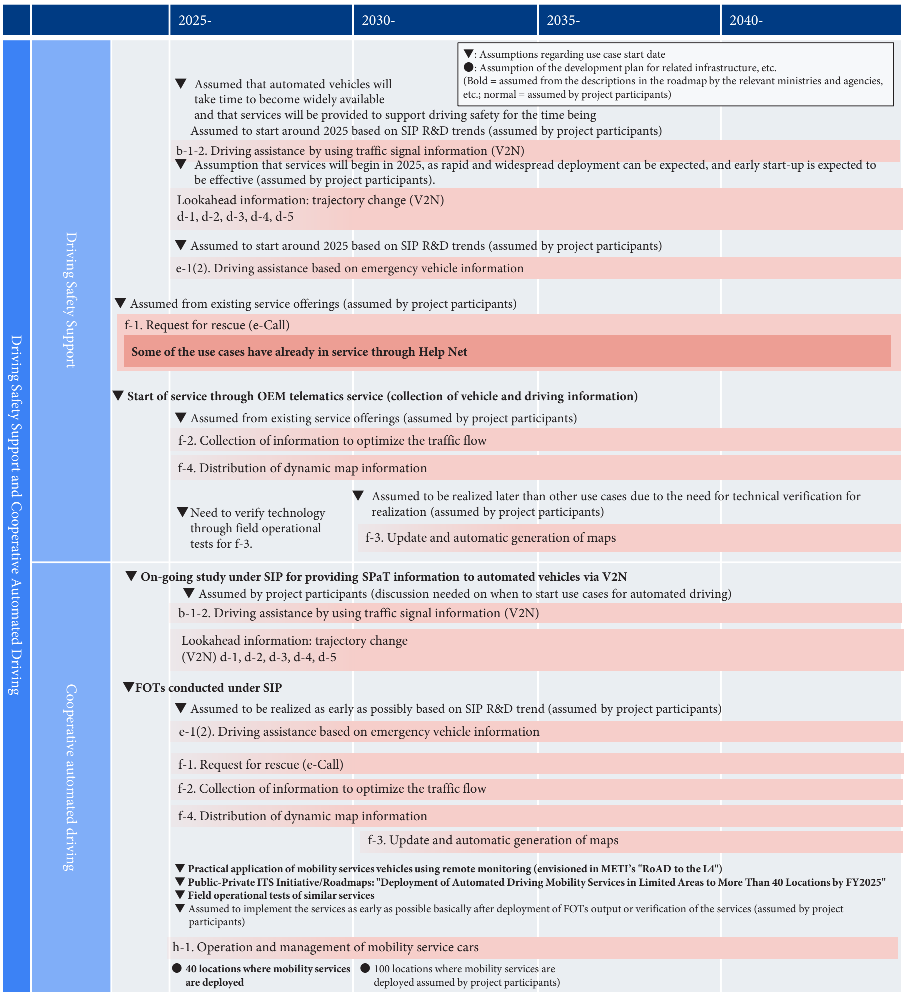

Fig.8: Use case deployment plan (V2N)

A) Activities toward practical application of use cases

Approach

- In regard to practical use cases for V2I/V2V/V2N, the ITS Information and Telecommunication Systems Promotion Council and the study the TF have pointed out various issues (discussion points) via the study the TF
- These stakeholders need to cover a wide range of issues (discussion points) through examination and discussion among the concerned entities, making clear the direction that should be taken.

Implementation Item

A-1) Formulation of security and privacy measures
A-2) Establishment of policy on shared use of onboard unit
A-3) Formulation of policy on generational changes in communication methods
A-4) Establishment of business model
A-5) Secure communication quality
A-6) Clarification of division of responsibilities

Fig.9: Undertakings toward practical application of use-cases

B) Activities toward the practical application of new communication methods

Approach

- Negotiation use cases are expected to begin after 2040, when automated vehicles will be in full use.
- It is difficult to realize negotiation use cases with the current 700 MHz band ITS.
- On the other hand, the 5.9 GHz band is mainstream internationally. New communication methods need to be put to practical use.

Implementation Item

B-1) Frequency utilization study
B-2) Standardization and specifications
B-3) Equipment development and commercialization

Fig.10: Activities toward practical application of new communication methods

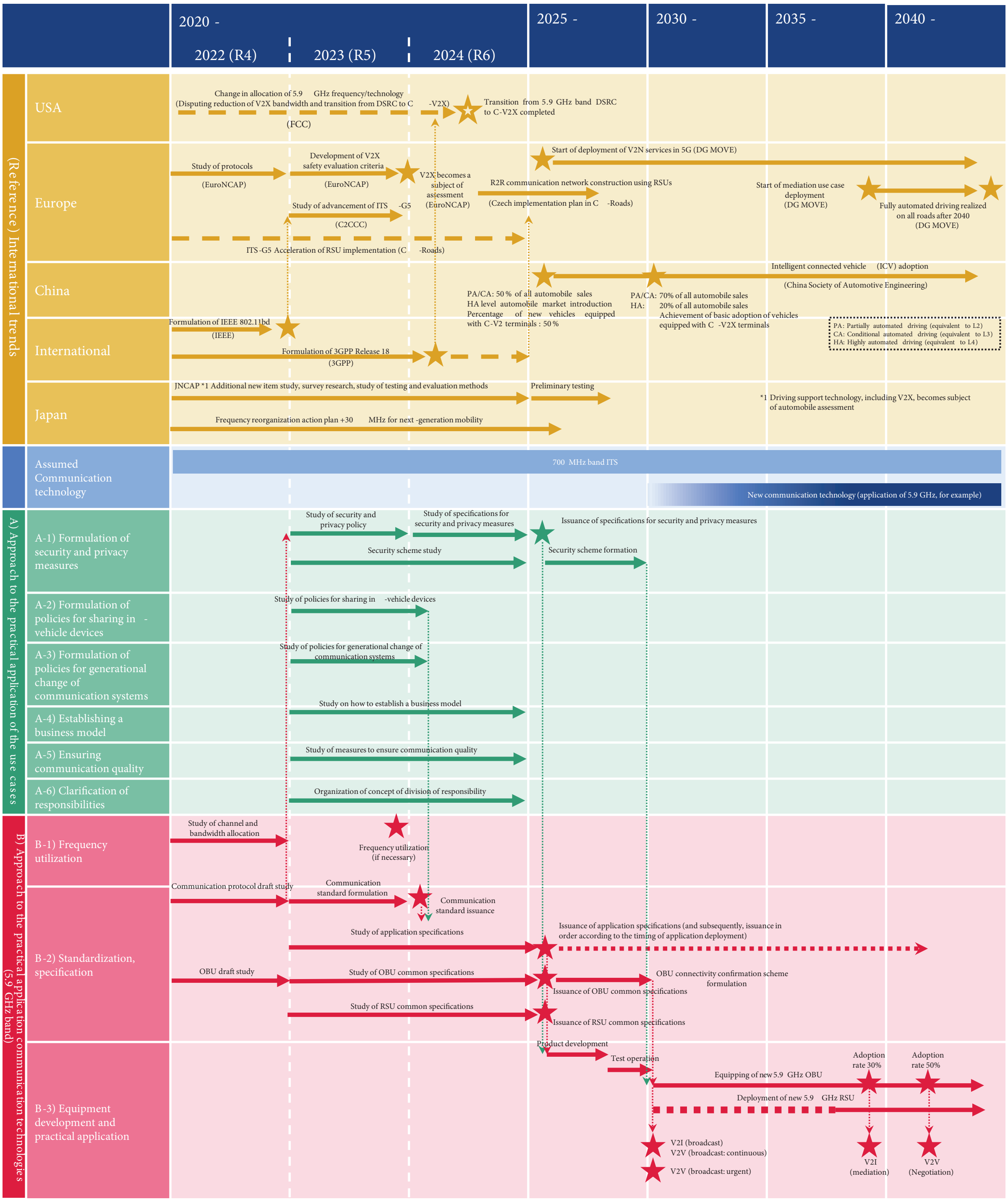

Fig.11: Proposed Roadmap

4 Conclusion

Through the verification of the compatibility of the existing wireless communication cellular V2X system, and the planning and verification of measures to solve any issues that arose, a direction has been determined for the realization of the issues facing SIP-UC.

Through the verification of the compatibility of the existing wireless communication 700MHz band ITS, and the planning and verification of measures to solve any issues that arose, it has been shown that the long-term utilization of the 700 MHz band ITS is an effective means to realize SIP-UC.

The roadmap formulated based on the above was compiled based on discussions among academic experts, relevant ministries and agencies, and members of industry associations (automotive industry, electronics industry) in the TF, as well as technological development trends and practical application trends in communications as of October 2021 to March 2022. The practical application of new communication methods (e.g., application of 5.9GHz band) necessary to realize cooperative automated driving is assumed to take place around 2030, and efforts for frequency utilization, standardization and specifications, and equipment development and practical application should be made toward the practical application of these new methods. In addition, for the practical application of the use-cases themselves, it is necessary to discuss and clarify the direction of various related issues, such as cybersecurity and privacy measures for the provided services, policies for the shared use of onboard unit, policies for the generational changes of equipment, business models, ensuring communication quality, and sharing of responsibility.

It is expected that, starting from the roadmap and use-cases, each of the parties concerned, including vehicles and infrastructure as well as telecommunication, will play their respective roles in the study, and that deepening discussion and cooperation across industries will promote efforts toward the realization of cooperative automated driving.

[References]

(1) Collaborative Automated Driving Communication Method Consideration The TF: SIP Use-cases for Cooperative Driving Automation-Activity Report of Task Force on V2X Communication for Cooperative Driving Automation in FY2019-, https://en.sip-adus.go.jp/rd/rddata/usecase.pdf, 2022.
(2) ITS Info-communications Forum: Study report on communication scenarios and requirements for "SIP Use-cases for Cooperative Driving Automation" ITS FORUM RC-017 Version 1.0, ITS Info-communications Forum, https://itsforum.gr.jp/Public/E3Schedule/p40/ITS_FORUM_RC-017eng_v10s.pdf, 2022.
(3) Inter-vehicle Communication Message Specifications ITS Connect TD-001 ver. 1.1, 2018, https://www.itsconnect-pc.org/en/_img/about/TD-001_210310.pdf.
(4) Land Mobile Communications Committee, Information and Communications Technology Subcommittee, Information and Communications Council Report No. 2029, July 28, 2009, on "Technical Conditions for ITS Radio System," referring specifically "Technical Conditions for Advanced 700 MHz Band Intelligent Transport Systems."
(5) ITS Info-communications Forum Cellular System The TG: Issue Survey Report of Advanced ITS and Automated Driving Using Cellular Communications Technologies, Supplementary Material: Issue Survey for SIP Use-cases for Cooperative Driving Automation, ITS Information and Telecommunication Systems Promotion Council, https://itsforum.gr.jp/Public/J7Database/p69/Cellular_system_202205.pdf, 2022.

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2) Development of New Technologies, V2X and Others, for Communication

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(Abstract) In this study, based on the road map , which describes specific requirements for wireless communication technologies applied to the cooperative automated driving use cases developed through R&Ds in the 2nd phase of SIP-adus, we proposed a specification of wireless devices including communication protocol requirements for implementation of the V2X system with radio wave in 5.9GHz band, in order to accelerate to solve relevant issues and to proceed study for the realization of cooperative automated driving.

Keywords: cooperative automated driving , V2X, cellular V2X (C-V2X), DSRC, communication protocol

1 Scope of Study

1.1. General Concept

We have studied feasibility of communication technologies such as requirements for wireless communication technology applied to the cooperative automated driving use cases(1) (hereafter the Use cases) through the R&D project named as "Research on Communication Methods to Realize Cooperative Automated Driving Use Cases" as part of the 2nd phase of SIP-adus. As a result of this study, including expectation to communication technologies to be developed for the future, the project proposed the use cases and the road map (hereafter the Roadmap) defining requirements for each wireless communication technology.

In this study, based on output from the above mentioned feasibility study and the Roadmap development, the wireless device specification was prepared mentioning communication protocols required for the implementation of V2X system with radio wave in 5.9 GHz band (hereafter V2X system in 5.9 GHz band) in order to advance solving related issues and study. (V2X: Vehicle to X, V2I: Vehicle to Infrastructure, V2V: Vehicle to Vehicle)

1.2. Actions and Objectives

The activities shown in Figure 1 were carried out with medium and long term perspectives in mind.

a) International standardization trends research

We researched and analyzed standardization and institutionalization trends related to the V2X system in 5.9 GHz band communication protocol, message sets, as well as relevant communication specifications in countries and regions including the U.S., Europe and China.

b) Research aimed at developing communication protocol proposals

The V2X system with 5.9 GHz band communication requirements for the technological research of communication protocols was studied based on the communication requirements and message sets discussed through ITS Info-communication Forum, as well as on the result of the Roadmap development.(2)

c) Designing communication protocol proposals

Based on the evaluation results of the communication simulation, we designed the communication protocol for the V2X system in the 5.9 GHz band, which was concluded as communication protocol proposal mentioning communication procedures and protocol stack, along with message sets.

d) Proposing wireless device specifications

Taking into account functions required for practical implementation and cooperation with existing wireless systems, we developed a specification for on-board unit and roadside

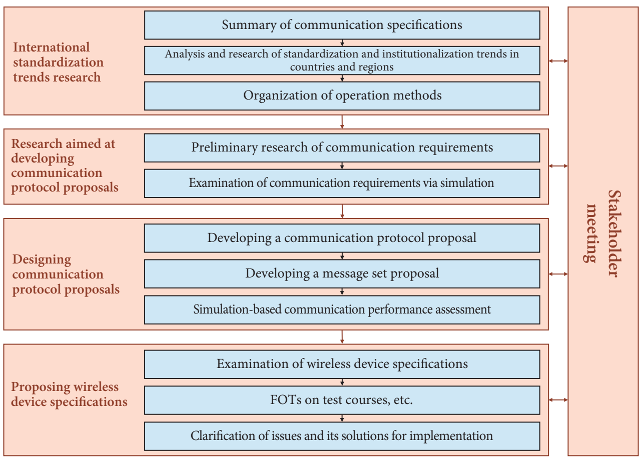

Fig.1: Activities for study

unit using V2X system in 5.9 GHz band then clarified issues for implementation and counter measures to solve the issues.

Further, we carried out verification and discussions concerning evaluation results and issues at the meeting structure as shown in Fig.2 with stakeholders when necessary to appropriately apply these results to the study.

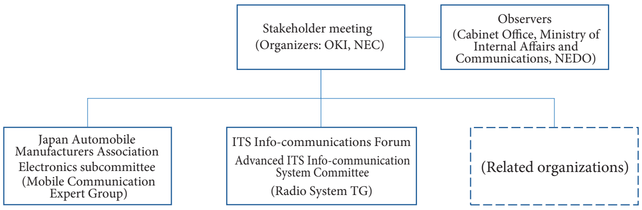

Fig.2: Stakeholder meeting structure

2 International standardization trends research

For the Use cases,[1] we prepared the Roadmap defining specific action items related to the wireless communication technologies. The result of this process was utilized to research and analyze the latest and consistent trend of standardization and institutionalization in terms of V2X system in 5.9 GHz band communication protocol (communication procedures and stacks etc.) adapted to traffic circumstances in foreign countries and regions including the US, Europe, and China, also message sets and relevant communication specifications are involved. The output of the range of these efforts was applied to the studies described in Chapter 3, 4, and 5. Please see Fig.3 for specifications of standardization organizations in regions subject to the study.

3 Research aimed at developing communication protocol proposals

The communication requirements for the V2X system in the 5.9 GHz band required for technological study of communication protocol were studied as shown below, taking into account cooperation with the driving safety support system in 700 MHz band. This was conducted based on the results of the International standardization trends research, the study report on communication scenarios and requirements developed by the Radio System Technology Task Group of Advanced ITS Info-communication System Committee in ITS info-communication Forum (hereafter Radio System TG (2)), and the result of the Roadmap development. The results of this research was used for studies described in Chapter 4 and 5.

(1) Communication channel allocation

The Use cases were broken up to groups based on communication medias (V2I, V2V) applied in the Use cases and communication contents (broadcasting, negotiation), then the channel allocation proposal for each group was developed following the estimation of communication volumes based on case studies under specific circumstances. The grouping criteria for the Use cases is in Fig.4.

(2) Communication congestion control methods at upper layers

Based on the results of study on specifications in SAE, ETSI and other organizations and the communication channel allocation proposal, the study of communication congestion control methods at upper layers was conducted.

Overview of communication congestion control methods at upper layers are shown in Fig.5.

(3) Traffic flow simulation-based effectiveness evaluation

Based on the results of research for (1) and (2), we ran

		SAE (U.S.)		ETSI (Europe)		CCSA (China)
Total		[DSRC] SAE J2945	[C-V2X] SAE J3161	[DSRC] ETSI TS302 665	[C-V2X] ETSI TS103 723	[C-V2X] YD/T 3400
Profile	Application • Facility	[BSM, etc.] SAE J2735		[CAM/DENM] ETSI EN302 637		[BSM, etc.] YD/T 3709
Profile	Transport network	[WSMP] IEEE 1609.3		[GeoNetwork] ETSI EN302 636-5 [DSRC] ETSI EN302 636-4-1	[C-V2X] ETSI TS102 636-4-3	[DSMP] YD/T 3707
Profile	Access	[DSRC] IEEE 1609.4 IEEE 802.11p	[C-V2X] 3GPP TS23.285	[DSRC] EN302 663 IEEE 802.11p	[C-V2X] EN303 613	[C-V2X] YD/T 3340
Operation method	Congestion control	[DSRC] SAE J2945/1	[C-V2X] SAE J3161/1	[DSRC] TS102 687	[C-V2X] TS103 574	[C-V2X] Refer to (3GPP C-V2X)
Operation method	Cybersecurity	[Security] IEEE 1609.2 IEEE 1609.2.1 SAE SS V2X 001		[Security] TS102 940, 941, 942, 943 TS103 097		[Security] GB/T 40856

Fig.3: Standardization organization specifications, etc. in regions subject to study

SAE: Society of Automotive Engineers

ETSI: European Telecommunication Standards Institute

CCSA: China Communication Standards Association

		V2I	V2V
Broadcast	Continuous	**Vehicle receives broadcast from roadside units** a-1-1. Merging assistance by preliminary acceleration and deceleration a-1-2. Merging assistance by targeting the gap on the main lane b-1-1. Driving assistance by using traffic signal information (V2I) c-2-2. Driving assistance based on intersection information (V2I)	**Vehicle broadcasts every time position, speed, etc.** c-2-1. Driving assistance based on intersection information (V2V) e-1. Driving assistance based on emergency vehicle information
	Emergency		**Vehicle broadcasts alert warning when taking sudden hard breaking** c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly c-3. Collision avoidance assistance by using hazard information
Negotiation		**Automated vehicle negotiates for merging with using V2I communication** a-1-3. Cooperative merging assistance with vehicles on the main lane by roadside control	**Automated vehicle negotiates for merging using V2V communication** a-1-4. Merging assistance based on negotiations between vehicles a-2. Lane change assistance when the traffic is heavy a-3. Entry assistance from non-priority roads to priority roads during traffic congestion

Fig.4: Use case grouping criteria

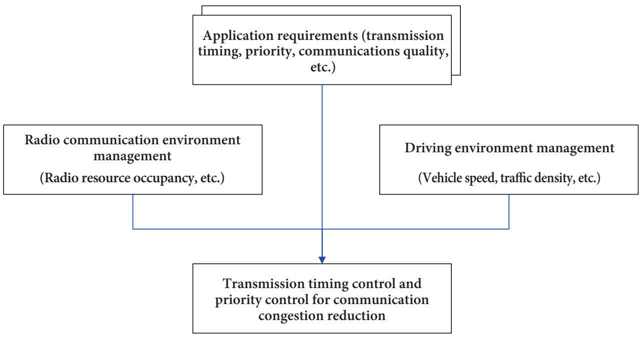

Fig.5: Communication congestion control methods for upper layers

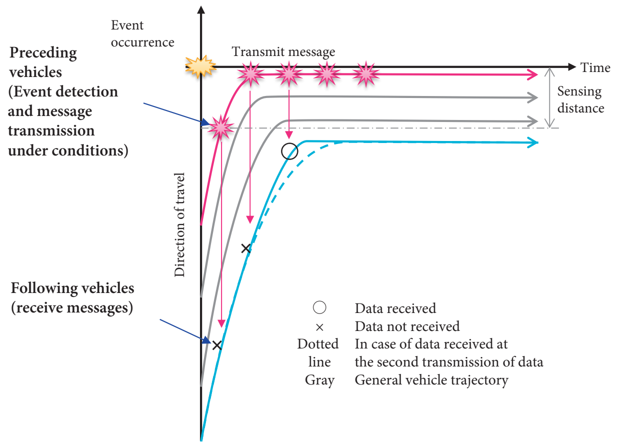

Fig.6: Model of vehicle behaviors during traffic flow simulation

traffic flow simulation to evaluate the effectiveness of the V2X system in 5.9 GHz for the Use cases, including both situations where the intelligent transportation systems in 700 MHz band was and was not being used.

This traffic flow simulation re-creates the Use cases based on case studies under specific conditions and evaluates differences in vehicle behavior (deceleration, etc.) due to differences among communication specifications (communication timing, etc.). A model showing vehicle behaviors during traffic flow simulation is shown in Fig. 6.

4 Designing communication protocol proposals

In response to the results of the research described in Chapters 2 and 3, we developed a communication protocol for the V2X system in the 5.9 GHz band shown below based on status of institutionalization in Japan related to traffic environment and frequency allocation, etc.

(1) Developing communication protocol proposals

Based on the results of research described in Chapters 2 and 3, and on the results of simulation-based communication performance evaluations described below, we researched communication content, procedures, layer configuration, requirements, etc. for each Use case and developed communication protocol proposals. Table 1 shows examples of communication protocols for reference standards.

(2) Developing a message set proposal

A message set proposal was prepared considering status of standardization and its studies in and outside Japan,[(2)] the communication requirements and the communication channel allocation mentioned in Chapter 3 etc. For this, possibilities of reuse/ communalization of messages were also included in the consideration as another perspective.

(3) Simulation-based communication performance evaluation

Through a system-level communication performance evaluation conducted using a computer simulation, we studied the impact of deploying V2X systems when the communication protocol proposal and message set proposal we developed as described in (1), (2) above were implemented.

Based on the expectations and assumptions used for the communication channel allocation and others in Chapter 3, we defined an evaluation scenario, such as combination of use cases, traffic road models (road scale, installation of intersections etc.) and traffic flow models (driving speed, inter-vehicle gap etc.) to study radio propagation models and congestion/interference models, then built up an evaluation model. Fig.7 shows examples of radio propagation models.

Table 1: Examples of communication protocols for reference standards

Layer	Communication control flow				Protocol stack			
	U.S.		Europe		U.S.		Europe	
	DSRC	C-V2X	DSRC	C-V2X	DSRC	C-V2X	DSRC	C-V2X
Application	Request message generation upon event detection				EEBL, FCW, etc. (DSRC: SAE J2945/1, etc., C-V2X: SAE J3161/1, etc.)		Co-operative Awareness, Road Hazard Warning, etc. (ETSI TS 102-637-1, etc.)	
Corresponds to upper layers (layers 5-7)	・Collect required data, generate message ・Congestion control (bandwidth control (*1))				Communication services: BSM Exchange, etc. (DSRC: SAE J2945/1, etc., C-V2X: SAE J3161/1, etc.), Message: BSM, etc. (SAE J2735, etc.)		Communication services: CA Basic Service, DEN Basic Service, etc. (ETSI TS 102-894-1, etc.), Message: CAM, DENM ,etc. (ETSI TS 102-894-2, etc.)	
Transport layer (layer 4)	Adds data that specifies upper layer services				WSMP Transport Protocols (IEEE 1609.3)		Basic Transport Protocol (ETSI EN 302 636-5)	
Network layer (Layer 3)	No substantial functions		Adds data that specifies network addresses		WSMP Networking Protocols (IEEE 1609.3)		GeoNetworking (ETSI EN 302 636-4)	
Data link layer (layer 2)	Adds data that specifies upper layer protocols				LLC (IEEE 1609.3)	PDCP (ETSI TS 136 323)	LLC (ISO/IEC 8802-2)	PDCP (ETSI TS 136 323)
	Splits packets				-	RLC (ETSI TS 136 322)	-	RLC (ETSI TS 136 322)
	Performs switching when multiple channels exist				Channel Coordination (IEEE 1609.4)	-	-	-
	・Adds data that specifies sender link ・Send timing control ・Congestion control (priority control (*2))				MAC (IEEE 802.11)	MAC (ETSI TS 136 321)	MAC (IEEE 802.11)	MAC (ETSI TS 136 321)
Physical layer (layer 1)	Sends after encoding and modulating				PHY (IEEE 802.11)	PHY (ETSI TS 136 201)	PHY (IEEE 802.11)	PHY (ETSI TS 136 201)
Cybersecurity layer	Adds data (signature) to guarantee sender authenticity and message integrity				Electronic signature (IEEE 1609.2)			

(*1) Output control available through U.S. DSRC (*2) Bandwidth control and output control available through Europe DSRC

Category	Overview	Study model
Metric property	Attenuation due to communications range	ITU-R P.1411 (assuming urban environment)
Shadowing	Fading due to surrounding environment changes	Log-normal distribution Standard deviation at 5.9 GHz: 3.68 dB
Multipath fading	Fading by symbol	3GPP Extended Vehicular A model (EVA)
Shadowing loss	Attenuation when there are large vehicles between transmitter and receiver	• 3GPP TR 38.901 Blockage model B (Model using knife-edge diffraction) • Attenuation is a fixed value based on blockage by one adjacent large vehicle (One second of space between vehicles at 40 km/h and 5.9 GHz: 10 dB)

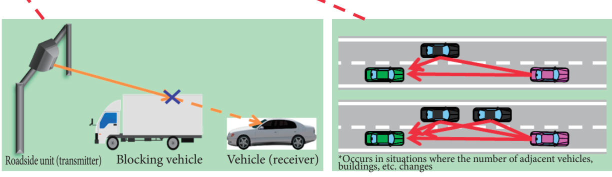

Fig.7: Examples of radio propagation models for communication performance evaluation systems

5 Proposing wireless device specifications

We examined wireless device (on-board devices and roadside units) specifications for the V2X system in the 5.9 GHz and developed a proposal for wireless device specifications. Based on the results of studies described in Chapters 2, 3, and 4 concerning specifications and functions for each communication layer, we conducted the study taking into account the possible cooperation with existing wireless systems. Examples of items to study for wireless device specifications are shown in Table 2.

Further, we carried out the FOTs (Field Operational Tests) on test courses under the condition that multiple use cases co-exist, then analyzed the result of this communication performance evaluation with multiple channels in comparing with the result of evaluation with simulation in Chapter 4.

6 Conclusion

For the realization of cooperative automated driving, we defined a wireless devices specification including communication protocols to be required for implementation of the V2X system in the 5.9 GHz band, as we need to accelerate to study and solve issues for this implementation.

Studies aimed at developing communication protocols involved examining communication requirements for the V2X system in the 5.9 GHz band (communication content, communication channels, communication congestion control, etc.) based on international trends (related institutions and standards). In designing a communication protocol proposal and wireless device specifications proposal, based on communication simulation evaluation results that took into account radio propagation characteristics and the impact of interference between communication channels, among other factors, we studied communication protocol proposal including communication procedures and protocol stacks, and also

Table 2: Examples of items to study for wireless device specifications

V2X communication function, characteristics, and interface details		
General requirements and technical requirements for wireless device	General requirements	Data rate
		Coding Rate
		Channel
		Modulation method
	Transmitter characteristics	Antenna power
		Antenna power permissible deviation
		Transmit spectrum mask
		Leakage power during carrier off
		Transmitter spurious
		Frequency permissible deviation
		Modulation accuracy
		Transmission timing accuracy
	Receiver characteristics	Receiver sensitivity
		Adjacent channel rejection
		Non-adjacent channel rejection
		Secondary emitted radio wave strength
		Receiving maximum input power
		CCA requirements
	Antenna	Antenna structure
		Antenna gain
		Antenna polarization
		Antenna installation

V2X communication function, characteristics, and interface details				
Communication control section functions, characteristics, interface	Layer 1 functions	Overview	-	-
		Layer 1 Service interface	Service primitive	Functions
				Parameters
		Layer 1 communication control	Protocol data unit	Data format
			Transmit/receive procedure	-
	:	:	:	:
	Layer 7 functions	Overview	-	-
		Layer 7 Service interface	Service primitive	Functions
				Parameters
			Security primitive	Functions
				Parameters
		Layer 7 communication control	Protocol data unit	Data format
			Transmit/receive procedure	-
	Layer management Entity functions	Layer management Service interface	Layer 1	Functions
				Management information base (MIB)
			:	:
			Layer 7	Functions
				Management information base (MIB)
	Security layer functions			
	Other functions	Transmission requirements	Use cases a-1-1	Communication sequence
				Interface of service in use
				Transmission parameters
			:	:
			Use cases g-2	Communication sequence
				Interface of service in use
				Transmission parameters
			Congestion control	-
	Between antenna section and transmission/receiving section	Physical interface	-	-
	Between transmission/receiving section and communication control section	Physical interface	-	-
	Between application and layer 7	Physical interface	-	-
		Logical interface	-	-

message set proposal such as communalization and expandability when coexisting multiple use cases.

With the wireless device specification including communication protocol developed in this study, it is expected that all relevant research institutes and companies align and work together for the realization of cooperative automated driving.

[References]

(1) SIP Use Cases for Cooperative Driving Automation-Activity Report of Task Force on V2X Communication for Cooperative Driving Automation in FY2019, 2020.

(2) Study report on communication scenarios and requirements for "SIP Use Cases for Cooperative Driving Automation" ITS FORUM RC-017 Version 1.0, ITS Info-communication Forum, 2022.

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3) Research and Development Concerning the Collection and Transmission of Mid-Scale Network Information

Tomohiko Saito, Shota Taki (NTT Communications Corporation)

(Abstract) There are a number of issues that will need to be addressed in order to make automated driving ubiquitous in the future. One of these is the fact that automated vehicles cannot themselves perform adequate sensing in complex environments such as intersections, forcing these vehicles to stop or slow down in front of intersections in order to safely proceed through intersections, potentially interrupting the flow of traffic. As part of research and development conducted in fiscal 2019 and fiscal 2020, preliminary research and field tests were conducted involving core technologies concerning the collection of data on objects such as vehicles and pedestrians from sensors, etc. in the vicinity of intersections, as well as data distribution control technologies for automated vehicles. In fiscal 2021, steps were taken to support a broader range of data such as emergency vehicle data and traffic signal schedule information, as well as steps to support information distribution in mid-scale network for a variety of use cases. Meanwhile, tests were run to gauge server load in mid-scale network area and data transmission efficiency, in addition to assessing the usefulness of information distribution system in mid-scale network, with the goal of practical application of these technologies. The results of this research and tests led to the creation of the Mid-Scale Network Server Implementation Guidelines for business operators considering V2N information distribution in mid-scale network.

Keywords: V2N, V2X, Information distribution system in mid-scale network, emergency vehicle information, SPaT information, PULL/PUSH data delivery

1 Overview of this Research and Development

There are a number of issues that will need to be addressed in order to put automated driving into practical use in the future. One of these is the fact that automated vehicles cannot themselves perform adequate sensing in complex environments such as intersections, forcing these vehicles to stop or slow down in front of intersections in order to safely proceed through intersections, potentially interrupting the flow of traffic.

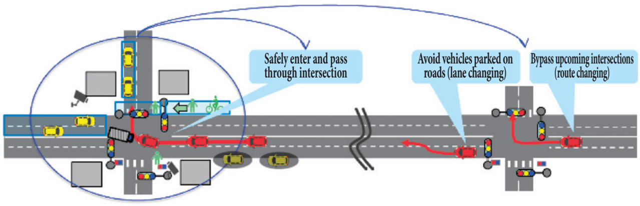

Fig.1: Vision and goals for this R&D

In this study, as shown in Fig.1, to resolve these issues, we have established use cases for assisting easier entrance to intersections, avoiding cars parked on streets, and assisting to change route to avoid upcoming intersections. Based on the use cases, the target information in blind spots from multiple information sources was collected and integrated, and distributed to the small-scale network area surrounding an intersection around which the information was collected and to mid-scale network area which covers multiple intersections blocks or municipal(s). These are the research and development we have carried out since fiscal 2019 to contribute to passage assistance at intersections and lane-change assistance before entering to intersections. In fiscal 2019, preliminary research was done for core technologies to efficiently collect, integrate, and distribute multiple object data from roadside infrastructure, and others. Then the Field Operational Tests (FOTs) were conducted in fiscal 2020. Based on these results, specifications for a common interface, as well as data distribution methods, integration methods, and edge server installation standards were established in the interest of building a "system to assist automated vehicles."

These efforts shed light on the fact that practical application of these technologies would require addressing a broad range of data encompassing more than just object data to support automated driving, as well as identifying issues for different use cases.[1]

2 Fiscal 2021 R&D activities and results

As part of fiscal 2021 R&D activities aimed at solving problems with a view to implement the above technologies in societies, research was conducted with respect to the expansion and application of technologies concerning the distribution of data to automated vehicle at mid-scale network area. In addition, through FOTs with user participation conducted in coordination with the large scale FOTs carried out in the Tokyo waterfront area, a more detailed research was performed with the goal of practical use of the technologies, while examining the adaptability of the whole system of mid-scale network information distribution system.

2.1. Research into the expansion and application of distribution-related technologies

With respect to information distribution in mid-scale network, it is necessary to examine the need for immediacy and the effective distribution area for each kind of information based on the use cases, and then to formulate distribution methods. In light of this and given the characteristics of distribution systems (PULL/PUSH), these FOTs have centered on distribution systems, communications protocols, distribution areas, and distribution frequencies for each information to be distributed.

(1) Research concerning distribution methods for use cases

With regard to information to be distributed as part of these R&D efforts, the use cases we assumed and the immediacy that will be required for each of the use cases are presented in Table 1. Also the adequate distribution method in light of the distribution system characteristics was examined as shown in Table 2.

Table 1: Use cases and other conditions for distributed information

Information	Assumed UC	Needs for real-time distribution
Rainfall information	Handover to manual driving & underpass avoidance (route changing)	Low
Lane-level road traffic information	Avoid medium and wide range congestion/ restrictions (route/path changing)/detect jam endpoints and slow down in advance	Low
Emergency vehicle information	Detect emergency vehicles approaching and slow down/stop	High
SPaT information	Dilemma avoidance/assistance when traffic lights are at blind angles/ adjust to best route/ speed	Medium/high

Table 2: Characteristics of data suited to distribution via each system

Distribution system	Best information use case	Best information type	Needs to be distributed in real-time
PULL system Distribute information based on user request	When the receiver chooses and uses needed data from broad ranging and profuse data	Static data Semi-static data Semi-dynamic data	Low
PUSH system Distribute information to target vehicle from distribution source	When wanting to distribute information upon event occurrence or in short intervals	Dynamic data	High

For lane-level road data and rainfall information, because of the low update frequency, the PULL system was deemed to be the most suitable as a vehicle can acquire information when they need it. The PUSH system, on the other hand, was deemed to be the most suitable for emergency vehicle information and SPaT (Signal Phasing and Timing) information as the information can be distributed from the server to the vehicle, satisfying the need for immediate information processing.

Due to the likelihood of data volume increasing with the PUSH system as information is sent to individual vehicles at a higher frequency, this R&D focused on studying emergency vehicle data and SPaT information, which was distributed by two methods: distance-based and intersection-based.

(2) Communications protocols used for information distribution in mid-scale network

MQTT was selected as the communications protocol used for distribution in mid-scale network. The MQTT protocol, which uses a Publish/Subscribe model and is simple, lightweight, and fast, with an extensive library, was made to send and receive short messages frequently among numerous devices. It is also easy to sort transmissions differently depending on the Topic, and has seen extensive use in connection with IoT devices. These and other factors give MQTT more advantages than other protocols. MQTT was selected as it was deemed the best fit for these FOTs. Its QoS controls the assurance of message delivery between client and broker depending on its level setting. Fig.2 shows a system configuration diagram for mid-scale network servers using MQTT, while Fig.3 shows a software chart.

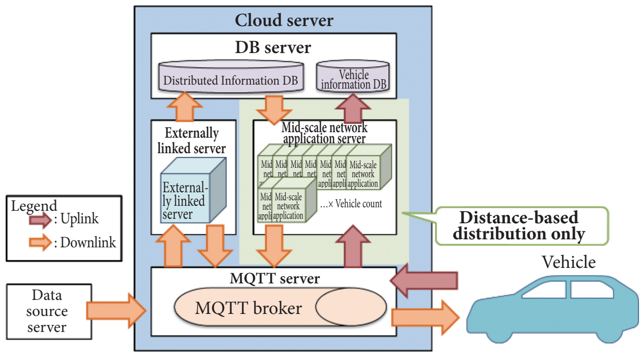

Fig.2: Mid-scale network server system configuration diagram

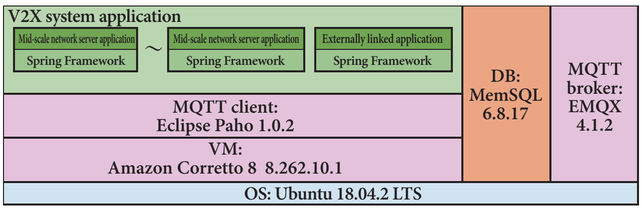

Fig.3: Mid-scale network server software configuration diagram

(3) Mid-scale network server application configuration examination

For PUSH distribution system, based on the location information of a vehicle, we implemented a server in mid-scale network to distribute information narrowed down to that of vicinity of the vehicle. As required and searched information differs for each vehicle, we had an application launch for each vehicle. Using this configuration, in order to reduce the delay between information update and distribution, information was distributed from the server every second (parameters can be changed) and MQTT Topics were given unique values for each vehicle. Application installation was performed using Java's Spring Framework.

(a) Emergency vehicle information

Emergency vehicles require responding in real time when they approach from behind or from out of view, but do not affect vehicle travel when they are far away. We consequently studied using PUSH distributions for emergency vehicle information within a certain radius around the vehicle, as shown in Fig.4.

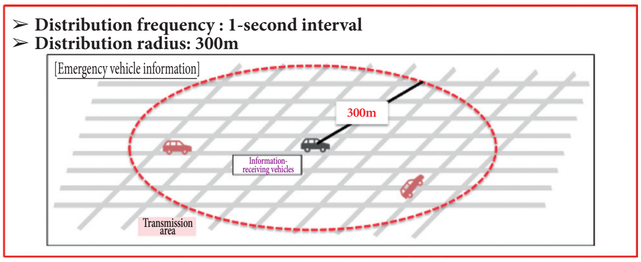

Fig.4: Emergency vehicle information distribution frequency and distribution area

(b) SPaT information (distance-based method)

Drivers sometimes cannot make out a traffic light color due to sunlight or obstruction, for example. For such situations, we considered having vehicles receive SPaT information in advance as a means to support dilemma avoidance at intersections, plan routes efficiently, and achieve green waves. To reduce communications traffic using the distance-based system, SPaT information is transmitted within a rectangle around the direction of the distributing vehicle's travel. This is shown in Fig.5.

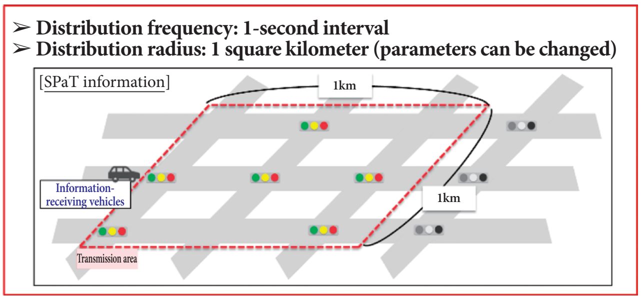

Fig.5: SPaT information distribution method (distance-based method)

(c) SPaT information (intersection-based system)

The intersection-based system sends out PUSH transmissions every time SPaT information is updated at an intersection. As shown in Fig.6, vehicles designate intersections on their own travel routes and divergent routes and continuously receive SPaT information.

When a vehicle designates a new intersection, the updated version of the SPaT information it has received. It also stops receiving unneeded data about previous intersections.

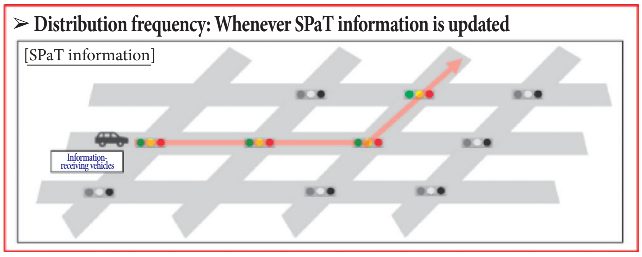

Fig.6: SPaT information distribution method (intersection-based system)

This system was achieved as follows. For SPaT information distributed to a server in mid-scale network from a data source server, an intersection ID that identifies each intersection is published as a Topic. When a vehicle first subscribes, it immediately distributes up-to-date information through MQTT's retain function. As long as a vehicle is subscribed, it receives data every time data is updated.

Under this system, while vehicles need to designate the intersections for which they require data, server load can be reduced as working servers do not have to process information for every vehicle. Moreover, as data is only transmitted upon subscription and SPaT information update, distribution frequency and communications traffic can be decreased.

2.2. Examination of system configuration feasibility at the time of social implementation

As a step toward practical application of an information distribution system in mid-scale network, we measured server load in mid-scale network area and communications traffic, and assessed the effectiveness of an information distribution system in mid-scale network.

(1) Measuring server load for PUSH distributions

Using the configuration in Table 3, we measured the load imposed on a server in mid-scale network when simulated emergency vehicle information and SPaT information were sent to vehicles, based on the number of information-receiving vehicles.

Table 3: Test server specifications

Server name	vCPU core count	Memory (GB)
DB server	4	16
Externally linked server	2	8
Mid-scale network application server	8	56
MQTT server	4	16

As described in Section 2.1 (3), when using the distance-based method for emergency vehicle information and the SPaT information, one server application was launched for each vehicle. However, under intense resource usage, it was not possible to launch more than 70 server applications due to a lack of enough CPU resources. Likely reasons for this are that one application was launched for each vehicle, the Spring Framework was running for each application, and transmissions were processed every second for each application.

By contrast, the intersection-based method for SPaT information has none of these issues, with a server load lower than that of the distance-based method. There was also no increased MQTT server load with the intersection-based method. Table 4 shows CPU and memory usage when distributing information to 70 vehicles.

Table 4: CPU/ memory usage for information distribution from server in mid-scale network

Load test delay verification (Average)		Server in mid-scale network CPU max usage	Server in mid-scale network memory max usage	MQTT server CPU max usage	MQTT server memory max usage
		Distribute to 70 vehicles simultaneously			
[Distribution methods]	Simulated emergency vehicle location information/ Distance-based method	46.58%	58.14%	2.75%	2.42%
	SPaT information/ Distance-based method	50.19%	58.02%	8.77%	2.47%
	SPaT information/ Distance-based method			3.23%	2.38%

(2) Measuring communications traffic for PUSH distributions

We conducted a theoretical measurement of communications traffic discrepancies between the two methods when data was distributed via the PUSH methods from a server in mid-scale network. We looked at SPaT information for which both the distance-based and intersection-based methods were available.

As shown in Table 5, when the data distributing intersection count was the same, the distance-based method distributed with a higher frequency as data updating experienced no delay. With the intersection-based method, distribution data volume was reduced to less than 1/100 as data was only transmitted when SPaT information was updated. Consequently, from the perspective of communications traffic, the intersection-based method has the advantage.

Table 5: Results of theoretical measurement of communications traffic for SPaT information

	Distribution method	Number of intersection per area	Distribution frequency	Data-receiving vehicles	Communications per hour	Data distributed per hour
Mid-scale network area server → Vehicle	SPaT information (Distance-based)	12 (1km^2)	1 second	258 (*)	928,800	Approx. 2.79 GB
	SPaT information (Intersection-based)	12	120 seconds (Signal cycle length)		7,740	Approx. 9.68 MB

*Average Vehicles per kilometer in Tokyo (fiscal 2022)

(3) Examination of distribution system feasibility

As a step toward practical use of an information distribution system in mid-scale network, we calculated costs of server in mid-scale network that would be incurred to transmit a larger amount of dada then examined feasibility of the system.

Based on calculations performed in Section 2.2.(1), we calculated what the cost would be if they were to hypothetically distribute information to vehicles using a Microsoft Azure server. As shown in Table 6, we found that when using the intersection-based method the cost of using the distance-based method per distributing vehicle could be kept to less than 1/100.

Table 6: Number of supportable vehicles and per-server cost calculation

Information	Azure D96ads v5 Supportable vehicles under one configuration (one server)	Server cost per vehicle
Emergency vehicle information SPaT information (distance-based)	For Approx. 840 vehicles	188 yen/month
SPaT information (Intersection-based)	For Approx. 88,800 vehicles	1.78 yen/month

2.3. Examination of functions needed for practical use

This section looks at functions and issues to be examined when considering the social implementation of technologies for distributing data to large areas, with a view to deploying such technologies nationwide.

(1) Re-examination of requirements

Further reducing costs per information-receiving vehicle will require re-examining requirements aimed at achieving more efficient information distribution (distribution methods, function allocation, etc.). The server load tests have shown that, for every type of data, distribution control per information-receiving vehicle places considerable load on the server. As a result, distribution methods need to undergo a re-examination that also factors in use cases. For example, this could mean to apply the intersection-based method for SPaT information, or to distribute emergency vehicle information not to information-receiving vehicles as shown in Fig.7 but to vehicles passing within a certain size of area centered on an emergency vehicle.

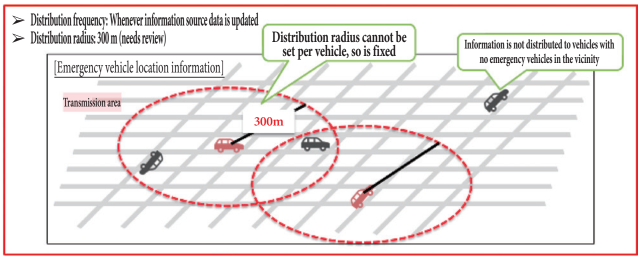

Fig.7: Proposal method of information distribution to vehicles passing within a certain size of area centered on an emergency vehicle

(2) Creation of a system with a view to practical implementation

Creating an information distribution system in mid-scale network area with a view to at-scale deployment will require consideration of overall system architecture. Further research into availability and scalability is needed, including, for example, the addition of functions for specifying available servers from multiple distributing servers as shown in Fig.8, further boosting efficiency through application optimization, and implementing non-functional requirements such as redundancy and security.

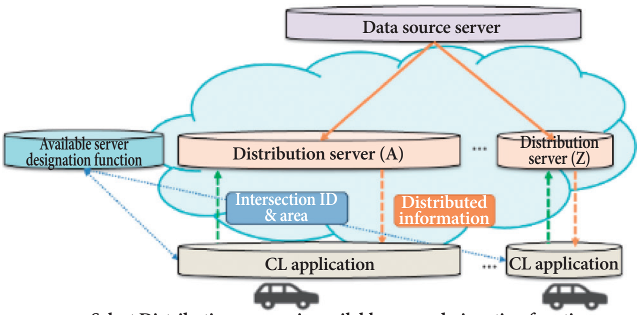

Fig.8: Proposal for designating multiple distributing servers in order to enable the use of available servers

(3) Establishment of server in mid-scale network implementation guidelines

Based on the results of this research and development, we identified areas requiring consideration ahead of creating and studying server in mid-scale networks, and established implementation guidelines for business entities who are considering to distribute information in mid-scale network to vehicles through V2N system. Such business entities may include OEM and content providers.

3 Conclusion

As part of research and development efforts in fiscal 2021 aimed at promoting the use and expansion of distribution system in mid-scale network nationwide, we examined the feasibility of expanding and applying distribution-related technologies and conducted verifications by way of a large-scale field operational tests.

In the future, we plan to accelerate efforts to put the results of this R&D into practical use and apply the knowledge gained from these activities toward a range of fields through guidelines, among other things.

[References]

(1) "Yuji Aburakawa: SIP 2nd Phase:Automated Driving for Universal Services—Mid-TermResults Report (2018–2020), pp.43-49, September 2021, https://www.sip-adus.go.jp/file/rd03/chapter2_s.pdf (accessed November 2022)

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