“the Second Phase of Cross-ministerial Strategic Innovation Promotion Program (SIP)
- Automated Driving for Universal Services /
Research and Development on the Collection, Integration, and Delivery of Short-range and Medium-range Information"

FY2021 Results Report

Overview

NTT DOCOMO Inc.

April 2022

Table of Contents

*Field Operational Tests

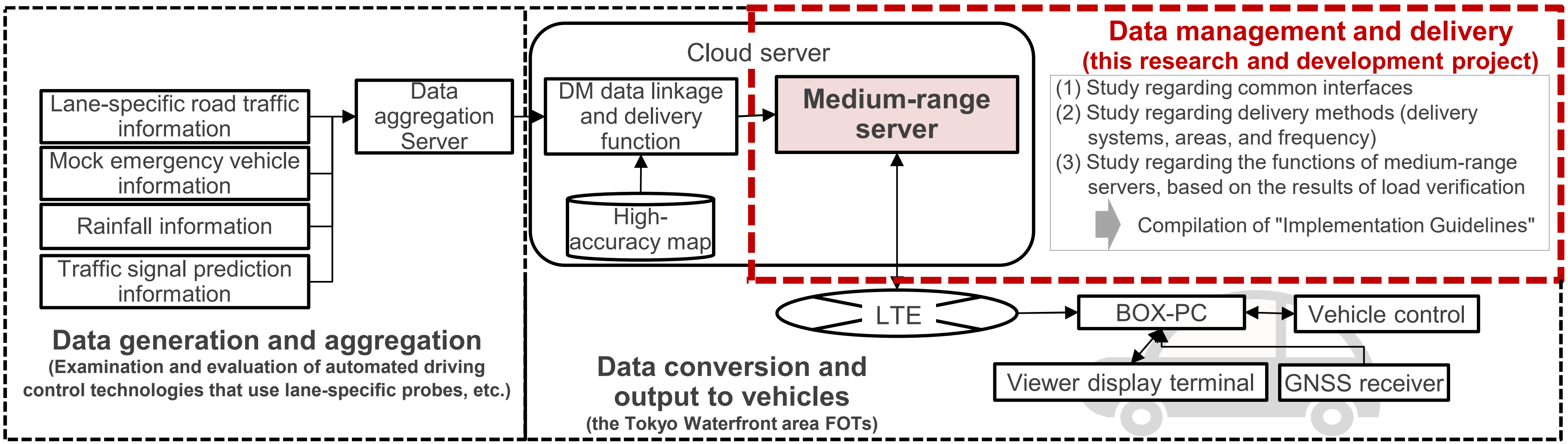
1. Overview of this research and development project

Background behind this research and development project

- The research and development conducted up through FY2020 attempted to address issues affecting automated vehicle operation in complex environments, such as intersections, as the result of on-board sensor blind spots. It consisted of research and development of elemental technologies for efficiently collecting, integrating, and delivering dynamic information obtained from diverse roadside infrastructure elements and other sources. Common interfaces for collecting and delivering information were created, and guidelines for integration and delivery methods were formulated.
- In preparation for the practical implementation of these technologies, it is essential to work with a wide range of information that contributes to automated driving and to identify issues with diverse use cases that could be encountered during actual operation.

Objectives of this research and development project

➢ This research and development project explored the extension and application of technologies related to the delivery of information over medium-range distances to autonomous vehicles. Furthermore, it conducted large-scale FOTs in order to carry out investigations aimed at the practical implementation of these technologies, such as confirming the suitability of the technologies for use in systems in actual environments.



Output

■ Common interfaces ■ Delivery methods ■ Guidelines regarding medium-range server deployment

2. Contents of implemented measures and project implementation structure

- In our studies regarding common interfaces, we identified additional data items based on data specifications from another project.
- In our studies regarding delivery methods, we considered the characteristics and use cases of the delivered information and identified and developed delivery methods that were appropriate for each type of information. Through the Tokyo Waterfront area FOTs, we confirmed the effectiveness of these delivery methods and evaluated the load that they placed on servers and the efficiency with which information was delivered.
- For medium-range servers, based on the results of our load verification, we evaluated and investigated the functions that would be required of system architecture when it is deployed in the real world.
- Based on the above results, we envisioned the placement of medium-range servers by content providers, OEMs, and others, and formulated implementation guidelines concerning the delivery of information by medium-range servers.

Scope

[System scope]

- Systems for delivering information from medium-range servers to vehicles

[Information to be delivered]

- Lane-specific road traffic information
- Rainfall information
- Mock emergency vehicle location information
- Traffic signal prediction information

[Area in which information is to be delivered]

- Waterfront City area, Metropolitan Expressways, etc. (evaluated through FOTs)
- Nationwide (evaluated through theoretical study)

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Study contents

Study in conjunction with the Tokyo Waterfront Area FOTs

1. **Study regarding common interface**
2. **Study regarding delivery methods**
   - ✓ Study, development, and implementation for delivery systems, areas, and frequency
   - ✓ System operation confirmation
3. **Study regarding medium-range server installation standards, specifications, functions, etc.**
   - ✓ Confirmation of delivery delays and delivery loads
   - ✓ Study of feasibility for areas other than the FOTs area
   - ✓ Study regarding server functions, etc.

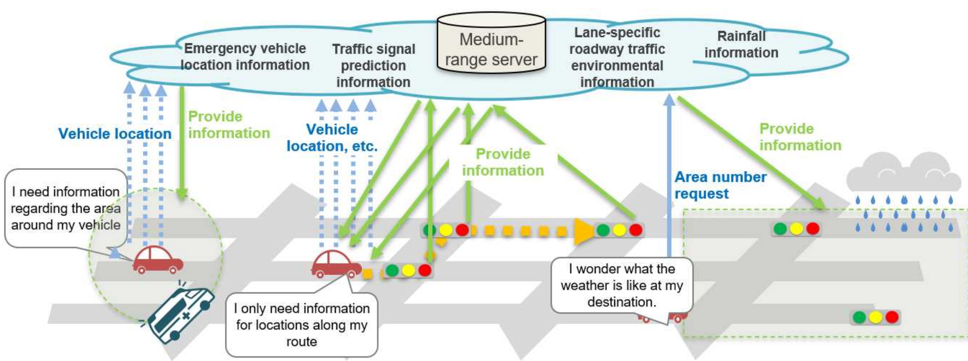
Performed by NTT DOCOMO

3. Research and development evaluation and study (summary)

- Through the Tokyo Waterfront area FOTs, we used the medium-range servers and delivery methods we developed to confirm that information could be delivered to test participants without significant delays or other problems.
- We organized information regarding common interfaces and delivery methods in preparation for practical implementation of the information delivery system for medium-range areas, and compiled recommendations regarding medium-range server architecture, functions, etc.

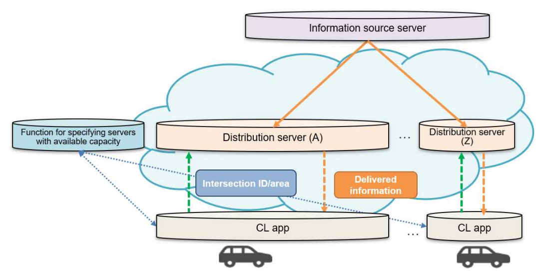
Studies regarding the expansion and application of delivery-related technologies

- Common interfaces:
  - ✓ Confirmed data items necessary for each type of delivered information
  - ✓ Identified data items that need to be added
- Delivery methods:
  - ✓ Identified delivery methods appropriate for each type of information (delivery systems, areas, and frequency) and conducted development and implementation



Evaluation through large-scale FOTs

- Implementation of the Tokyo Waterfront Area FOTs:
  - ✓ Confirmed behavior of information delivery systems in actual environments and confirmed that information could be delivered without significant delays
  - ✓ Gathered opinions from users via an evaluation questionnaire
- Study aimed at usage and deployment of the project at a nationwide level:
  - ✓ Verified effectiveness of PUSH method of delivery for designated intersections and feasibility of system based on results of load verification and traffic verification
  - ✓ Based on identified issues, organized information regarding system architecture at time of practical implementation, server functions, and important points to note during operation



(1) Studies regarding the expansion and application of delivery-related technologies

■ (1) Studies regarding the expansion and application of delivery-related technologies
1) Studies regarding common interface specifications

- **We confirmed that each type of delivered information contained the items necessary for integration and delivery interfaces.**
- **We added management items necessary for delivering information to vehicles (data generation times, information content, etc.).**

Integration and delivery interface considered last year: ● Required items

Item	Type	No. of bytes	Required	Remarks
Object ID	Numerical value	9	●	* Added for efficient medium-range delivery control, etc.
Information acquisition time	Numerical value	9	●	
Object type (vehicle, pedestrian, etc.)	Numerical value	1	●※	* Not necessary when the data is formatted in units by information types
Location coordinates	Numerical value, character string	-	●	Set to "Look up by latitude/longitude" or, based on the ISO17572-4 high-accuracy location referencing method, "Look up by distance from CRP" or "Look up by road distance + offset"
Direction of movement	Numerical value	3	●※	* Used in FY2000 integration processing, but not necessary this year
Speed	Numerical value	3	●※	* As above
Lane number of outermost lane	Numerical value	1	-	
Lane number of innermost lane	Numerical value	1	-	
Orientation of object	Numerical value	3	-	
Size of object Width, depth, and height	Numerical value	3 x 3 elements	-	
Reliability	Numerical value	1	-	
ID information	Character string	1	-	* Added for efficient medium-range delivery control, etc. 0 to 4 (Reserved) 0: Unknown, 1: Vehicle stopped, 2: Oncoming traffic, 3: Accident, 4: Other

Confirmation of data formats

[Delivered information]

- ✓ Lane-specific road traffic information
- ✓ Rainfall information
- ✓ Mock emergency vehicle location information
- ✓ Traffic signal prediction information

(1) We **confirmed** that each of the above types of delivered information **contained the items necessary** for integration and delivery interfaces

(2) **We confirmed and added information management items necessary for delivering information to vehicles (data generation times, information content, etc.)**

■ (1) Studies regarding the expansion and application of delivery-related technologies
2) Study regarding delivery methods

- **We organized information, including real-timeliness information, for each envisioned information use case, and, based on the characteristics of each delivery method (PUSH/PULL), decided on which delivery method was most appropriate.**
  - ■ **PULL delivery (transmission of compressed files)**
    - ✓ **Lane-specific road traffic information, rainfall information, traffic signal prediction information.**
  - ■ **PUSH delivery (transmission of binary data)**
    - ✓ **Mock emergency vehicle location information, traffic signal prediction information.**

❑ Envisioned use cases for delivered information

Information	Envisioned UC	Real-timeliness
Lane-specific road traffic information	Medium- and long-range traffic congestion and traffic restriction avoidance (changing routes/paths), confirming the tail ends of traffic congestion and slowing down in advance	Low
Rainfall information	Handover to manual driving/underpass avoidance (changing routes)	Low
Emergency vehicle location information	Detecting approaching emergency vehicles and slowing/stopping	High
Traffic signal prediction information	Dilemma avoidance/assistance when traffic signals are located in blind spots/optimal route and speed adjustment	Medium/high

✖

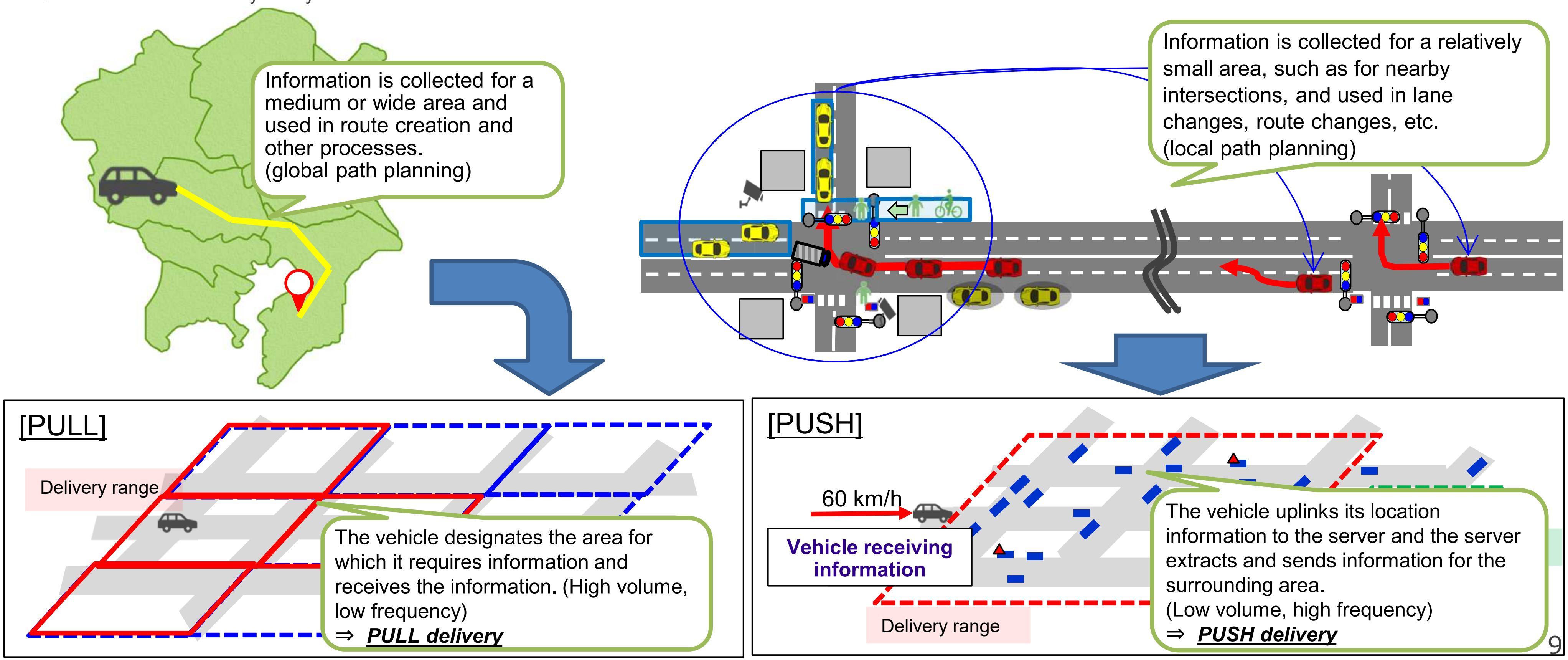
❑ Characteristics of information appropriate for each delivery method

Delivery method	Appropriate information and usage situations	Appropriate information type	Real-timeliness nature of delivered information
PULL method(information delivered when requested by user) ⇒ Method adopted for 2020 the Tokyo Waterfront Area FOTs	• Used when the recipient selects which information it needs from a diverse pool of information for a wide area and uses the selected information	• Static information • Semi-static information: • Semi-dynamic information	Low
PUSH method (information delivered by the provider to corresponding vehicles) ⇒ Method adopted for this 2020 project	• Used for information regarding events and when sending information in short cycles	• Dynamic information	High

■ (1) Studies regarding the expansion and application of delivery-related technologies
2) Study regarding delivery methods

- **The PULL and PUSH methods were used as appropriate given the information source in accordance with the policy below.**
  - ✓ **PULL delivery: Information that applies to medium and wide areas is <u>selected by the vehicle</u> and received.**
    *** FTP is used because the amount of data that is delivered is large and the frequency of delivery is low.**
  - ✓ **PUSH delivery: Servers extract information for the area around the vehicle, based on the vehicle's location information, and deliver this information to the vehicle.**
    *** MQTT is used because the amount of data that is delivered is small and the frequency of delivery is high.**

* Due in part to the costs of real-world implementation of transmission protocols, this project used the transmission protocols that were used in the previous year's Tokyo Waterfront City area FOTs and which are already widely used.



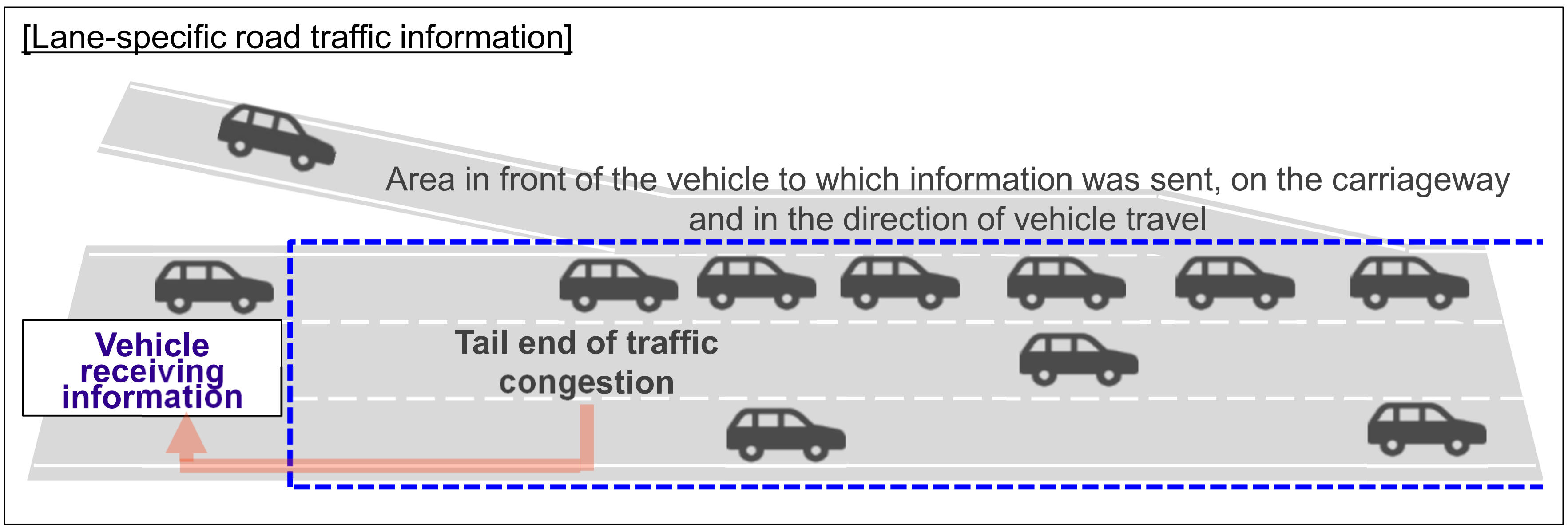
■ (1) Studies regarding the expansion and application of delivery-related technologies
2) Study regarding delivery methods

[Lane-specific road traffic information]

- We delivered lane-specific road traffic information for the areas in front of vehicles (caution information) to provide driving assistance for traffic congestion areas, branches, and merging points on expressways.
- Lane-specific road traffic information was distributed for the Haneda Route and Bayshore Route of the Metropolitan Expressway. Information was delivered when requested by a vehicle (for designated areas, in one-minute intervals) for the area in front of the vehicle on the carriageway and in the direction of vehicle travel.

Method for delivering information in FOTs

- Delivery interval: one-minute intervals
- Delivery range: Area in front of the vehicle on the carriageway and in the direction of vehicle travel



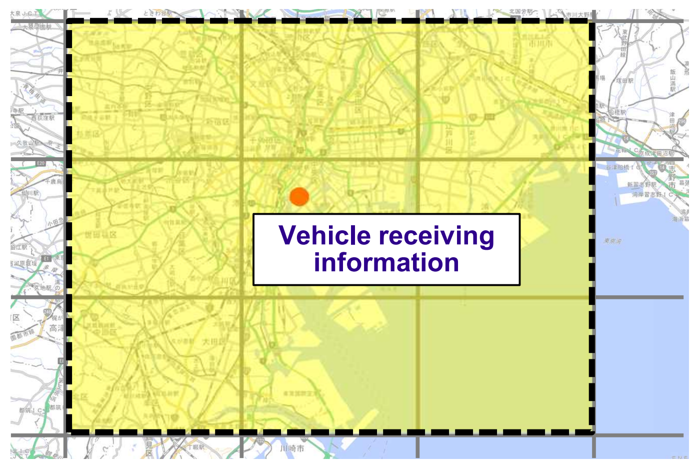
(1) Studies regarding the expansion and application of delivery-related technologies
2) Study regarding delivery methods

[Rainfall information]

- We delivered information regarding the amount of rainfall in designated areas or in the area around the vehicle for use in handing over operation of the vehicle to manual driving in the event of rainfall levels that would reduce the accuracy of on-board sensors, to avoid underpasses, and to enable the driver to confirm how much rain there is on the way to the destination.
- Vehicles issued requests for one of the following areas: (1) the area around the vehicle itself, (2) the entire area, (3) the Waterfront City area/Metropolitan Expressways, (4) the Joban Expressway, or (5) the Tomei/Shin-tomei Expressways. Information was delivered every five minutes for the areas designated in the requests.
- When the area around the vehicle was designated, information was sent for a 9 blocks area (each block measuring 10 km x 10 km), with the block containing the vehicle as the center block (all together a 30 km x 30 km area).

Method for delivering information in FOTs

- Delivery interval: 5 minutes intervals
- Delivery range:
  (1) Area around vehicle
  (2) Entire area (all of (3) to (5) below)
  (3) Waterfront City + Metropolitan Expressway area
  (4) Joban Expressway
  (5) Tomei Expressway/Shin-Tomei Expressway



Source: Geospatial Information Authority of Japan map acquired on September 28, 2021. https://maps.gsi.go.jp/#12/35.632884/139.810982/&base=pale&ls=pale&disp=1&vs=c0j0h0k0l0u0t0z0r0s0m0f0

(1) Conceptual image of delivery of information for the area around the vehicle

* Created using Geospatial Information Authority of Japan light color map

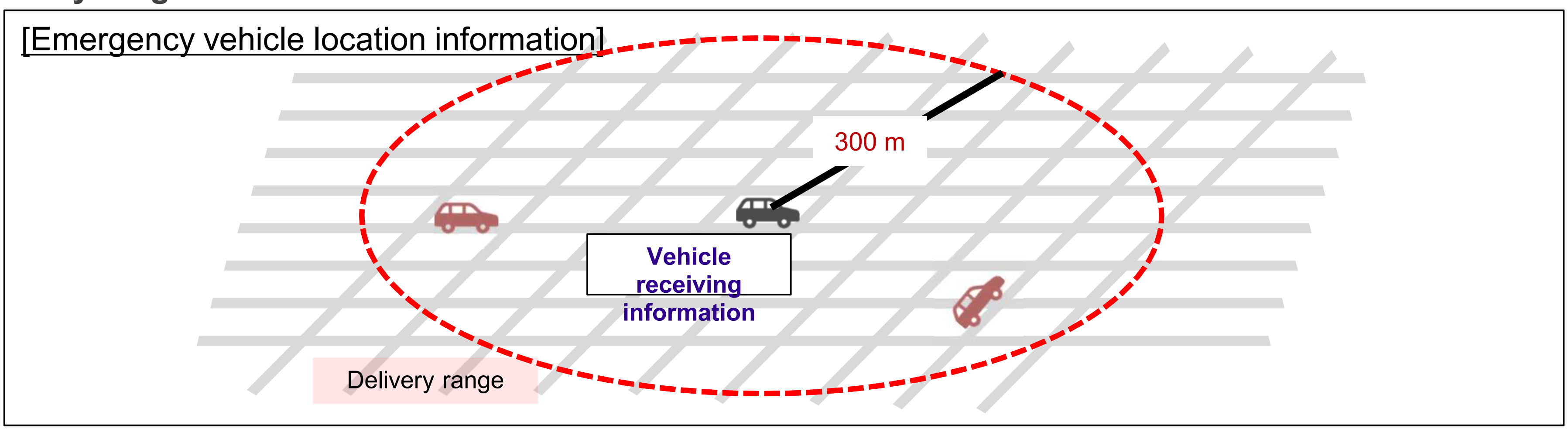
(1) Studies regarding the expansion and application of delivery-related technologies
2) Study regarding delivery methods

[Mock emergency vehicle information]

- We delivered information for the vehicle periphery for emergency vehicles approaching from behind the test vehicle or in areas which could not be seen from the test vehicle.
- According to Article 231 of the Announcement Specifying Detailed Safety Standards for Road Vehicles, requirements for emergency vehicles include that warning lamps must be red and must be visible from a distance of 300 meters in front of the vehicle, and that sirens must be between 90 dB and 120 dB at a distance of 20 meters in front of the emergency vehicle, so we used a radius of 300 meters for the information delivery range*.
  - ※ We believe a radius of 300 meters would be sufficient for vehicles to deal sufficiently with approaching emergency vehicles.
  - ※ The information delivery range could be changed to any other value desired by individual test participants.

Method for delivering information in FOTs

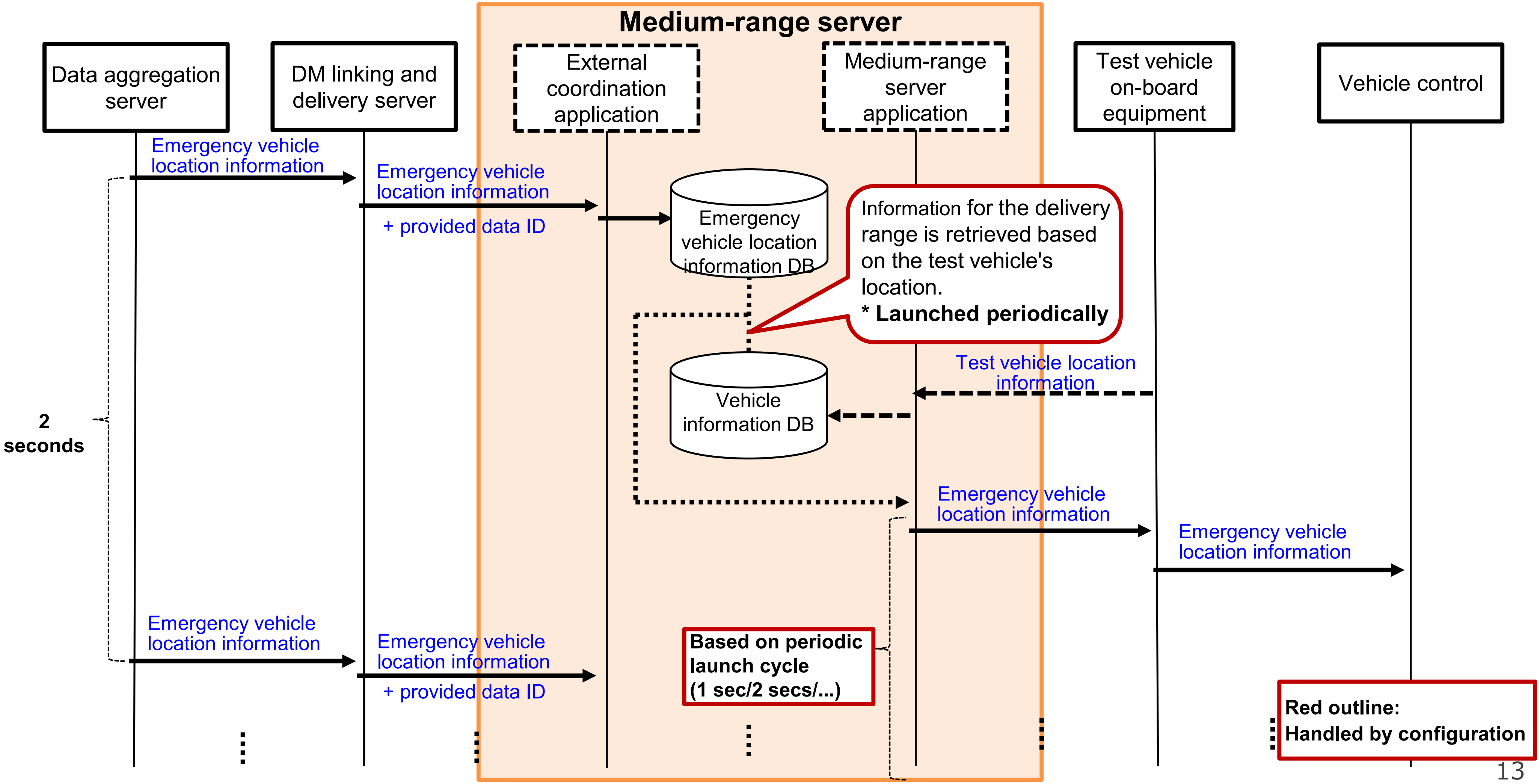
- Delivery frequency: Once per second
- Delivery range: 300 m radius



■ (1) Studies regarding the expansion and application of delivery-related technologies
2) Study regarding delivery methods

[Mock emergency vehicle location information sequence]

- We stored information received from the dynamic map data linking and delivery server in a database in the medium-range server.
- Information was retrieved from the emergency vehicle location information database based on test vehicle location information and delivered to test vehicles.



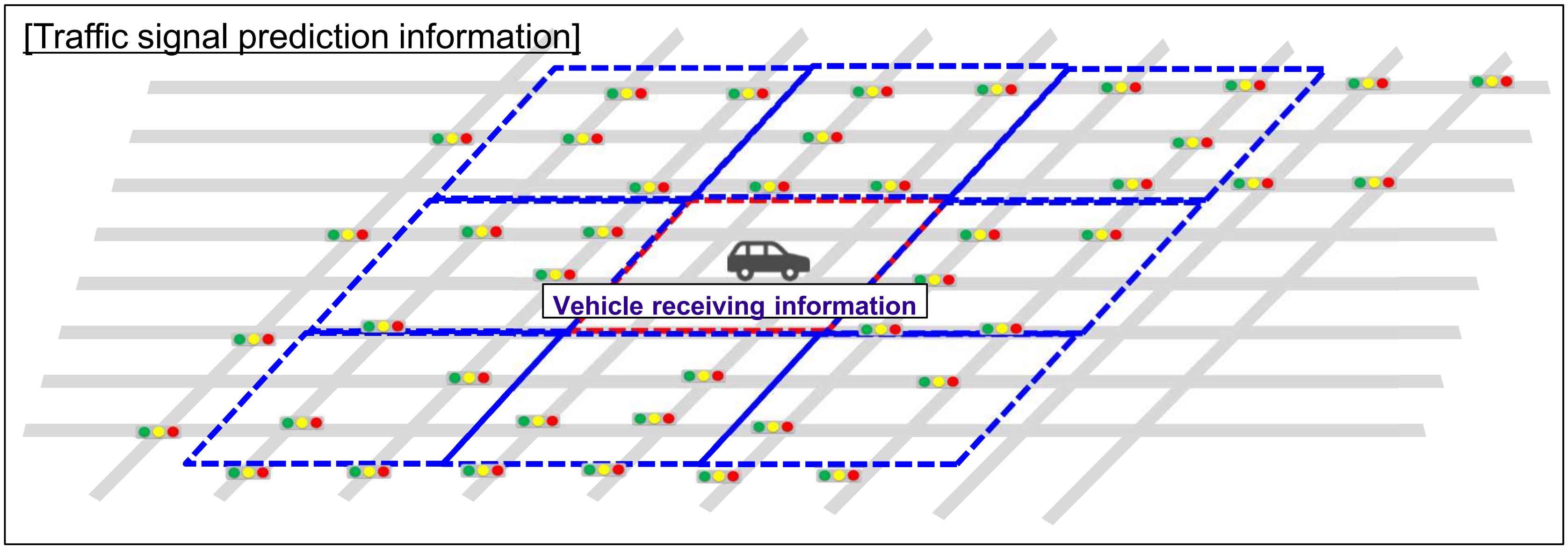
■ (1) Studies regarding the expansion and application of delivery-related technologies
2) Study regarding delivery methods

[Traffic signal prediction information] a. PULL delivery

- Traffic signal prediction information data for a large area was summarized and delivered for potential use in route planning, etc.
- The delivery range was set to a 9-block area, centered around the vehicle's area. Each block measured 500 meters on a side.

Method for delivering information in FOTs

- Delivery frequency: 10 second intervals
- Delivery range: 500m square for each area



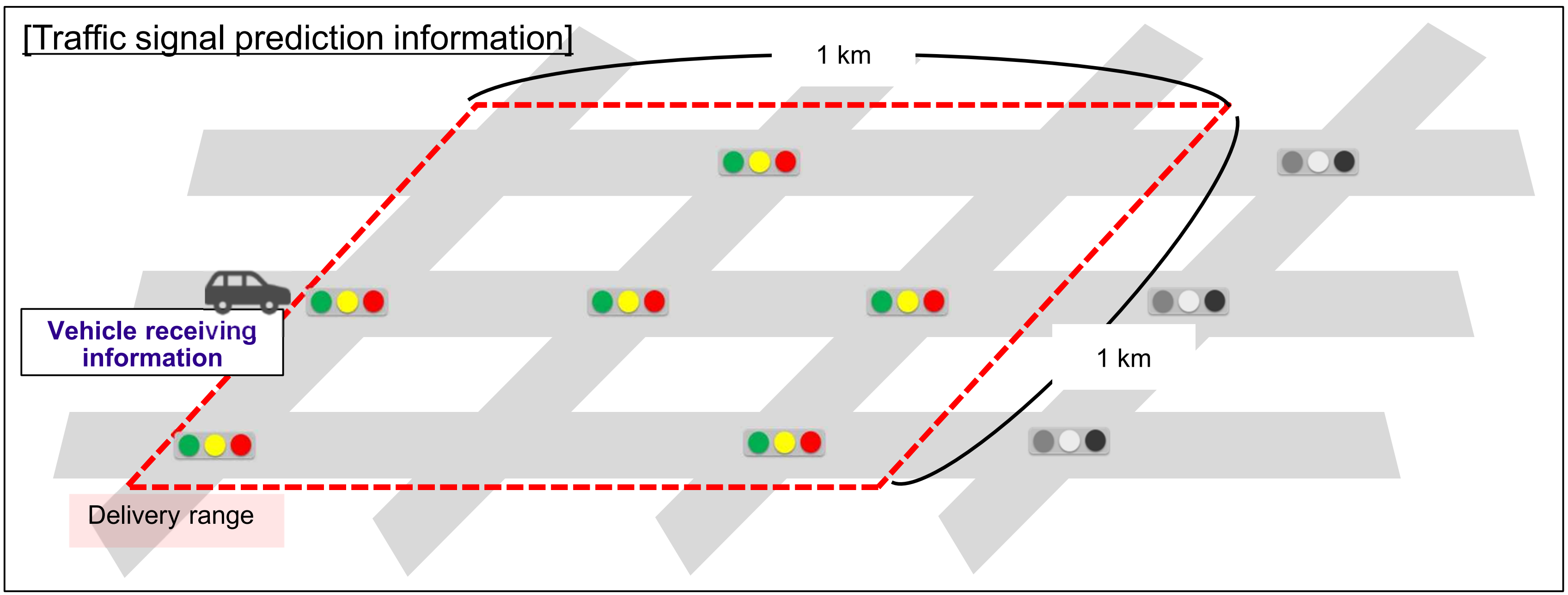
■ (1) Studies regarding the expansion and application of delivery-related technologies
2) Study regarding delivery methods

[Traffic signal prediction information] b. PUSH delivery (specified distance)

- We considered methods for delivering traffic signal information for a square area in front of the vehicle so that ordinary vehicles, etc., without route information could use the information when experiencing difficulties visually confirming traffic signal colors.
- Given the traffic signal cycle length of traffic signals in the Waterfront City area (generally 80 to 160 seconds), there was the possibility of traffic signal cycles rolling over to the next cycle before information for distant signals arrived. The default delivery area was therefore set to a 1 km square. * The delivery area could be changed as desired.

Method for delivering information in FOTs

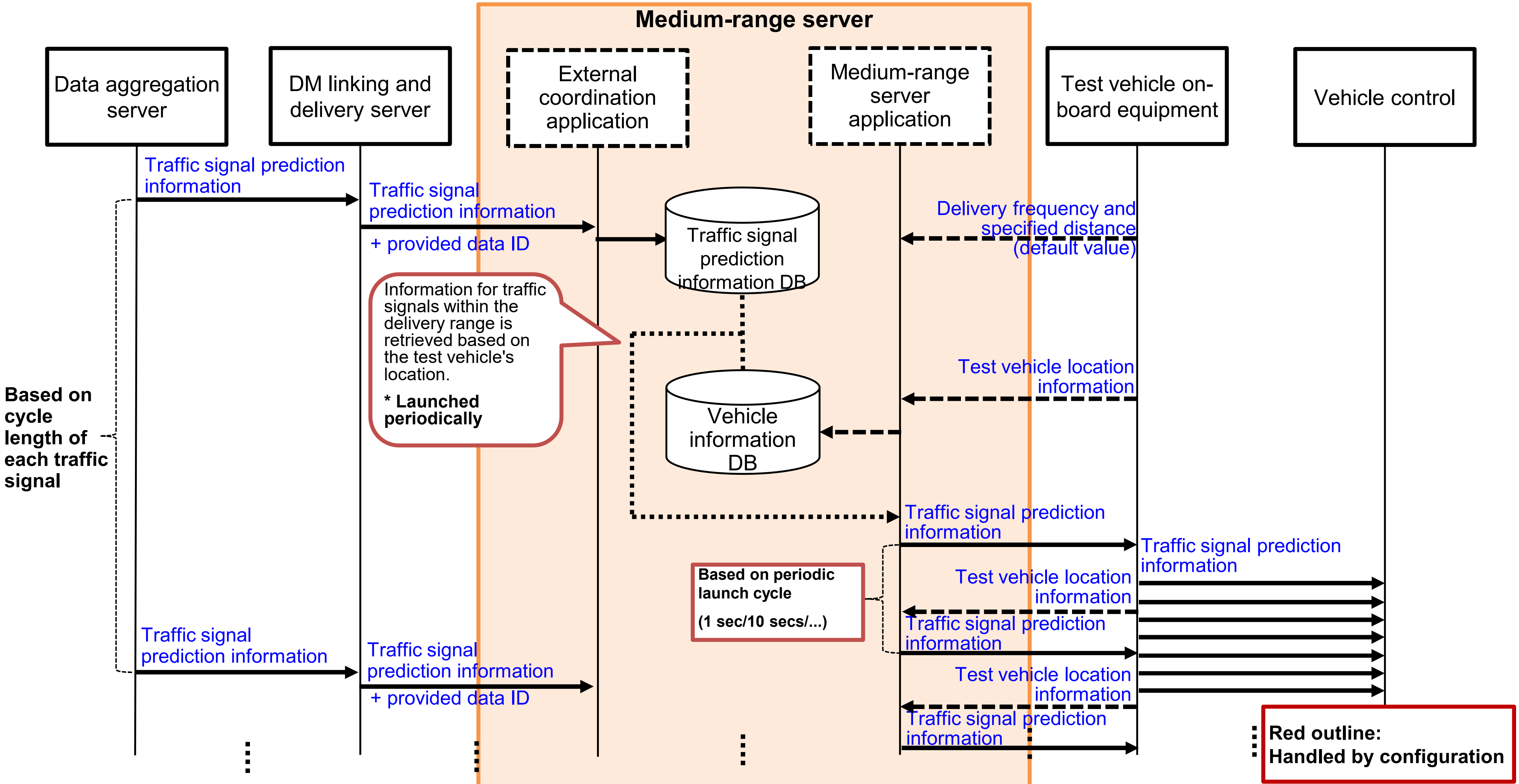
- Delivery frequency: Once per second
- Delivery range: 1 km square (parameters can be changed)



■ (1) Studies regarding the expansion and application of delivery-related technologies
2) Study regarding delivery methods

[Traffic signal prediction information sequence] b. PUSH delivery (specified distance)

- The delivery method was the same as that used for emergency vehicle location information.



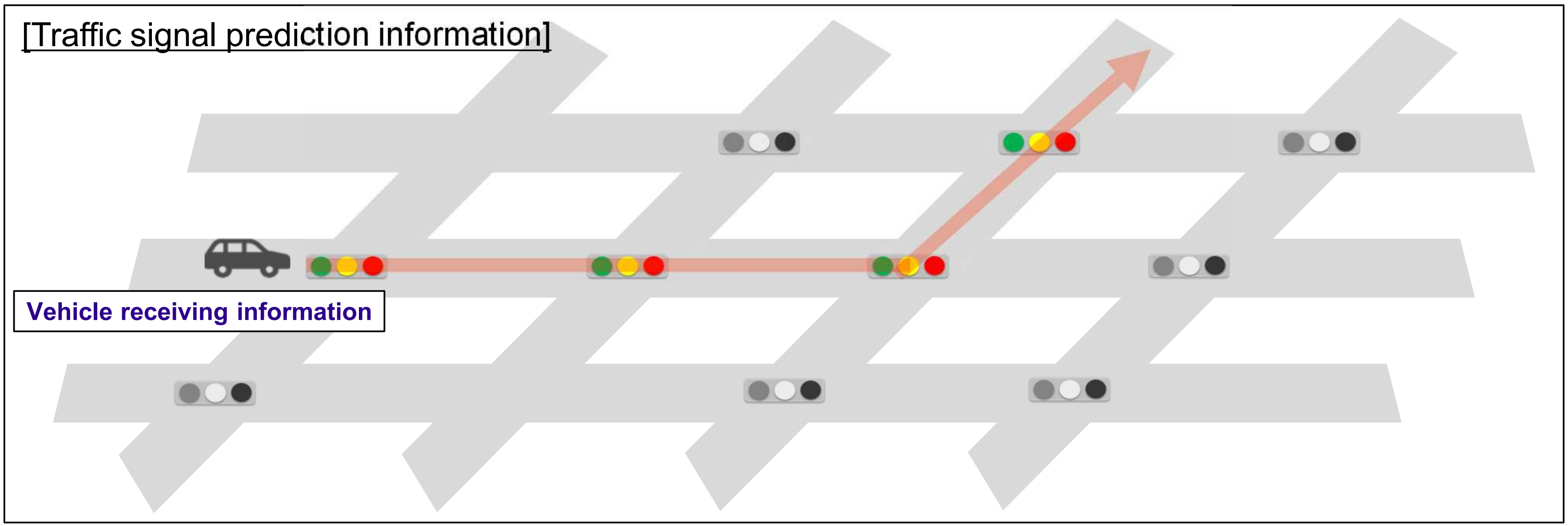
(1) Studies regarding the expansion and application of delivery-related technologies
2) Study regarding delivery methods

[Traffic signal prediction information] c. PUSH delivery (specified intersection)

- Vehicles requested information about the intersections they were going to traverse and received essential traffic signal prediction information for use in automated vehicle route planning and green wave driving.

Method for delivering information in FOTs

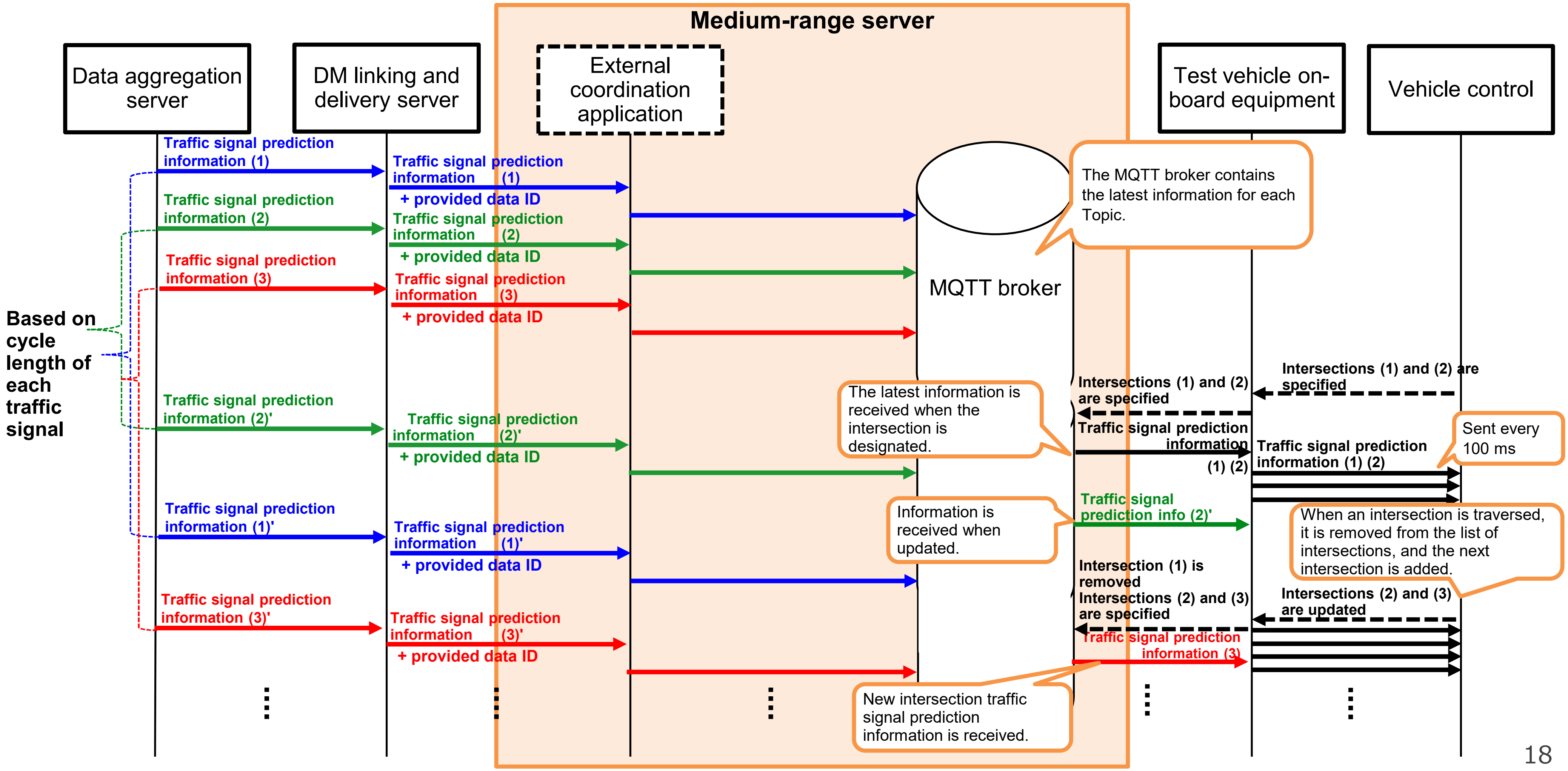
- Delivery frequency: When traffic signal prediction information is updated



(1) Studies regarding the expansion and application of delivery-related technologies
2) Study regarding delivery methods

[Traffic signal prediction information sequence] c. PUSH delivery (specified intersection)

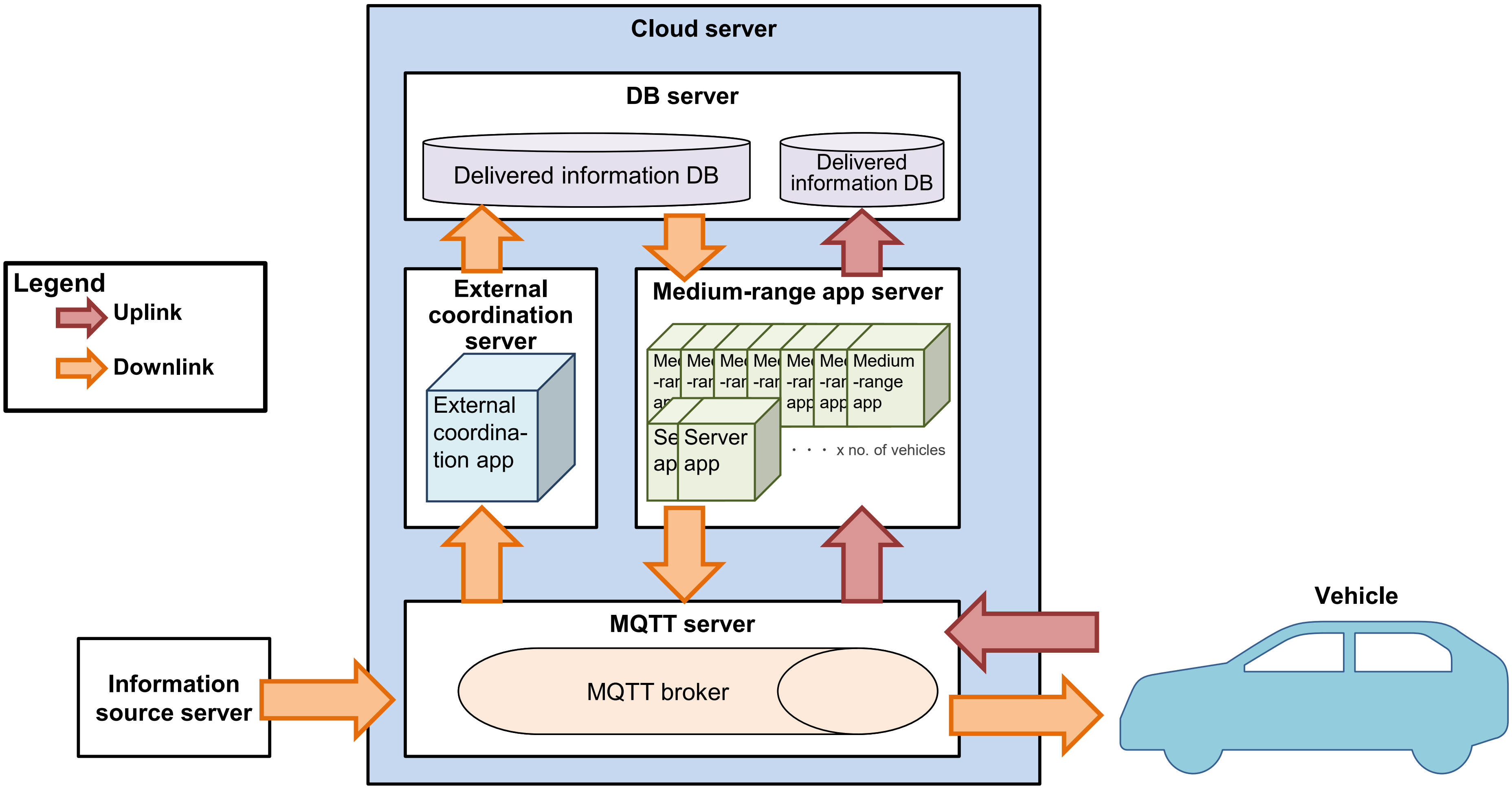
- The MQTT server has the latest information on each Topic, so regardless of the timing of transmission by relay servers, each vehicle immediately receives the latest information for each intersection when it designates it.
- When information for target intersections is updated, that updated information is immediately received.



(2) Evaluation through large-scale FOTs

(2) Evaluation through large-scale FOTs 1) Tokyo Waterfront City FOTs

- A medium-range server system was developed, constructed, and deployed in the Tokyo Waterfront area FOTs test system used by the Tokyo Waterfront area FOTs Consortium conducted by the Tokyo Waterfront Area FOTs Consortium.
- In the Tokyo Waterfront area FOTs, the delivery methods discussed in Section (1) were used to deliver information to test participants. We confirmed that information was delivered without any major delays.



Medium-range server system configuration diagram

(2) Evaluation through large-scale FOTs 1) the Tokyo Waterfront area FOTs

- **A user evaluation of the Tokyo Waterfront area FOTs was conducted through an evaluation questionnaire concerning delivery methods, issues related to delivering information via V2N, and the like.**
- **Questionnaire results included valuable suggestions regarding changes to delivery areas and delivery frequency to help reduce the load placed on the medium-range information delivery system, medium-range server functions and operation methods to use in practical implementation, overall system architecture, and more.**

【Consideration】

- There was a request to use the PUSH method to deliver information that was delivered only by the PULL method. Considering that various technologies and services related to automated driving and safe driving assistance will become widespread in the future, it is expected that the delivery method required by the vehicles for even the same information will differ depending on the use cases. Therefore, **the setting of the delivery method is considered to be with in the scope of the competitive area.**

- **For the PUSH method, the frequency, range, and number of intersections for distribution** required by vehicles vary depending on the use cases. Therefore, **when building a server to distribute data** regardless of competitive and cooperative areas, **it is desirable to have a system that allows parameters to be changed in consideration of server load.**

- Regarding the function to calculate the delivery range, opinions were divided between those who preferred that it be handled by the server and those who preferred that it be handled by the vehicle. Based on the results of the load verification described later, **the method of specifying necessary information at the vehicle is preferable for large-scale information distribution.**

- Regarding V2N information distribution, many expressed the desire for the distribution business to be conducted in the scope of the cooperative area. **Considering maintenance costs and system versatility**, **distribution of information that is highly public and of limited use cases to some extent,** such as emergency vehicle location information, **should be developed in the scope of cooperative area, while distribution of information used in highly flexible use cases should be developed in the scope of competitive area.**

(2) Evaluation through large-scale FOTs 1) the Tokyo waterfront area FOTs

【Summary of the evaluation questionnaire result】

Information	Summary
Rainfall information	● Participants indicated that they wanted pinpoint road flooding information to be delivered using PUSH delivery, and they wanted to be able to check conditions at distant locations such as destinations.
Lane-specific road traffic information	● Participants indicated that PUSH delivery was essential in order to reduce the time gap between when traffic congestion occurs and when it is detected and announced.
Mock emergency vehicle location information	● 300 m delivery range: Feedback included "There wasn't enough time or distance to change lanes in order to cede the road." and "It would be best if it were possible to detect the vehicle 20 seconds or so in advance (assuming a vehicle speed of 60 km/h, that would work out to a distance of approximately 400 meters. Taking the 9 seconds of possible delay into consideration, the information should be provided 700 meters in advance.)" ● Optimal delivery range in order to provide safe driving assistance when emergency vehicles are approaching **Radius of roughly 300 to 1,000 meters.**
Traffic signal prediction information	● Regarding PUSH method (specified distance), a participant stated that using a delivery range of 500 meters during route planning "seldom provided enough information to select alternate routes." (requested delivery range: 500 to 1,000 meters or more) ● Regarding PUSH method (specified intersection), there were comments that information on one or two intersections is needed for dilemma avoidance and three to six intersections is needed for optimal route and speed adjustment.
Issues and concerns regarding practical implementation of V2N	● Many participants pointed out issues with delays in delivering information. ● There were concerns regarding scalability, delivery methods, and nationwide standardization of information contents. ● There were many expressed the desire for the distribution business to be conducted in the scope of the cooperative area.

(2) Evaluation through large-scale FOTs
2) Deliberations aimed at nationwide deployment and usage: Overview of steps 1 to 3

- **With regard to the system for delivering information from the medium-range server deployed for the Tokyo Waterfront Area FOTs to the on-board equipment, we verified the load placed on the medium-range server and the amount of traffic that was transmitted in order to evaluate the delivery methods used in the FOTs and consider server installation standards and functions with an eye towards nationwide deployment and usage.**
- **Verification was performed for PUSH delivery, which places a heavy load on the servers used to relay the information.**

Step 1	Verification using FOTs environments	■ Verify loads and communication traffic. Consider delivery methods that efficiently utilize medium-range server resources.
Step 2	Deliberation regarding feasibility of system configuration for practical implementation	■ Based on verification data, consider the feasibility of using the system configuration used for the FOTs in servers installed nationwide, on a prefecture-by-prefecture basis.
Step 3	Investigation of functions, etc., that should be provided in preparation for practical implementation	■ Identify challenges and policies involved in practical implementation. ✓ Information provision range of medium-range servers (range of data to be stored in servers) ✓ Method for switching to connected medium-range servers (Switching at the network layer level, at the application layer level, etc.) ✓ Delivered based on information priority ✓ Methods for dealing with numerous simultaneous requests, etc.

(2) Evaluation through large-scale FOTs

2) Deliberations aimed at nationwide deployment and usage

STEP 1 (1) Load verification and transmitted traffic verification parameters

- **Load verification: We set the following parameters and measured transmission delay and the load placed on the server (CPU and memory utilization).**
- **Transmitted traffic verification: We investigated the factors that placed loads on the server, using the number of transmissions per hour as a standard.**

Verification parameters

	Load verification (actual measurement)	Transmitted traffic verification (theoretical)
Information category	Emergency vehicle location information/traffic signal prediction information	
Delivery method	Emergency vehicle location information: PUSH delivery (specified distance) Traffic signal prediction information: PUSH delivery (specified distance)/PUSH delivery (specified intersections)	
Measurement item	PUSH delivery (specified distance): Processing delay/load conditions PUSH delivery (specified intersections): Processing delay/load conditions	Transmitted traffic (Traffic signal prediction information only)
No. of vehicles to which information was transmitted	1/ 20/ 40/ 50/ 60/ 70	258 (average number of vehicles per square kilometer in Tokyo)
Delivery frequency	Default value	PUSH delivery (specified distance) : 1 sec/ 15 secs/ 30 secs PUSH delivery (specified intersections): 120 secs
Delivery range	Default value	PUSH delivery (specified distance) : 12 locations per square kilometer PUSH delivery (specified intersections): 5 locations/ 15 locations / 50 locations
Remarks	The number of vehicles to which information is delivered is determined based on the number of medium-range applications that can be launched in the field operational test environment this year. We verify the server load when delivering to a plurality of vehicles.	Based on data volume, frequency, and scope, the amount of delivery data per hour is calculated and compared for each delivery method.

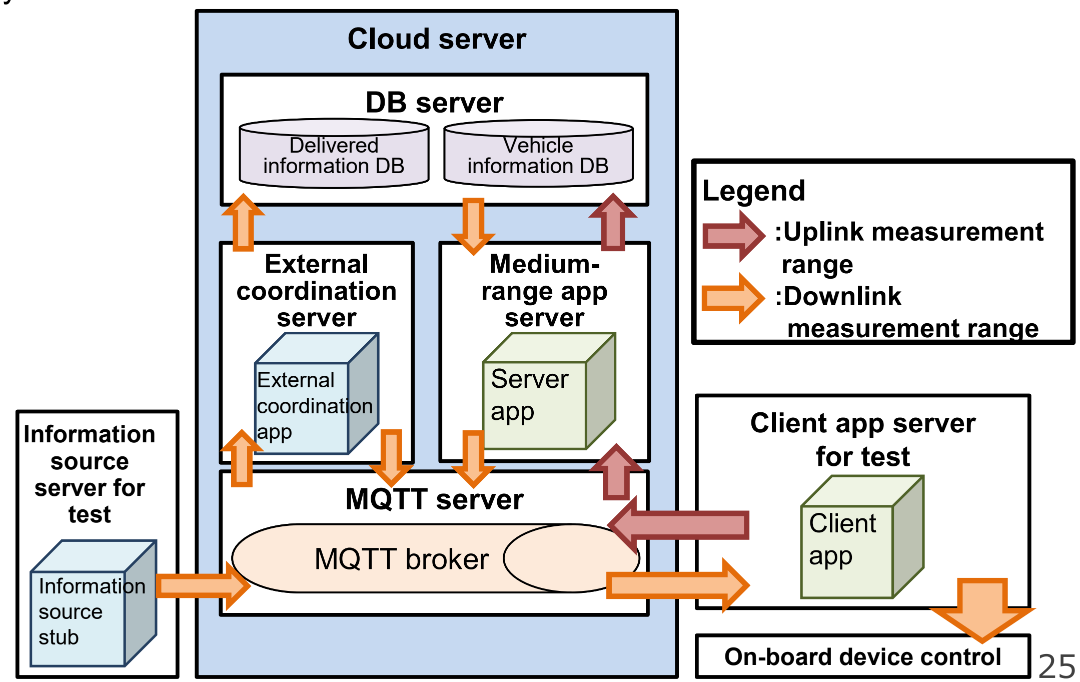
■ (2) Evaluation through large-scale FOTs
2) Deliberations aimed at nationwide deployment and usage
STEP 1 (2) Load verification (A) Processing delay measurement results

- **Even when information is delivered simultaneously to 70 vehicles, processing delay is under 30 ms, and uplinks from information sources and linkage processing times within on-board equipment are not affected by increases in the number of vehicles.**
- **The primary bottleneck encountered during simultaneous information delivery is a lack of CPU resources when starting up the server app.**

■ Specified distance delivery
- ✓ Location information uploaded from the vehicle is used by the server app to narrow down the information to information for the area in front of and around the vehicle.

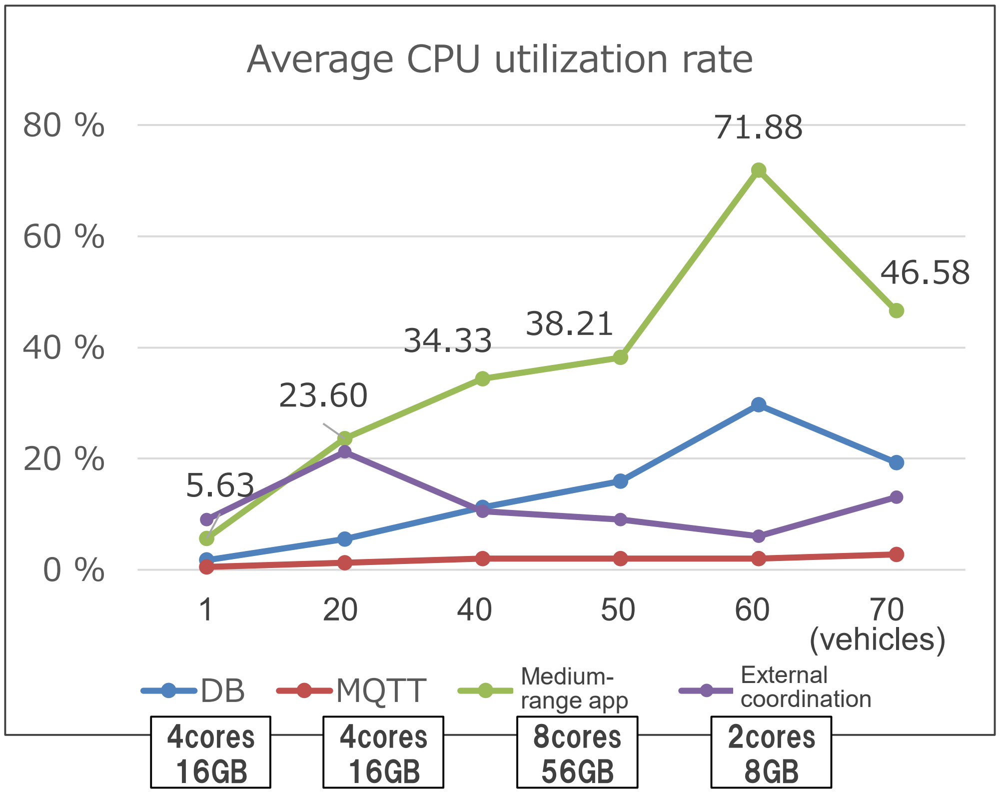
■ Specified intersection delivery
- ✓ Information is not narrowed down on the server side. Instead, the vehicle indicates which intersections it wants information for.
- ✓ Data is not stored in the database, but instead immediately delivered from an external coordination server.

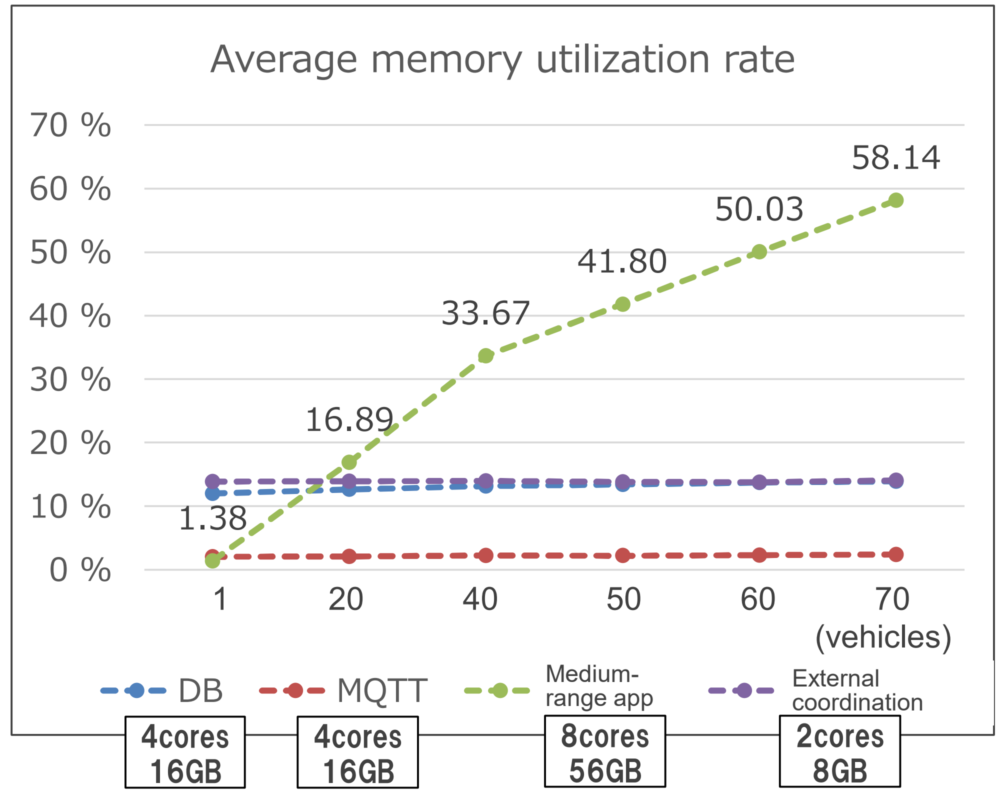
Load verification Processing delay verification (Average)		Processing delays in medium-range area
		Simultaneously delivered to 70 vehicles
[No. of vehicles information is delivered to]	Mock emergency vehicle location information Specified distance	16.99 ms
	Traffic signal prediction information Specified distance	25.77 ms
	Traffic signal prediction information Specified intersection	23.09 ms



(2) Evaluation through large-scale FOTs
2) Deliberations aimed at nationwide deployment and usage
STEP 1 (2) Load verification (B) Load measurement results
a. Mock emergency vehicle location information

- For servers other than the medium-range app server, increases in the number of vehicles to which information was delivered had almost no effect.
- For medium-range app servers, when the number of vehicles to which information was delivered exceeded 70, the CPU utilization rate climbed to and remained at 100% while attempting to start the app. This created a bottleneck and prevented the medium-range server app from starting.
- Even when information was to be delivered to 70 vehicles, the number of vehicles for which the CPU presented a bottleneck, the memory utilization rate was under 60%, so in this environment, the CPU appears to have been a bigger factor than the CPU.





(2) Evaluation through large-scale FOTs
2) Deliberations aimed at nationwide deployment and usage
STEP 1 (2) Load verification (B) Load measurement results
b. Traffic signal prediction information (specified distance)

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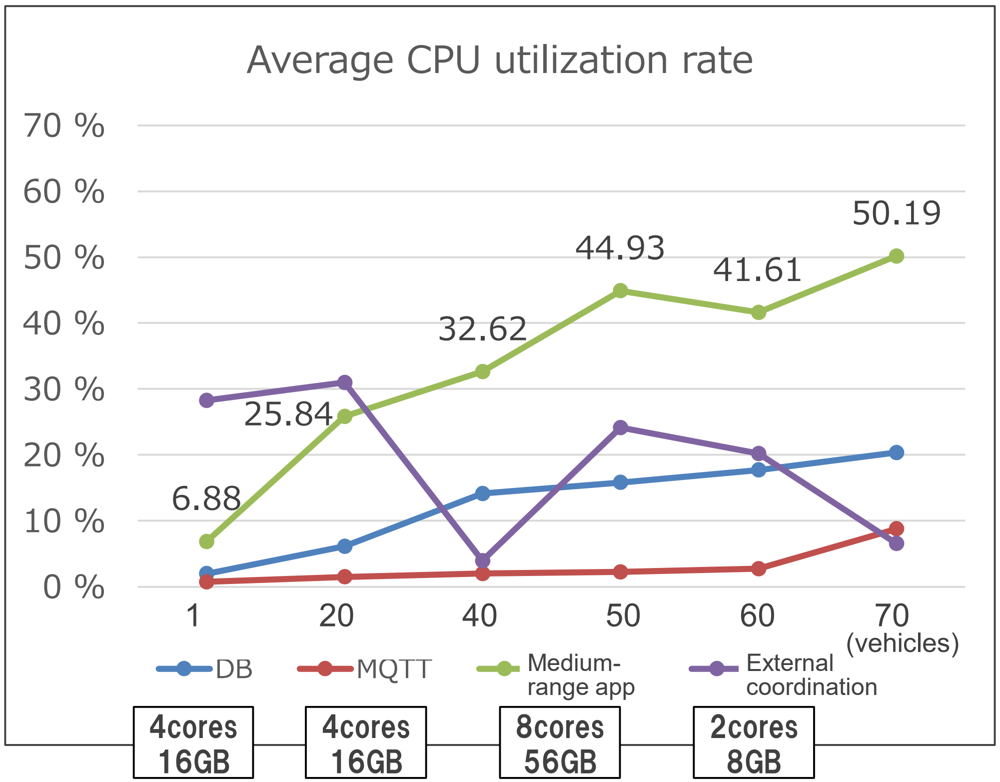
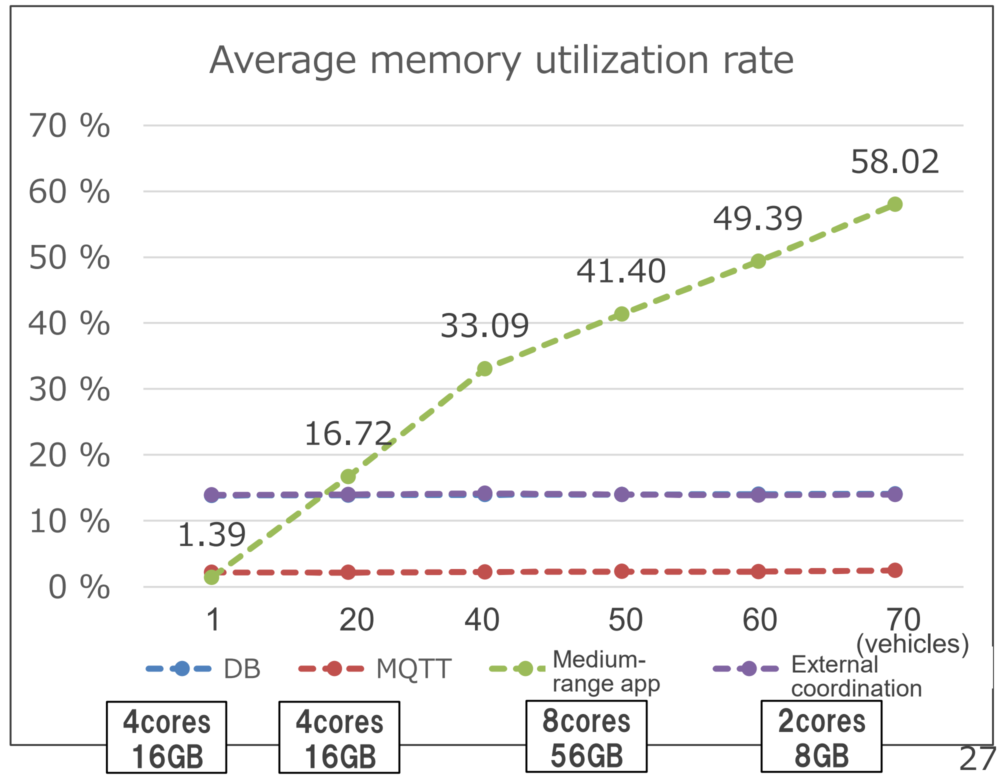
- Even when information was to be delivered to 70 vehicles, the number of vehicles for which the CPU presented a bottleneck, the memory utilization rate was under 60%, so in this environment, the CPU appears to have been a bigger factor than the CPU.

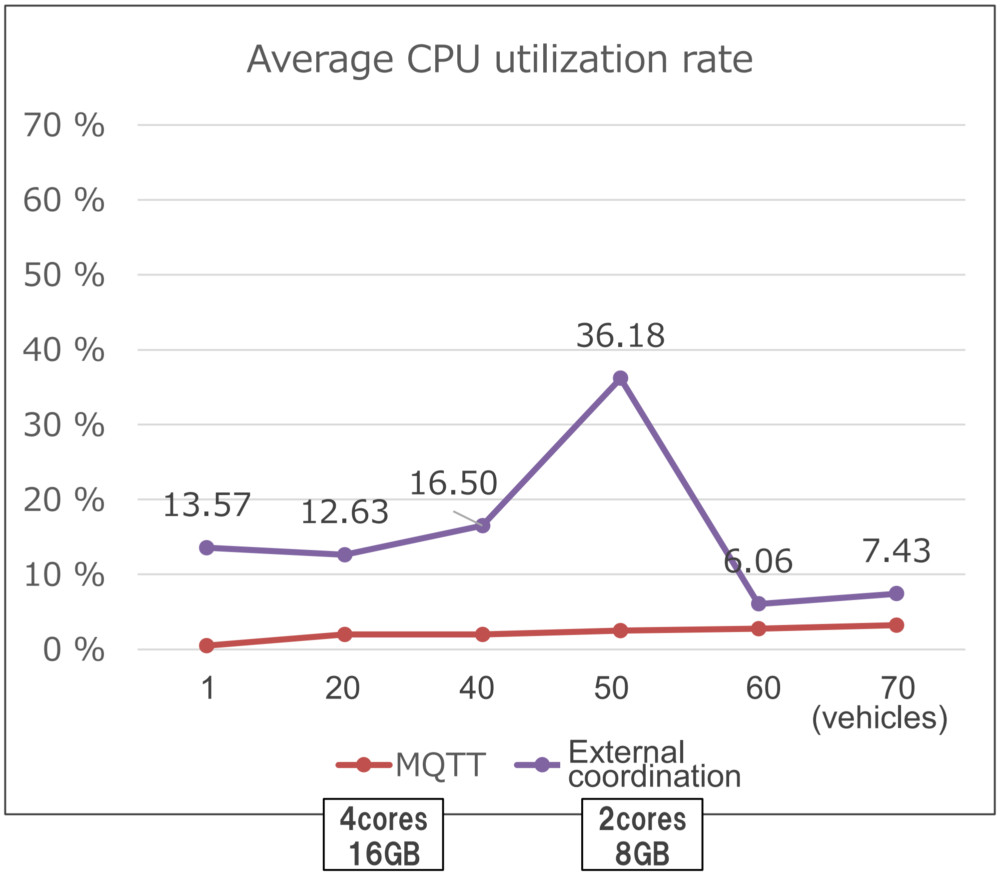


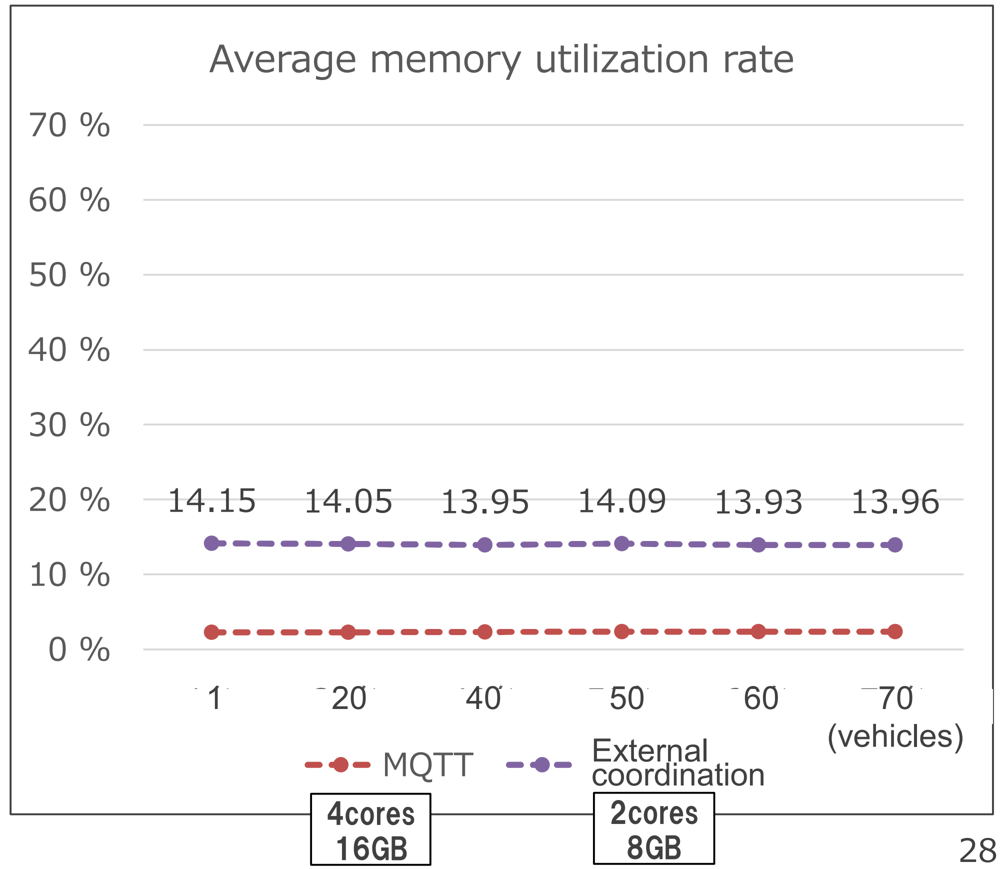


■ (2) Evaluation through large-scale FOTs
2) Deliberations aimed at nationwide deployment and usage
STEP 1 (2) Load verification (B) Load measurement results
c. Traffic signal prediction information (specified intersection)

- **When intersections were specified, although the MQTT's retain function* was used, no significant increase was observed in the load placed on the MQTT server due to specifying intersections.**
- **Data was not stored in the DB, so no resources were consumed other than those used to maintain server operation.**

※ Retain function: MQTT server function that retains the last published message for each topic





(2) Evaluation through large-scale FOTs
2) Deliberations aimed at nationwide deployment and usage
STEP 1 (3) Transmitted traffic verification

- **The medium-range server connects to each individual vehicle, so an increase in the number of vehicles results in a major increase in the number of connections.**
  - **Specified distance delivery: Delivery is governed by where vehicles that receive information move to, so this approach requires information to be delivered with high frequency.**
  - **Specified intersection delivery: Information is delivered when it is updated, which is advantageous from the perspectives of both server load and traffic volume.**

[Traffic signal prediction information]

	Delivery method	No. of intersections for which information is delivered	Delivery frequency	No. of vehicles to which information is delivered	No. of transmissions per hour	Amount of data sent per hour
Medium-range server → Vehicle	Traffic signal prediction information (specified distance) Delivery range: 1 km^2	12	1 second	258 (*)	**928,800**	**Approx. 2.79 GB**
			15 seconds		61,920	Approx. 185.76 MB
			30 seconds		30,960	**Approx. 92.88 MB**
	Traffic signal prediction information (specified intersection)	5	120 seconds		**7,740**	**Approx. 9.68 MB**
		15				Approx. 29.03 MB
		50				**Approx. 96.75 MB**

・No. of traffic signals per square kilometer: 12 ・Traffic signal cycle length: 120 seconds (2 minutes) ・Amount of data per intersection: Approx. 250 bytes

* Average number of vehicles per square kilometer in Tokyo (data from last year)

(2) Evaluation through large-scale FOTs
2) Deliberations aimed at nationwide deployment and usage
STEP 2 (1) Deliberation method

- **In STEP 2 "Deliberation regarding feasibility of system configuration for practical implementation," we used the results of STEP 1 and the procedure shown below to deliberate regarding the server specifications and server costs that would be required to deliver information nationwide and confirmed whether doing so would be feasible.**

STEP 2 deliberation process

(1) Based on the number of vehicles to which information could be delivered by the FOTs system (the results of STEP 1), we calculated the server costs per vehicle.

↓

(2) We calculated the maximum number of vehicles which could receive information simultaneously in each prefecture, based on the maximum number of vehicles per km^2 x the area of the prefecture.

↓

(3) We investigated the server specifications that would be necessary to deliver information nationwide, calculated the server cost per vehicle, and explored the feasibility of this approach.

(2) Evaluation through large-scale FOTs

2) Deliberations aimed at nationwide deployment and usage

STEP 2 (2) Deliberation results

- **Based on the results of STEP 1, we determined that with the verification environment 1 configuration (1 server), emergency vehicle location processing and traffic signal prediction information (specified distance) processing could be performed for 70 vehicles and traffic signal prediction information (specified intersection) processing could be performed for 3,700 vehicles*.**

  ***Since the server load relative to the number of vehicles is relatively small and actual measurement is not possible, we calculated by regression analysis based on the average CPU usage of MQTT servers (at 90.67%).**

- **The server costs per vehicle were:**
  - **1,250 yen/month for emergency vehicle location/traffic signal prediction information (specified distance) and 23.6 yen/month for traffic signal prediction information (specified intersection).**

- **Rough calculations of the number of servers that would be needed for Tokyo and for Tottori Prefecture, which has the lowest number of vehicles, found that the number of servers that would be required could be as much as several hundred to several thousand times as many as the number used in the verification environment (rough calculations for environments using cloud servers are shown on the following page).**

Number of vehicles supported by the verification environment and server costs per vehicle (When using the server for the FOT's environment).

Delivered information	Number of vehicles supported by the verification environment 1 configuration (one server)	Server cost per vehicle
Emergency vehicle location/traffic signal prediction information (specified distance)	70 vehicles	1,250 yen/month
Traffic signal prediction information (specified intersection)	3,700 vehicles	23.6 yen/month

Rough calculations for Tokyo and Tottori Prefecture*

Delivered information	Example 1: Entire Tokyo area	Example 2: All Tottori residents
Emergency vehicle location/traffic signal prediction information (specified distance)	If the same configuration as the verification environment were used, **8,087 servers would be needed.**	If the same configuration as the verification environment were used, **546 servers would be needed.**
Traffic signal prediction information (specified intersection)	If the same configuration as the verification environment were used, **153 servers would be needed.**	If the same configuration as the verification environment were used, **11 servers would be needed.**

(2) Evaluation through large-scale FOTs
2) Deliberations aimed at nationwide deployment and usage
STEP 2 (2) Deliberation results

- **We revised our cloud server estimate by recalculating figures for the highest spec Azure cloud servers*, and found that the maximum number of vehicles processed by each server could be raised and the server cost per vehicle could be lowered.**

※ Calculated based on use of D2ads - D96ads v5 (96 vCPU, 384 GB memory), three-year contract: 157,630.2376 yen/month.

Number of vehicles supported and server costs per vehicle (when using Azure D96ads v5)

Information	No. of vehicles supported by an Azure D96ads v51 configuration (1 server)	Server cost per vehicle
Emergency vehicle location/traffic signal prediction information (specified distance)	Approx. 840 vehicles	188 yen/month
Traffic signal prediction information (specified intersection)	Approx. 88,800 vehicles	1.78 yen/month

Method of calculation

- These calculations assume that the CPU performance of the medium-range app server is the limiting factor for emergency vehicle location/traffic signal prediction information (specified distance) processing in the verification environment and the CPU performance of the MQTT server is the limiting factor for traffic signal prediction information (specified intersection) processing in the verification environment.
- Given the above, a rough estimate of the number of vehicles that could be supported was performed by comparing the CPU performance of Azure cloud servers with the highest specs to the CPU performance of the server used in the verification environment.
- A rough estimate of the cost per vehicle was calculated for convenience's sake based on the server costs and the number of vehicles supported (other servers are minimally affected by increases in the number of vehicles, so these increases do not affect server costs).

(2) Evaluation through large-scale FOTs
2) Deliberations aimed at nationwide deployment and usage
STEP 3 (1) Observations

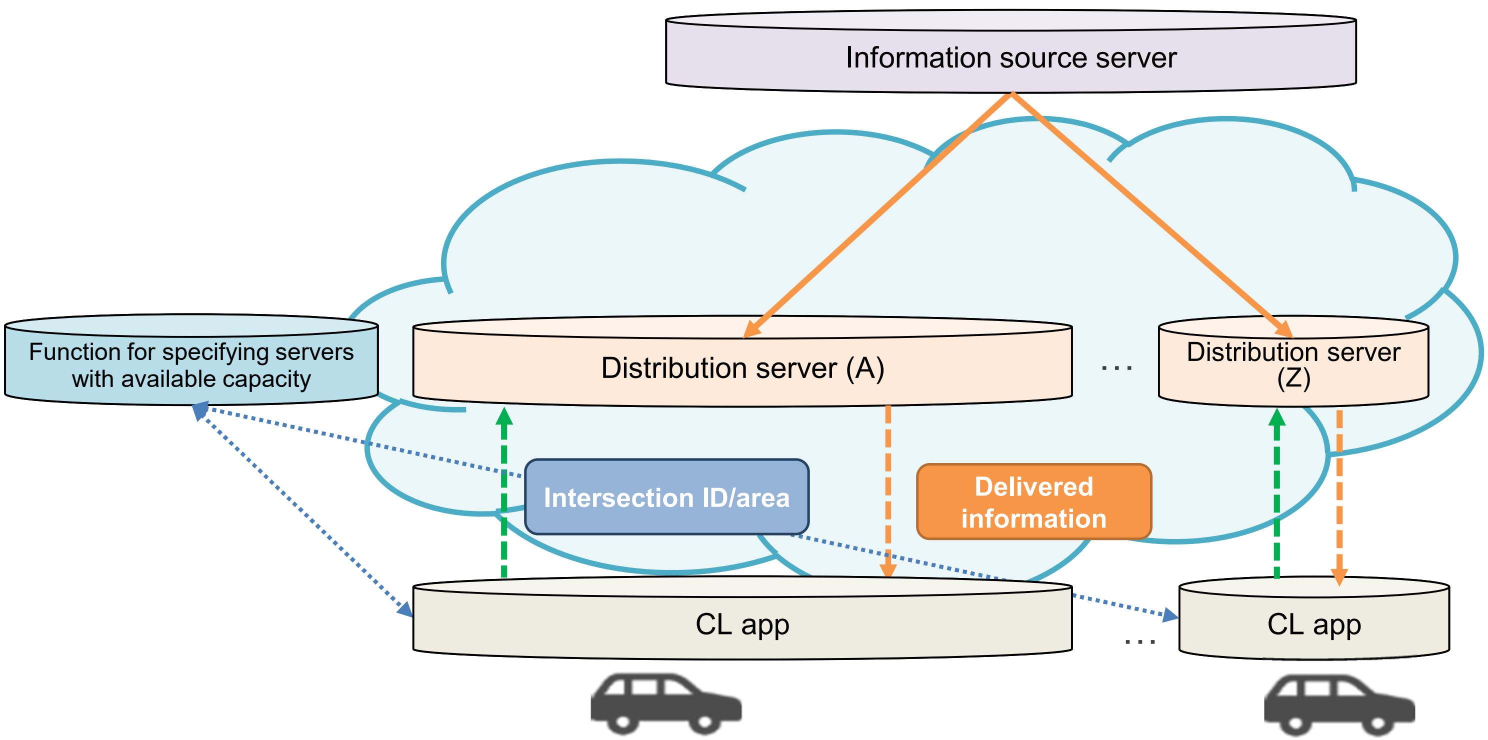
- **In STEP 3, we identified issues based on the deliberations of STEP 2 and other matters that must be taken into consideration during practical implementation. We then considered the system architectures and server functions that would be necessary to address these issues.**

- **When actually deploying information delivery systems covering medium-range areas, it is essential not only to review the requirements of delivery methods but also to optimize system architectures and individual applications with an eye towards delivering information over wide areas.**
  - **Deliberate regarding system architecture in anticipation of practical implementation (see following page)**
  - **Reduce CPU loads by revising delivery methods**
  - **Improve resource efficiency by optimizing applications, etc.**

Examples of functions and deliberations essential for future practical implementation	
(1) Review and revise requirements	• Review and revise delivery methods (range, frequency reduction) • Reconsider how functions are allocated between medium-range delivery servers and vehicles • Consider simultaneous processing functions and prioritization involved in delivering multiple items of information • Consider method used to determine areas at the network layer, etc.
(2) Create system in anticipation of actual deployment	• Consider overall system architecture, taking into account large-scale delivery and backup systems, etc. • Optimize applications for large-scale delivery • Implement non-functional requirements such as redundancy and security, etc.
(3) Consider business models	• Consider industry-spanning operation structure, etc.

(2) Evaluation through large-scale FOTs
2) Deliberations aimed at nationwide deployment and usage
STEP 3 (2) Deliberation regarding system architecture

- The approach of having the server calculate delivery ranges, etc., for each vehicle and perform delivery accordingly places a heavy load on the server and results in frequent information delivery. Therefore, for large-scale information delivery, a more appropriate approach would be to have the vehicles specify the information they require.
- This would require the formulation of rules regarding how vehicles select the information they need.
  Example: Traffic signal prediction information ・・・ Intersection ID
  Emergency vehicle location information ・・・ Area
- There are limits to the number of vehicles that can be supported by a single distribution server, so there must be functions that enable the use of multiple distribution servers (such as a function for specifying the use of servers with available capacity).



4. Summary (recommendations, etc.)

Item	Contents
Results of this research and development project	● We investigated delivered information and common interface requirements and identified data items that need to be added. ● We considered and developed delivery methods appropriate for each type of delivered information (delivery methods, frequency, and areas). ● We developed and set up systems used in the delivery of medium-range information and deployed them in the Tokyo Waterfront area FOTs environment. ● We confirmed through the Tokyo Waterfront area FOTs that information could be delivered without major delays, etc. ● We gathered valuable input from test participants regarding practical system implementation through evaluation questionnaires regarding delivery methods and the practical implementation of information delivery via V2N. ● We performed load verification, found that the PUSH intersection specification approach offers benefits both in terms of server load and traffic, and, in anticipation of practical implementation, considered system architectures and which functions should be provided on the server side. ● We created a results report and implementation guidelines.
Recommendations based on this research and development project	☐ The approach of having the server calculate delivery ranges, etc., for each vehicle and perform delivery accordingly places a heavy load on the server and results in frequent information delivery. **Therefore, for large-scale information delivery, a more appropriate approach would be to have the vehicles specify the information they require.** ☐ Achieving the above **would require the formulation of rules regarding how vehicles select the information they need (such as intersection IDs and delivery areas).** ☐ **There are limits to the number of vehicles that can be supported by a single distribution server, so there must be functions that enable the use of multiple distribution servers (such as a function for specifying the use of servers with available capacity).**

This report documents the results of Cross-ministerial Strategic Innovation Promotion Program (SIP) 2nd Phase, Automated Driving for Universal Services (SIP-adus, NEDO management number: JPNP18012) that was implemented by the Cabinet Office and was served by the New Energy and Industrial Technology Development Organization (NEDO) as a secretariat.