戦略的イノベーション創造プログラム

TF3-21-005-1 Ⅲ6

"Cross-ministerial Strategic Innovation Promotion Program (SIP) Phase Two - Automated Driving (Expansion of Systems and Services) /Implementation of FOTs in the Tokyo Waterfront Area"

- 2020 Results Report Overview -

FOTs in the Tokyo Waterfront Area Consortium

Mitsubishi Electric Corporation (representative)

Aisan Technology Co., Ltd.
Increment P Corporation
Sumitomo Electric Industries, Ltd.
Zenrin Co., Ltd.
Toyota Mapmaster Incorporated
Nippon Koei Co., Ltd.
Pacific Consultants Co., Ltd.
Pasco Corporation

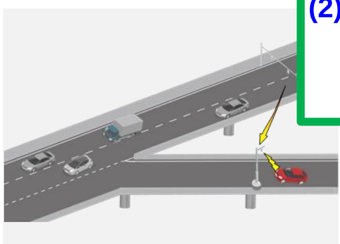
May 2021

Results Overview

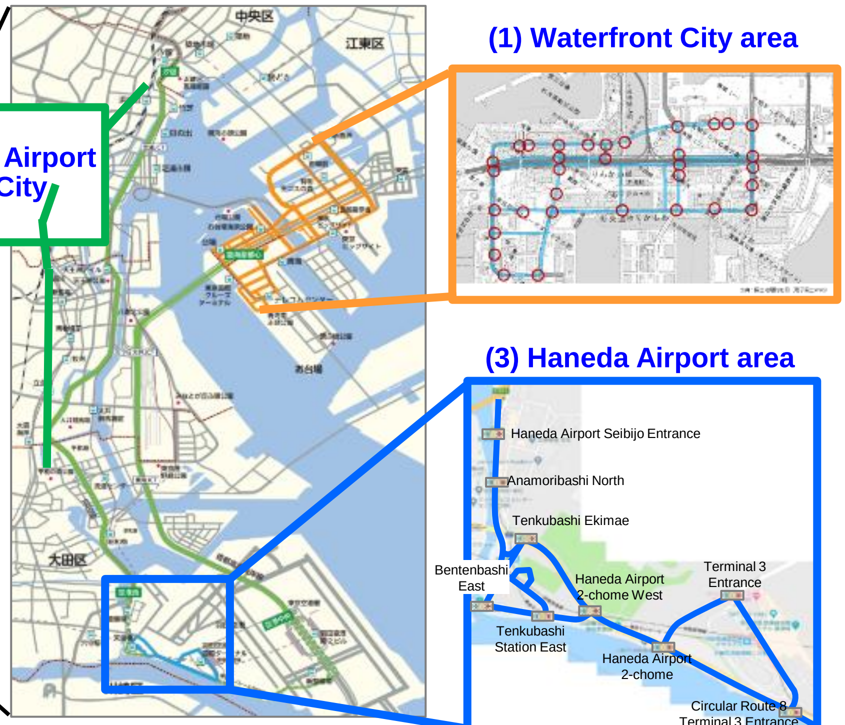
Initiative overview

- We performed cooperative FOTs in the Tokyo Waterfront City area using traffic environmental data (traffic signal information, ETC gate information, and merging support information) provided by roadside infrastructure with the aim of expanding the ODD of autonomous vehicles in mixed transportation environments such as general roads and the Metropolitan Expressway.
- Participants: 29 (foreign and Japanese automotive manufacturers, automobile component manufacturers, universities, venture companies, etc.)
- Data acquired from test vehicles (including autonomous vehicles), information from video cameras installed on roadsides, and information from participant questionnaires and interviews were analyzed, and the effectiveness of the use of traffic environmental data was verified.

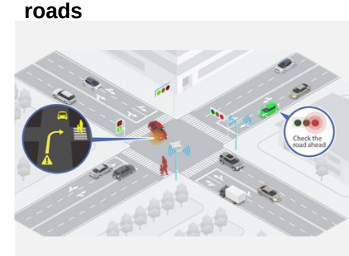
Advanced automated driving on expressways through distribution of driving support information and lane-level roadway traffic environment information



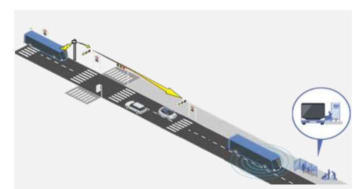
(2) Expressway routes connecting Haneda Airport and the Waterfront City area, etc.



Transmitting traffic signal information by wireless ITS devices to **implement advanced automated driving on ordinary roads**



ART using bus automated driving technology in mixed transportation environments through the use of infrastructure equipment using ODD settings, advanced PTPS, etc.



ODD: Operational Design Domain

Results Overview

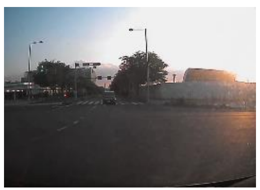
(1) Waterfront City area

- We confirmed that providing traffic signal color information and remaining seconds information using Dedicated Short Range Communications (DSRC) infrastructure was effective at enabling autonomous vehicles to safely and smoothly traverse intersections with traffic lights on general roads.
- We confirmed conditions, such as road structures, under which infrastructure is necessary
  "Roads with curves, etc., that result in traffic signals coming into view at short distances from the traffic signals," "roads with high speed limits," "intersections with traffic signals located near other intersections with traffic signals," "nonpermanent conditions (such as backlighting/direct lighting, rain, obstruction by preceding vehicles, nighttime driving, and blending into the background) under which it is difficult for on-board cameras to determine traffic signal colors"

  ➡ Vehicle-infrastructure cooperation can be used to introduce and expand safe, smooth autonomous vehicle usage by preparing infrastructure covering entire areas after defining areas where autonomous vehicles, including those providing mobility services, will be used
- Although a consensus was reached with test participants regarding information distributed by ITS wireless roadside units for existing services (ISO/TS19091 specification compliant), there were requests that remaining seconds information for actuated traffic signal be confirmed earlier. The impact will be even greater for V2N, so future consideration will need to be given to the delivery of this information using V2N.

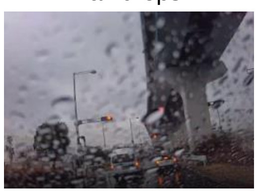
Backlighting

Direct lighting



Concealment/ obstruction

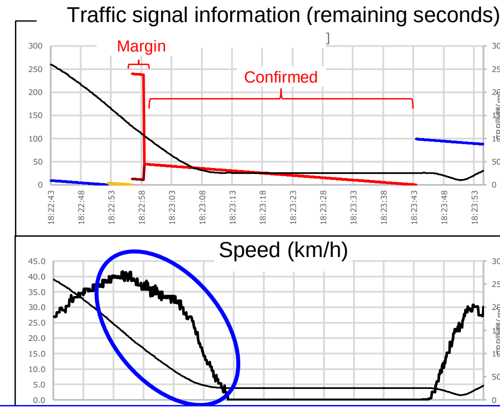
Raindrops



Blending into background

Nighttime

Providing traffic signal information was effective at enabling autonomous vehicles to safely and smoothly traverse intersections with traffic lights on general roads, even in environments where traffic signal identification is difficult



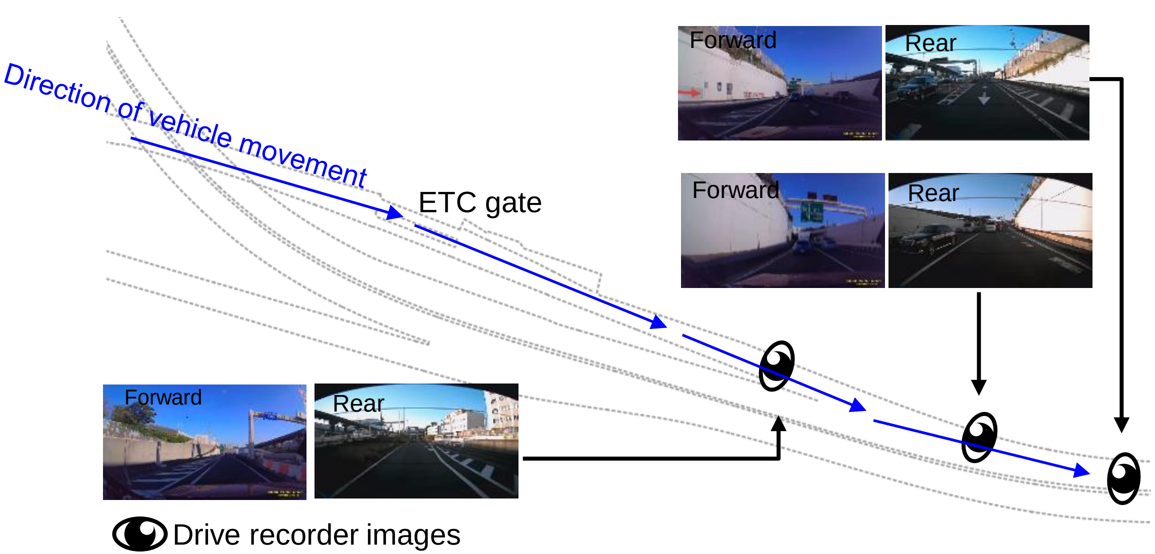
Camera-based traffic signal recognition functions were not used. **Instead, infrastructure information alone was used to identify red lights and stop safely.**

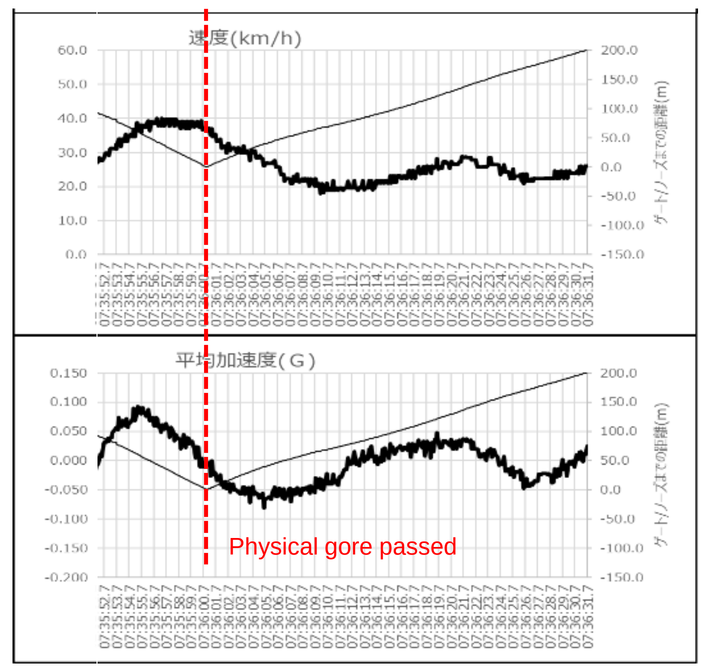
Results Overview

(2) Expressway routes connecting Haneda Airport and the Waterfront City area, etc.

- We verified that ETC gate passing support information provided at an early point via Dedicated Short Range Communications (DSRC) was effective not only for autonomous vehicle route planning but also as information that assisted drivers with smooth driving.
- Information regarding vehicles driving on cruising lines with poor visibility was provided via DSRC to merging vehicles, and we verified that it was effective for merging support provided by automated driving functions and as caution information for drivers.
- Information was provided on spot detection of vehicles on cruising lines, so we observed that the accuracy of the information fell when cruising line vehicle speeds were not consistent between detection points and merging points due to signs of traffic jams, etc.

Note) Based on the results of this FOT, consideration must be given to improving the accuracy of information in diverse conditions.





Results Overview

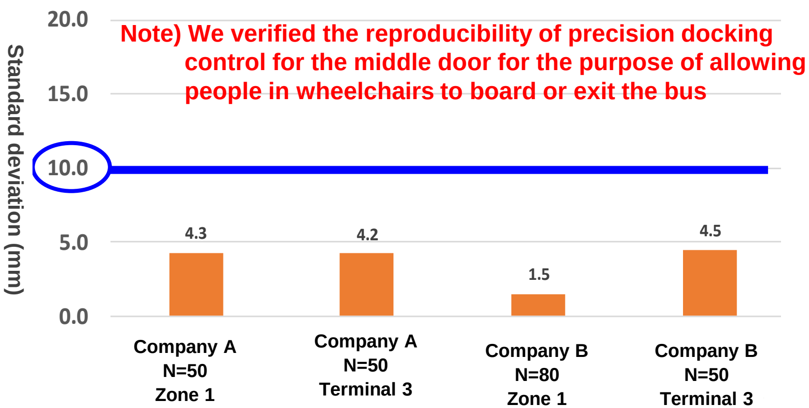
(3) Haneda Airport area

- We verified that magnetic markers, dedicated bus lanes, traffic signal information provided via DSRC, and PTPS vehicle-infrastructure cooperation made it possible for buses with automated driving technologies to provide punctual service on bus routes without manual intervention by the driver.
- We verified that precision bus docking control using magnetic marker and automated driving technologies produced a higher level of accuracy than driving by a professional driver, and that it could be used to produce buses that are more people-friendly for everyone However, we observed various situations on dedicated bus lanes that necessitate disengaging automated driving, such as routes being impeded by vehicles parked on the street or driver involvement due to unexpected cutting, and we identified issues related to societal acceptability and operation.

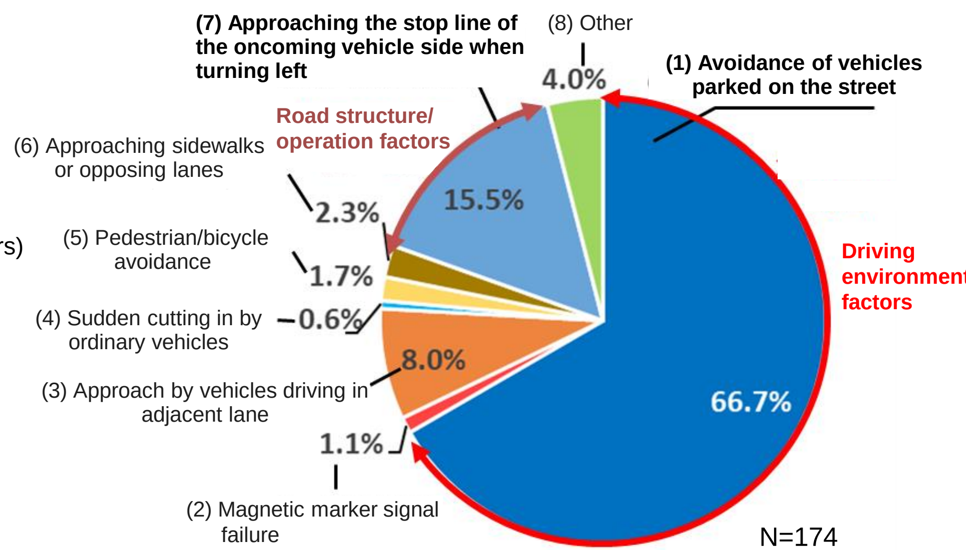

Zone 1 bus stop


Terminal 3 bus stop

Standard deviation was calculated from the results of precision docking control at Zone 1 and Terminal 3 bus stops (Own vehicle location estimation: magnetic markers)



Composition rates of the causes of manual interventions - Magnetic marker driving (applies to manual intervention by companies A and B)



Driving environment factors (potential for reductions through improvement of driving environment)

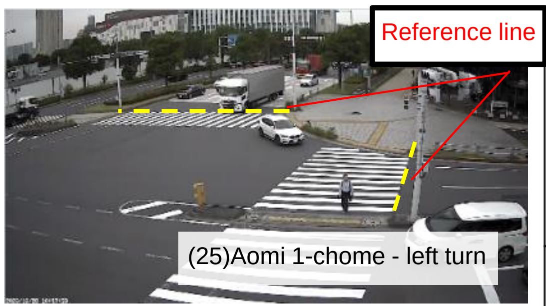
Road structure and usage factors (potential for reductions through improvement of road structures and their usage

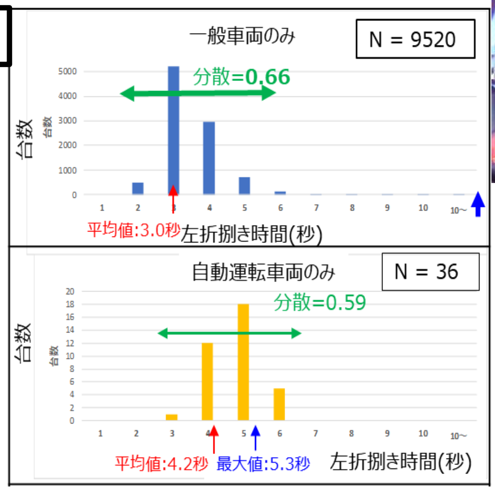
Results Overview

Impact assessment

- The intersection left and right turn processing volumes were not observed to fall significantly when autonomous vehicles were present, and were observed to be more consistent than the processing volumes when only ordinary vehicles were present.
- We observed that when look-ahead information was used, sudden deceleration did not occur when stopping at traffic lights.
- Autonomous vehicles were observed to consistently stop at designated locations when pedestrians were detected at pedestrian crossings at intersections or on basic road sections.
- With regard to dilemma zone behavior, sudden braking was observed in following vehicles as the result of sudden braking by test vehicles resulting from differences in driver decisions, the timing of detection of other vehicles by vehicle sensors, etc.
- It would be best to widely share gathered situation information, not only with other test participants but with a wide range of parties, to assist with future automated driving development.

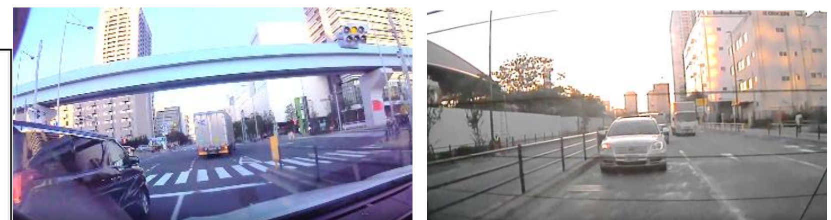
Evaluation of processing when turning left





Evaluation method:
Measure reference line traversal times based on fixed-point camera video data and calculate processing times based on differences in these times

Sudden braking by following vehicle



The traffic signal arrow turned yellow, so the test vehicle rapidly braked. The following vehicle intended to turn right, so it accelerated.

Because the test vehicle stopped, the following vehicle suddenly stopped with a small amount of knocking. It was a close call.

Table of Contents

1. Overview of the FOTs in the Tokyo Waterfront Area

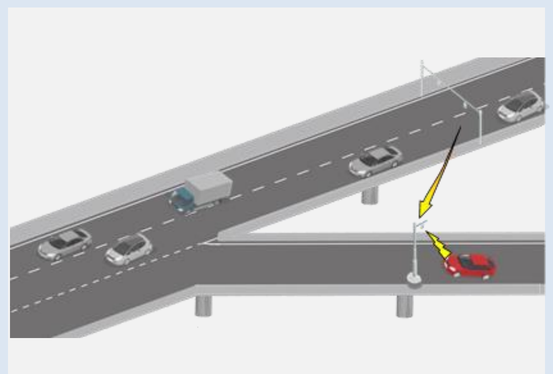
(1) Implementation contents

- Testing was performed with the following three themes in order to verify how cooperative systems deal with challenges involved in realizing advanced automated driving

Transmitting traffic signal information by wireless ITS devices to **implement advanced automated driving on ordinary roads**

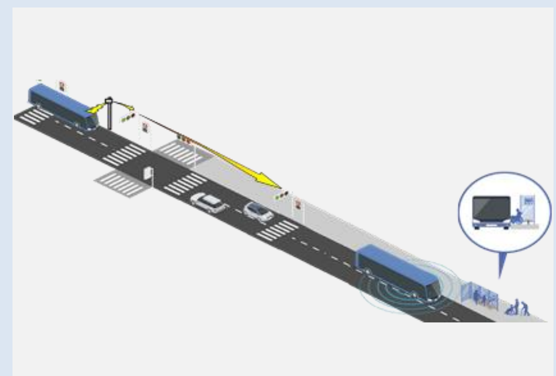
(1) Waterfront City Area
(3) Haneda Airport area

Transmitting driving support information and lane-level traffic environment information to **implement advanced automated driving on highways**



(2) Expressway routes connecting Haneda Airport and the Waterfront City, etc.

Defining ODDs and using infrastructure facilities such as advanced PTPS in mixed traffic environments to **implement ART using automated driving technology**

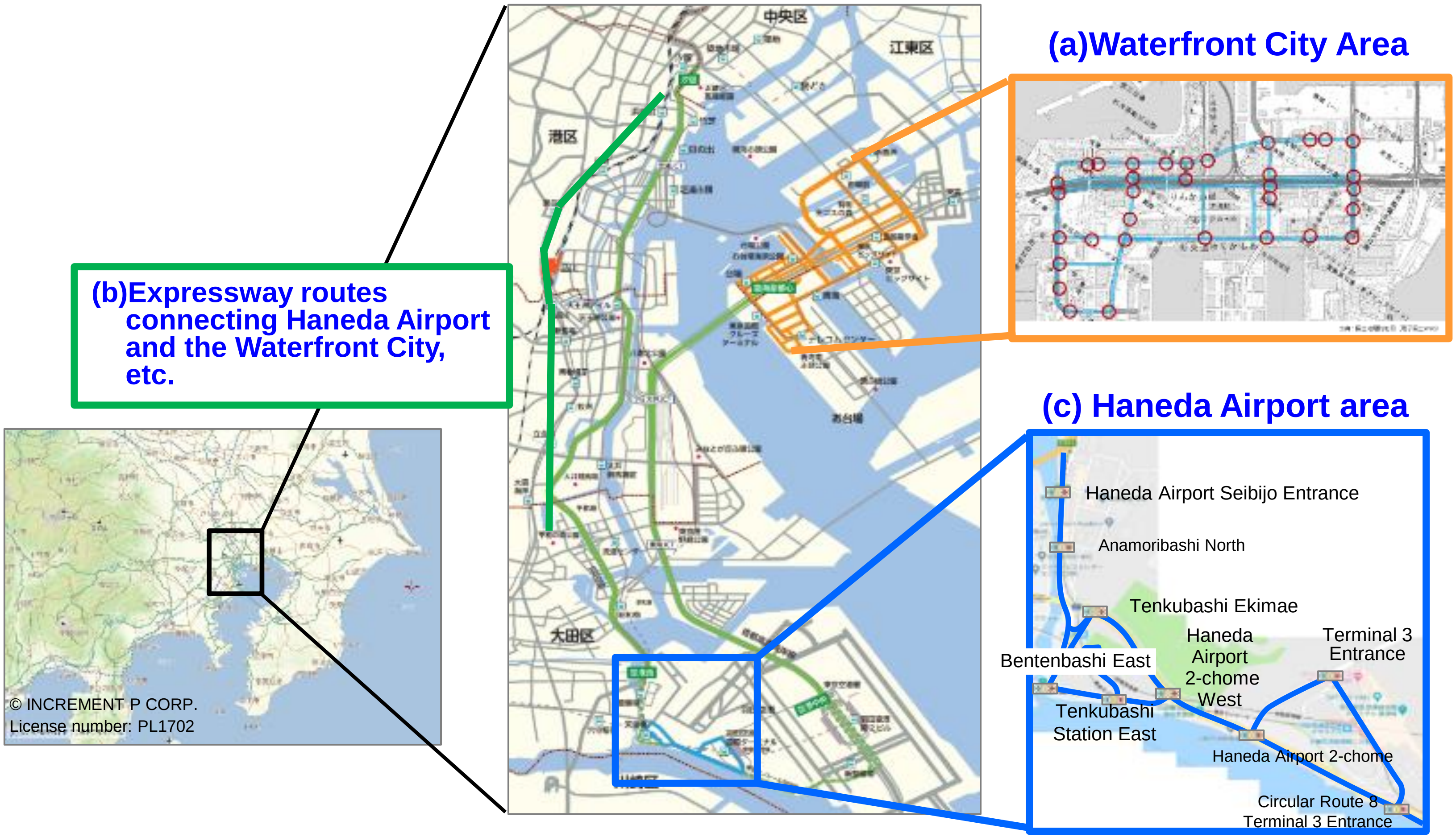


(3) Haneda Airport area

1. Overview of the FOTs in the Tokyo Waterfront Area

(2) Testing areas

- Testing was performed in the three testing areas shown below.



1. Overview of the FOTs in the Tokyo Waterfront Area

(3) Organization of the FOTs in the Tokyo Waterfront area WG

- There were a total of 29 participants, including foreign and domestic automotive manufacturers, component manufacturers, universities, and venture companies.

FOTs in the Tokyo Waterfront Area Consortium

Mitsubishi Electric Corporation (representative)

Aisan Technology Co., Lt
Increment P Corporation
Toyota Mapmaster Incorporated
Pacific Consultants Co., Ltd.
Zenrin Co., Ltd.
Pasco Corporation
Nippon Koei Co., Ltd.
Sumitomo Electric Industries, Ltd.

Cabinet Office /
New Energy and Industrial Technology Development Organization(NEDO)

FOTs in the Tokyo Waterfront area TF

FOTs in the Tokyo Waterfront area WG

FOTs in the Tokyo Waterfront Area Consortium*

FOTs Participants

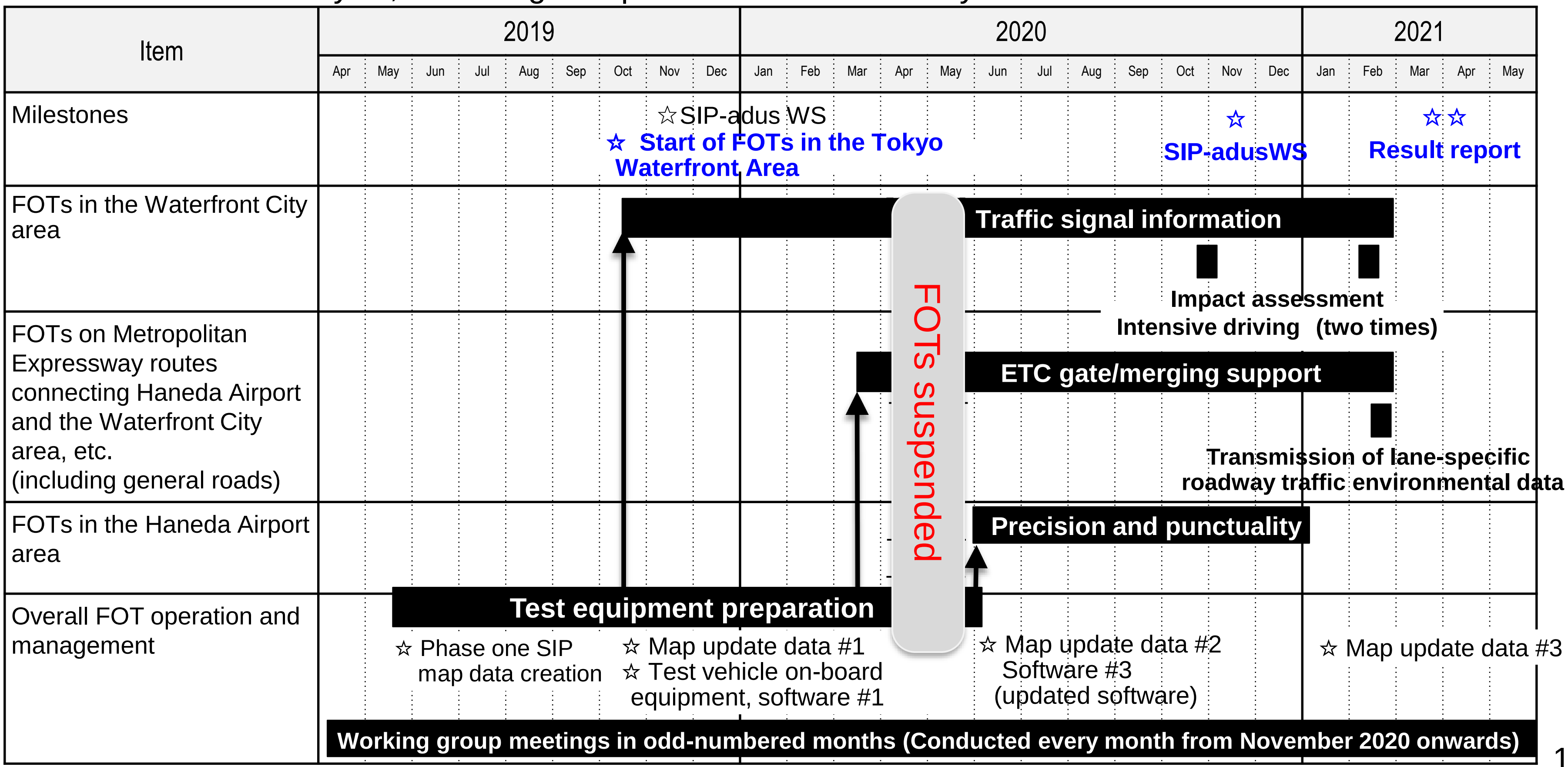
Other government stakeholders

	JPN	Overseas
Automotive manufacturers	**9**	**4**
Component manufacturers	**3**	**2**
Universities	**5**	—
Others	**5**	**1**
Total	**29 parties**	

1. Overview of the FOTs in the Tokyo Waterfront Area

(4) Testing schedule

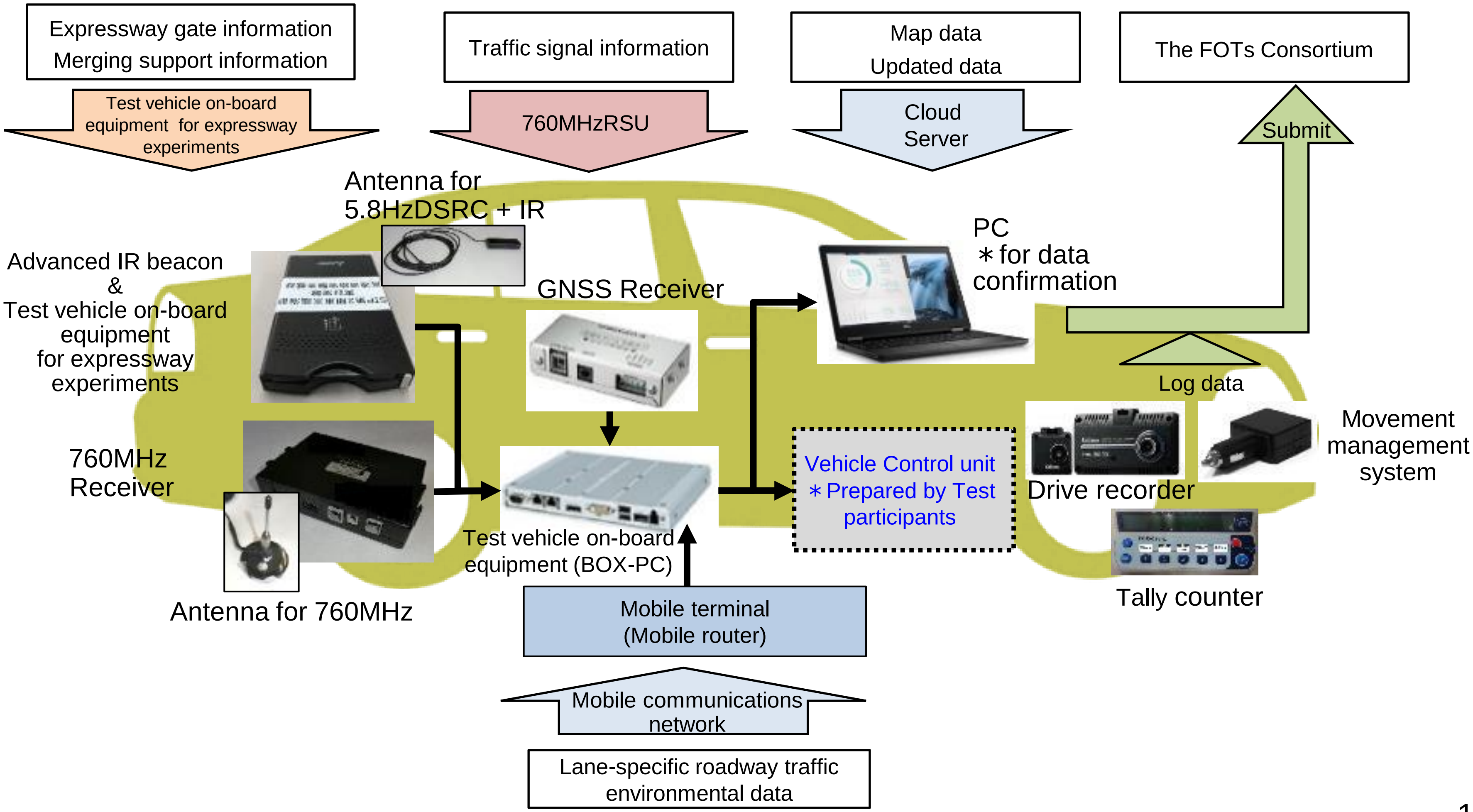
- In consideration of the development time required by test participants, a two-year testing schedule was created.
- Due to the interruption of testing (for roughly two months) as the result of the state of emergency, the testing end date was pushed back two months to enable participants to secure sufficient data for their evaluation and analysis, so testing was performed until February 2021.



1. Overview of the FOTs in the Tokyo Waterfront Area

(5) Test system structure

- Wireless communication devices and test vehicle on-board equipment were prepared and lent out to test participants so that they could receive infrastructure information.

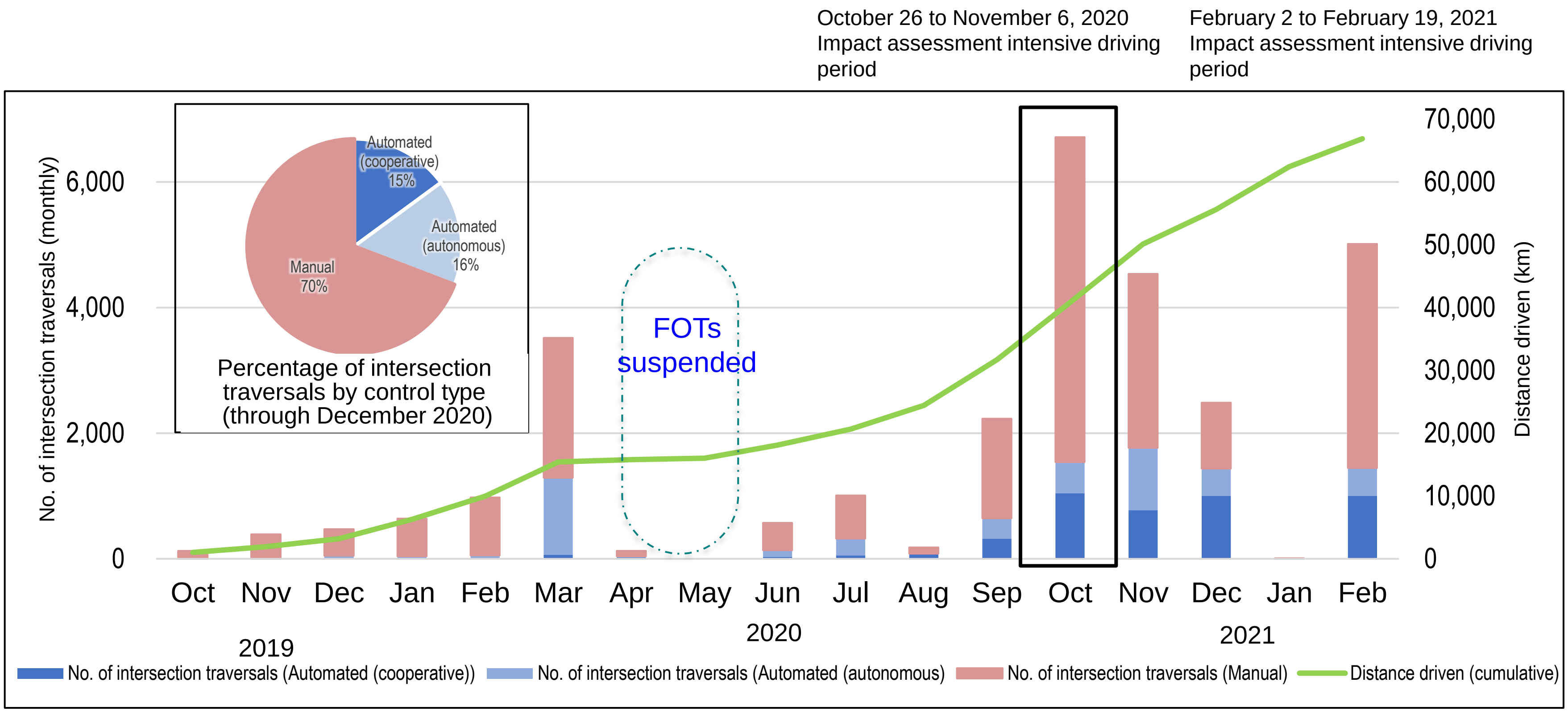


2. Test participant driving to date and results

(1) Waterfront City area

* Figures tabulated using confirmed data as of the end of February 2021

October 15, 2019 to February 28, 2021 (16 months)
: Approx. **64,591 km** (figures collected via movement management system)
The total mileage exceeded the planned 54,000km.



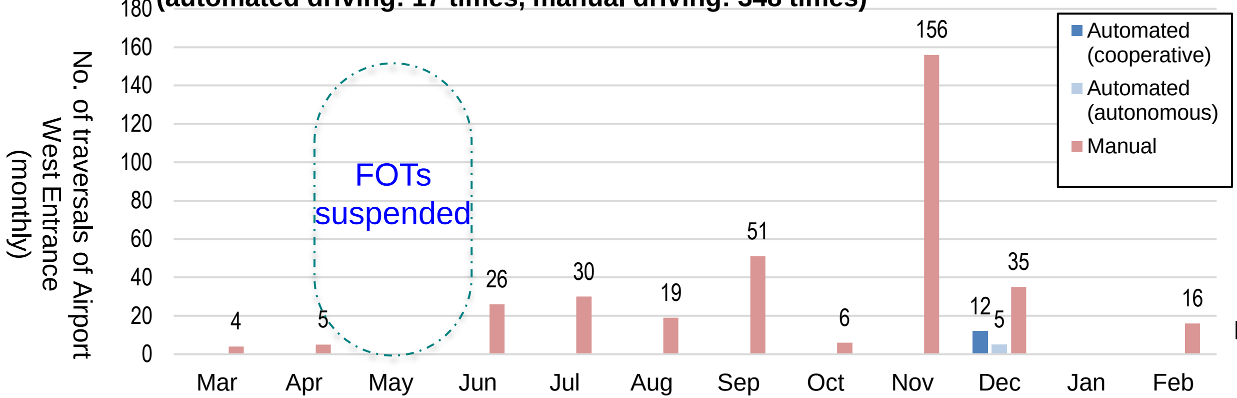
Driving results to data

Driving performed with vehicle control that used traffic signal information provided by infrastructure has been tabulated as cooperative driving

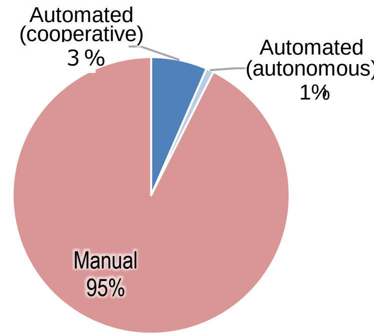
2. Test participant driving to date and results

(2) Metropolitan Expressway routes connecting Haneda Airport and the Waterfront City area, etc.

Total: 365 times
(automated driving: 17 times, manual driving: 348 times)



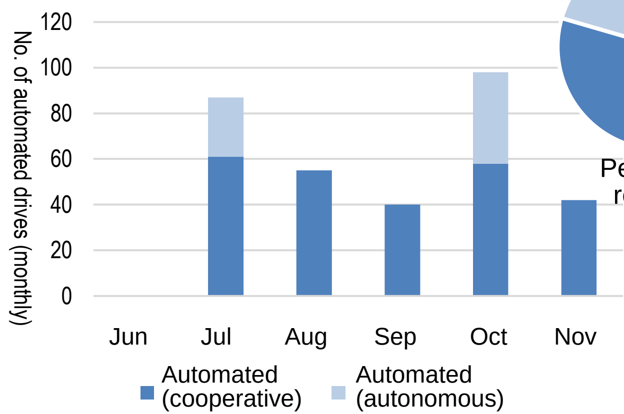
Driving performed with vehicle control that used ETC gate passing/merging support information provided by infrastructure has been tabulated as cooperative driving

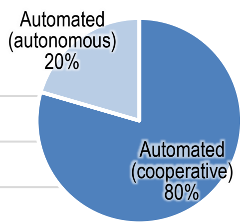


Percentage of Airport West entrance test drives by control type
ETC gate + merging
(through February 2021)

(3) Haneda Airport area

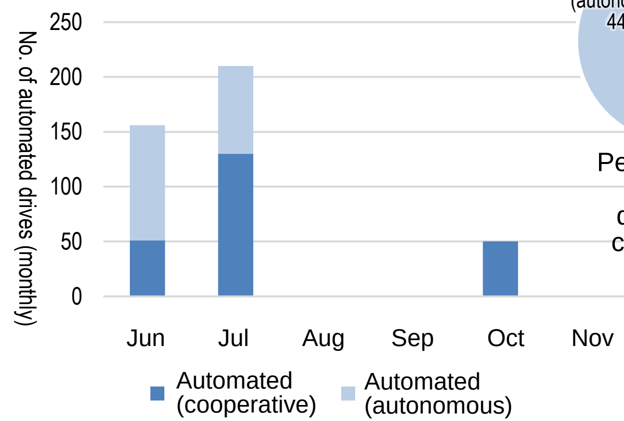
Route drives: 322
(Cooperative = using magnetic markers or PTPS)

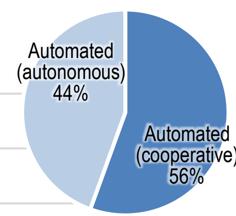




Percentage of route drives by control type

Precision docking: 416 times
(Cooperative = using magnetic marker)





Percentage of precision docking by control type

2. Test participant driving to date and results

(5) Effectiveness evaluation process

- Effectiveness evaluation is carried out in order to [analyze and summarize] whether or the goals of the FOTs in the Tokyo Waterfront area (its verification items and targets) have been achieved. The process used to carry out this effectiveness evaluation is shown at right.

- The following sections report on the results of the FOTs based on this effectiveness evaluation process.

(i) Verification items and targets

↓

(ii) Developing issue hypotheses

↓

(iii) Macro analysis
- Event incidence throughout the entire test area
- Event incidence by intersection

↓

(iv) Micro analysis
- Introduction of specific examples
- Introduction of examples of application to automated driving

↓

(v) Cooperative infrastructure system recommendations (for achieving targets)
- Recommendations based on testing data
- Recommendations based on questionnaires

3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | (iv) Micro | (v) Recommendations

[Issues, verification items, and targets]

Issues

- **Ensure reliability of signal recognition by vehicle**
- **Presence of dilemma zones* interfering with smooth traffic flow**

Verification items

(1) Infrastructure information effectiveness and conditions for traffic signal intersections
  (a) Effectiveness of traffic signal color information
  (b) Effectiveness of traffic signal remaining seconds information

(2) Assessment of impact of autonomous vehicle driving on traffic flow and factors causing this impact

➡ Evaluation results are shown on the following pages

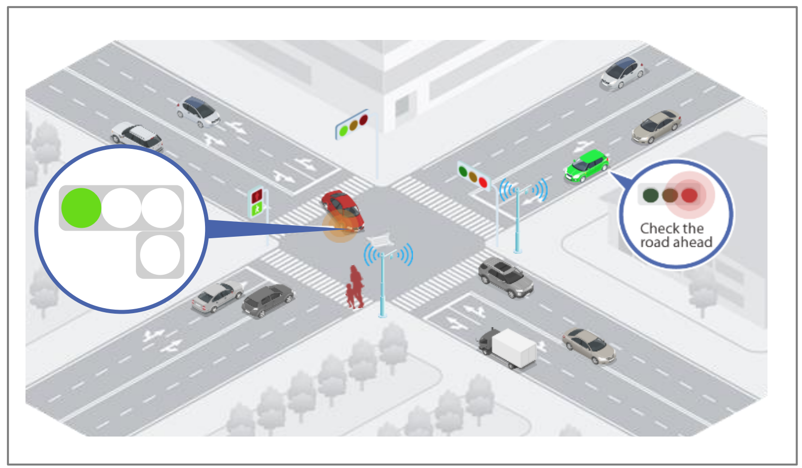
*Dilemma zone definition
Region in which, when the traffic light turns yellow, the vehicle would not be capable of stopping before the stop line when decelerating at the normal deceleration rate but the vehicle would not be able to traverse the intersection (stop line) while the traffic light was still yellow if maintaining the same pace

Hypotheses regarding effectiveness of cooperative infrastructure technologies

- Recognition improved by use of dual information systems
- Avoidance of dilemma zones* through use of predictive traffic signal information (number of remaining seconds)

Target

- **Verify effectiveness of distributing traffic signal information**
- **Confirm specifications aimed at standardization and consensus by test participants**
- **Identify environmental conditions required for traffic signal information distribution**
- Clarify issues to be addressed in order to cultivate a sense of acceptability in society



(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions
(a) Effectiveness of traffic signal color information

Factors that interfere with traffic signal color recognition*1

Backlighting

The sun, the headlights of oncoming vehicles, reflections from buildings, or other light sources shine light from the approach direction, making it difficult to determine the traffic signal color.

Direct lighting

The sun or light sources from behind approach direction make it difficult to determine the traffic signal color.

Concealment/ obstruction*2

Large nearby vehicles, vegetation, elevated road sections, or other structural elements obstruct the view of the traffic signal.
This includes cases in which the above phenomenon is the result of curves, grades, or other road structure elements.

Blending into background

While the color of a traffic signal can itself be determined, the outline, etc. of the traffic signal blends in with the building behind it or other background elements, reducing the reliability of traffic signal detection.

Nighttime

At night, there are light sources such as street lamps and building lights that make traffic signal color recognition difficult.

Raindrops

Rain has fallen on the front camera, making traffic signal color recognition difficult.

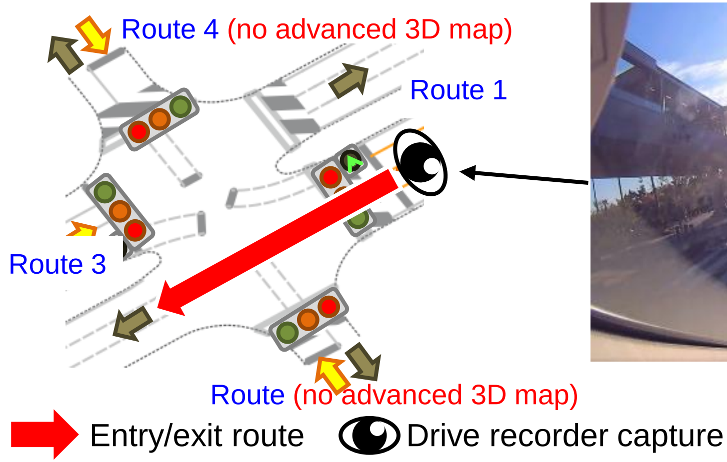
*1 Identified based on test participant driving data and feedback from test participant driving

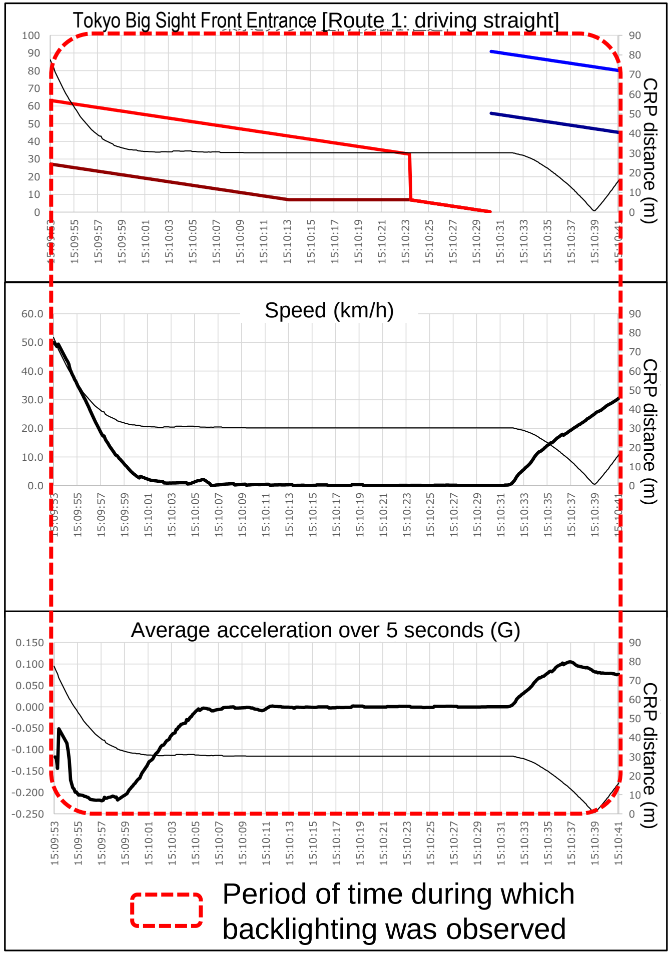
*2 This refers to situations in which there are obstructions, such as **preceding vehicles** or **nearby structures**, between a driving vehicle and a traffic signal, preventing the vehicle's on-board camera from being able to identify the traffic signal color
(This includes curves, grades, and other road structures)

3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | **(iv) Micro** | (v) Recommendations

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions
(a) Effectiveness of traffic signal color information
1) In the event of backlighting (part 1)





Experiment date/time	Automated driving	Intersection no.	Name of intersection	Conditions	Entry route	Exit route	Traffic signal color	Camera recognition accuracy	Duration of decrease in camera recognition accuracy	Remaining seconds information used?
2020/11/5 15:10	Automated (Autonomous)	21	Tokyo Big Sight Front Entrance	Backlighting	Route 1	Route 3	Red → Green	Recognition accuracy fell slightly	Recognition accuracy fell slightly for a very short amount of time	No

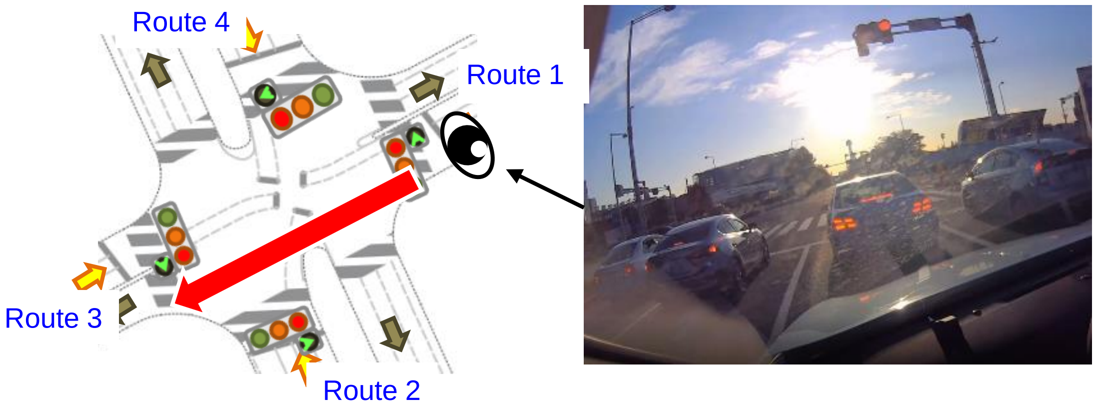
[Results of signal color detection by test participant systems]

- The traffic signal color recognition accuracy of the camera dropped slightly for just a moment
- We confirmed several frames during which a distant red traffic signal was mistakenly identified as being yellow

3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | **(iv) Micro** | (v) Recommendations

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions
(a) Effectiveness of traffic signal color information
1) In the event of backlighting (part 2)

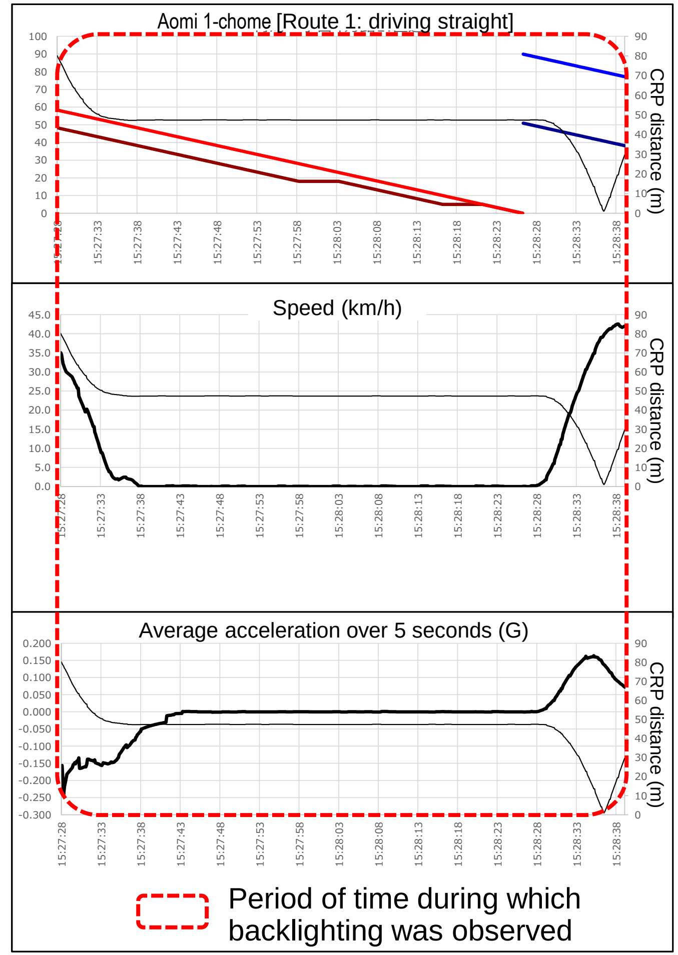


Entry/exit route Drive recorder capture

Experiment date/time	Automated driving	Intersec-tion no.	Name of intersec-tion	Conditions	Entry route	Exit route	Traffic signal color	Camera recognition accuracy	Duration of decrease in camera recognition accuracy	Remaining seconds information used?
2020/11/5 15:28	Manual	25	Aomi 1-chome	Backlighting	Route 1	Route 3	Red → Green	Recognition accuracy fell slightly	Recognition accuracy fell slightly for a very short amount of time	No

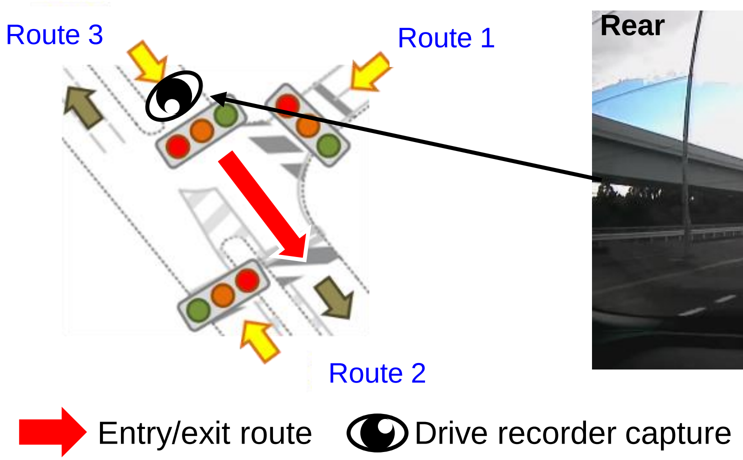
[Results of signal color detection by test participant systems]

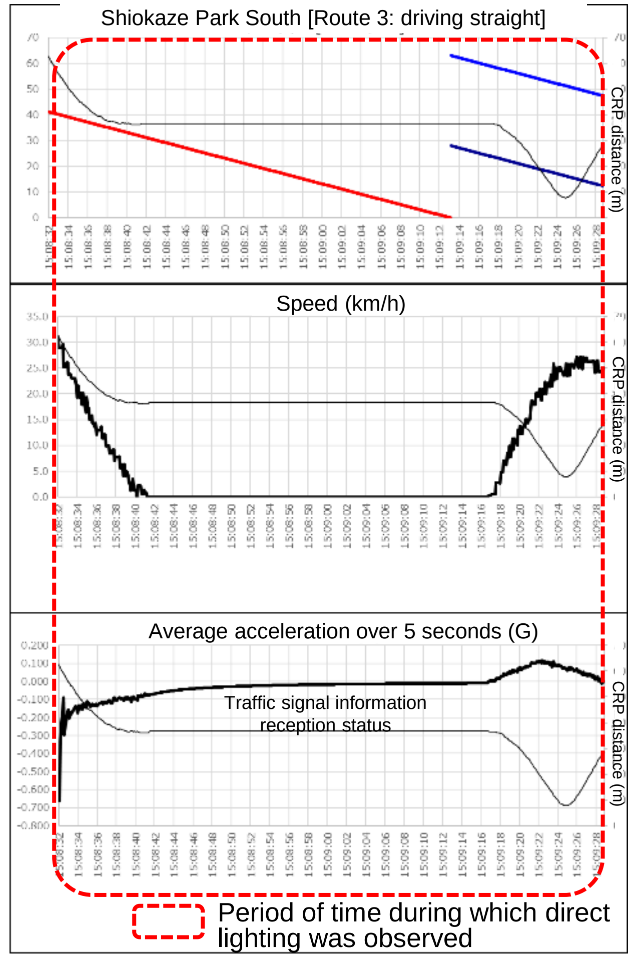
- The traffic signal color recognition accuracy of the camera dropped slightly for just a moment
- We confirmed cases in which some red traffic signals were mistakenly identified as being yellow



3. Results of the FOTs in the Waterfront City area

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions
(a) Effectiveness of traffic signal color information
2) In the event of direct lighting (part 1)





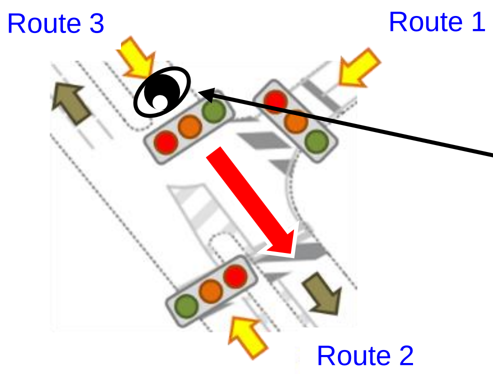
Experiment date/time	Automated driving	Intersec-tion No.	Name of intersec-tion	Conditions	Entry route	Exit route	Traffic signal color	Camera recognition accuracy	Duration of decrease in camera recognition accuracy	Remaining seconds information used?
2020/11/20 15:09	-	2	Shiokaze Park South	Direct lighting	Route 3	Route 2	Red → Green	Recognized without problem	No impact	No

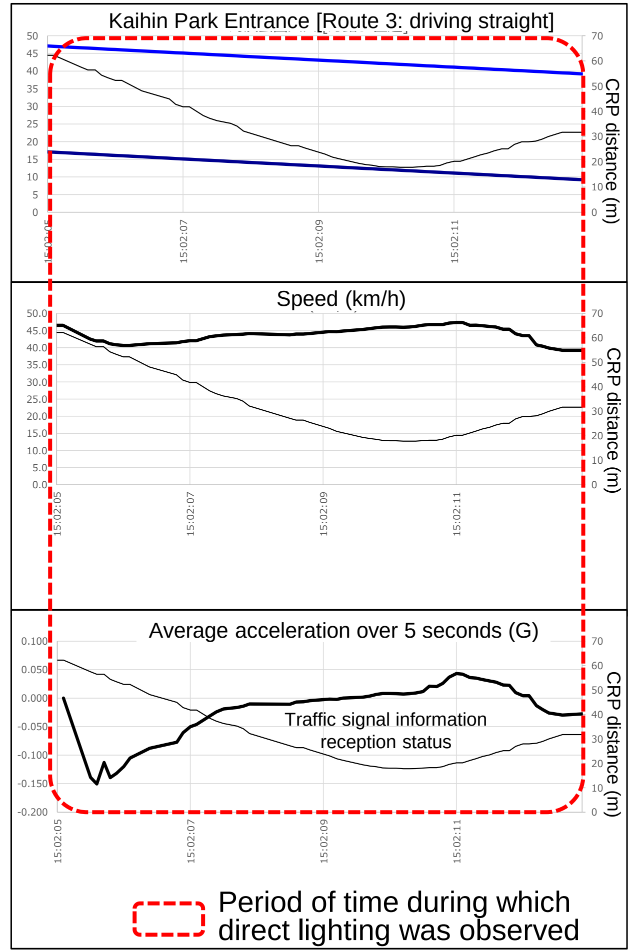
[Results of signal color detection by test participant systems]

- There was no impact on the camera's traffic signal color recognition accuracy, so there were no problems with intersection traversal decision-making.

3. Results of the FOTs in the Waterfront City area

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions
(a) Effectiveness of traffic signal color information
2) In the event of direct lighting (part 2)





Experiment date/time	Automated driving	Intersection No.	Name of intersection	Conditions	Entry route	Exit route	Traffic signal color	Camera recognition accuracy	Duration of decrease in camera recognition accuracy	Remaining seconds information used?
2020/11/20 15:02	Automated (Autonomous)	12	Kaihin Park Entrance	Direct lighting	Route 3	Route 1	Green	Recognition accuracy fell slightly	Recognition accuracy fell slightly for a very short amount of time	No

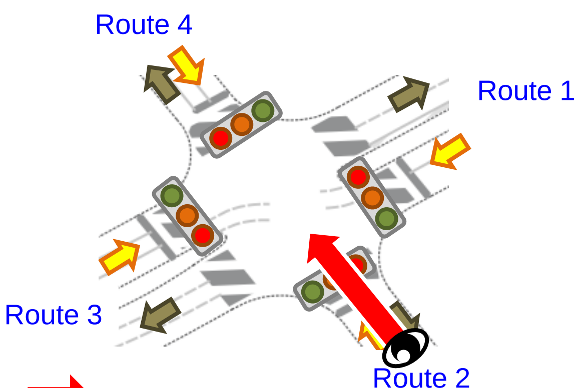
[Results of signal color detection by test participant systems]

- The traffic signal color recognition accuracy of the camera dropped slightly for just a moment, but this did not cause problems with intersection traversal decision-making.
- We confirmed several frames during which a distant blue traffic signal was mistakenly identified as being yellow

3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | **(iv) Micro** | (v) Recommendations

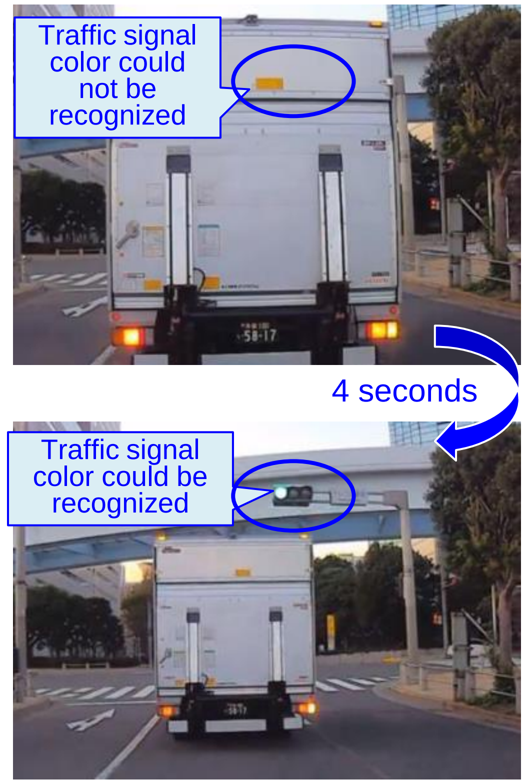
(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions
(a) Effectiveness of traffic signal color information
3) In the event of concealment/obstruction (part 1)

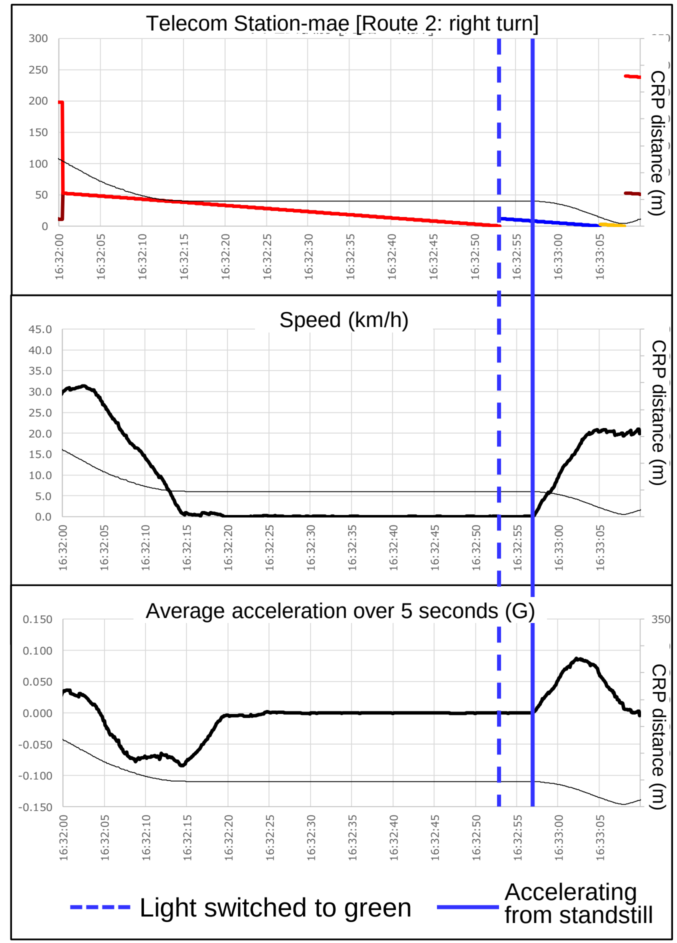


Entry/exit route
Drive recorder capture

Experiment date/time	Automated driving	Intersection no.	Name of intersection	Conditions
2020/10/26 16:33	-	B	Telecom Station-mae	Obstruction

Entry route	Exit route	Traffic signal color	Duration of period when traffic signal color could not be recognized
Route 2	Route 1	Red → Green	4 seconds





[Traffic signal color recognition results based on drive recorder video]

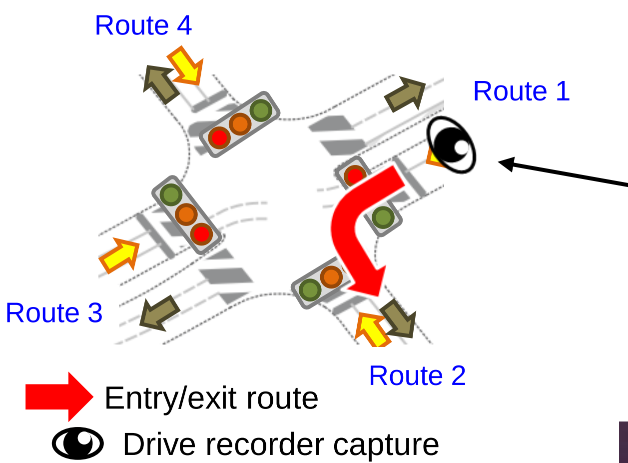
- A large truck concealed the traffic signal, so when the traffic signal color changed to green, the vehicle did not recognize the change for four seconds.

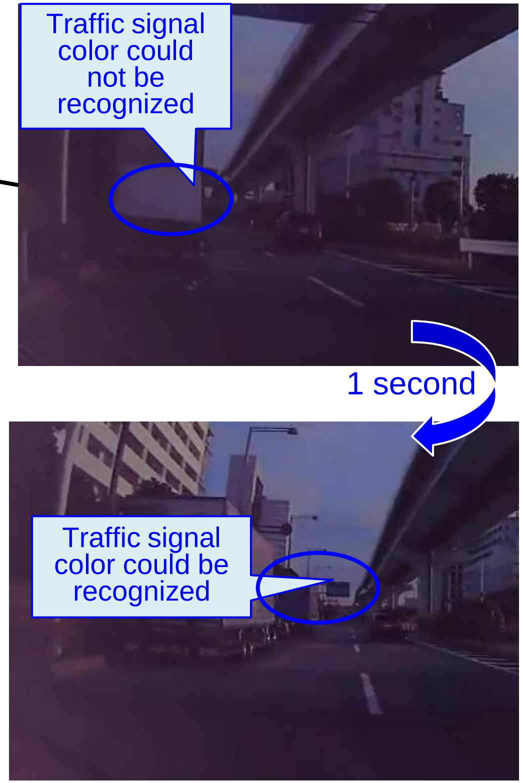
3. Results of the FOTs in the Waterfront City area

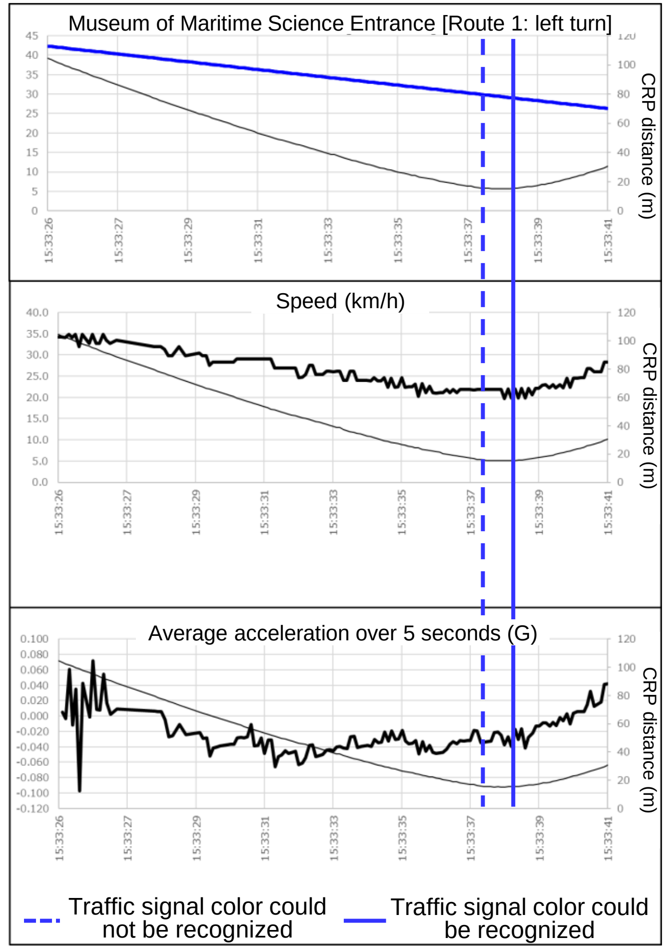
(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions

(a) Effectiveness of traffic signal color information

3) In the event of concealment/obstruction (part 2)







Experiment date/time	Automated driving	Intersection no.	Name of intersection	Conditions
2020/01/22 15:33	-	3	Museum of Maritime Science Entrance	Obstruction

Entry route	Exit route	Traffic signal color	Duration of period when traffic signal color could not be recognized
Route 1	Route 2	Green	1 second

[Traffic signal color recognition results based on drive recorder video]

- The traffic signal color could not be recognized for one second due to concealment by a large truck.

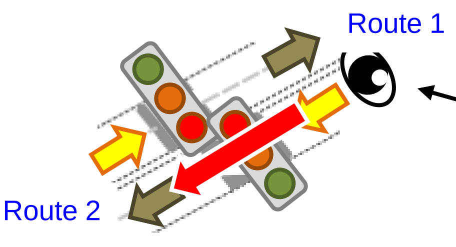
3. Results of the FOTs in the Waterfront City area

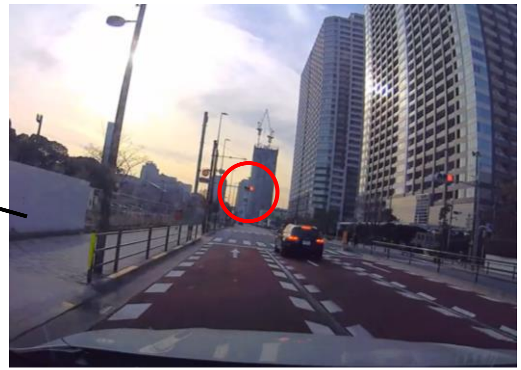
(i) Target | (ii) Hypothesis | (iii) Macro | **(iv) Micro** | (v) Recommendations

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions

(a) Effectiveness of traffic signal color information

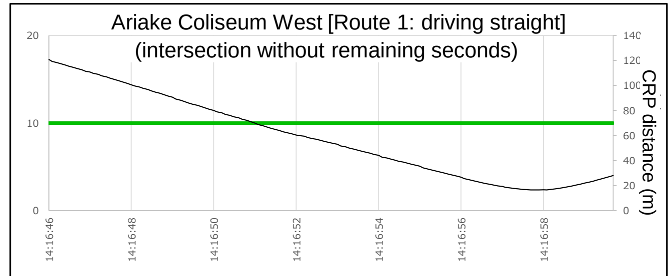
4) In the event of blending into the background

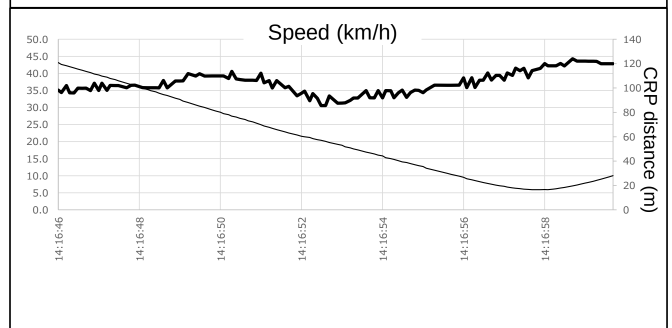


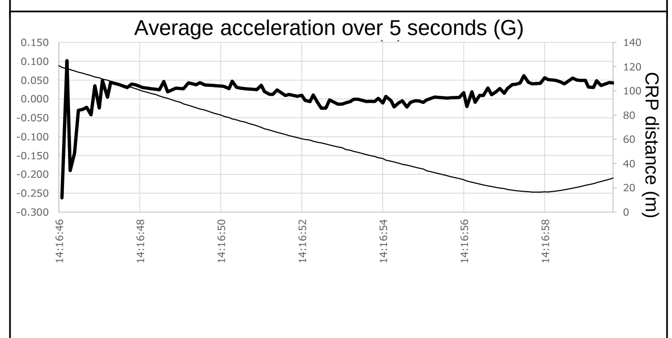


Entry/exit route

Drive recorder capture







Experiment date/time	Automated driving	Intersection no.	Name of intersection	Conditions	Entry route	Exit route	Traffic signal color	Duration of period when traffic signal color could not be recognized
2020/12/18 14:16	Auto/ cooperative	20	Ariake Coliseum West	Blending into background	Route 1	Route 2	Red	No

[Traffic signal color recognition results based on drive recorder video]

- At intersections in which buildings were visible behind traffic signals, we confirmed that in some cases, the traffic signals blended into the background and their borders were unclear.
- We confirmed that blending into the background occurred when distant traffic signals were visible

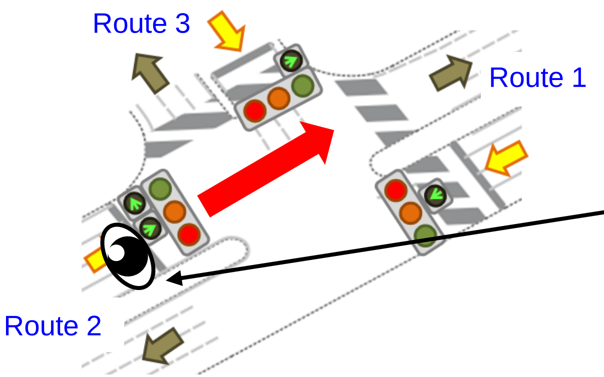
3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | **(iv) Micro** | (v) Recommendations

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions

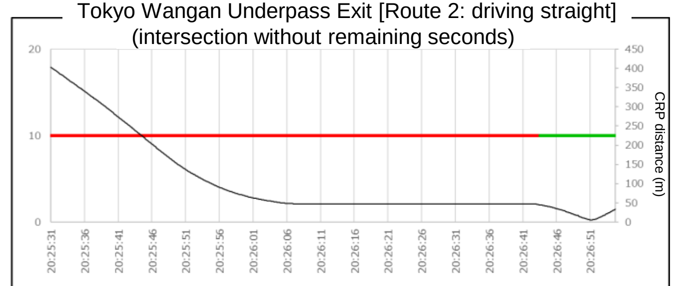
(a) Effectiveness of traffic signal color information

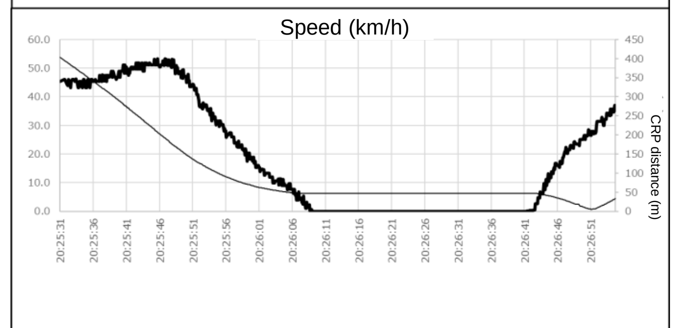
5) In the event of nighttime driving

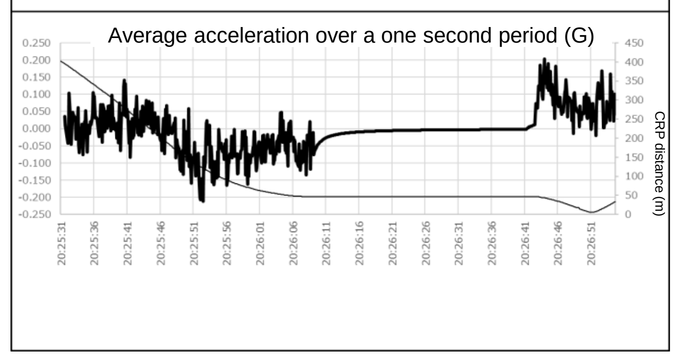


Entry/exit route

Drive recorder capture







Experiment date/time	Automated driving	Intersection no.	Name of intersection	Conditions	Entry route	Exit route	Traffic signal color	Duration of period when traffic signal color could not be recognized
2020/09/17 20:26	Auto/autonomous	15	Tokyo Wangan Underpass Exit	Nighttime	Route 2	Route 1	Red → Green	No

[Traffic signal color recognition results based on drive recorder video]

- We confirmed that the arrow light directions on the traffic signal in front of the intersection could be determined, but those on the traffic signal beyond the intersection was blurry and therefore difficult to determine.
- Driving at night appears likely to have an impact on arrow light recognition on distant traffic signals (failure to recognize or improper recognition of arrow lights)

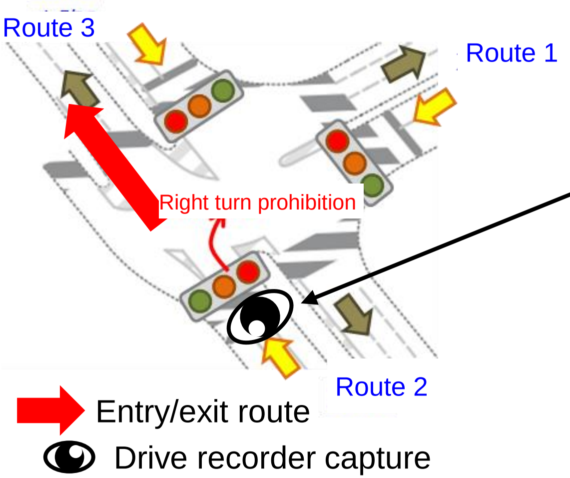
3. Results of the FOTs in the Waterfront City area

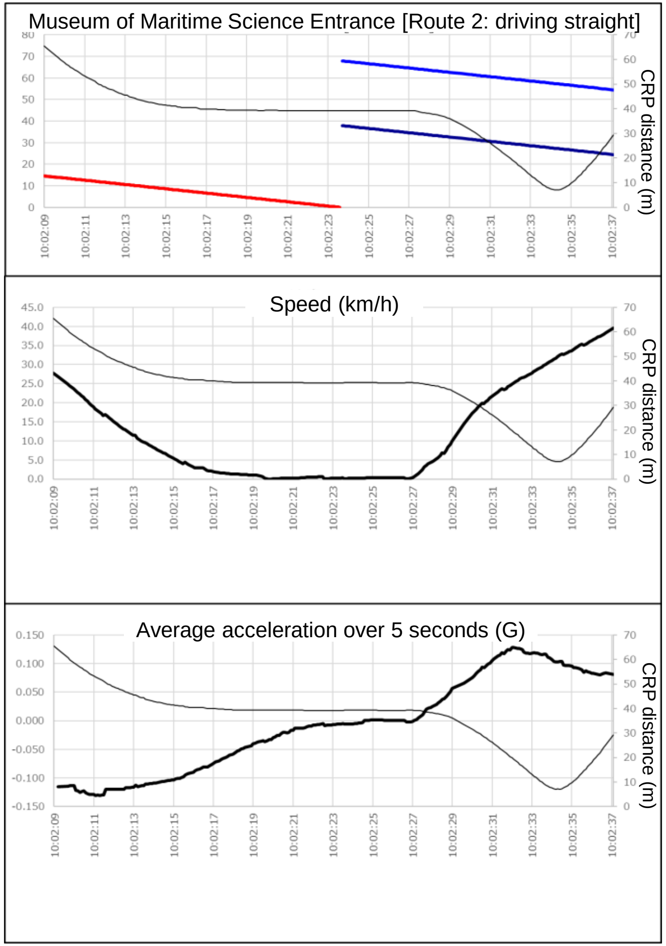
(i) Target | (ii) Hypothesis | (iii) Macro | **(iv) Micro** | (v) Recommendations

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions

(a) Effectiveness of traffic signal color information

6) In the event of raindrops





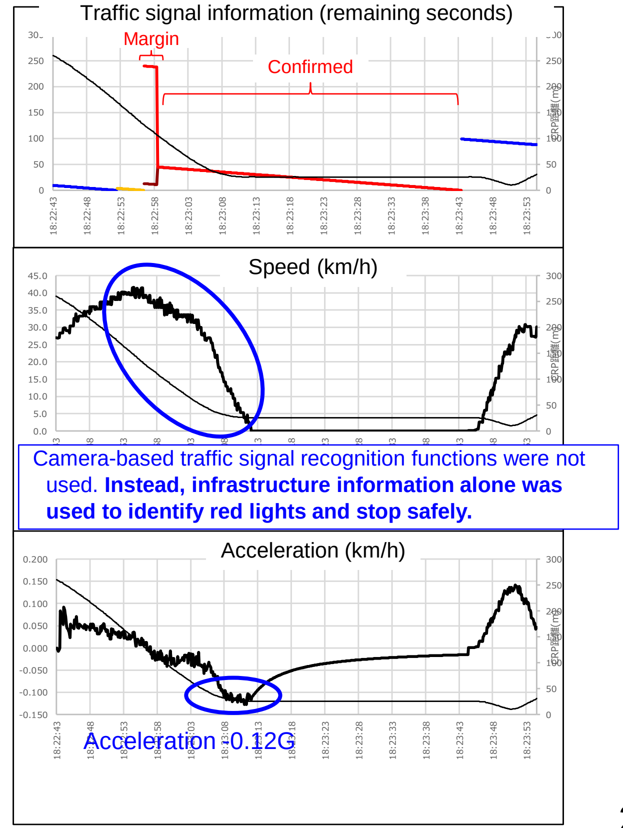
Experiment date/time	Automated driving	Intersection no.	Name of intersection	Conditions	Entry route	Exit route	Traffic signal color	Duration of period when traffic signal color could not be recognized
2020/01/28 10:02	Auto/ autonomous	3	Museum of Maritime Science Entrance	Raindrops	Route 2	Route 3	Red → Green	No

[Traffic signal color recognition results based on drive recorder video]

- When driving in heavy rain, if raindrops overlap light from traffic signals, this may reduce traffic signal color recognition accuracy.

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions
(a) Effectiveness of traffic signal color information

- Automated driving situations using infrastructure information (traffic signal information) were confirmed through test driving by test participants
  (Vehicle sensors were not used for traffic signal recognition; instead sensors near the vehicle were used)
  ⇒When lights were red, infrastructure information was used to stop safely, **confirming the effectiveness of infrastructure information**



Experiment date/time	Intersection no.	Name of intersection	Conditions	Solar elevation	Solar orientation	Entry route	Exit route	Traffic signal information reception	Traffic signal color information	Impact on vehicle control
2020/3/25 18:23:51	18	Ariake 3-chome	Automated driving	Approx. 7°	Approx. 278°	Route 2	Route 3	Yes (received information was used)	18:22:56-18:23:43 Red	The vehicle slowed and stopped

3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | (iv) Micro | **(v) Recommendations**

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions

(a) Effectiveness of traffic signal color information(findings based on test results)

[Situations in which traffic signal color information is effective (findings based on test results)]

- Providing traffic signal color information to autonomous vehicles is effective in the following situations:
  - Backlighting: Times of day when sunlight from behind traffic signals (including light reflected by buildings) competes with light from traffic signals → occurs during certain times of day
    Traffic conditions in which the headlights of oncoming vehicles compete with light from traffic signals
  - Direct lighting: Times of day in which sunlight from behind vehicles competes with traffic signals → occurs during certain times of day
  - Concealment/obstruction: Traffic conditions in which traffic signal colors are concealed by nearby large vehicles, etc. → occurs during certain traffic conditions)
    Road structures in which traffic signals are located in blind spots, such as immediately after curves and on crest vertical curves → occurs with certain road structures
  - Blending into background: Times of day and road structures in which traffic signals themselves blend into background buildings, etc.
  - Nighttime: Times of day in which multiple light sources reduce traffic signal color recognition accuracy
  - Raindrops: Weather conditions in which raindrops get on cameras and reduce traffic signal color recognition accuracy

3. Results of the FOTs in the Waterfront City area

[Issues, verification items, and targets]

Issues

- **Ensure reliability of signal recognition by vehicle**
- **Presence of dilemma zones* interfering with smooth traffic flow**

Hypotheses regarding effectiveness of cooperative infrastructure technologies

- Recognition improved by use of dual information systems
- Avoidance of dilemma zones* through use of predictive traffic signal information (number of remaining seconds)

Verification items

(1) Infrastructure information effectiveness and conditions for traffic signal intersections
  (a) Effectiveness of traffic signal color information
  (b) Effectiveness of traffic signal remaining seconds information
(2) Assessment of impact of autonomous vehicle driving on traffic flow and factors causing this impact

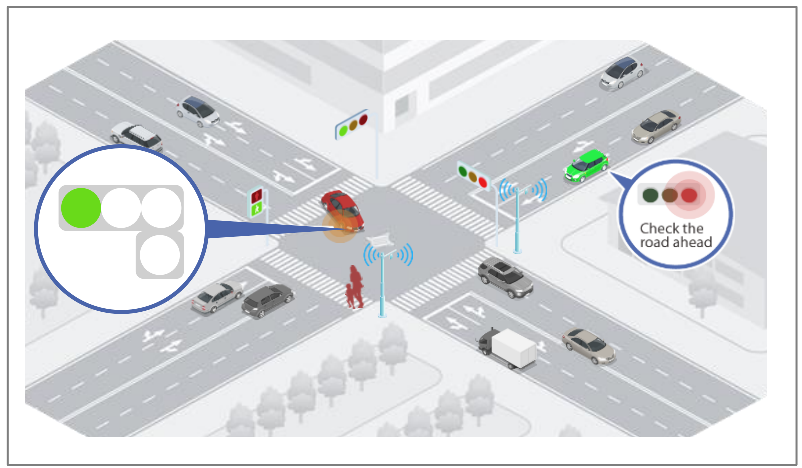
Target

- **Verify effectiveness of distributing traffic signal information**
- **Confirm specifications aimed at standardization and consensus by test participants**
- **Identify environmental conditions required for traffic signal information distribution**
- Clarify issues to be addressed in order to cultivate a sense of acceptability in society

➡ Evaluation results are shown on the following pages

*Dilemma zone definition

Region in which, when the traffic light turns yellow, the vehicle would not be capable of stopping before the stop line when decelerating at the normal deceleration rate but the vehicle would not be able to traverse the intersection (stop line) while the traffic light was still yellow if maintaining the same pace



3. Results of the FOTs in the Waterfront City area

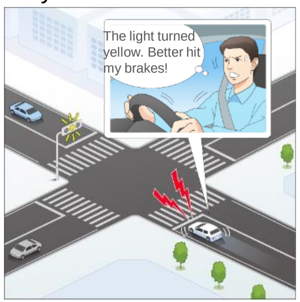
(i) Target | (ii) Hypothesis | **(iii) Macro** | (iv) Micro | (v) Recommendations

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions
(b) Effectiveness of traffic signal remaining seconds information:

Factors causing differences in intersection traversal decision-making

Stopping in traversal areas

Situations in which the vehicle sudden decelerates and stops when it could have traversed safely

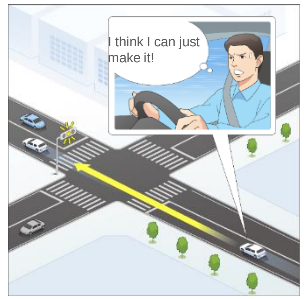


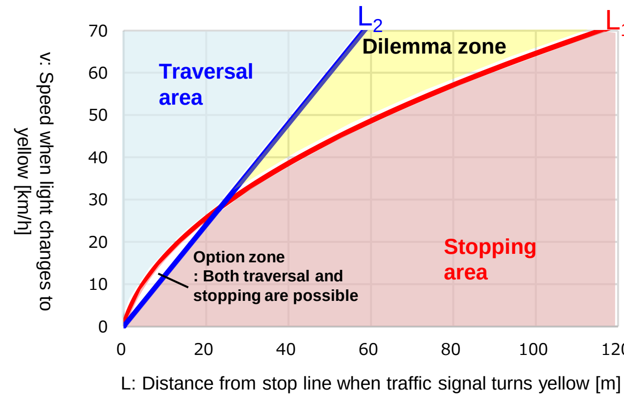
Encountering dilemma zones

Situations in which the vehicle cannot safely traverse the intersection or stop, and has difficulty deciding what to do

Traversal in stopping areas

Situations in which the vehicle should stop but instead traverses the intersection





Of the total of 29,728 intersection traversals, participants confirmed 127 cases of stopping in traversal areas, 12 encounters with dilemma zones, and 9 cases of traversal in stopping areas

Stopping in traversal areas	Encountering dilemma zones	Traversal in stopping areas
127 (0.43% of total)	12 (0.04% of total)	9 (0.03% of total)

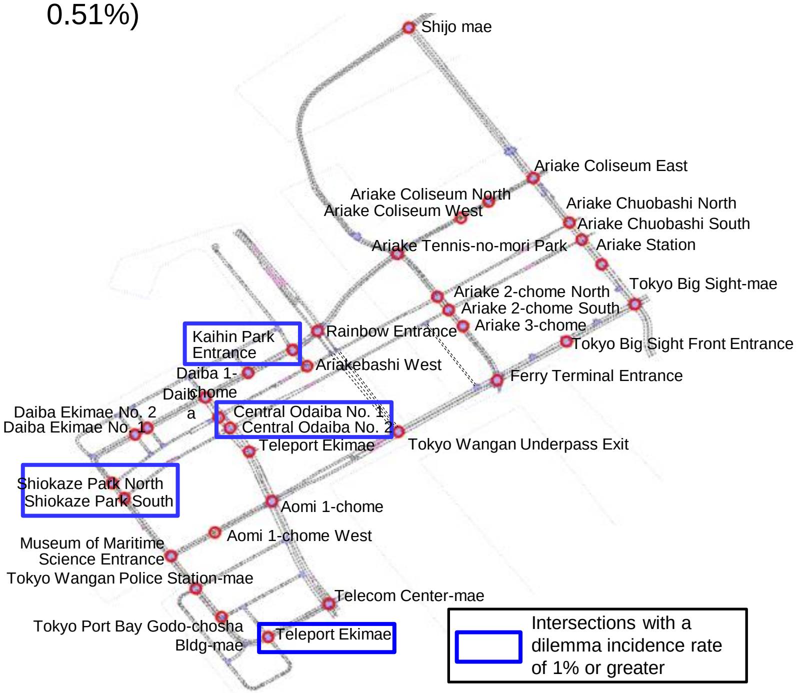
Occurrence of differences in judgment when passing through an intersection in the entire test area

3. Results of the FOTs in the Waterfront City area

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions

(b) Effectiveness of traffic signal remaining seconds information:

Percentage resulting in differences in intersection traversal decision-making: 0.00 to 2.70% (average: 0.51%)



Name of intersection	Manual	Auto-mated	Traversal decision diff. *1	Traversal decision diff. ratio (traversals)	Traversal decision diff. ratio (%)	Speed restrictions*2
Shiokaze Park North	555	214	9	9/769	1.17%	Route1:60/Route2,3:40
Shiokaze Park South	646	217	15	15/863	1.74%	Route1:60/Route2:50/Route3:40
Museum of Maritime Science Entrance	737	208	2	2/945	0.21%	Route1:60/Route2,3:50
Tokyo Port Bay Godo-chosha Bldg-mae	377	166	0	0/543	0.00%	Route1,2:50
Daiba Ekimae No. 1 (West)	396	208	2	2/604	0.33%	Route1,3:50
Daiba Ekimae No. 2 (East)	441	204	5	5/645	0.78%	Route1,3:50
Aomi 1-chome West	530	49	5	5/579	0.86%	Route1,2:60
Daiba	576	306	4	4/882	0.45%	Route1,3:50/Route2:60
Central Odaiba No. 1 (North)	310	270	9	9/580	1.55%	Route1,2,3,4:60
Central Odaiba No. 2 (South)	509	299	17	17/808	2.10%	Route1,2,3,4:60
Teleport Ekimae	489	276	1	1/765	0.13%	Route2,3:60
Telecom Center-mae	447	164	0	0/611	0.00%	Route3:50/Route4:60
Daiba 1-chome	432	122	1	1/554	0.18%	Route1,2:50
Kaihin Park Entrance	477	121	8	8/598	1.34%	Route1,3:50/Route2:40
Ariakebashi West	50	5	0	0/55	0.00%	Route1,2:60/Route3:40
Rainbow Entrance	484	114	1	1/598	0.17%	Route1,3:50
Tokyo Wangan Underpass Exit	591	45	0	0/636	0.00%	Route1,2:60/Route3:50
Ariake Tennis-no-mori Park	508	111	2	2/619	0.32%	Route1,2,3:50
Ariake 2-chome North	216	2	0	0/218	0.00%	Route1,3:60/Route2,4:50
Ariake 2-chome South	407	4	1	1/411	0.24%	Route1,3:60/Route2,4:50
Ariake 3-chome	400	1	0	0/401	0.00%	Route2,3:50
Ferry Terminal Entrance	806	120	4	4/926	0.43%	Route1,2:60/Route3:50
Ariake Coliseum West	301	110	0	0/411	0.00%	Route1,2:50
Tokyo Big Sight Front Entrance	491	118	1	1/609	0.16%	Route1,3:60
Ariake Coliseum North	297	115	0	0/412	0.00%	Route1,2:50
Ariake Chuobashi North	357	108	2	2/465	0.43%	Route2,3,4:60
Ariake Chuobashi South	359	107	2	2/466	0.43%	Route2,3,4:60
Aomi 1-chome	1007	317	1	1/1324	0.08%	Route1,2,3,4:60
Tokyo Big Sight-mae	339	122	0	0/461	0.00%	Route3,4:60
Tokyo Wangan Police Station-mae	800	262	0	0/1062	0.00%	Route1,2,4:50
Telecom Station-mae	514	163	6	6/677	0.89%	Route1,3:50
Ariake Coliseum East	323	111	0	0/434	0.00%	Route2:60/Route3:50
Ariake Station-mae	377	144	5	5/521	0.96%	Route1,3:60

*1 Number of dilemmas (traversals/stops), traversals in stopping areas, and stops in traversal areas.
*2 Speed restrictions are abbreviated in the following manner: “R1:60” = “Route 1 speed limit = 60 km/h”.

3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | **(iv) Micro** | (v) Recommendations

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions

(b) Effectiveness of traffic signal remaining seconds information:

For routes **with 4 second yellow lights**, the distributions of speeds and distances from stop lines were checked when lights turned yellow

- When driving was performed without traffic signal remaining seconds information, traversal and stopping were broadly mixed within the traversal area
- When driving was performed using traffic signal remaining seconds information (cooperative infrastructure driving), there was less mixing of traversal and stopping.

The distribution diagrams and parameters for both, for driving straight only, are as shown below

• Allowable deceleration: 0.2[G], reaction time: 1.0[s], yellow signal duration: 4.0[s]

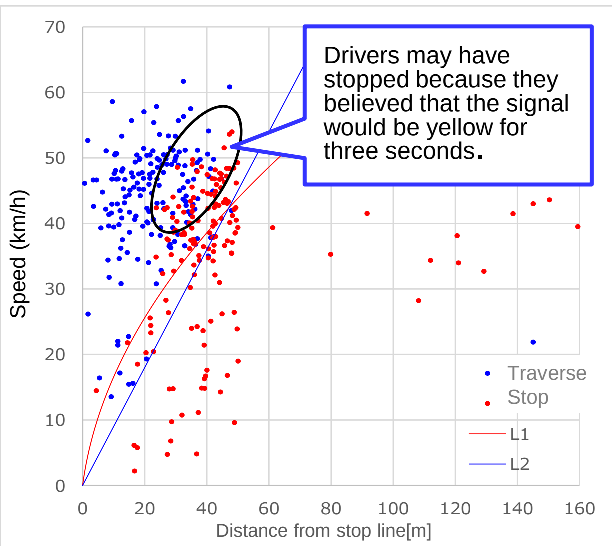


Fig.: Distribution of intersection traversal decisions during manual driving

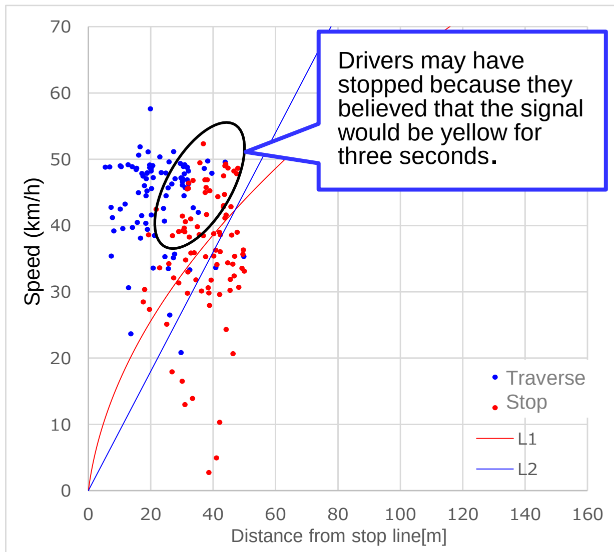


Fig.: Distribution of intersection traversal decisions during automated driving (cooperative [no remaining seconds]/autonomous)

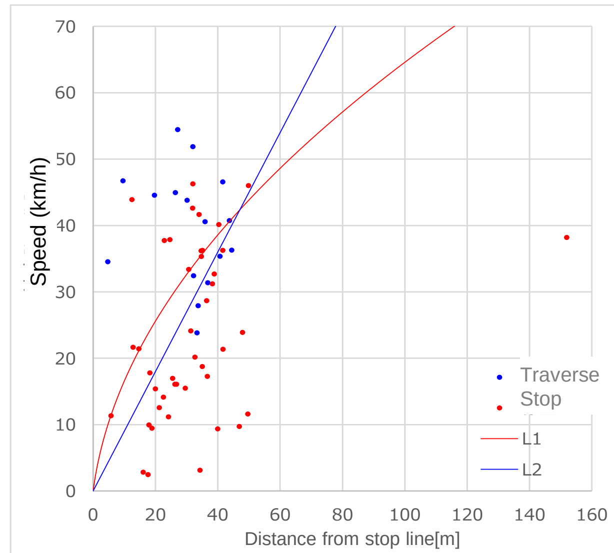
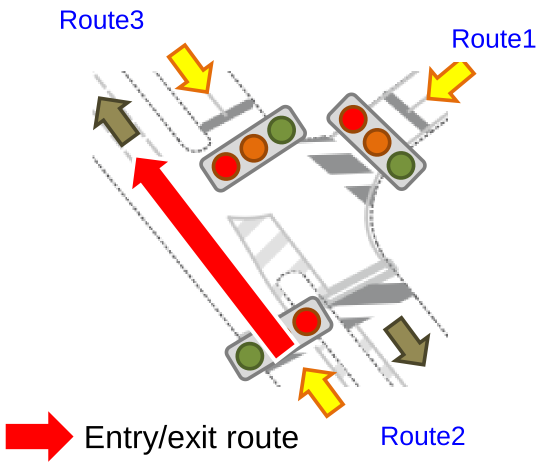


Fig.: Distribution of intersection traversal decisions during automated driving (cooperative [remaining seconds])

3. Results of the FOTs in the Waterfront City area

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions
(b) Effectiveness of traffic signal remaining seconds information:

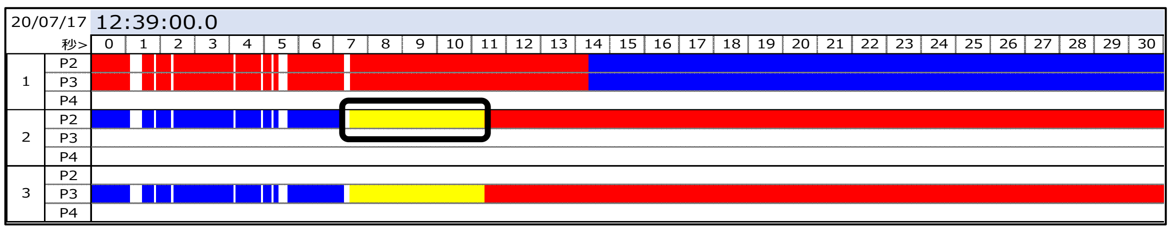
2) Routes with 4 remaining seconds of yellow light (stopping in traversal areas)



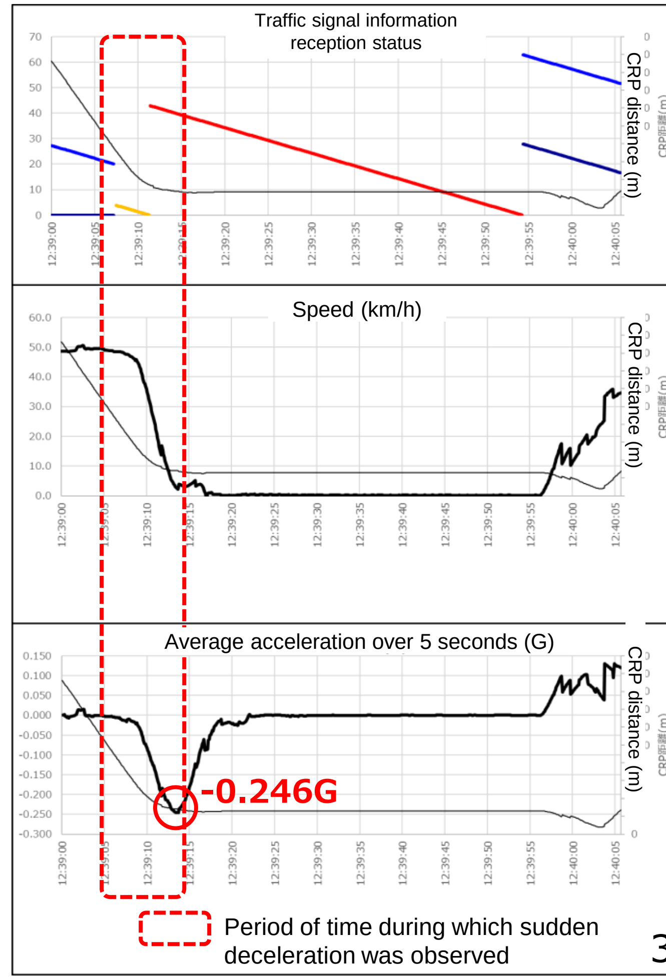
Name of intersection	Intersection no.	Entry route	Exit route
Shiokaze Park South	2	Route 2	Route 3

Driving speed		Type of remaining seconds
Entry route	Exit route	
50 km/h	40 km/h	Margin

Yellow remaining seconds	Impact on vehicle control	Deceleration following changing to yellow
4 seconds	Sudden deceleration and stopping	-0.246G



[Results of analysis of dilemma candidates based on test vehicle on-board equipment log data]



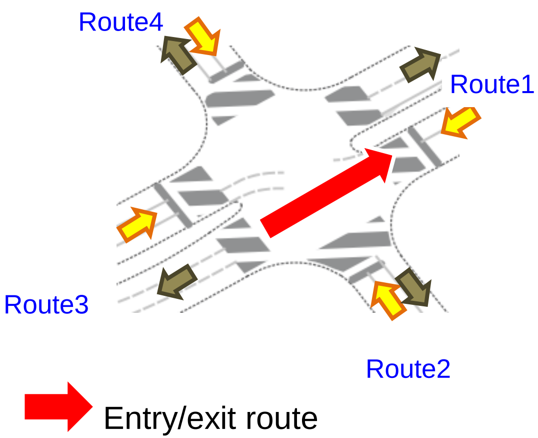
- When a test vehicle attempted to drive straight from route 2 to route 3 of the Shiokaze Park South intersection, it was confirmed to have stopped within the traversal area.
- The vehicle was confirmed to decelerate suddenly, and had a maximum deceleration of -0.246G.

3. Results of the FOTs in the Waterfront City area

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions

(b) Effectiveness of traffic signal remaining seconds information:

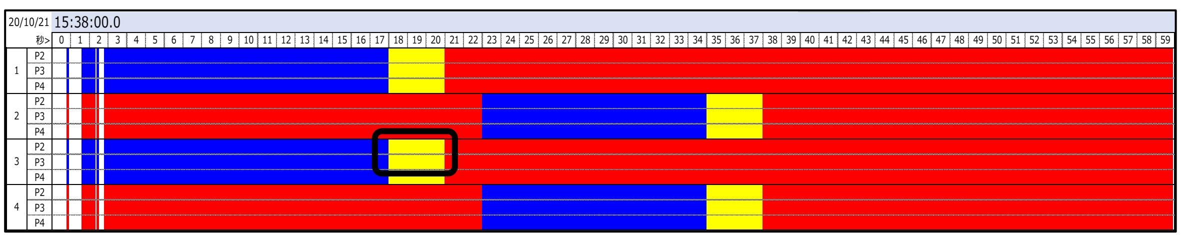
2) Routes with 4 remaining seconds of yellow light (**driving using traffic signal remaining seconds information and performing preliminary deceleration**)



Name of intersection	Intersection no.	Entry route	Exit route
Telecom Station-mae	B	Route 3	Route 1

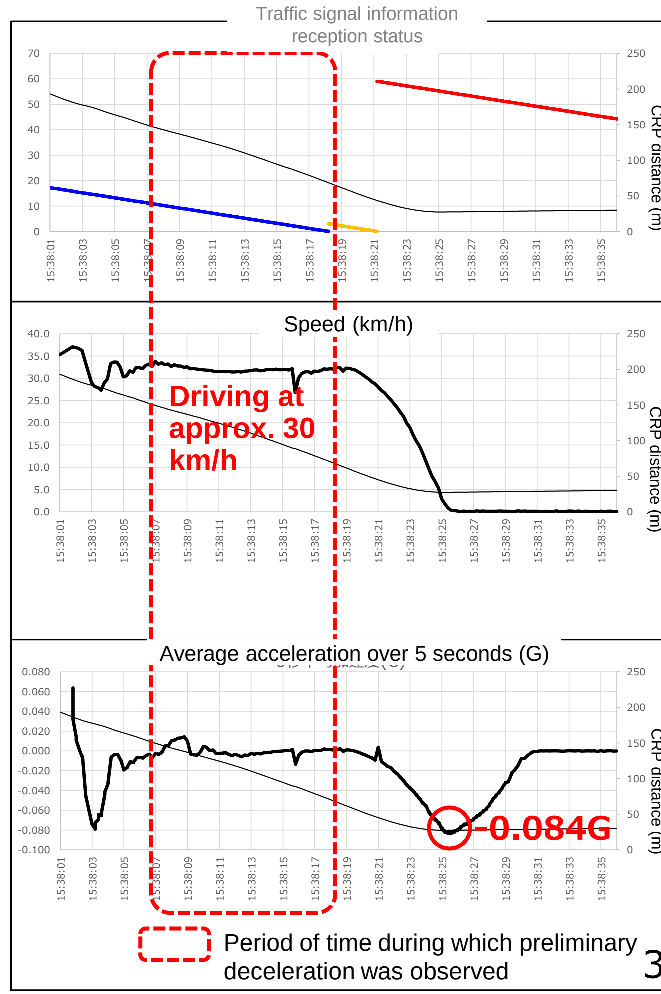
Driving speed		Type of remaining seconds
Entry route	Exit route	
50km/h	50km/h	Confirmed

Yellow remaining seconds	Impact on vehicle control	Deceleration following changing to yellow
3 seconds	The vehicle slowed and stopped	-



[Results of analysis of dilemma candidates based on test vehicle on-board equipment log data]

- We confirmed that traffic signal remaining seconds information was used to perform preliminary deceleration, causing the vehicle to gradually decelerate and come to a stop when approaching the Telecom Station-mae intersection from route 3.



3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | (iv) Micro | **(v) Recommendations**

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions
(b) Effectiveness of traffic signal remaining seconds information (findings based on test results):

[Situations in which traffic signal remaining seconds information is effective (findings based on test results)]

- Providing traffic signal remaining seconds information to autonomous vehicles is effective in the following situations:
  - Intersections located short distances from other intersections with traffic signals
  - Intersections on routes with high speed limits
  - Intersections with short yellow signal durations

3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | (iv) Micro | **(v) Recommendations**

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions
[Environmental requirements for traffic signal information distribution]

[Situations in which traffic signal color information is effective (findings based on test results)]

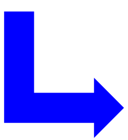
■ Providing traffic signal color information to autonomous vehicles is effective in the following situations:

- ◆ Backlighting: Times of day when sunlight from behind traffic signals (including light reflected by buildings) competes with light from traffic signals → occurs during certain times of day
  Traffic conditions in which the headlights of oncoming vehicles compete with light from traffic signals
- ◆ Direct lighting: Times of day in which sunlight from behind vehicles competes with traffic signals
  → occurs during certain times of day
- ◆ Concealment/obstruction: Traffic conditions in which traffic signal colors are concealed by nearby large vehicles, etc. → occurs during certain traffic conditions
  Road structures in which traffic signals are located in blind spots, such as immediately after curves and on crest vertical curves → occurs with certain road structures
- ◆ Blending into background: Times of day and road structures in which traffic signals themselves blend into background buildings, etc.
- ◆ Nighttime: Times of day in which multiple light sources reduce traffic signal color recognition accuracy
- ◆ Raindrops: Weather conditions in which raindrops get on cameras and reduce traffic signal color recognition accuracy

[Situations in which traffic signal remaining seconds information is effective (findings based on test results)]

■ Providing traffic signal remaining seconds information to autonomous vehicles is effective in the following situations:

- ◆ Intersections located short distances from other intersections with traffic signals
- ◆ Intersections on routes with high speed limits
- ◆ Intersections with short yellow signal durations



Approach to determining for which intersections to prioritize traffic signal information delivery
= Derive based on traffic signal installation policy and the results of this FOT

3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | (iv) Micro | **(v) Recommendations**

(1) Infrastructure information utilization in intersections with traffic signals - effectiveness and conditions

Traffic Signal Installation Policy (National Police Agency)

Requirements

- Secure sufficient width
- Secure sufficient space for crosswalk pedestrians to wait
- As a general rule, intersections on major roads traversed by 300 vehicles or more per hour during peak times, including traffic in both directions
- As a general rule, traffic signals must be 150 m or more from adjacent traffic signals
- Install on traffic signal poles that are visible to both drivers and pedestrians

Selectable conditions

- Number of accidents involving injury/death
- Proximity to elementary schools, junior high schools, etc.
- Main and minor road traffic volume
- Need for crossing by pedestrians

Source: National Police Agency "Traffic Signal Installation Policy" (Dec. 28, 2015)

✖

Situations in which traffic signal information is effective (this FOT)

Factors impeding color recognition: Traffic signal color information

- Curves and crests (rising/falling sections)
- Backlighting/direct lighting
- Obstruction by large vehicles
- Arrow signals
- Raindrops, blending into the background
- Intersections located short distances from adjacent traffic signals

Differences in intersection traversal decision-making: Traffic signal remaining seconds information

- Intersections located short distances from other intersections with traffic signals
- Intersections on routes with high speed limits
- Intersections with short yellow signal durations

Traffic Signal Installation Policy (National Police Agency) : Premises of infrastructure device installation policy

Features of intersections in which there are often factors impeding color recognition or differences in intersection traversal decision-making (results of FOT)

It would be best for traffic signal information to be provided for all intersections in sections in which automated driving is performed.
Traffic signal information also appears to be effective for providing driving assistance, so, if prioritizing installation, the following intersections should be prioritized:

- Intersections which cannot be seen past/fall outside of line of sight (curves and crests)
- Intersections on routes with high speed limits
- Intersections located short distances from adjacent traffic signals

3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | (iv) Micro | (v) Recommendations

[Issues, verification items, and targets]

Issues

- **Ensure reliability of signal recognition by vehicle**
- **Presence of dilemma zones* interfering with smooth traffic flow**

Verification items

(1) Infrastructure information effectiveness and conditions for traffic signal intersections
 (a) Effectiveness of traffic signal color information
 (b) Effectiveness of traffic signal remaining seconds information

(2) Assessment of impact of autonomous vehicle driving on traffic flow and factors causing this impact

Hypotheses regarding effectiveness of cooperative infrastructure technologies

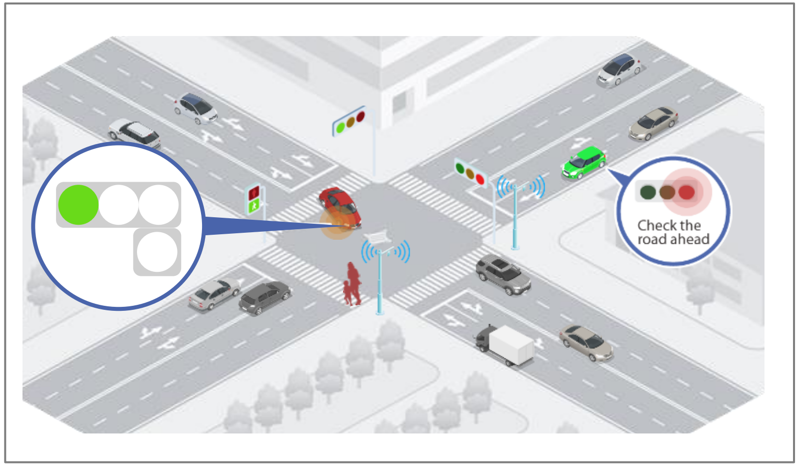
- Recognition improved by use of dual information systems
- Avoidance of dilemma zones* through use of predictive traffic signal information (number of remaining seconds)

Target

- Verify effectiveness of distributing traffic signal information
- Confirm specifications aimed at standardization and consensus by test participants
- Identify environmental conditions required for traffic signal information distribution
- **Clarify issues to be addressed in order to cultivate a sense of acceptability in society**

➡ Evaluation results are shown on the following pages

*Dilemma zone definition
Region in which, when the traffic light turns yellow, the vehicle would not be capable of stopping before the stop line when decelerating at the normal deceleration rate but the vehicle would not be able to traverse the intersection (stop line) while the traffic light was still yellow if maintaining the same pace



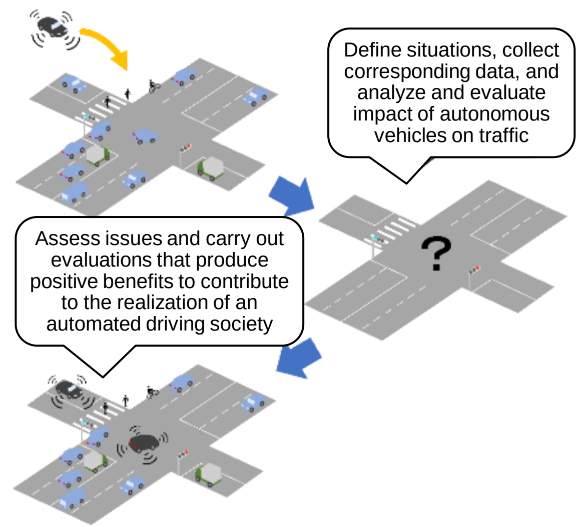
3. Results of the FOTs in the Waterfront City area

(2) Assessment of impact of autonomous vehicle driving on traffic flow and the factors involved

[Impact assessment]
Assessment of impact of autonomous vehicles on surrounding environment when driving safely in actual traffic environments. This includes their impact on nearby ordinary vehicles, crosswalk pedestrians, etc.

- **Evaluation approach**
  - ➢ Define situations in which autonomous vehicles driving in actual roadway traffic environments influence traffic, collect information about these situations, and analyze situations when autonomous vehicles are in actual roadway traffic environments and when they are not

- **Areas of focus in evaluations**
  - ➢ When autonomous vehicles are in traffic
    - ✓ Whether traffic flows as normal
    - ✓ Whether the environment is safer than normal
    - ✓ Whether the flow of traffic gets better/worse
    - ✓ Whether there are changes in the behavior of vehicles near the autonomous vehicle
  - ➢ When autonomous vehicles encounter pedestrians/bicycles at intersections, etc.
    - ➢ Whether traffic flows as normal, etc.



Assess evaluations and points to note as automated driving gradually becomes more prevalent in society

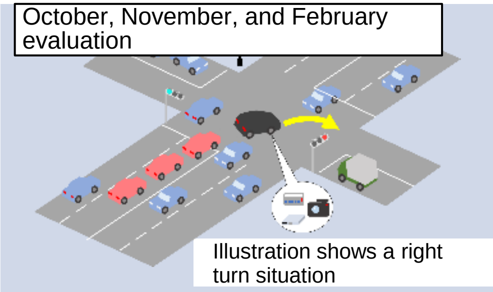
3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | (iv) Micro | (v) Recommendations

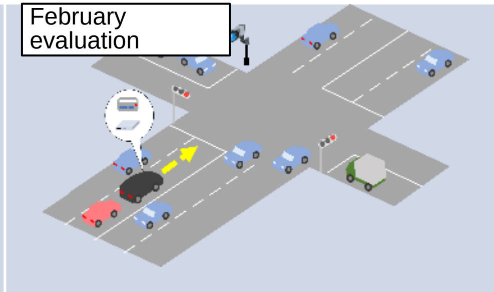
(2) Assessment of impact of autonomous vehicle driving on traffic flow and the factors involved

- **Evaluation item**
  - ➢ Collect data for traffic consisting only of ordinary vehicles and traffic which includes autonomous vehicles
  - ➢ Perform analysis and evaluation of the following items

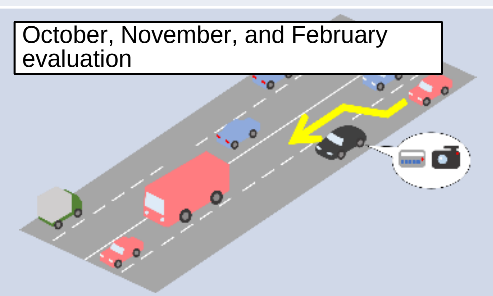
(1) Impact and issues related to driving environments



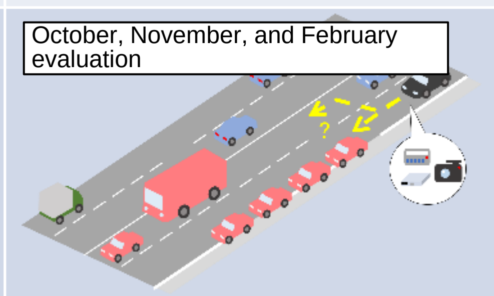
Evaluation of processing when turning left/right



Stopping at red lights when driving straight (February evaluation)

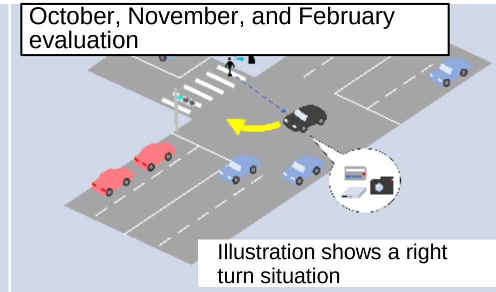


Behavior of nearby vehicles when driving straight (sudden braking, cutting in, etc.)

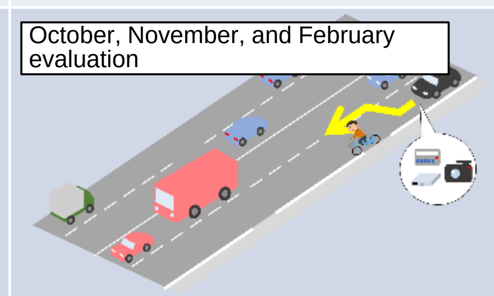


Handling of on-street parking (avoidance, left turns)

(2) Impact and issues related to pedestrians, etc.



Crossing pedestrians when going straight, turning right, or turning left

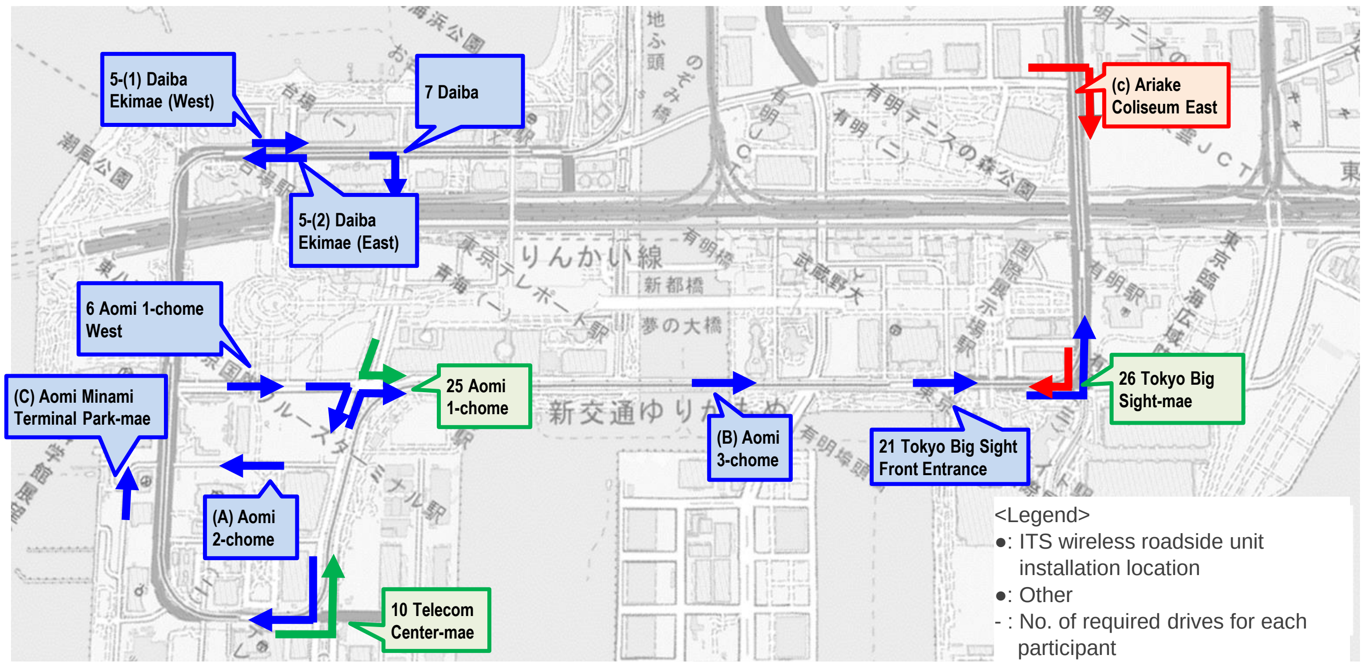


Handling of bicycles

(2) Assessment of impact of automated vehicle driving on traffic flow and the factors involved

■ Status of data collection

- Data submitted by participants was tabulated and the following **numbers of automated driving samples** were collected for the locations of the fixed-point cameras installed in October, November, and February
  - ➢ Period (intensive driving period): Oct. 26 to Nov. 6, 2020, and Feb. 8 to Feb. 19, 2021
  - ➢ Submission method: Intersection traversal samples were extracted by the visualization system



Intersection no.	Name of intersection	Direction	Automated driving samples
5-(1)	Daiba Ekimae (West)	Forward	0
5-(2)	Daiba Ekimae (East)	Forward	43
6	Aomi 1-chome West	Forward	20
7	Daiba	Right turn	0
10	Telecom Center-mae	Left turn	326
10	Telecom Center-mae	Right turn	16
21	Tokyo Big Sight Front Entrance	Forward	37
25	Aomi 1-chome	Left turn	62
25	Aomi 1-chome	Right turn (2→1)	44
25	Aomi 1-chome	Right turn (3→1)	0
26	Tokyo Big Sight-mae	Left turn	37
26	Tokyo Big Sight-mae	Right turn	8
(c)	Ariake Coliseum East	Right turn	92
(A)	Aomi 2-chome	Forward	93
(B)	Aomi 3-chome	Forward	73
(C)	Aomi Minami Terminal Park-mae	Forward	0

Fixed point cameras installed from October 26 to November 6

Fixed point cameras installed from February 8 to February 19

Fixed point cameras installed From October 26 to November 6 and from February 8 to February 19

(2) Assessment of impact of automated vehicle driving on traffic flow and the factors involved

A) Impact on surrounding environment (driving space)

(i) Evaluation of processing when turning left

(ii) Evaluation of processing when turning right

(iii) Behavior of nearby vehicles when driving straight

(iv) Evaluation of handling of on-street parking

(v) Behavior when stopping at a red light when driving straight

(vi) Speed deviation when driving straight

(vii) Evaluation of impact on encounters between test vehicles turning right and oncoming cars driving straight

B. Impact on the surrounding environment (pedestrians, etc.)

(i) Crossing pedestrians when going straight

(ii) Crossing pedestrians when turning left or right

(iii) Impact on bicycles and motorcycles

3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | **(iii) Macro** | (iv) Micro | (v) Recommendations

(2) Assessment of impact of autonomous vehicle driving on traffic flow and the factors involved

A) Impact on surrounding environment (driving space) (i) Evaluation of processing when turning left

1) Evaluation items: Changes in left turn processing time resulting from the presence of autonomous vehicles (no crosswalk pedestrians)

- Areas of focus: (a) Does the presence of autonomous vehicles in traffic affect processing time?
  (b) Does the processing time change for nearby vehicles (following vehicles)?
- Evaluation method: Measure reference line traversal times (※1) based on fixed-point camera video data and calculate processing times based on differences in these times ※1: Only for standard-sized cars

2) Results: Target intersection: (25) Aomi 1-chome - left turn(※2)

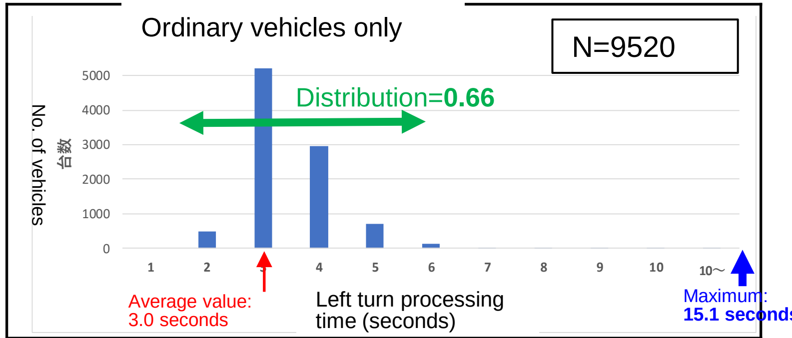
※2: All of the vehicles following the autonomous vehicle at this intersection were ordinary vehicles (not involved in the testing)

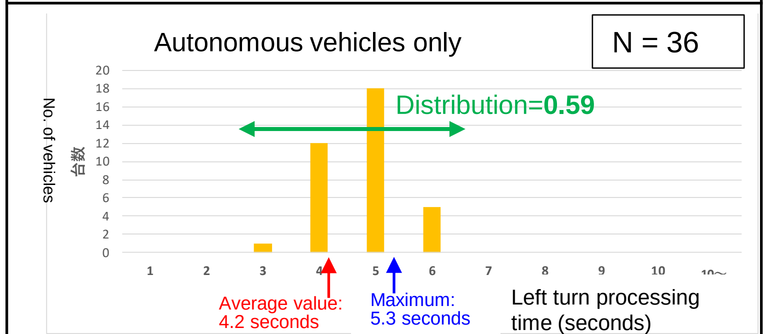
- The average processing times for ordinary vehicles was low, but the maximum values were high.
- When there are autonomous vehicles in traffic, average processing times, including the behavior of following vehicles, tends to be longer (but the maximum values are stable).

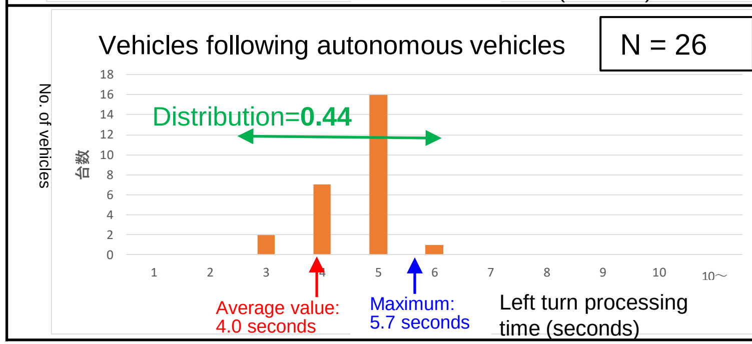
3) Observations and future prospects

- Nearby vehicles (following vehicles) tend to behave more like autonomous vehicles, influenced by their safe driving.
- The FOTs suggest that the presence of autonomous vehicles could produce more stable driving environments (roadway traffic environments which are not influenced by differences in driver characteristics or proficiency).

Reference line







(2) Assessment of impact of autonomous vehicle driving on traffic flow and the factors involved

A) Impact on surrounding environment (driving space) (ii) Evaluation of processing when turning right

1) Evaluation items: Changes in right turn processing time resulting from the presence of autonomous vehicles
(no crosswalk pedestrians or oncoming vehicles driving straight forward)

- Areas of focus: (a) Does the processing time change for the autonomous vehicle?
(b) Does the processing time change for nearby vehicles (following vehicles)?
- Evaluation method: Measure reference line traversal times(*1) based on fixed-point camera video data and calculate processing times based on differences in these times

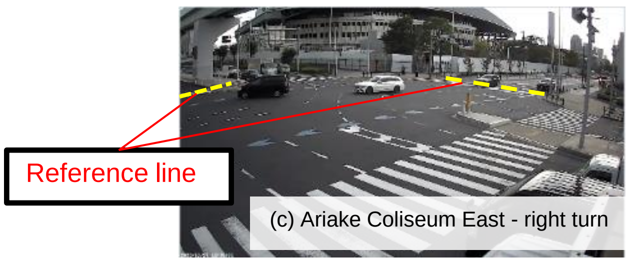
*1: Only for standard-sized cars

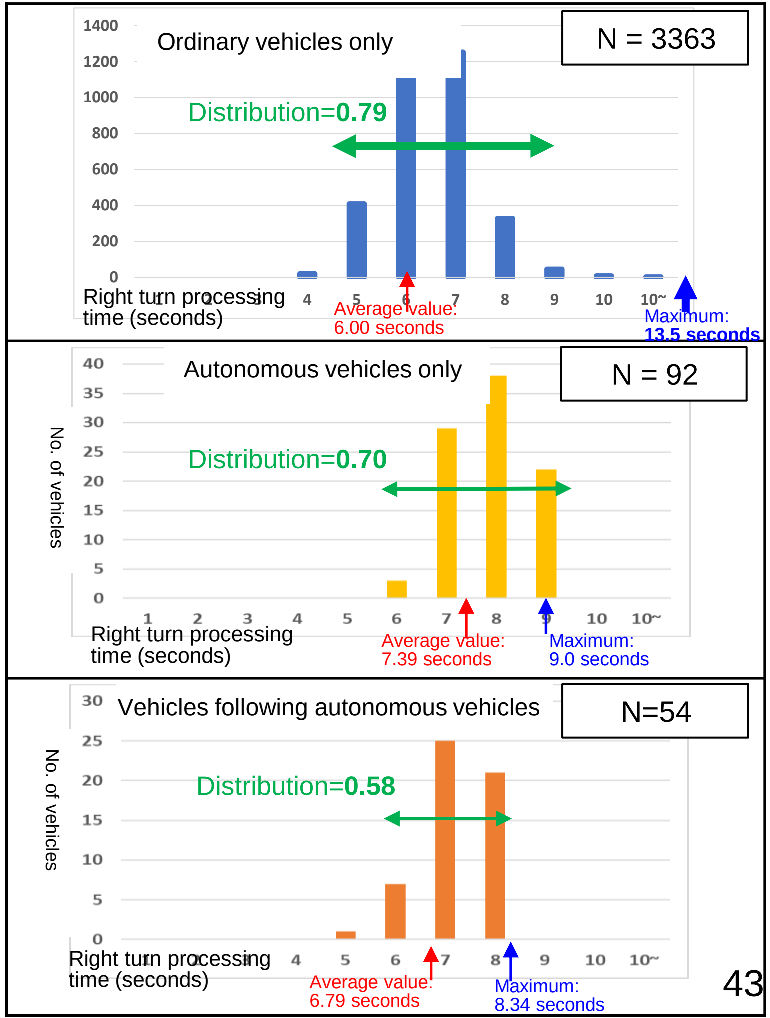
2)Results: Target intersection: (c) Ariake Coliseum East - right turn(*2)
*2: All of the vehicles following the autonomous vehicle at this intersection were ordinary vehicles (not involved in the testing)

- The average processing times for ordinary vehicles was low, but the maximum values were high.
- Average processing times were high for autonomous vehicles and nearby vehicles (following vehicle), but maximum values were low. There was also little variation for nearby vehicles.

3)Observations and future prospects

- Nearby vehicles (following vehicles) tend to behave more like autonomous vehicles, influenced by their safe driving.
- The FOTs suggest that the presence of autonomous vehicles could produce more stable driving environments (roadway traffic environments which are not influenced by differences in driver characteristics or proficiency).





3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | **(iv) Micro** | (v) Recommendations

(2) Assessment of impact of autonomous vehicle driving on traffic flow and the factors involved

A) Impact on surrounding environment (driving space) (iii) Behavior of nearby vehicles when driving straight

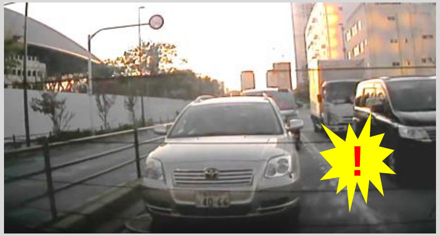
■ **Behavior of automated driving when the traffic signal changes when driving straight forward, etc. (right turn)**

ID: 16161

* Case of an autonomous vehicle entering a queue of vehicles waiting to turn right and the traffic signal changing from yellow to red. The following vehicle intended to pass through the intersection, but the autonomous vehicle in front of it stopped, resulting in the risk of a rear-end collision

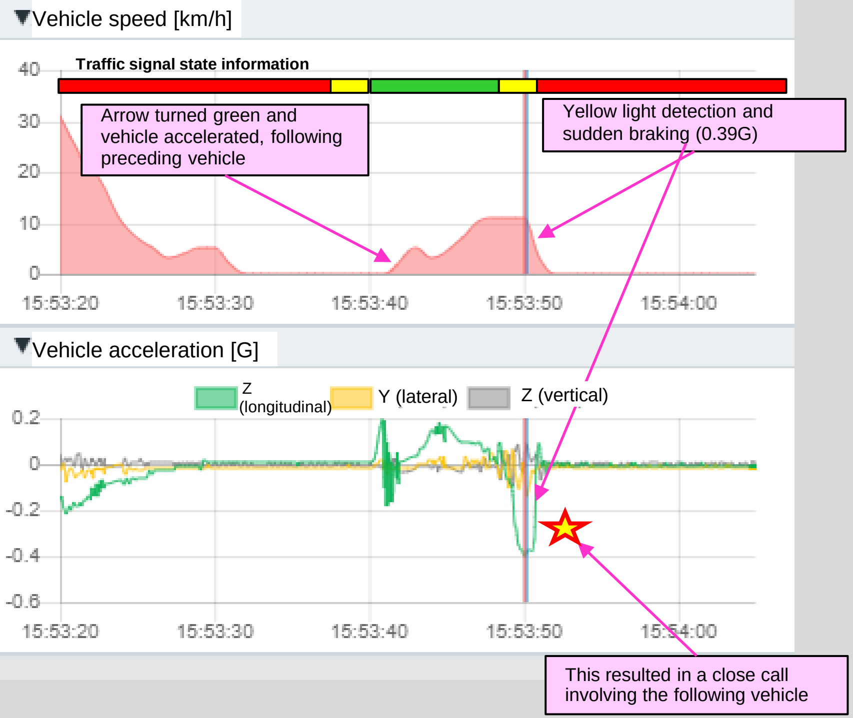
A group of cars was waiting to turn right. The right turn traffic signal turned green and vehicles accelerated (following timing was somewhat slow). Following vehicles also lined up.

The traffic signal arrow turned yellow, so the test vehicle rapidly braked. The following vehicle intended to turn right, so it accelerated.



Because the test vehicle stopped, the following vehicle suddenly stopped with a small amount of knocking. It was a close call.

Autonomous vehicle attributes	Passenger vehicle	No cooperative infrastructure use	Image processing



Analysis: Behaving more safely when turning right affects following vehicles

* The way the vehicle was behaving, it appeared that it would normally begin and carry through with turning right, but it stopped when the yellow signal was detected.
* Earlier stop/right turn decision-making could be performed if traffic signal information were available, so this case is an example of one where cooperative infrastructure could assist with risk avoidance.

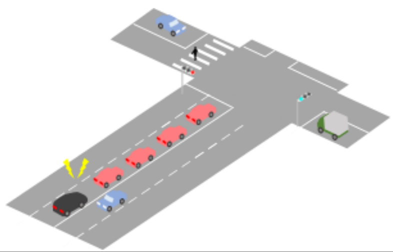
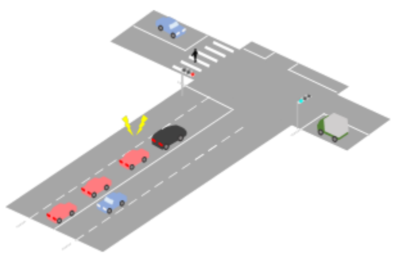
3. Results of the FOTs in the Waterfront City area

(2) Assessment of impact of automated vehicle driving on traffic flow and the factors involved

A. Impact on surrounding environment (driving space) (v) Behavior when stopping at a red light when driving straight

- We evaluated the speed distribution, maximum deceleration, and stop behavior when stopping at red lights
- We focused on differences in the infrastructure information that was provided (whether or not current light color information or remaining seconds information (confirmed/with margin) was provided). We confirmed that when current light color information and remaining seconds information (confirmed) were provided, test vehicles performed preliminary deceleration and drove safely.

1) [In-depth evaluation] Evaluation items: Changes in behavior when stopping at a red light when driving straight
We envisioned the two following types of impact and performed evaluations at (25) Aomi 1-chome and (14) Rainbow Entrance

Impact	Evaluation situation	Target intersection	Evaluation item
Congestion involving preceding vehicles		(25) Aomi 1-chome [Current traffic light color + remaining seconds information (w/ margin)] (Characteristic: High traffic volume)	• Presence/absence of congestion involving preceding vehicles • Did preliminary deceleration using infrastructure information result in gradual deceleration after the detection of preceding vehicles?
Congestion involving following vehicles		(14) Rainbow Entrance [Current traffic light color + remaining seconds information (w/ margin)] (Characteristic: High traffic volume)	• Presence/absence of congestion involving following vehicles (other than accompanying vehicles) • Did preliminary deceleration using infrastructure information result in smooth stopping by following vehicles?

3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | **(iv) Micro** | (v) Recommendations

(2) Assessment of impact of automated vehicle driving on traffic flow and the factors involved

A. Impact on surrounding environment (driving space) (v) Behavior when stopping at a red light when driving straight

■ **Behavior of automated vehicle when stopping at a red light while driving straight** ID: 4226

*[Autonomous]Situations involving sudden deceleration near an intersection and the possibility of a close call involving the preceding vehicle

The test vehicle detected a traffic light and a preceding vehicle (motorcycle) and began decelerating (72 meters before the stop line)

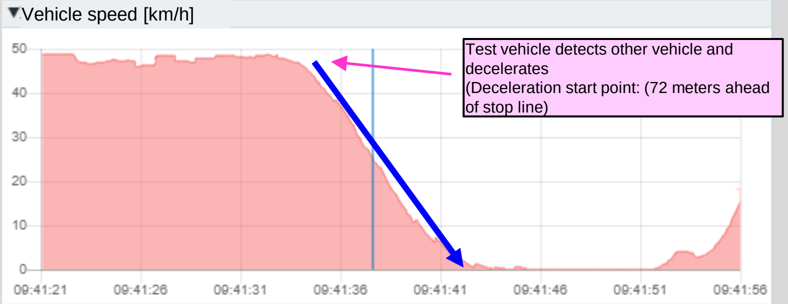
The test vehicle was close to the intersection, so it decelerated rapidly (-0.3G)

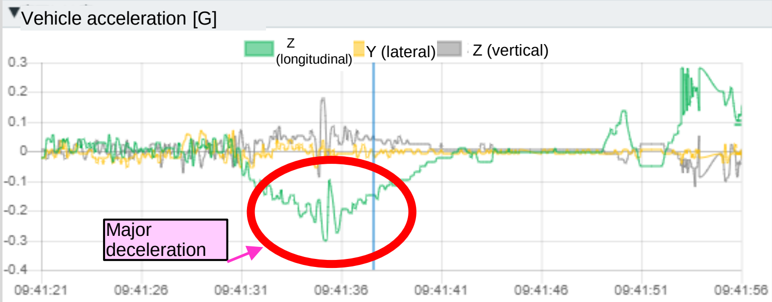
The test vehicle stopped after decelerating suddenly, and there was the potential for congestion involving the preceding vehicle

Analysis: Stopping based on spatial monitoring appears to be insufficient for carrying out safe driving

- Stopping was based on spatial monitoring alone, so stopping was performed near the intersection
- There was the potential for a close call involving the preceding vehicle

Autonomous vehicle attributes	Passenger vehicle	No cooperative infrastructure	Image processing





3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | **(iv) Micro** | (v) Recommendations

(2) Assessment of impact of automated vehicle driving on traffic flow and the factors involved

A. Impact on surrounding environment (driving space) (v) Behavior when stopping at a red light when driving straight

■ **Behavior of automated vehicle when stopping at a red light while driving straight [No congestion involving following vehicles]**

ID: 42358

* Current traffic light color + remaining seconds information alone were used to perform deceleration, and there was no congestion involving a following vehicle


The test vehicle was driving at 45 km/h, and there was a vehicle behind it

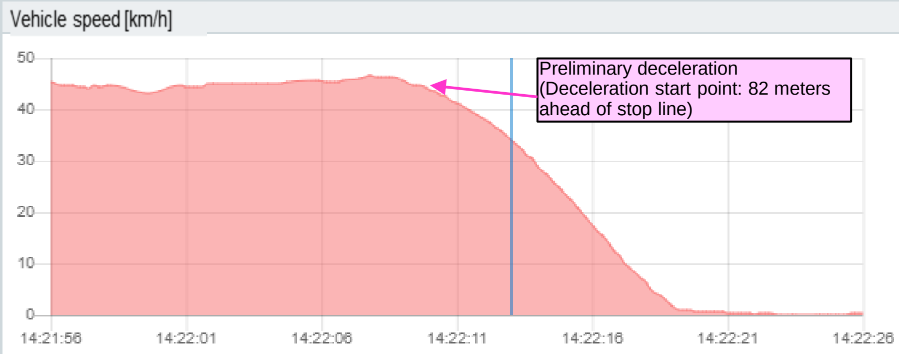

The test vehicle decelerated due to a red traffic light (-0.2G) (Deceleration start point: 82 meters ahead of stop line)

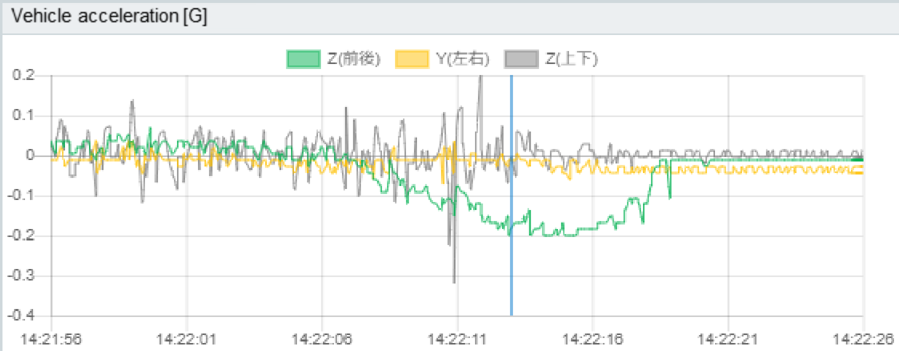

There was no congestion involving the vehicle following the test vehicle

Analysis: We confirmed the importance of current traffic light color + remaining seconds information

- Infrastructure information was used to perform preliminary deceleration, and there was no congestion involving a following vehicle

Autonomous vehicle attributes: Passenger vehicle | Cooperative infrastructure used | Image processing





3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | **(iv) Micro** | (v) Recommendations

(2) Assessment of impact of automated vehicle driving on traffic flow and the factors involved

A. Impact on surrounding environment (driving space) (v) Behavior when stopping at a red light when driving straight

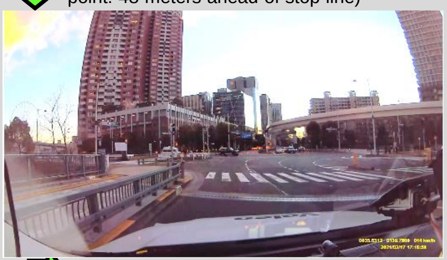
■ **Behavior of automated vehicle when stopping at a red light while driving straight [Congestion involving following vehicles]**

ID: 38831

* Situation in which deceleration was performed using current light color information alone and there was congestion involving a following vehicle

The test vehicle was driving at 50 km/h, and there was a vehicle behind it

The test vehicle decelerated somewhat suddenly due to a red traffic light (-0.24G) (Deceleration start point: 48 meters ahead of stop line)



There was congestion involving the vehicle following the test vehicle

Analysis: We confirmed the importance of remaining seconds information

- This situation appears to have occurred because no remaining seconds information was used, so there was no preliminary deceleration and the test vehicle suddenly decelerated

3. Results of the FOTs in the Waterfront City area

(2) Assessment of impact of autonomous vehicle driving on traffic flow and the factors involved

B. Impact on the surrounding environment (pedestrians, etc.) (i) Crossing pedestrians when going straight

1) Evaluation items: Evaluation of the impact of autonomous vehicles on crosswalk pedestrians

- Areas of focus:
  - ➢ When encountering crosswalk pedestrians, did autonomous vehicles wait for the pedestrians to cross before traverse the intersection?
  - ➢ Did autonomous vehicles that encountered crosswalk pedestrians stop before the stop line?

2) Results Target intersection:(A) Aomi 2-chome - driving straight

- When encountering crosswalk pedestrians, there were ordinary vehicles which did not wait for the pedestrians to pass, instead crossing the crosswalk first. However, autonomous vehicles always waited for the pedestrians to pass first.

3) Analysis and future prospects

- Autonomous vehicle always engaged in safe driving when detecting a crosswalk pedestrian.
- Confirmation has not yet been carried out of what risks might be created for nearby vehicles by the safe driving behavior of autonomous vehicles when encountering a pedestrian

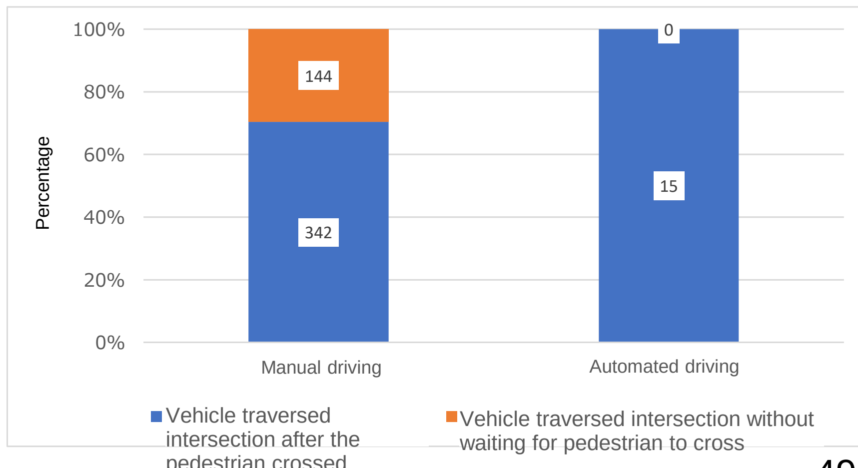
Manual driving (example of vehicle traversing intersection)

Automated driving (example of vehicle stopping)

■ Percentage of cases involving encountering pedestrians in which pedestrians were given right of way
(Evaluation of all vehicles that encountered crosswalk pedestrians during the intensive driving period)
* Lower percentages below indicate a greater likelihood of a vehicle crossing the crosswalk first, without waiting for the pedestrian to cross

	Ordinary vehicle	Autonomous vehicle
Percentage of cases in which pedestrians were given right of way	70.4%(N=486)	100%(N=15)

However, in addition to safe stopping cases, a case was also confirmed of approaching a pedestrian.



3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | **(iv) Micro** | (v) Recommendations

(2) Assessment of impact of autonomous vehicle driving on traffic flow and the factors involved

B. Impact on the surrounding environment (pedestrians, etc.) (i) Crossing pedestrians when going straight

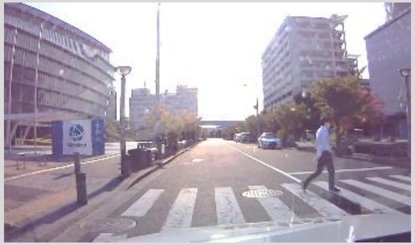
■ **Behavior of autonomous vehicles when driving straight and encountering crosswalk pedestrians**

ID: 16057

* Case of an encounter with a crosswalk pedestrian on a basic road section (with no traffic signal). The vehicle was slow to detect the crosswalk pedestrian, so it crossed the stop line by a large amount and drew near the pedestrian.

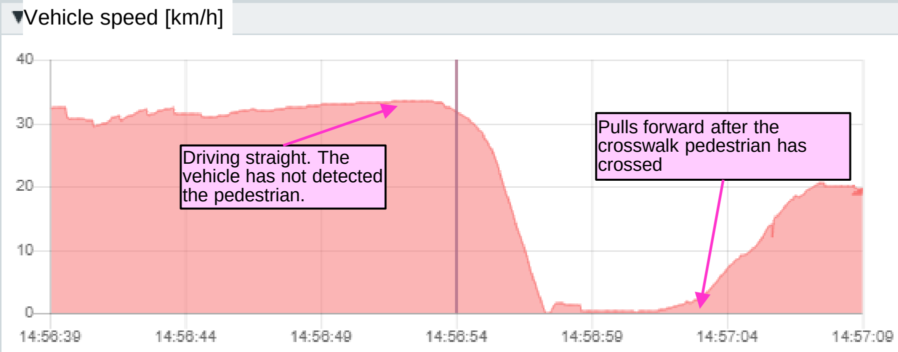
The vehicle approaches the pedestrian crossing. It has not yet detected the presence of the crosswalk pedestrian.

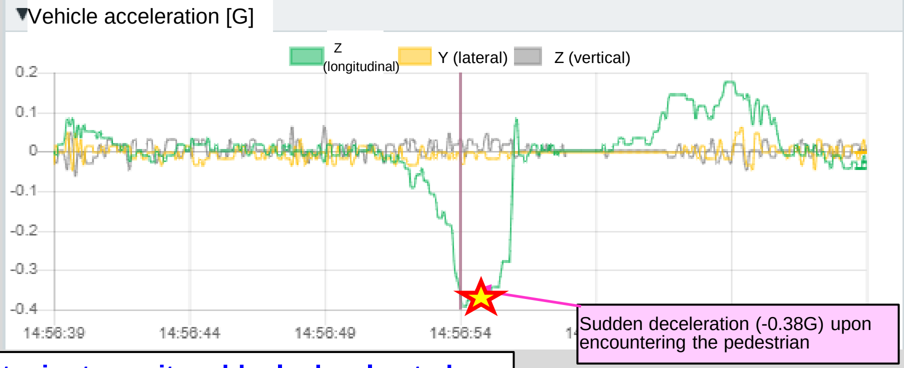
The vehicle detects the crosswalk pedestrian and suddenly decelerates (0.38G). The vehicle crosses the stop line by a large amount and draws near the pedestrian.



After confirming that the pedestrian has crossed, the vehicle pulls forward.

Autonomous vehicle attributes	Passenger vehicle	No cooperative infrastructure use	Image processing





Analysis: The vehicle did not detect the crosswalk pedestrian until the last minute, so it suddenly decelerated.

* Trees, light poles, etc., could have acted as obstacles, delaying the detection of the crosswalk pedestrian.

* The vehicle suddenly decelerated, but then waited until the pedestrian had crossed before pulling forward.

3. Results of the FOTs in the Waterfront City area

(i) Target | (ii) Hypothesis | (iii) Macro | (iv) Micro | (v) Recommendations

(2) Assessment of impact of automated vehicle driving on traffic flow and the factors involved

C. Summary and future prospects

[Findings based on test results]

- Impact on traffic flow (smooth flow, traffic jams): A (i)(ii)(vi), B (i)(ii)
  - The presence of automated vehicles causes right turn and left turn processing times to increase slightly, but we assessed driving stability for following vehiclesand confirmed that roadway traffic environments in which there were automated vehicles present became safer driving environments
  - The actual speeds of automated vehicles are equal to or below legal speeds, while ordinary vehicles tend to drive at somewhat high speeds, so consideration must be given to the possibility of reduced traffic flow smoothness when automated vehicles become more widespread, but automated vehicles have high promise for increasing safety
  - We confirmed that when encountering pedestrians, the extremely safety oriented behavior of vehicles resulted in situations in which vehicles could not turn right or left. Instead of simply making safety the first priority, there is a need to balance safety and smooth traffic flow, including the use of cooperation between vehicles and their surrounding environments
- Impact on pedestrians: B (i)(ii)
  - No cases were observed in automated driving of insufficient eye contact between drivers and pedestrians having an impact (such as hesitation to cross or a reduction in attention paid to other vehicles)
    We believe that this is because automated vehicles look like ordinary vehicles and there are drivers in the driver's seat even when automated driving is being performed
  - The impact and risks that may exist in the future, when driverless operation is used, were not confirmed (this falls outside the scope of this test)
- Impact on safety (accidents): A(iii) to (vi)
  - We confirmed that cooperation with infrastructure, primarily within intersections, contributes to cooperation with the behavior of nearby vehicles, pedestrians, bicycles, etc.
  - However, we also observed cases of close call due to sudden deceleration on basic road sections and in front of intersections, etc., and confirmed the possibility of impact on the surrounding environment
    We confirmed that one of the improvement requirements during the development of autonomous driving systems is the ability to handle a greater diversity of surrounding environments (approaching ordinary vehicles, obstruction by large vehicles, etc.)

4. Results of the FOTs on the Metropolitan Expressway

[Issues, verification items, and targets]

Issues

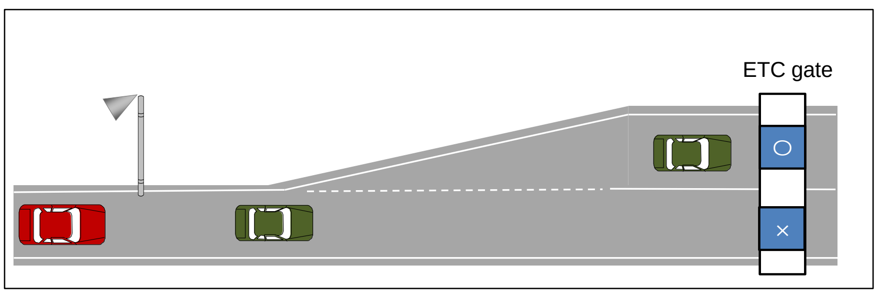
- **Smooth toll booth gate passing support**
- **Support for merging with cruising lines based on actual cruising line vehicle speeds**

Verification items

(1) Appropriateness of operation of cooperative infrastructure system
- (a) Confirmation of the data received from roadside wireless units for expressway experiments and the data output to vehicle control
- (b) Measurement of transmission time between roadside wireless units for expressway experiments and test vehicle on-board equipment

(2) Effectiveness of support information provided to autonomous vehicles, etc.
- (a) Confirmation of the effectiveness of ETC gate passing support information
- (b) Confirmation of the effectiveness of merging support information

➡ Evaluation results are shown on the following pages

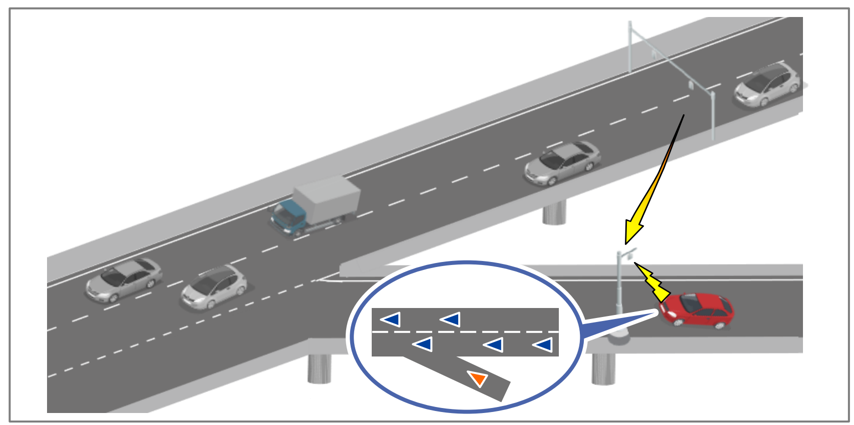


Benefits of cooperative infrastructure technologies

- Support toll booth gate selection and passing by providing information
- Support adjustment of vehicles speeds in order to merge into cruising lines by providing information

Targets

- **Investigation of infrastructure information provision specifications (including improvements)**
- **Identify infrastructure installation conditions for Airport West entrance**
- **Clarify issues in order to define specifications based on FOTs**
- **Identify need for infrastructure and prioritization requirements**

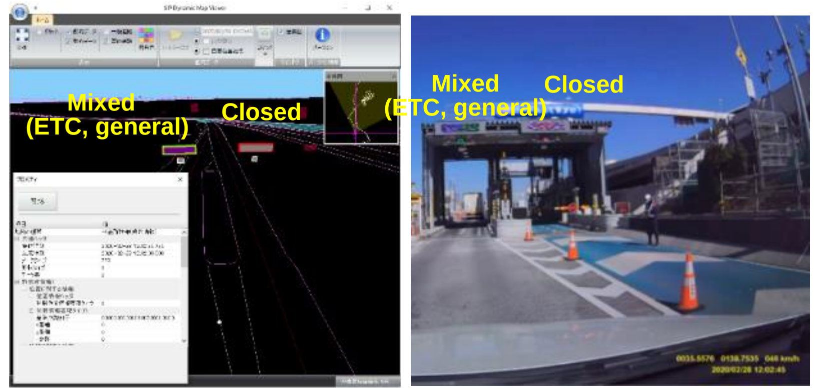


4. Results of the FOTs on the Metropolitan Expressway

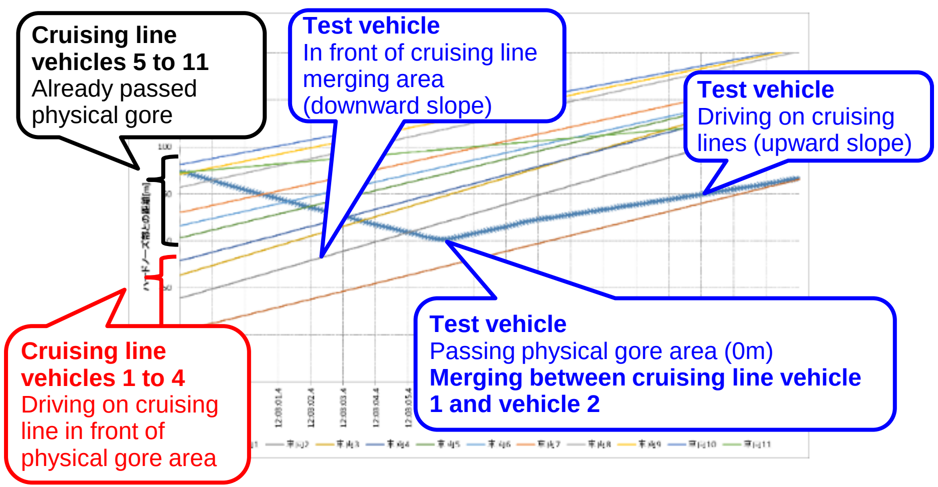
(1) Appropriateness of operation of cooperative infrastructure system

(a) Confirmation of the data received from roadside wireless units for expressway experiments and the data output to vehicle control

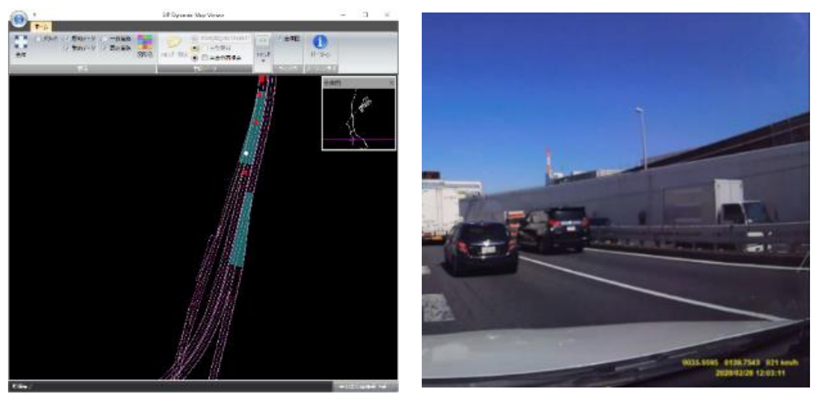
	Test item
ETC gate passing support information	Information pattern: 4x4=16 patterns (booth 1=ETC, mixed, general, not defined) (booth 2=ETC, mixed, general, not defined)
	Change to number of vehicle control outputs
Merging support information	Driving pattern change (normal driving/driving off-center/single-file two vehicle driving)
	Change to number/timing of vehicle control outputs
	Sensor abnormality display confirmation



ETC gate passing support information
(comparison of viewer display and test video data recording device image)
February 28, 2020, 12:02:49



Data displayed on merging support information conversion tool



Merging support information
(comparison of viewer display and test video data recording device image)
February 28, 2020, 12:03:11

4. Results of the FOTs on the Metropolitan Expressway

(i) Target | (ii) Hypothesis | **(iii) Macro** | **(iv) Micro** | (v) Recommendations

(1) Appropriateness of operation of cooperative infrastructure system

(b) Measurement of transmission time between roadside wireless units for expressway experiments and test vehicle on-board equipment

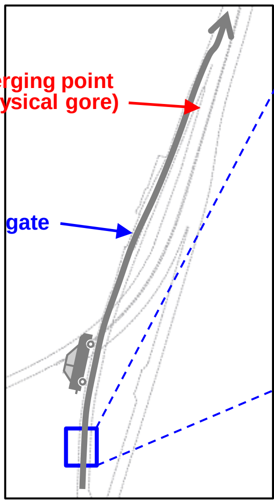
(2) Effectiveness of support information provided to autonomous vehicles, etc.

(a) Confirmation of the effectiveness of ETC gate passing support information

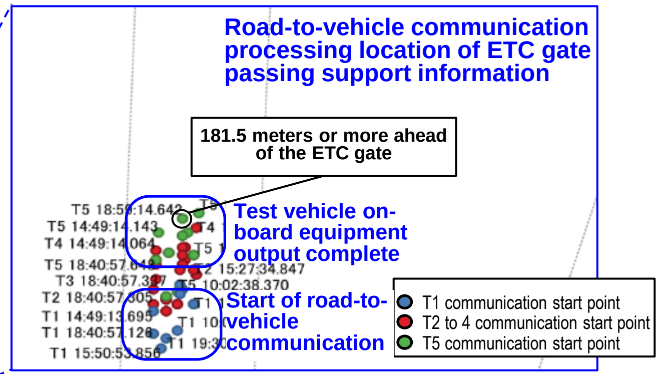
*1JAMA requirement

- ETC gate passing support information: Processing completed 181.5 meters*1 or more ahead of the ETC gate
- Automated driving situations involving the use of ETC gate passing support information were confirmed through test participant driving

➡ Vehicles safely passed through usable ETC gates and **the effectiveness of ETC gate passing support information was confirmed**



Airport West entrance (ETC gate to merging ramp)



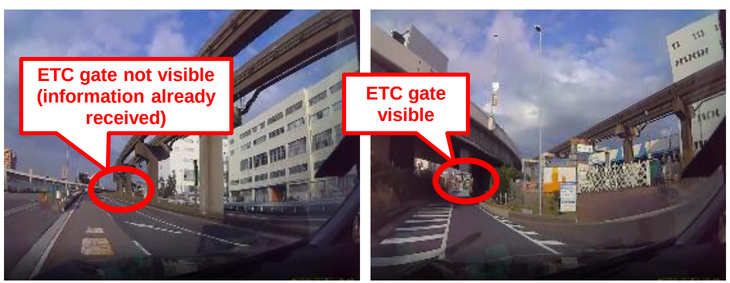
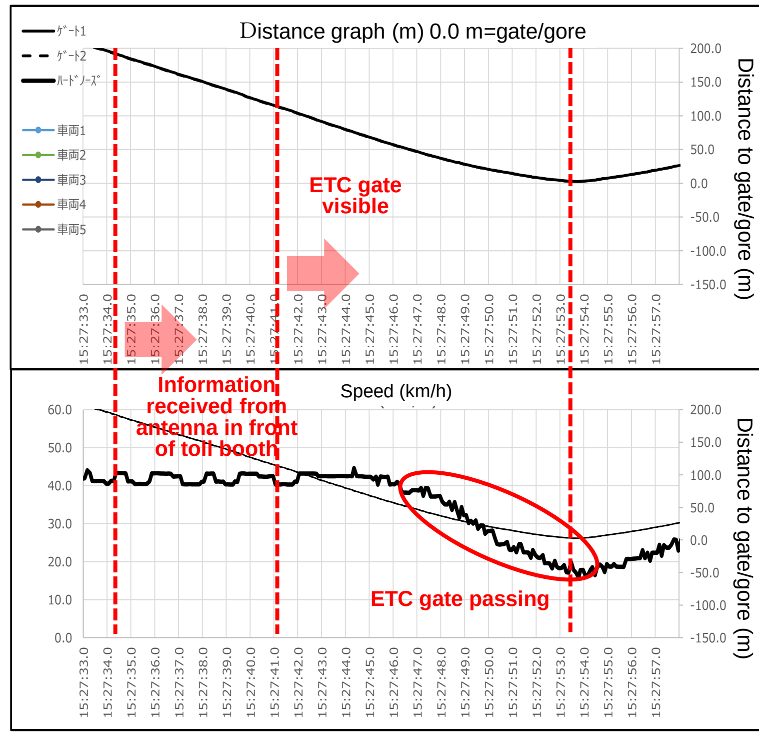


Fig.: Information already received from antenna in front of toll booth, ETC gate not visible (left), ETC gate visible (right)



4. Results of the FOTs on the Metropolitan Expressway

(1) Appropriateness of operation of cooperative infrastructure system

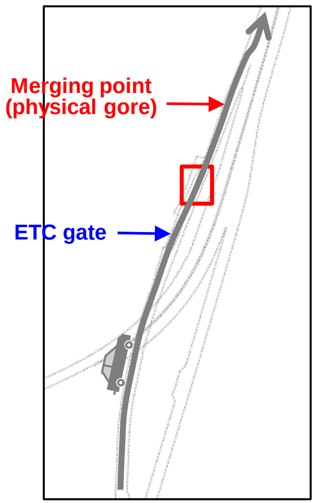
(b) Measurement of transmission time between roadside wireless units for expressway experiments and test vehicle on-board equipment

(2) Effectiveness of support information provided to automated vehicles, etc.

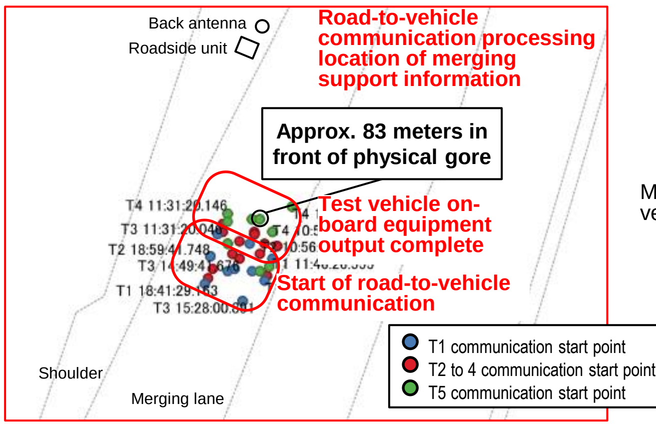
(b) Confirmation of the effectiveness of merging support information

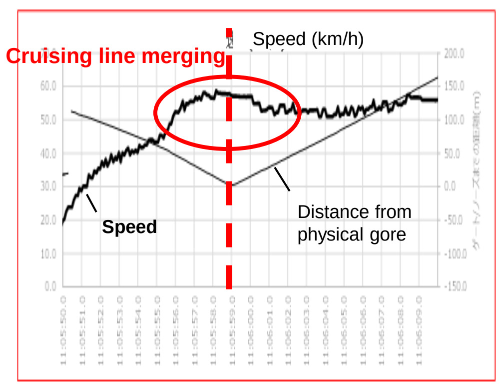
*1This is less than the 95 meters required by the Japan Automobile Manufacturers Association, but we confirmed that the communications processing time did not cause any problems

- Merging support information: Output completed approx. 83 meters*1 in front of physical gore
- Total of 365 test drives performed at Airport West entrance (of which 17 were automated driving test drives): Sudden behavior occurred thirty times during manual driving



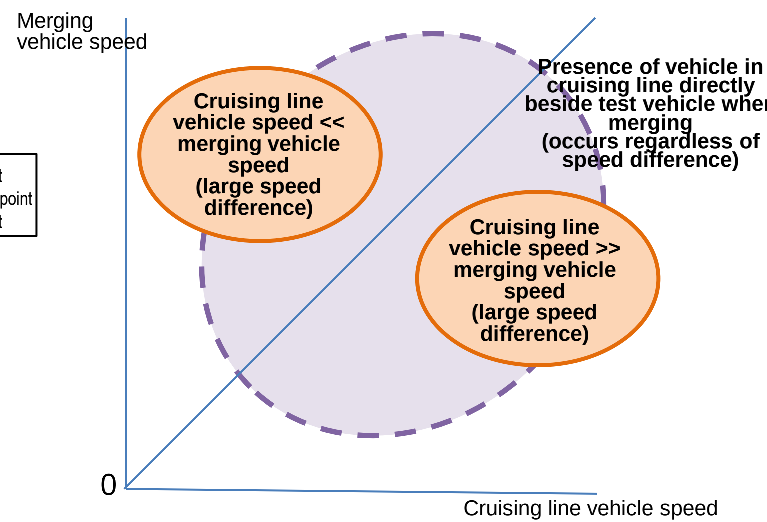
Airport West entrance
(ETC gate to merging ramp)





Contributing factors to sudden behavior

- **Speed differences between cruising line vehicles and merging vehicles**
- **Presence of vehicle in cruising line directly beside test vehicle when merging**



Relationship between cruising line vehicle speed and merging vehicle speed

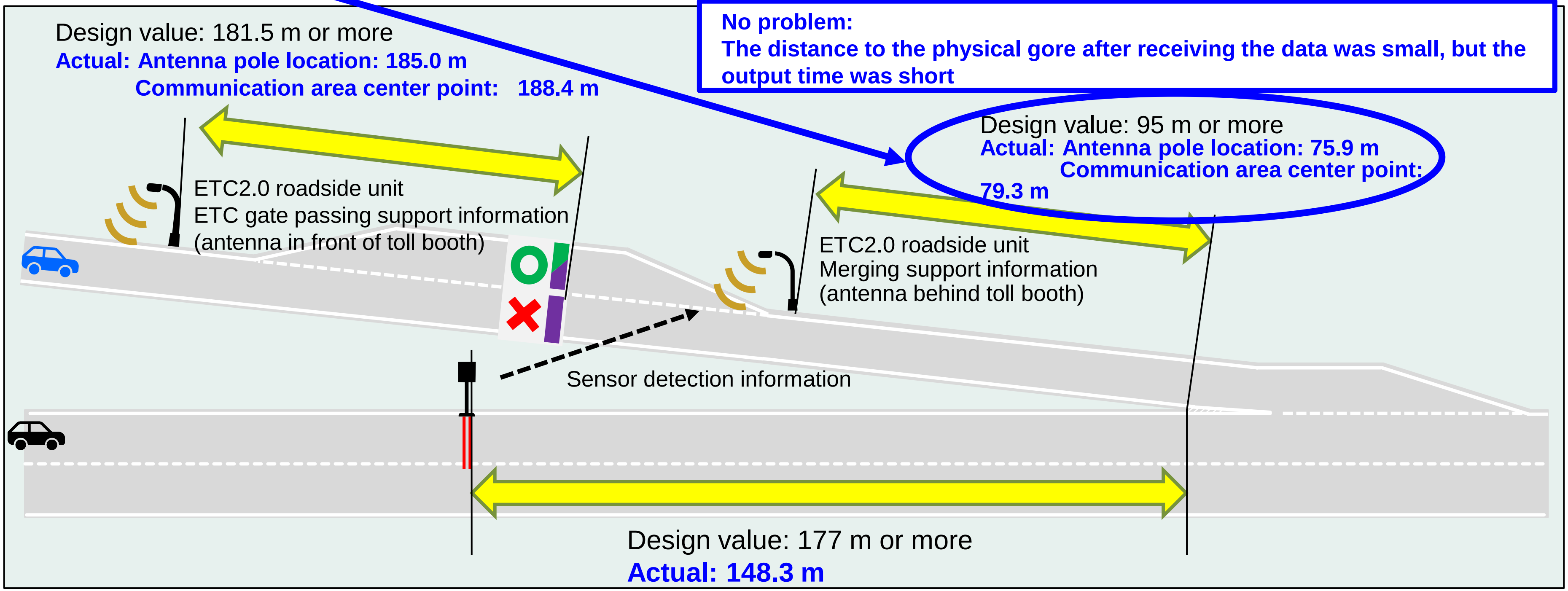
(1) Appropriateness of operation of cooperative infrastructure system

(b) Measurement of transmission time between roadside wireless units for expressway experiments and test vehicle on-board equipment

Item	Design value (m)	Measured value (m)
Distance between antenna in front of toll booth and gate	181.5 or more	188.4
Distance between antenna behind toll booth and merging end (physical gore)	95 or above	79.3
Distance between vehicle sensor ① and merging end (physical gore)	177 or more	148.3

NILIM design prerequisites
After receiving data on the vehicle side:
Time to CAN output=**1.3 seconds**
Measured value:**0.6 seconds**

No problem:
The distance to the physical gore after receiving the data was small, but the output time was short



Note) The device locations when the system was designed by NILIM and the locations of the actual installed devices differ, so confirmation was performed from the perspective of ensuring sufficient time for automated driving control

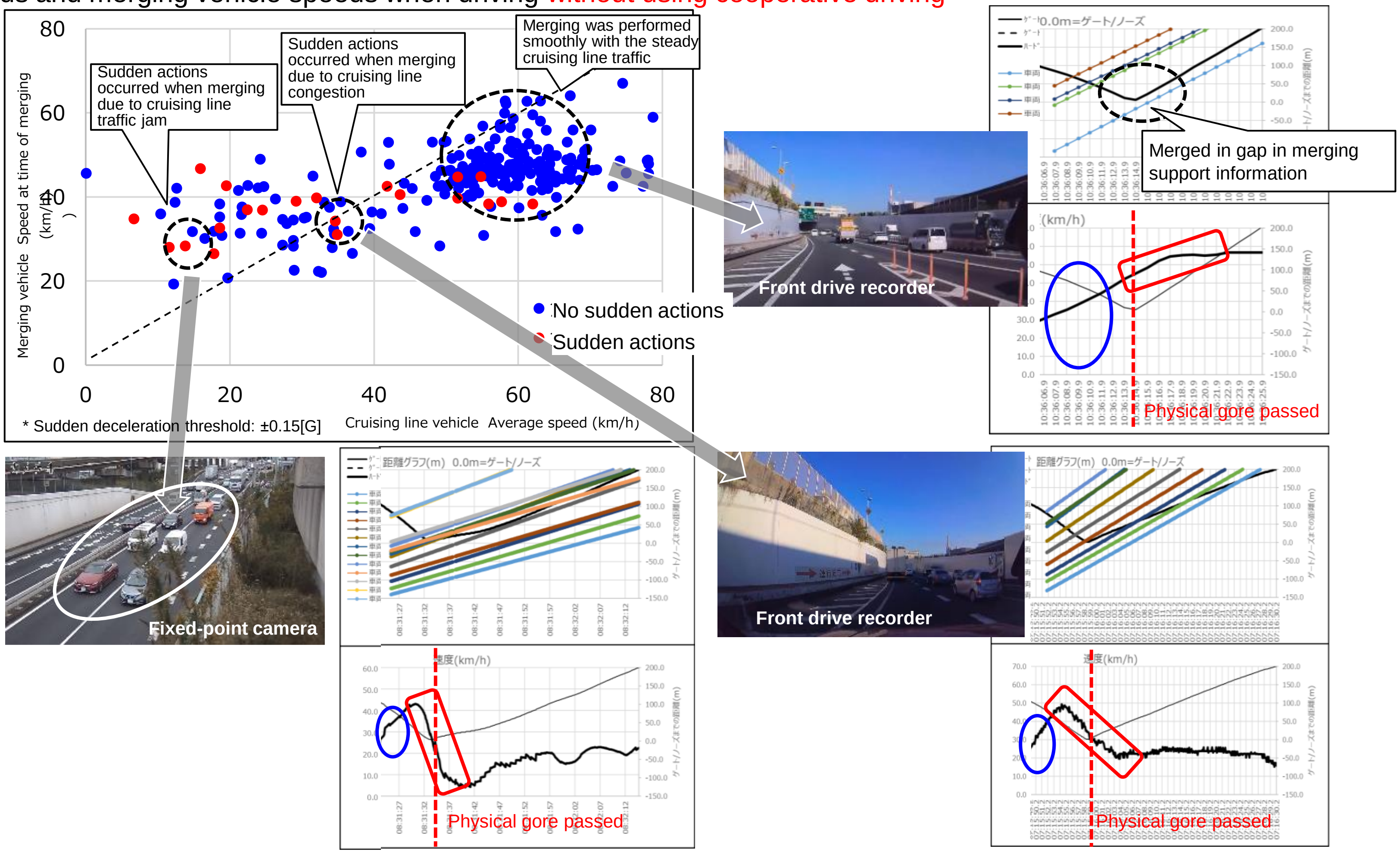
4. Results of the FOTs on the Metropolitan Expressway

(i) Target | (ii) Hypothesis | **(iii) Macro** | (iv) Micro | (v) Recommendations

(2) Effectiveness of support information provided to autonomous vehicles, etc.
(b) Confirmation of the effectiveness of merging support information

Without cooperative driving : Driving without using ETC gate passing/merging support information

- The behavior of individual vehicles was analyzed, taking into consideration the relationship between cruising line vehicle speeds and merging vehicle speeds when driving without using cooperative driving

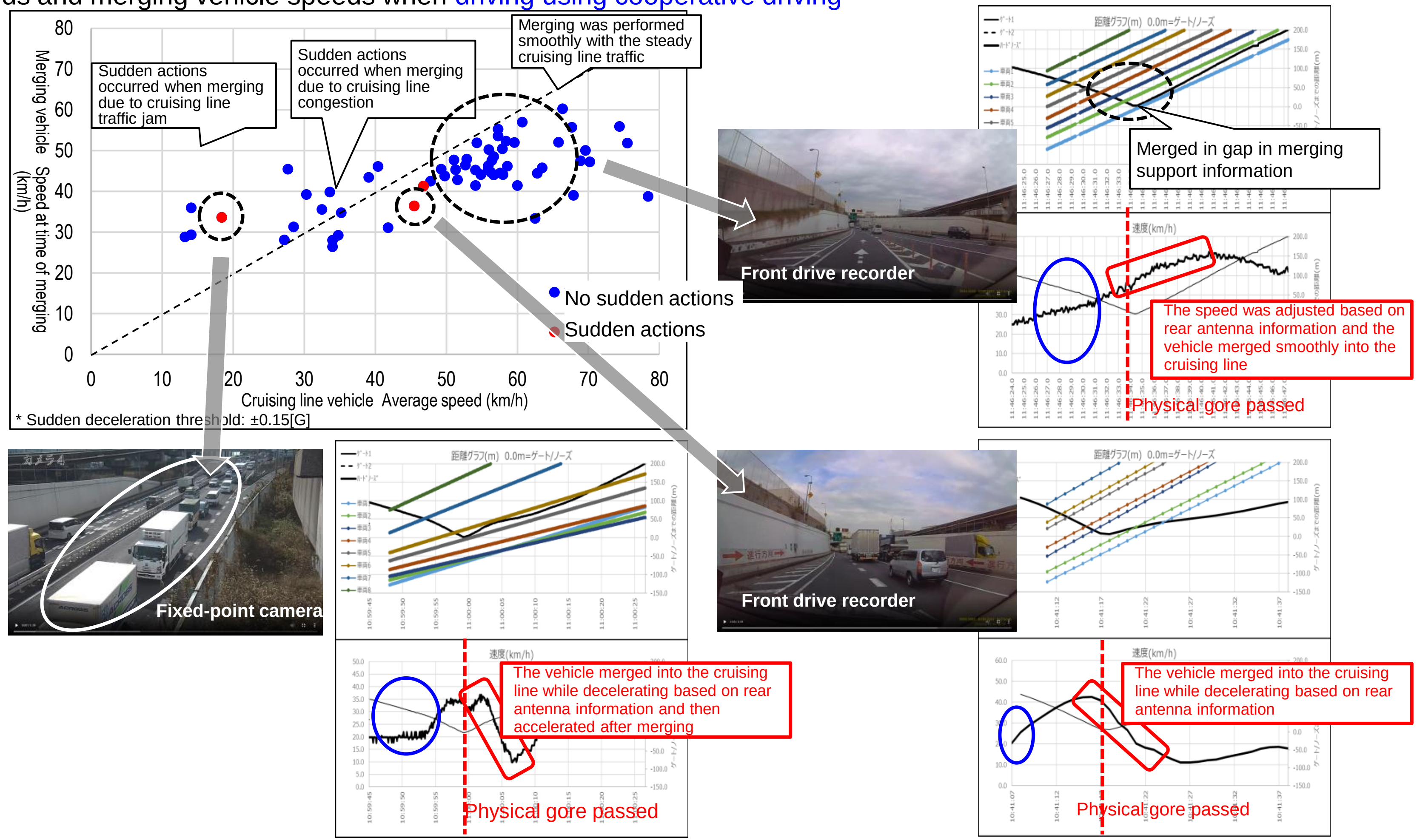


4. Results of the FOTs on the Metropolitan Expressway

(2) Effectiveness of support information provided to autonomous vehicles, etc.
(b) Confirmation of the effectiveness of merging support information

With cooperative driving : Driving using ETC gate passing/merging support information

- The behavior of individual vehicles was analyzed, taking into consideration the relationship between cruising line vehicle speeds and merging vehicle speeds when driving using cooperative driving

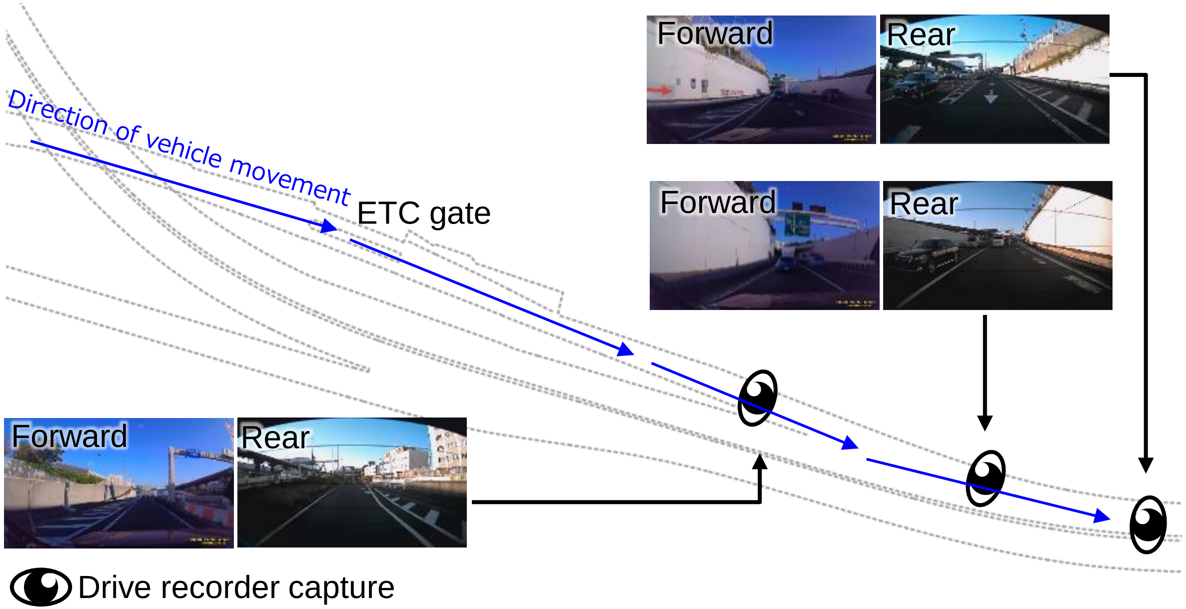


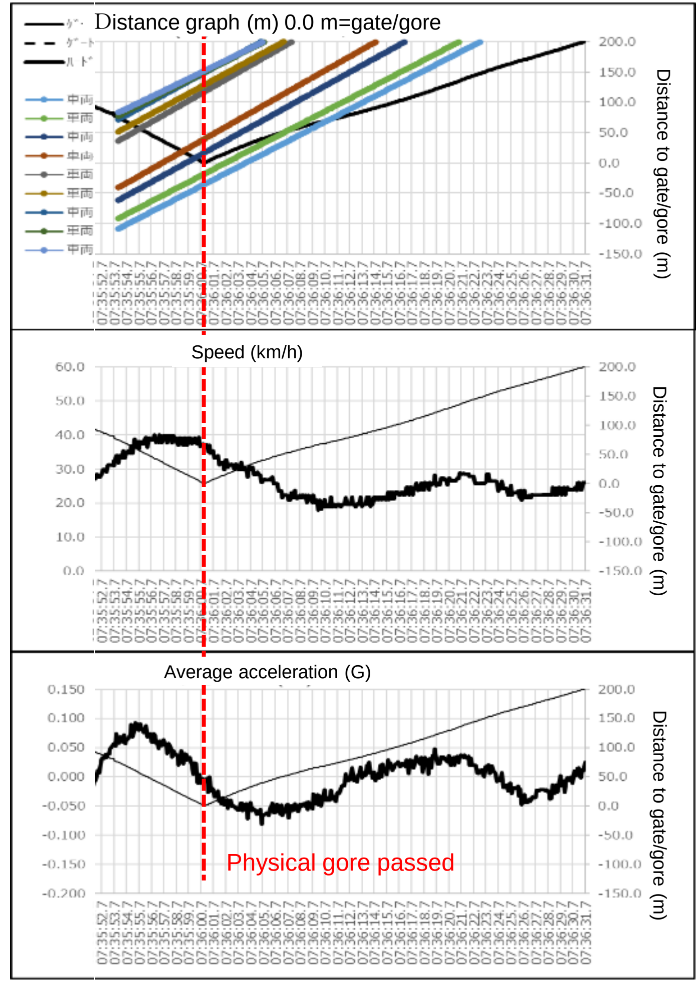
4. Results of the FOTs on the Metropolitan Expressway

(i) Target | (ii) Hypothesis | (iii) Macro | **(iv) Micro** | (v) Recommendations

(2) Effectiveness of support information provided to autonomous vehicles, etc.
(b) Confirmation of the effectiveness of merging support information

- Example of use of merging support information (manual driving)





FOT date	Automated driving	Merging conditions	Speed when merging (km/h)	Average acceleration (G)	Behavior after merging	Time of reception from front antenna	Time of reception from rear antenna	No. of cruising line vehicles	Cruising line average speed (km/h) (immediately preceding 10 seconds)
2020/11/5	×	Gap	34.7	-0.02	Deceleration	07:35:32	07:35:53	9	39.7

[Results of analysis of cruising line merging conditions]

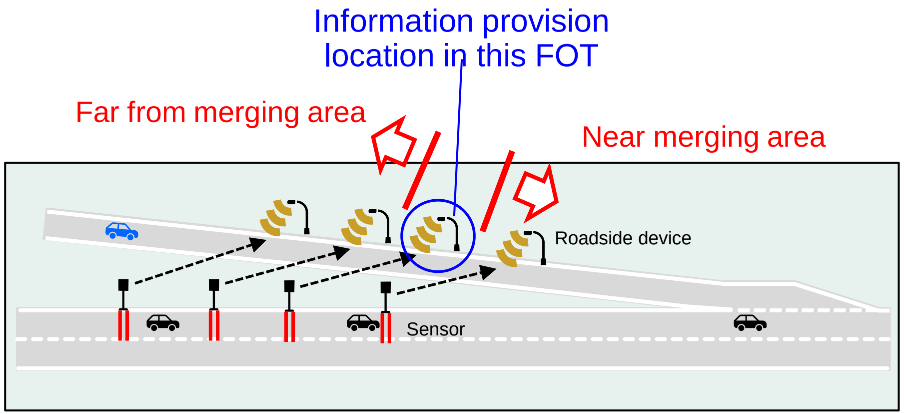
- After passing the physical gore, the vehicle slowed and merged into a gap between cruising line vehicles.

4. Results of the FOTs on the Metropolitan Expressway

(2) Effectiveness of support information provided to autonomous vehicles, etc.
(3) Confirmation of effectiveness of merging support information based on simul

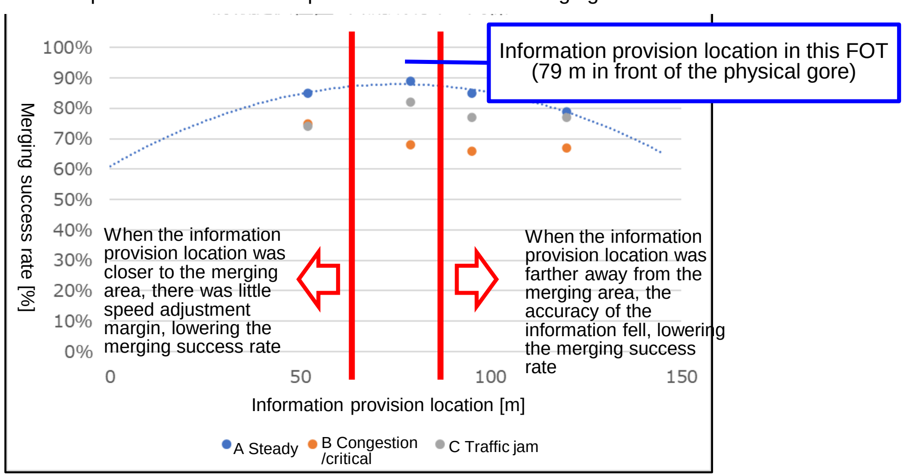
- The road structure of the Airport West Entrance and the congestion conditions of the cruising line (steady traffic/congestion/traffic jam) were reflected in the simulator
- We generated merging vehicles in the simulation and verified the merging success rates when using merging support information, depending on the location of the infrastructure (roadside units/sensors) used to provide the merging support information.

Merging simulation



Relationship between roadside unit location and sensor location

Relationship between information provision location and merging success rate



Merging success rates by roadside unit, sensor location, and cruising line traffic conditions

[Simulation verification results]

- When the traffic on the cruising line was steady, providing merging support information has the potential to improve merging success rates, but when there is congestion or a traffic jam, the accuracy of the predicted merging arrival time falls, lowering the merging success rate
- With regard to the location of the infrastructure, while the merging success rate was high for the installation location used in this test, the accuracy of the predicted merging arrival time falls for infrastructure located closer or further away, lowering the merging success rate

(2) Effectiveness of support information provided to autonomous vehicles, etc.

[Issues to be resolved in order to define specifications/related requests]

■ ETC gate passing support information

➡ Confirm transmission of accurate information to autonomous vehicles

➡ None of the participants indicated there were any issues to be addressed before practical implementation

➡ ETC gate passing support information could be used effectively as support information provided to the driver, etc.

➡ The following additional format request was made

✓ Request for cruising line traffic conditions to be added to gate passing support information (in order to rapidly determine if merging is possible)

4. Results of the FOTs on the Metropolitan Expressway

(i) Target | (ii) Hypothesis | (iii) Macro | (iv) Micro | **(v) Recommendations**

(2) Effectiveness of support information provided to automated vehicles, etc.

[Issues to be resolved in order to define specifications/related requests]

- Merging support information
  - ➡ The FOTs system may work when cruising line traffic is steady
  - ➡ Merging support information could be used effectively as support information provided to the driver, etc.
  - ➡ Changing cruising line conditions cannot be conveyed with one-time information, so smooth merging may be difficult especially in borderline traffic and when there are traffic jams
  - ➡The following additional format requests were made
    - ✓ Predicted arrival times and vehicle speeds are inferred based on the assumption that cruising line vehicles will travel at constant speeds. However, requests were made for acceleration/deceleration information and information regarding speed upon arrival →improvement of the reliability of delivered information
    - ✓ Continuous delivery of cruising line vehicle location information was requested → improvement of the reliability of delivered information
    - ✓ Cruising line traffic status information (overall speed of traffic flow, degree of congestion, average time between vehicles, etc.) was requested when delivering gate information → in order to rapidly determine if merging is possible
    - ✓ Information regarding lane speeds beyond the merging point was requested→ for prior determination of the need for acceleration or deceleration after merging
    - ✓ Information regarding the cruising lane and the passing lane were requested → for predicting the need to change lanes after merging

(2) Effectiveness of support information provided to autonomous vehicles, etc.

[Proposed infrastructure installation conditions]

- ETC gate passing support information
  - ➡ Install for both intracity and intercity expressways
  - ➡ Toll booths with numerous entrances and toll booths with a large amount of traffic inflow should be prioritized when installing equipment

- Merging support information
  - ➡ Calculated arrival times are calculated with the assumption that vehicles will travel at constant speeds, so having highly accurate information is important
  - ➡ Merging areas with a large amount of traffic, merging areas with short merging lanes, and merging areas with poor cruising line visibility should be prioritized when installing equipment

4. Results of the FOTs on the Metropolitan Expressway

(3) Lane-specific traffic information transmission testing

[Issues, verification items, and targets]

Issues

- **When driving at high speeds, detection is delayed when using on-board sensors alone, resulting in sudden braking**

Benefits of cooperative infrastructure technologies

- Providing information regarding conditions in front of vehicles, which they cannot detect with their on-board sensors, assists with selecting driving lanes in advance and contributes to safe, smooth driving

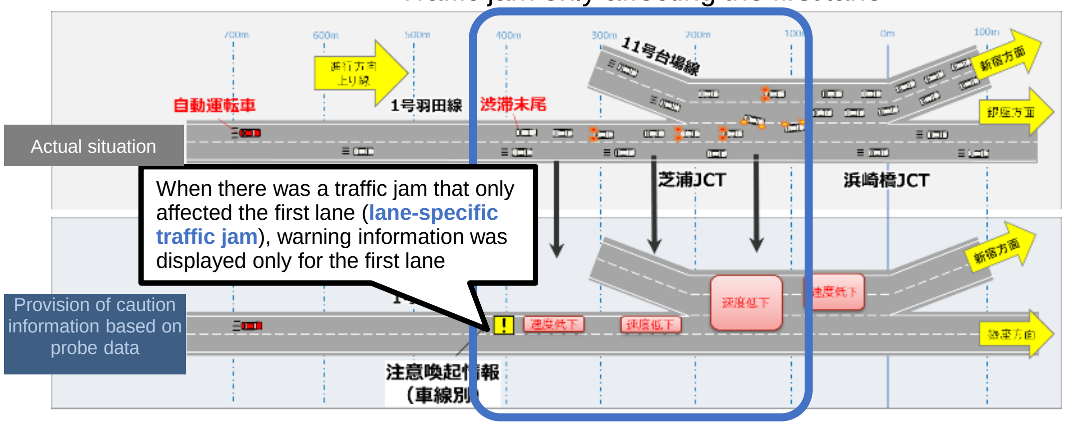
Verification items

(1) Appropriateness of use of lane-specific traffic information
  (a) Measurement of communication time between lane-specific traffic information distribution center and test vehicle on-board equipment
  (b) Accuracy of lane-specific traffic information
(2) Effectiveness of lane-specific traffic information provided to autonomous vehicles, etc.

Targets

- **Establish technologies for generating lane-specific road traffic information**
- **Clarify issues involved in V2N information transmission technologies**

Traffic jam only affecting the first lane



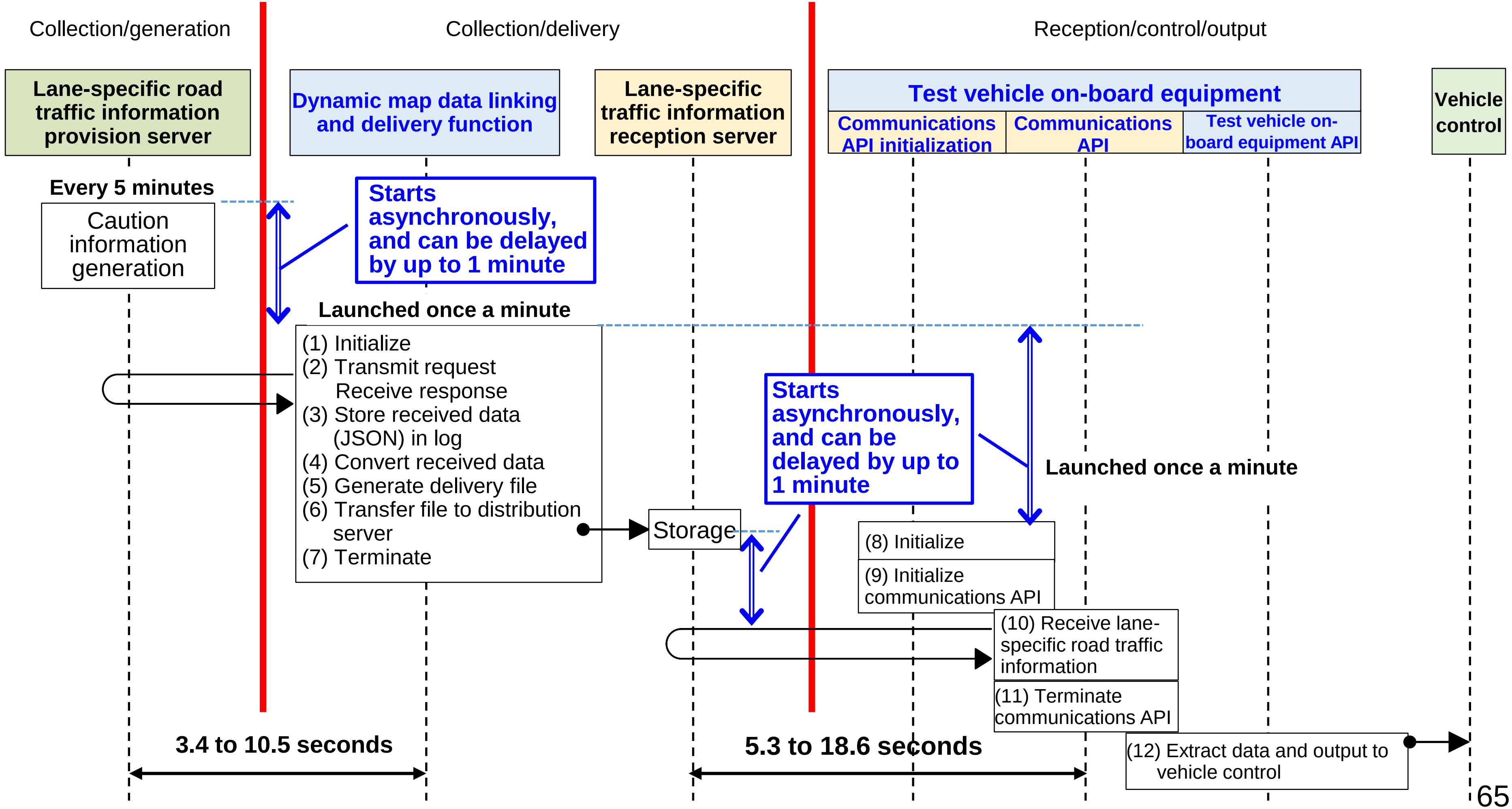
Source: FOTs in the Tokyo Waterfront Area 11th Working Group Session Material 11-2-1
Request for Cooperation in Verification of Effectiveness in Practical Implementation of Lane-specific Traffic Flow Information Generated from Probe Information (“Examination and Evaluation of Automated Driving Control Technologies that Use Lane-specific Probes, etc.” Contractor: Pacific Consultants Co., Ltd.)

4. Results of the FOTs on the Metropolitan Expressway

(i) Target	(ii) Hypothesis	**(iii) Macro**	(iv) Micro	(v) Recommendations

(3) Lane-specific traffic information transmission testing : Confirmation of communications processing time

The **execution times for each of processes (1) to (12) below were tabulated** based on the linking/delivery function and the operation logs of the test vehicle on-board equipment



(3) Lane-specific traffic information transmission testing : Confirmation of communications processing time

We measured processing time in multiple situations and confirmed that **lane-specific road traffic information could be output to vehicle control in one minute intervals**

<Comparison of receiving large amounts of data and normal amounts of data>

Measurement conditions		Date	Collection/delivery: Linking and delivery function processing time [s] ((1) to (7))			Reception/control/output: Test vehicle on-board equipment processing time [s] ((8) to (10))		
Reception environment	Received data		Max.	Avg.	Min.	Max.	Avg.	Min.
Factory	Test data (200 items, 71.3 KB)	12/18	8.934	**4.769**	4.548	19.719	**10.182**	5.491
Actual driving	Test data (200 items, 71.3 KB)	12/22	4.357	**3.084**	2.883	30.393	**11.622**	5.407
Factory	Online (Avg. 1.7 items)	1/13	10.524	**3.946**	3.437	16.017	**6.371**	5.328
Factory	Past data (Avg. 6.6 items)	1/15	8.424	**3.861**	3.649	18.580	**6.209**	5.484

<Comparison of receiving and not receiving traffic signal information>

Measurement conditions		Date	Collection/delivery: Linking and delivery function processing time [s] ((1) to (7))			Reception/control/output: Test vehicle on-board equipment processing time [s] ((8) to (12))		
Test environment	Received data		Max.	Avg.	Min.	Max.	Avg.	Min.
Actual driving (overall)	Past data (Avg. 2.4 items)	-	4.478	**3.677**	3.090	11.236	**6.700**	5.454
Actual driving (w/ traffic signal information)	Past data (Avg. 2.3 items)	-	-	-	-	11.236	**6.715**	5.454
Actual driving (w/o traffic signal information)	Past data (Avg. 2.8 items)	-	-	-	-	9.251	**6.664**	5.751

<Comparison of past data reception and online data reception>

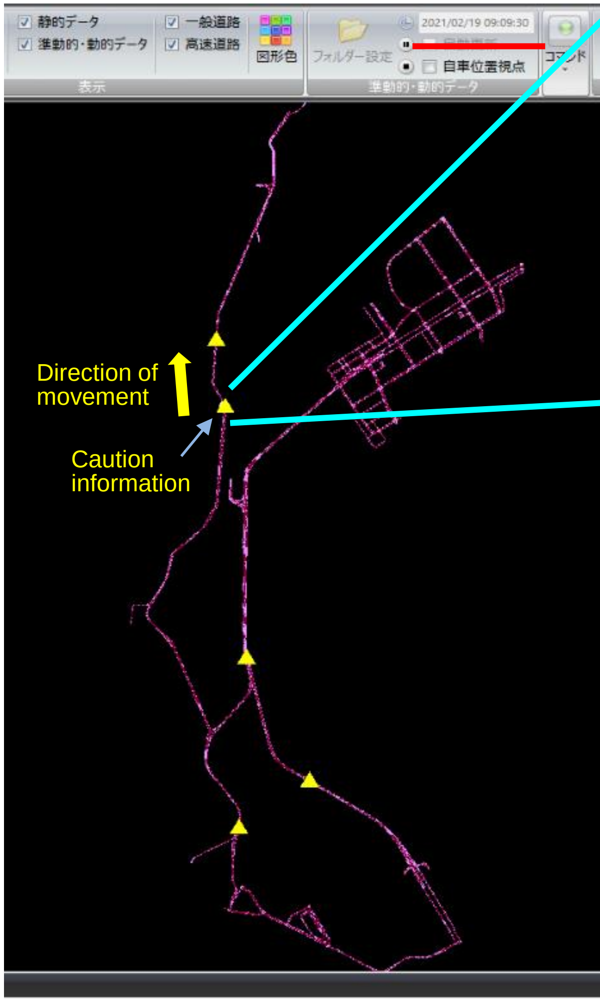
Measurement conditions		Date	Collection/delivery: Linking and delivery function processing time [s] ((1) to (7))			Reception/control/output: Test vehicle on-board equipment processing time [s] ((8) to (12))		
Test environment	Received data		Max.	Avg.	Min.	Max.	Avg.	Min.
Actual driving	Past data (Avg. 2.4 items)	2/9	4.478	**3.677**	3.090	11.236	**6.700**	5.454
Actual driving	Online (Avg. 1.6 items)	2/19	4.703	**2.803**	1.735	11.158	**6.413**	5.360

The average number of items of data received = average number of phenomena per 5 minutes between 9:00 and 17:00

(3) Lane-specific traffic information transmission testing: Field verification

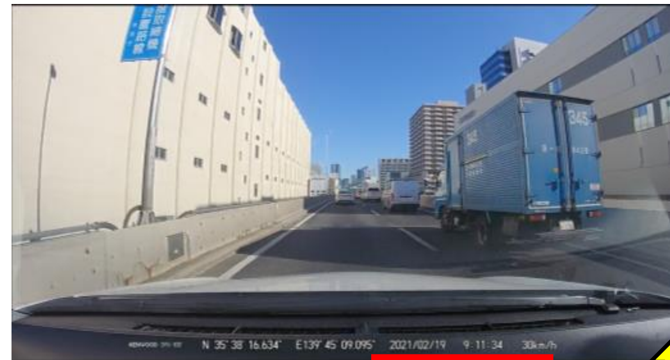
(1) Feb. 19, 2021. 9:09:30 (evaluated through on-site driving)

The tail end of the traffic jam was further forward than the location indicated in the caution information



Japan Road Traffic Information Center website screen
Feb. 19, 09:05 a.m.

Approximately 2 minutes later, after driving 2 km, the speed of the traffic slowed (to 30 km/h or less).
09:11:34 Speed: 30 km/h
Traffic in the right lane slowed approx. 20 seconds earlier.
The traffic jam was alleviating, so the situation is believed to have occurred because of the time lag between when the data was generated and when the location was reached.



At the point when the vehicle passed the location indicated in the data, there was no traffic jam and the traffic was steady
09:09:30 Speed: 54 km/h

[Issues, verification items, and targets]

Issues

- **Clarify environmental conditions required for practical implementation of level 4 ART in mixed transportation environments**

Verification items

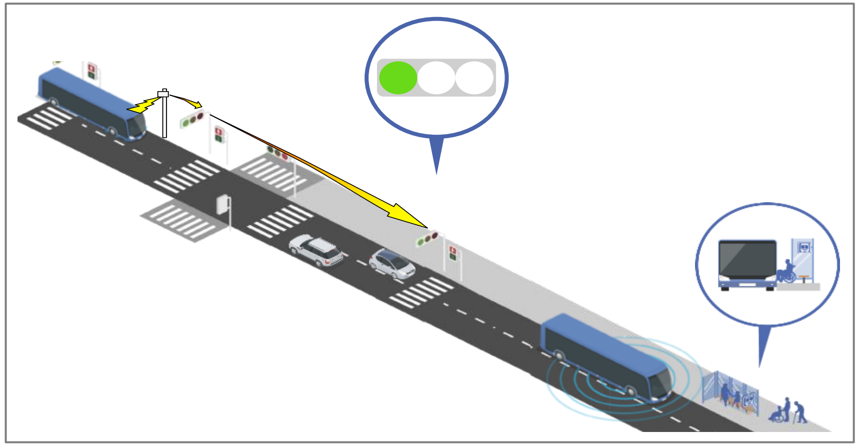
(1) Analysis of factors necessitating driver involvement in mixed transportation environments
  (a) Confirm implementation of automated driving in mixed transportation environments
  (b) Assess factors that can cause manual intervention
(2) Effectiveness of cooperative infrastructure in regularly scheduled transport
  (a) Confirm effectiveness of PTPS in improving arrival speed and punctuality
  (b) Confirm impact on driving in situations involving signal recognition difficulty
  (c)GNSS measurement deviation during automated driving
(3) Comfort when boarding/exiting
  (a) Assess acceleration when stopping and accelerating from a standstill
  (b)Evaluation of reproducibility of precision docking control
(4) Assessment of impact of automated vehicle driving on traffic flow, and factors causing this impact
  (a) Changes in traffic jam conditions resulting from the installation of a bus lane
  (b) Autonomous bus and ordinary bus processing times
  (c) Conflict occurrence related to autonomous buses

Benefits of cooperative infrastructure technologies

- Implement automated driving which does not require driver involvement
- Implement regularly scheduled transport
- Improve comfort (bus stop curb docking, gradual acceleration and braking)

Targets

- **Clarify which infrastructure is required for the expansion of ODD**
- **Identify what infrastructure conditions are required for the improvement of ART service**
- **Clarify issues to be addressed in order to cultivate a sense of acceptability in society**

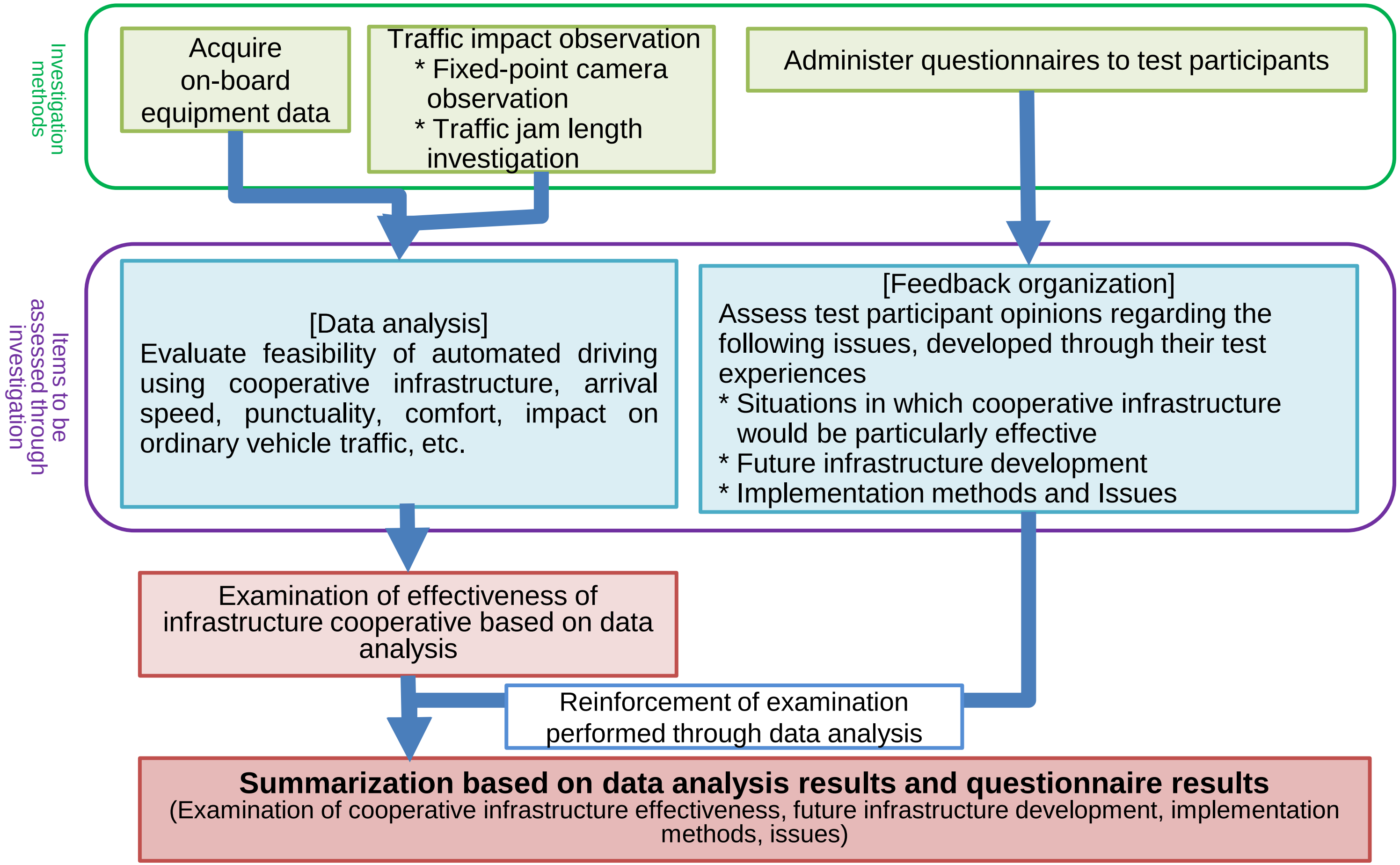


ODD: Operational Design Domain
ART: Advanced Rapid Transit

5. Results of the FOTs in the Haneda Airport area

Investigation procedures and procedure up through evaluation result and proposal draft creation

In addition to feedback from test participants, evaluation results and proposal drafts were created for the results of analyses of on-board equipment data and data from fixed-point camera observation and traffic jam length studies.



(1) Analysis of factors necessitating driver involvement in mixed transportation environments

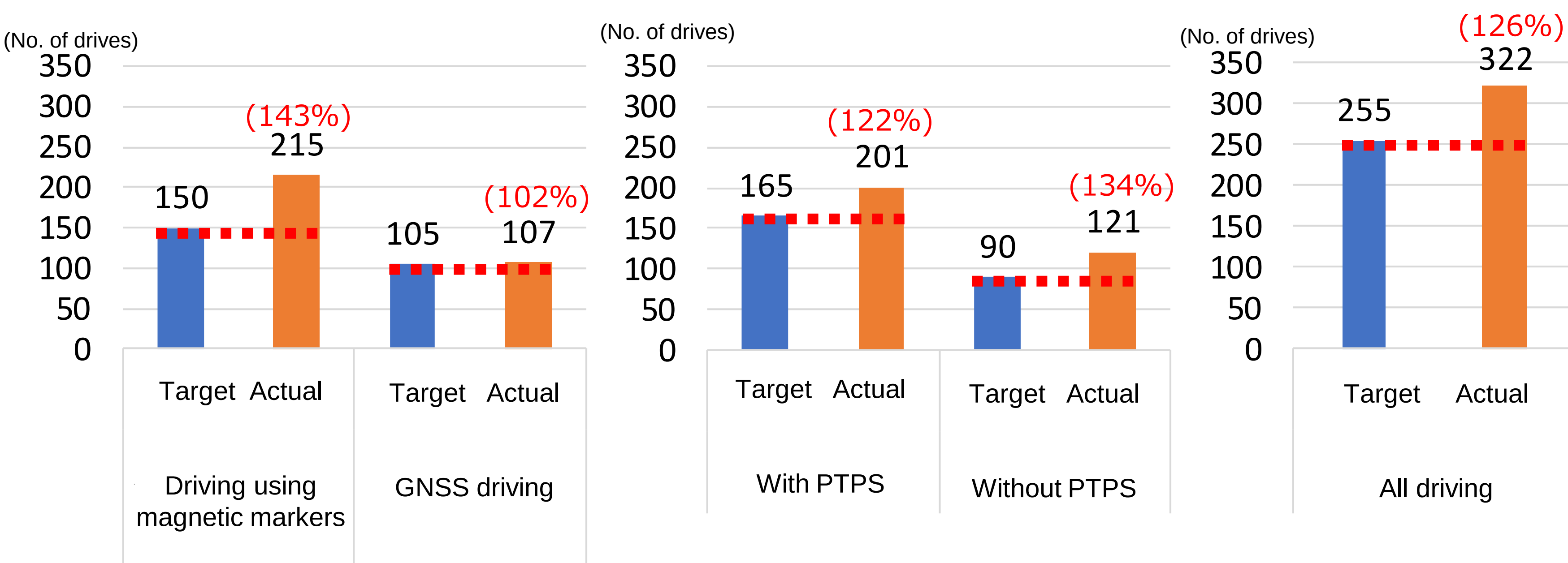
(a) Confirm implementation of automated driving in mixed transportation environments

◆ Confirmation of the number of route drives using automated driving in comparison to the target number of route drives

[Analysis results]

* The number of route drives using automated driving* exceeded the target number of route drives (the number of driving samples deemed necessary for performing statistically significant evaluation).
  * Drives were counted as being performed using automated driving even if there was momentary manual intervention as long as manual driving was not sustained or continuous.

Target number of route drives and driving results to date(total for three companies: No. of drives from June to November)



Figures in parentheses in red indicate achievement rates compared to targets

5. Results of the FOTs in the Haneda Airport area

(i) Target | (ii) Hypothesis | **(iii) Macro** | **(iv) Micro** | (v) Recommendations

(1) Analysis of factors necessitating driver involvement in mixed transportation environments
(b) Assess factors that can cause manual intervention (magnetic marker driving)

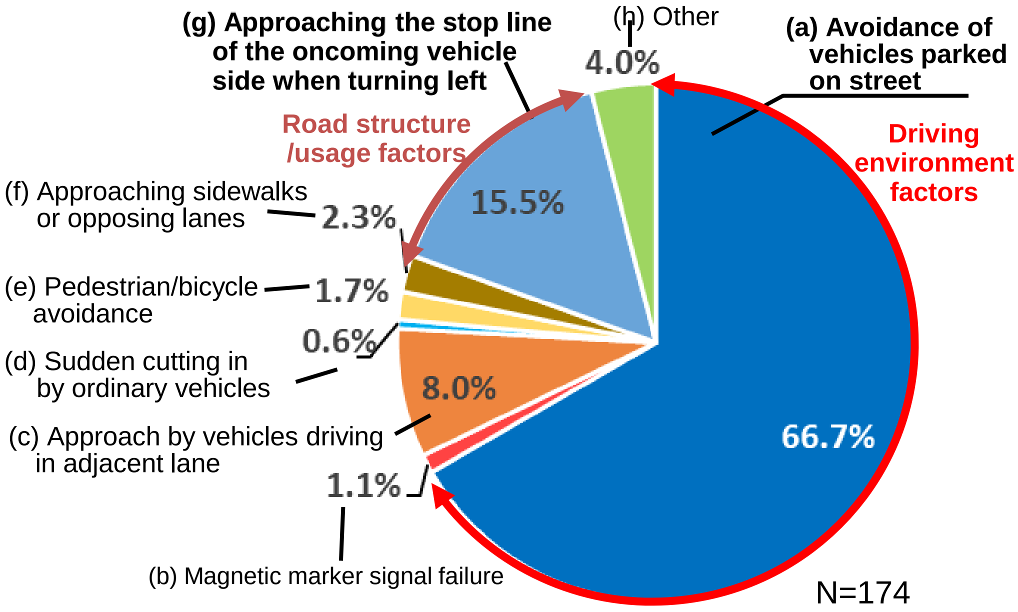
◆ We confirmed situations in which manual intervention occurred while automated driving was being performed and assessed the contributing factors

[Analysis results]

* Approximately 80% of manual intervention was due to “(a) avoidance of vehicles parked on streets” or “(g) approaching the stop line of the oncoming vehicle side when turning left”

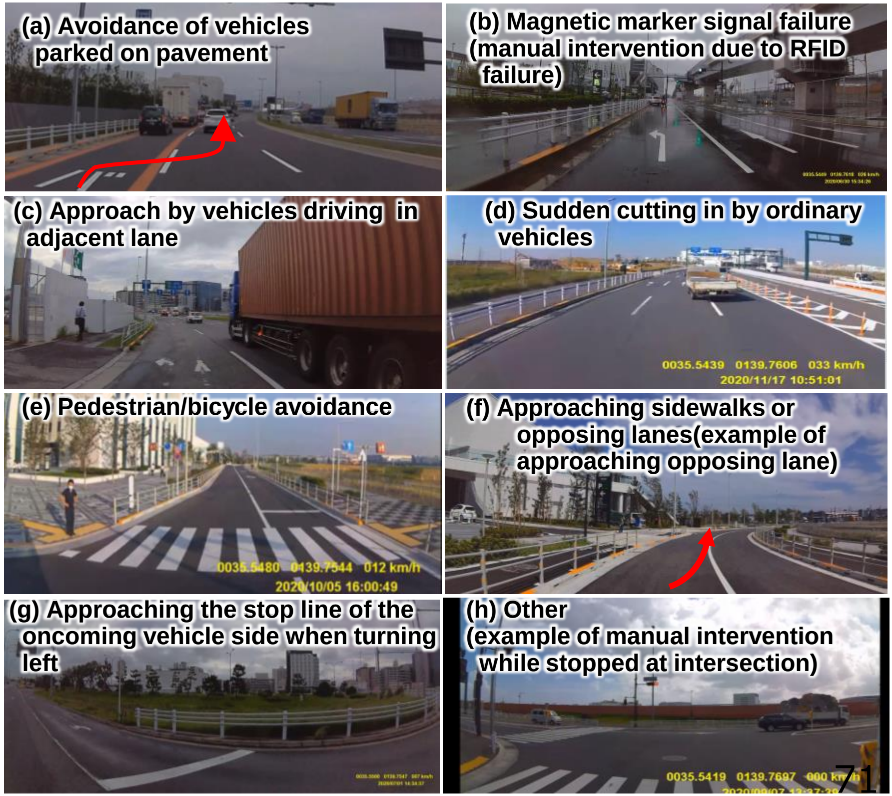
→ Automated driving function continuity is expected to increase as the result of driving environment improvement measures to address (a) and road structure and usage improvements (stop line position adjustment, etc.) to address (g)

Composition rates of the causes of manual interventions during magnetic marker driving (applies to manual intervention by companies A and B)



↔ Driving environment factors (potential for reductions through improvement of driving environment)

↔ Road structure and usage factors (potential for reductions through improvement of road structures and their usage)



5. Results of the FOTs in the Haneda Airport area

(i) Target | (ii) Hypothesis | **(iii) Macro** | (iv) Micro | (v) Recommendations

(1) Analysis of factors necessitating driver involvement in mixed transportation environments
(b) Assess factors that can cause manual intervention (magnetic marker driving)

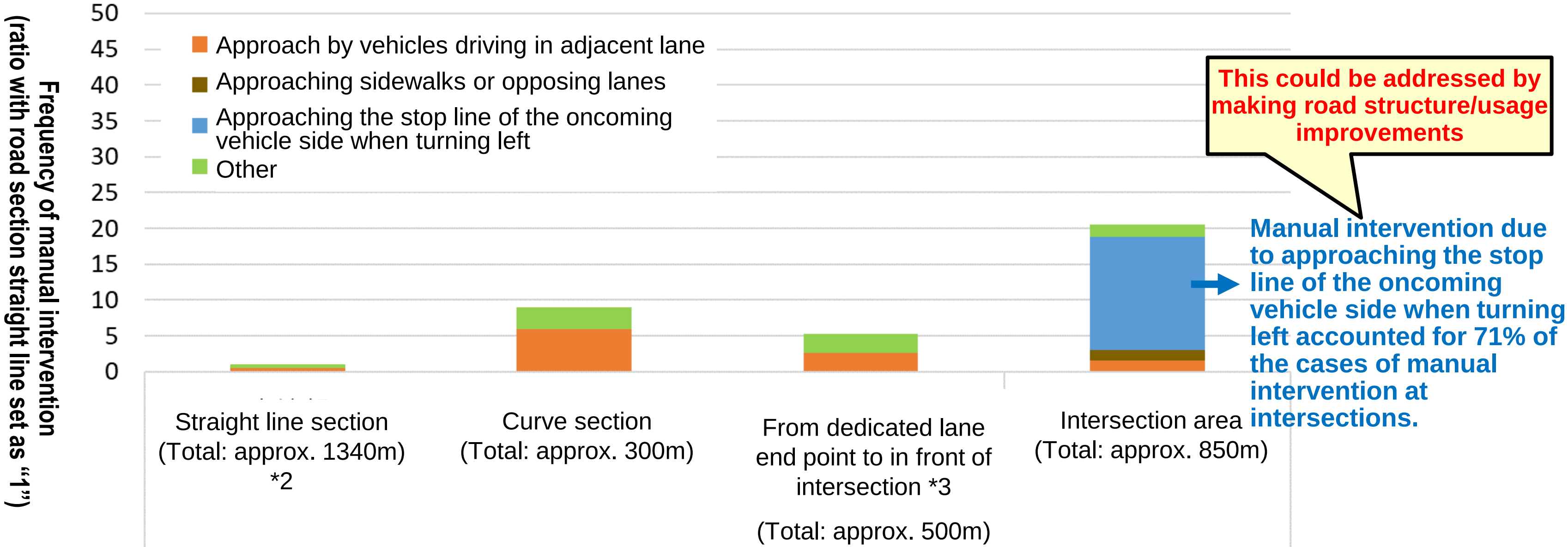
◆ Data for locations where manual intervention took place was organized by road structure and factor

[Analysis results]

・The incidence of manual intervention was high for intersections, but the majority of these consisted of manual intervention due to approaching the stop line of the oncoming vehicle side when turning left.

→The continuity of automated driving functions could be improved by making improvements to road structures and usage at intersections (adjusting stop line positions, etc.).

Ratio of manual intervention factors by road structure (Total for companies A and B: Driving using magnetic markers)*1



*1:Excluding manual intervention in special exception locations (areas with large amounts of on-street parking, area near Terminal 3, etc.) and due to on-street parking

*2:The figure in "(Total: approx. ○m)" refers to the total distance per route drive

*3:Refers to the section between where a dedicated lane ends and 30 meters in front of the intersection

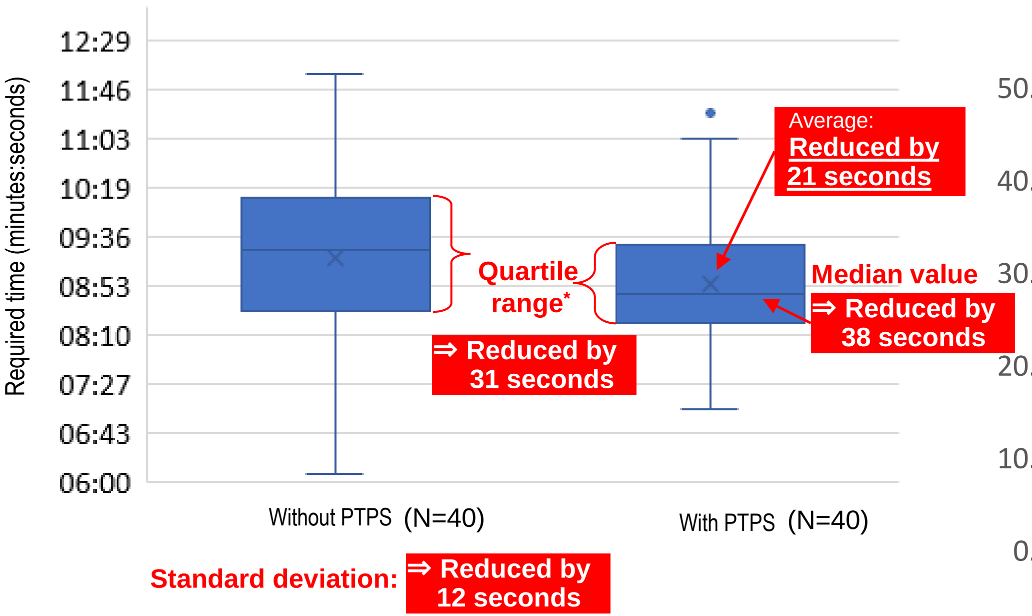
5. Results of the FOTs in the Haneda Airport area

(2) Effectiveness of cooperative infrastructure in regularly scheduled transport
(a) Confirm effectiveness of PTPS in improving arrival speed and punctuality

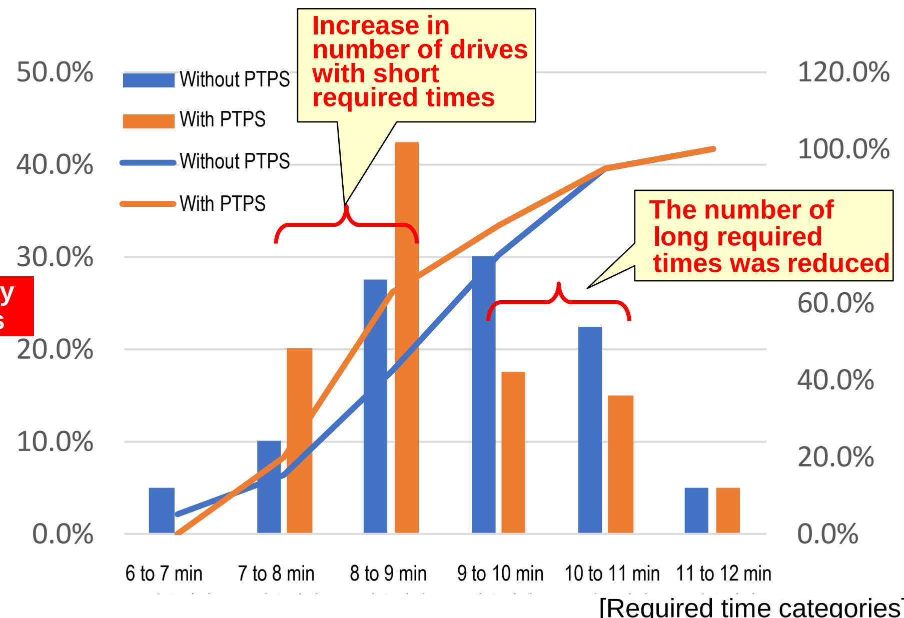
◆ Confirm effectiveness of PTPS in reducing required time and improving punctuality based on required time, standard deviation information, etc.

[Analysis results]
* The average required time per route when using PTPS was reduced by 21 seconds (approx. 4%), and the amount of disparity in required times was greatly reduced
→ **We quantitatively confirmed that PTPS contributed to speediness and punctuality**

Comparison of statistics related to required times with/without PTPS (for drives by Company C)



Comparison of distribution of required times with/without PTPS (for drives by Company C)



*Quartile range: One indicator of amount of disparity. Calculated by subtracting the 25 percentile required time from the 75 percentile required time.

5. Results of the FOTs in the Haneda Airport area

(3) Comfort when boarding/exiting

(a) Assess acceleration when stopping and accelerating from a standstill

◆ Assess incidence frequency for each maximum longitudinal acceleration category when stopping at or starting from a standstill at intersections and bus stops

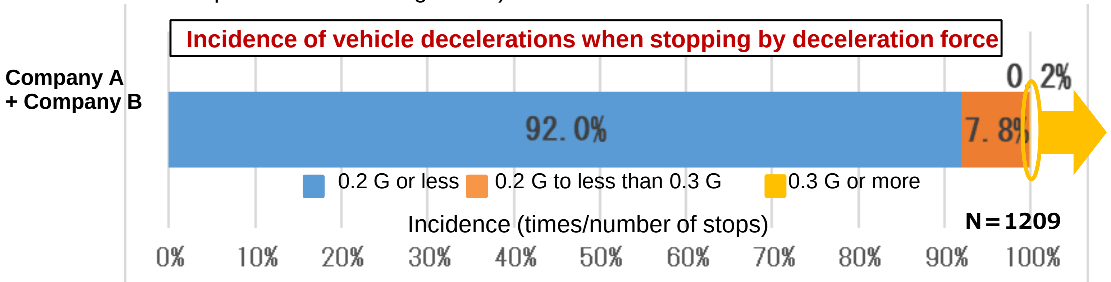
[Analysis results]

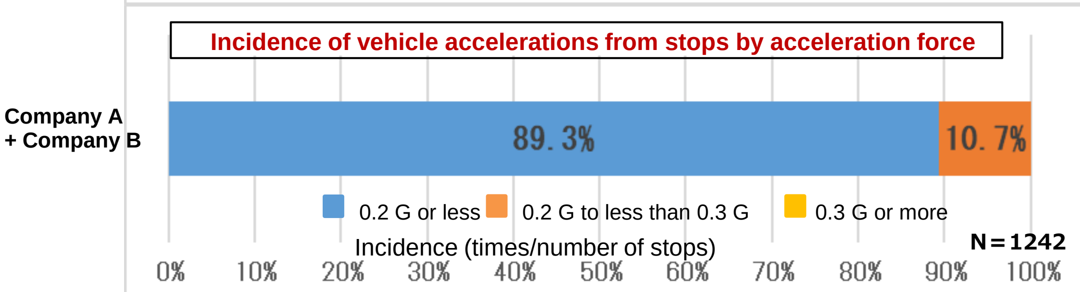
* Approximately 90% of stops and starts from standstills were done at acceleration or deceleration rates that do not cause passenger discomfort (0.2 G* or less), and the acceleration and deceleration were smooth enough that they did not present problems for standing passengers.

 * In drivers' education for heavy vehicle class 2 drivers licenses, the rule of thumb is that acceleration and deceleration rates must be 0.2 G or below to avoid subjecting passengers to discomfort.

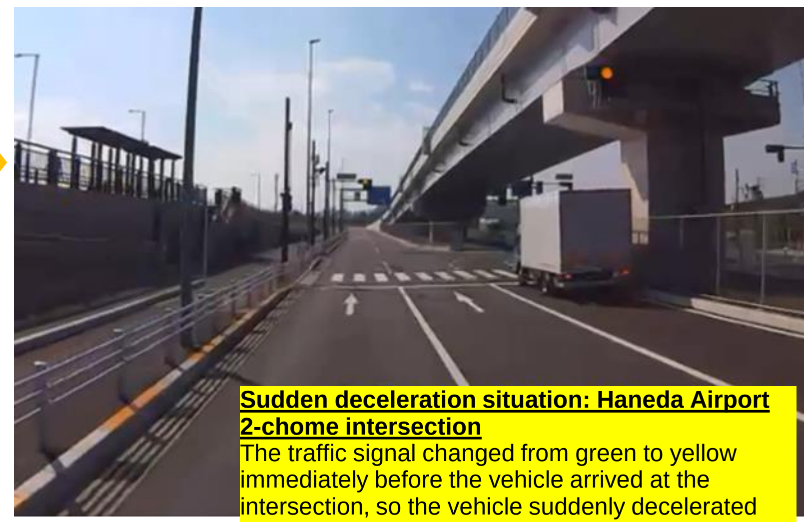
* The sudden deceleration of 0.3G or greater occurred because the traffic light turned yellow just before the vehicle entered the intersection
→ In the future, the use of traffic signal remaining seconds information is expected to eliminate the problem of sudden deceleration

◆ Incidence of vehicle acceleration/deceleration by acceleration/deceleration force (Company A + Company B, driving using magnetic markers)
(Data regarding maximum acceleration and deceleration rates for the 20 seconds before and after each vehicle stop and start were organized)





[Example of situation involving a deceleration of 0.3 G or more]



Sudden deceleration situation: Haneda Airport 2-chome intersection
The traffic signal changed from green to yellow immediately before the vehicle arrived at the intersection, so the vehicle suddenly decelerated

(3) Comfort when boarding/exiting

(b) Evaluate reproducibility of precision docking control

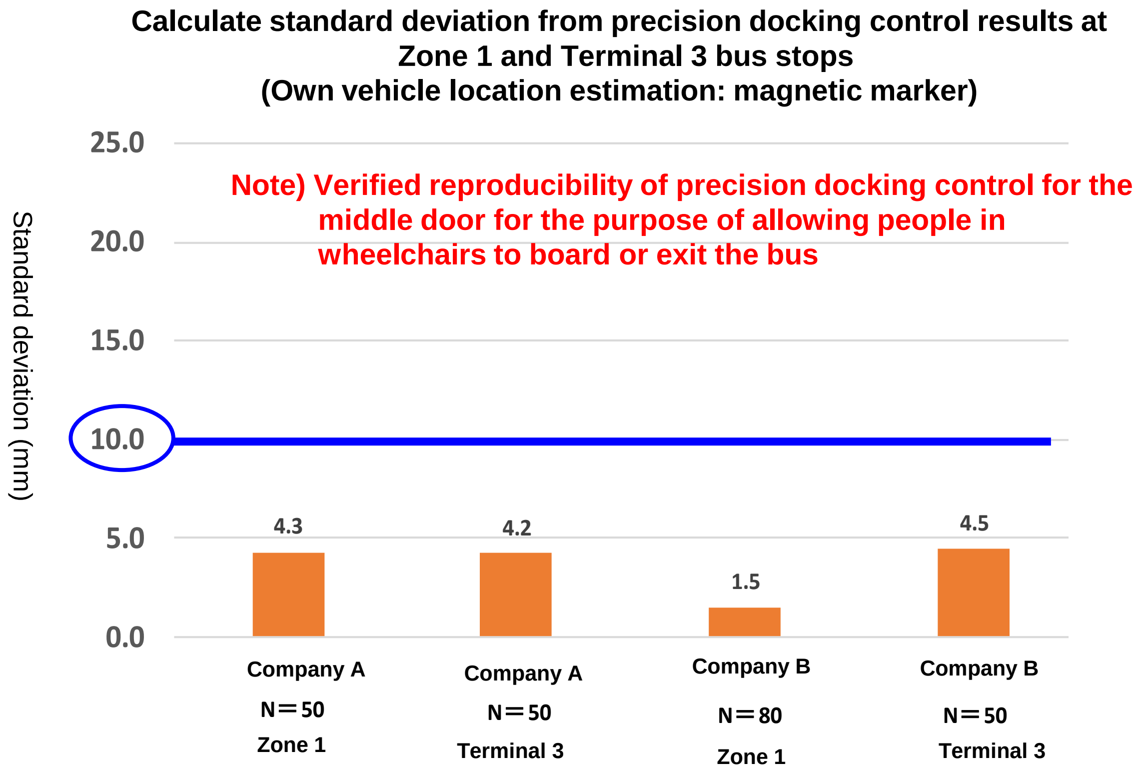
◆ Confirm degree of autonomous bus precision docking control reproducibility based on standard deviation between bus stop and bus when using precision docking control.

[Analysis results]

* Magnetic markers made it possible to perform precision docking control with a high degree of reproducibility (standard deviation of less than 10 mm) in Zone 1 and Terminal 3

Zone 1 bus stop

Terminal 3 bus stop



(5) Main feedback from test participants regarding prepared infrastructure in the Haneda Airport area

Below is feedback regarding the infrastructure development, infrastructure operation, and the effectiveness of infrastructure equipment in automated driving

Prepared infrastructure	Opinions regarding effectiveness	Opinions regarding future infrastructure preparation and operation approaches and issues
Magnetic markers	* Magnetic markers are effective in environments where GPS signals are blocked, where a high level of positioning control is necessary, or where there is little tolerance for deviation from actual driving trajectories.	* In locations (such as bus stops) where vehicles must estimate their own positions with a high degree of accuracy, and in locations with small turn radiuses, it would be best for the markers to be spaced relatively close to each other. * Numerous magnetic markers with RFID should be placed in locations with narrow turn radiuses. * In intersections, markers should be spaced evenly. * Consideration must be given when spacing markers far apart on straight road sections. * Consideration must be given to standardizing or creating guidelines concerning sensor locations.
Traffic signal information	* Traffic signal information is effective for avoiding sudden braking and safely decelerating to stop at red traffic lights.	* Traffic signal information is necessary for achieving safe automated driving. Furthermore, communication reliability should be improved and this technology should be widely used. * Confirming remaining seconds information and providing it to vehicles is effective for vehicle control. * Remaining seconds information could be made even more effective by communicating it to other traffic participants.
PTPS	* When using PTPS, there were route drives with multiple consecutive green lights.	* Notifications of PTPS control operation status should be provided to the vehicle.
Bus-only lanes	* Bus-only lanes involved few interactions with other vehicles and were effective for achieving safe driving.	* There is a need to increase awareness that ordinary vehicles must not drive in bus-only lanes or park on streets, and new ideas must be applied to pavement markings and signs to that effect. * Further consideration must be given to how to use the bus-only lanes and (especially) how to set them up in intersections.
Other	* Measures should be developed to improve the reliability of wireless PTPS uplinks. * Consideration should be given to the positions of oncoming vehicle stop lines in order to secure clearance from oncoming vehicles when turning left at intersections. * When considering the driving of large buses, it would be best for road structures to have some degree of leeway, such s large road radiuses and widths.	

5. Results of the FOTs in the Haneda Airport area

(i) Target | (ii) Hypothesis | (iii) Macro | (iv) Micro | **(v) Recommendations**

[Infrastructure effectiveness and proposed required infrastructure conditions]

- Magnetic markers
  - If prioritizing infrastructure preparation, highest priority should be given to locations where GNSS vehicle location accuracy is low and bus stops where precision docking control is used.
  - When preparing this infrastructure, improvements should be made to the roadway traffic environments, road structures, and road operation methods which can lead to manual intervention (such as by adjusting stop line locations).
  - Markers should be placed close together for locations with narrow turn radiuses, such as intersections.
- Traffic signal information/PTPS
  - Traffic signal information should be provided for smooth automated driving in situations where traffic signal identification is difficult, such as when traffic signal colors are obstructed by large vehicles.
  - It would be best to provide confirmed remaining seconds information after PTPS operation, etc., has been performed so that this traffic signal information could be used more effectively.
- Bus-only lanes
  - Bus-only lanes could help increase the continuity of automated driving at the current automated driving level, in which on-street parking makes continuous automated driving difficult.
  - For bus-only lanes to function effectively, it is important to implement additional publicity and awareness-raising regarding the behavior of automated vehicles, thoroughly inform drivers by using bus-only lane signs, and emphasize the need for compliance with bus-only lane rules.

[Impact of automated vehicle driving on traffic flow]

- The amount of traffic volume that was processed may decrease slightly when autonomous buses are present, so in future societal deployment, the impact on traffic where these routes are in use must be confirmed in advance.
- No crossing road traffic jams were caused by using PTPS to extend green lights and shorten red lights.