Strategic Innovation Promotion Program (SIP)
Phase Two – Automated Driving
(Expansion of Systems and Services)

Research on measures for the utilization of V2X information for ensuring traffic safety under mixed traffic conditions

Progress Report for Fiscal Year 2018

March 2019

UTMS Society of Japan
Pacific Consultants Co., Ltd.

1. Outline of the Project

<Purpose>

To contribute to the utilization of V2X information for ensuring traffic safety under mixed traffic conditions in which ordinary vehicles and automated driving vehicles coexist, the project investigates methods for utilizing vehicle-to-vehicle communication information and probe information for the evaluation of the impacts of automated driving vehicles on existing traffic flow and for the implementation of traffic control that responds to the evaluation.

<Outline>

(1) Examination of methods for investigating impacts of the travel of automated driving vehicles on traffic flow
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(2) Identification of the types of vehicle-to-vehicle communication information that can be utilized for traffic control operations
[UTMS Society of Japan]

(3) Examination of methods for utilizing vehicle-to-vehicle information in traffic control operations
[UTMS Society of Japan]

2. Flow of examining methods for investigating and analyzing impacts of the travel of automated driving vehicles on traffic flow

2.1
Identification of scenes in which coexistence with automated driving vehicles on public roads could affect traffic flow

Exhaustive identification of possible scenes in which automated driving vehicles traveling on roads mixed with ordinary vehicles affect traffic flow.

2.2
Identification of data that may be used to analyze impacts on traffic flow in the field operational test

Identification of data items and data collection intervals for data including probe data collected by the government and private sectors and vehicle-to-vehicle communication information that may be able to be obtained and used for analysis in the field operational test.

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2.3
Examination of methods of analyzing the impacts of automated driving vehicles on traffic flow observed during the field operational test

Examination of methods of investigating and analyzing the occurrence or non-occurrence of the impacts of automated driving vehicles on traffic flow for each of the scenarios in which the occurrence of the impacts are expected, based on the results of the identification 2.1 and 2.2 described above, by using the data that can be obtained during the field operational test

2.1 Identification of scenes in which coexistence with automated driving vehicles on public roads could affect traffic flow

To identify scenes, the following performances were assumed.

- Performance of automated driving vehicles: In comparison with ordinary drivers, conservative and low performance cases and proactive and high performance cases were assumed.
- Performance of automated driving vehicles were qualitatively assumed according to differences in levels of ordinary drivers, instead of setting up specific numerical values.

Classification	Driving performance (≒Items of simulation parameters)	Ordinary drivers	Automated driving vehicles (1) Conservative and low performance	Automated driving vehicles (2) Proactive and high performance
Startup determination	Startup (Startup delay)	Startup delay occurs to around first three vehicles in the queue. The occurrences vary	Startup delay occurs	No startup delay (due to acquisition of signal information and V2V communication information)
During driving	Driving lane keeping	Cases exist in which vehicles unnecessarily drive in a passing lane	Selects the current driving lane unless another lane is necessary	
During free driving	Speed (desired speed)	There is variability depending on the current speed	Uniform within the range of regulation speed	
	Acceleration or deceleration (Maximum/desired acceleration and deceleration rate)	There is variability	Uniform at a more moderate acceleration or deceleration rate	
Right turn determination	Right-turn gap acceptance	There is variability in Right-turn gaps	Longer minimum gap	Shorter minimum gap
:	:	:	:	:

State of automated driving vehicle

- Straight-forward travel
- Right turn
- Left turn
- Course change

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Vehicle location

- Single route section: with an adjacent vehicle traffic lane
- Single route section: Without an adjacent vehicle traffic lane
- Intersection: Inside
- Intersection: Outside

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Subjects of determination

- Front vehicle
- Rear vehicle
- Oncoming vehicle
- Other (people, light vehicles, fallen objects, etc.)

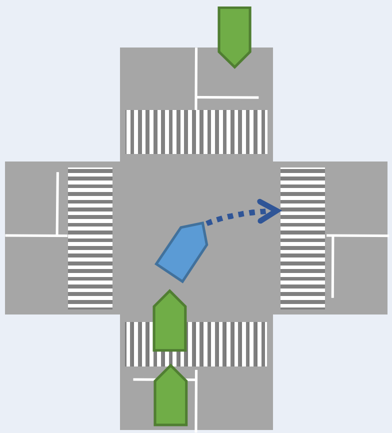
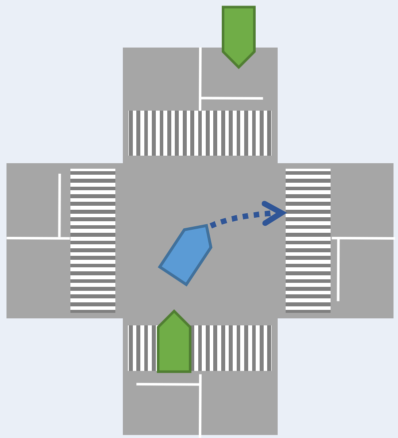
Basic case: 4 x 4 x 4 = 64 patterns

- Impacts on traffic flow are examined from two viewpoints of smoothness and safety.
- It is conceivable that higher performance of automated driving vehicles than that of ordinary drivers and their higher penetration rate will have positive impacts on traffic flow, because driving behavior becomes uniform.
- By contrast, there is a concern that lower performance of automated driving vehicles than that of ordinary vehicles and their low penetration rate will have negative impacts on traffic flow, because of the traffic mixed with vehicles with different driving behavior (particularly the driving behavior that is not smooth).

2.1 Identification of scenes in which coexistence with automated driving vehicles on public roads could affect traffic flow

Scenes of the 64 patterns in the basic case described in the previous page, in which the volume of automated driving vehicles have impacts on traffic flow, were identified for each of the conservative and low performance and the proactive and high performance.

〇Example of identification results (right turn x intersection (inside) x oncoming vehicle)

State of automated driving vehicle	Right turn	
Vehicle location	Intersection (inside)	
Subject of determination	Oncoming vehicle	
Performance	Conservative and low performance	Proactive and high performance
Image of scenes Automated driving vehicle Other vehicle Obstacle Pedestrian		
Impacts on smoothness	● Because vehicles turn right by waiting for a sufficient gap, the time the vehicles are stopped in the intersection increases, resulting in decrease in right-turn flow rate.	● The number of right-turn vehicles discharged increases because vehicles turn right smoothly by judging the movement of oncoming straight-ahead vehicles and (right-turning) vehicles in front.
Impacts on traffic flow	—	—

2.2 Identification of data that may be used to analyze impacts on traffic flow during the field operational test

The data that may be used to analyze impacts on traffic flow during the field operational test was identified by classifying them into three categories, from (1) to (3).

(1) Traffic-related data that can determine the total number of vehicles surrounding a test vehicle.
・Constantly monitored data from vehicle detectors, VICS, etc.
・Data that are considered effective and therefore should be acquired by installing equipment during the Field Operational Test (data from roadside cameras and others)

(2) Traffic-related data that provides accurate understanding on vehicles surrounding the test vehicle in the form of samples.
・Government and private probe data, vehicle-to-vehicle communication information

(3) Traffic-related data that can be measured by a test vehicle.
・Information from sensors and cameras installed on a test vehicle

◯ Example of identification results (traffic-related data that can determine the total number of vehicles surrounding a test vehicle)

Data source	Acquired data items					Remarks
	Traffic volume	Speed	Lane change	Vehicle trajectory	Close calls and near misses	
Vehicle detector	◯ Specific cross sections	◯ ※May be used depending on the purpose	–	–	–	Every 5 minutes
VICS information	–	◯ Information on 3 congestion levels of main roads, namely heavy congestion, light congestion and smooth traffic	–	–	–	Every 5 minutes
Installation of simple traffic counter	◯ At arbitrary points	◯ At arbitrary points	–	–	–	Accuracy of the count for inside lanes decreases in the case of multiple lanes
Installation of cameras (at low position such as sidewalk)	◎ At arbitrary points by lane	◎ At arbitrary points, by lane, Storage length	◯ Arbitrary points, by lane,	–	◯ Counting of number of times	Multiple cameras may need to be installed for storage length measurement
Installation of cameras (at high position such as surrounding buildings and lighting poles)	◎ At arbitrary points by lane	◎ At arbitrary points, by lane, Storage length	◯ At arbitrary points, by lane; trajectory and gap can also be measured	◯ Trajectory of following vehicles, oncoming vehicles, etc.	◎ Acceleration rate can also be measured in addition to number of times	High places where cameras can be installed are needed in the vicinity

2.3 Examination of methods of analyzing impacts of automated driving vehicles on traffic flow observed during the field operational test

As a method of analysis, evaluation in two stages, namely a field verification and a simulation verification that utilizes the results of the field verification was examined.

Time	Schedule for field operational test	Field verification	Simulation verification
Fiscal year 2018	• Examination of test contents • Recruitment of test participants	• Examination of methods of investigation and analysis	• Examination of methods of investigation and analysis
Fiscal year 2019	• Explanation to test participants • The test starts around fall	• Examination of data acquisition method and its preparation • Acquisition of data of ordinary vehicles (current state)	• Construction of simulation models • Replication of the current state of ordinary vehicles
Fiscal year 2020	• Implementation of the field operational test	• Acquisition of data of the field operational test • Implementation of the field verification	• Implementation of simulations utilizing the results of the field verification

- Field verification: Verification of the occurrence or absence of, frequency of, and occurrence conditions for assumed scenes in which automated driving vehicles could have impacts, using data obtained during the field operational test.

- Simulation verification: Evaluation of impacts for cases in which the penetration rate and performance of automated driving vehicles change, after setting the performance of automated driving vehicles based on the results of the field verification
  - The evaluation is assumed to be mainly from the viewpoint of smoothness, because safety evaluation is not easy from the aspect of accuracy.
  - Because it is difficult to evaluate all of the 64 assumed scene patterns, scenes to be analyzed were selected taking into consideration the scenes that have particularly significant impacts, possibility to obtain data during the test and others. (In the cases of ordinary roads, intersection areas are assumed to be the main target of analysis from the standpoint of smoothness.)
  - About two scales are assumed to be set for the performance of automated driving vehicles (conservative and low performance ⇔ proactive and high performance) and about three scales (low, medium, high) for penetration .

2.3 Examination of a method of analyzing impacts of automated driving vehicles on traffic flow observed during the field operational test

Data required to perform simulations were identified as follows:

Stage	Data required	Utilization	Method to acquire data (draft)
Network configuration	Road shape information	Required for basic simulation setting	Web maps
	Setting of the number of seconds and cycle length	Required for basic simulation setting	Materials provided by the police Videos from fixed cameras
Reproduction of current situation	Startup delay	Used for setting the startup performance of ordinary vehicles	Videos from fixed cameras Past literature
	Inter-vehicle distance/time headway distribution	Used for setting the tracking performance of ordinary vehicles	Videos from fixed cameras Past literature
	Lane change judgment/right turn judgment	Used for lane change judgment/right-turn judgment performances of ordinary vehicles	Videos from fixed cameras Past literature
	Acceleration and deceleration and stop	Used for the setting of acceleration and deceleration performances and others of ordinary vehicles	Videos from fixed cameras Past literature
Data acquired during filed verification	Start delay	Used for the setting of startup performance of automated driving vehicles	Videos from fixed cameras
	Inter-vehicle distance/time headway distribution	Used for the setting of tracking performance of automated driving vehicles	Millimeter-wave radars, GPS location data, speed data Videos from fixed cameras
	Lane change judgment/right turn judgment	Used for the setting of lane change judgment/right-turn judgment performances of automated driving vehicles	Videos from fixed cameras
	Acceleration and deceleration and stop	Used for the setting of acceleration and deceleration performances and others of automated driving vehicles	GPS location data, speed data, acceleration and deceleration data Videos from fixed cameras
Reproduction of behavior of automated driving vehicles during experiment	Traffic volume by lane/Left turn to right turn ratio/speed	・Used for the reproduction of current situation in simulation ・Used for traffic volume estimate ・Used for the evaluation of impacts of automated driving vehicles at the time of introduction	Vehicle detector data Traffic volume survey Videos from fixed cameras

2.3 Examination of a method of analyzing impacts of automated driving vehicles on traffic flow observed during the field operational test

Of the scenes in which impacts are assumed, draft field verification methods for the basic road section were identified.

State	Judgment target	Impacts on traffic flow (assumption)		Field verification		
		Conservative and low performance	Proactive and high performance	Analysis item	Analysis data	Analysis method
Straight traveling	Front vehicle	・Low-speed driving in consideration of maintaining longer headway or performance and safety of the vehicle causes light congestion in the following vehicles, resulting in the emergence of a new congestion area. ・The need to secure headway in preparation for a cutting-in vehicle that cuts in between the vehicle and a front vehicle causes light congestion in the following vehicles. ・Aggressive overtaking occurs by a vehicle frustrated with an automated driving vehicle driving at a low speed in compliance with regulation speed or in consideration of vehicle performance and safety, resulting in increase in accident occurrence probability. ・Unable to judge the state of front vehicles (stopped, congestion due to accident, waiting for entry into roadside parking, etc.) and therefore stops behind a front vehicle.	・Headway becomes uniform and shorter, dissipating traffic congestion and lowering accident occurrence probability	・Change in headway during driving	• Inter-vehicular distance measurement information (millimeter waves, etc.)	・Aggregate calculation of average and variation
				[Evaluation of impacts on following vehicles] ・Speed of the following vehicle ・Headway of the following vehicle ※Hereafter such evaluation is referred to as [Evaluation of impacts on following vehicles].	・Government and private probe information ・Simple vehicle detector ・Roadside camera	・Comparison of average speed ・Measurement of cross-section headway ・Identification of relationship between headway (flow rate) and accident occurrence probability)
				・Number of times of cutting (lane change) in front of a vehicle ・Number of times of overtaking	・On-board camera	・Confirmation of the occurrence of cut-in of vehicles ・Qualitative identification of risks from the positional relation between an overtaking vehicle and oncoming vehicle
				・Number of occurrences/frequency and duration of stops	・Speed data (number of times and duration of stops ・On-board camera	・Aggregate calculation from the number of times and duration when the speed became 0 ・Visual cause analysis
	Other	・The number of stops increases due to pedestrians and cyclists on the sidewalk area (particularly around crossings), causing light congestion in the following vehicles. ・Unable to detect obstacles and others early, causing stops to occur. ・Speed is maintained even in sag sections and others, dissipating congestion. ・Stops (rapid decelerations) and snaking caused by GPS communication disconnection may induce contact accidents	・Performs flexible route changes by obtaining information about fallen objects and obstacles on travel routes. ・Speed is maintained even in sag sections and others, dissipating congestion.	・Number of occurrences/frequency and duration of stops for pedestrians on the sidewalk section, cyclists and obstacles	・Speed data (number of times and duration of stops ・On-board camera	・Aggregate calculation from the number of times and duration when the speed became 0 ・Visual cause analysis
				・Number of occurrences/frequency and duration of stops (rapid deceleration)/snaking	・On-board camera	・Qualitative identification of risks caused by stops (rapid decelerations) and snaking
				[Evaluation of impacts on following vehicles]		
Right turn	On-coming vehicle	・Because vehicles turn right by waiting for a sufficient gap, the time they are stopped in a lane increases, resulting in lower per-lane capacity than before.	・Startup delay decreases when right-turn vehicles are in a queue at the entrance of large-scale commercial facilities, etc., resulting in an increase in the number of right-turn vehicles discharged.	・Right-turn gap ・Number of right-turn vehicles discharged	・Simple vehicle detector ・Roadside camera	・Measurement of right-turn cross section headway ・Measurement of the number vehicles discharged
				[Evaluation of impacts on following vehicles]		
	Other	・Stops caused by delayed judgment for pedestrians on a sidewalk and resulting decrease in the number of right-turn vehicles discharged	・Increase in the number of right-turn vehicles discharged as a result of smooth right turns determined from the movement of crossing pedestrians	・Number of occurrences/frequency and duration of stops	・Speed data (number of times and duration of stops ・On-board camera	・Calculation from the number of times and duration when the speed became 0 ・Visual cause analysis
				(For the number of right-turn vehicles discharged, analysis data and method are the same as those of oncoming vehicles in the column above.) [Evaluation of impacts on following vehicles]		
Left turn	Other	・Stops caused by delayed judgment for pedestrians on a sidewalk and resulting decrease in the number of left-turn vehicles discharged	・Increase in the number of vehicles discharged as a result of a quick judgment on the sidewalk situation following a judgment by the front vehicle.	・Number of left-turn vehicles discharged	・Roadside camera	・Measurement of the number vehicles discharged
				[Evaluation of impacts of following vehicles]		
Course change	Front/ rear/ Oncoming vehicle	・When a vehicle tried to change course, stop and delay in changing course occurs due to judgment on rear, front and oncoming vehicles, causing subsequent congestion. ・Dangerous overtaking occurs by a vehicle frustrated with an autonomous vehicle which is confused in making judgment. ・Cautious course change being made by an automated driving vehicle was blocked by the following vehicle, inducing a contact accident and causing subsequent congestion. ・Lower accident occurrence probability due to a decrease in unnecessary course changes	・Decrease in accidents with a front, rear and oncoming vehicle as a result of appropriate situation judgment when trying to change a course. ・Lower accident occurrence probability due to a decrease in unnecessary course changes	・Number of times of course changes ・Gap in the course change destination lane	・Inter-vehicular distance measurement information (millimeter waves, etc.) ・On-board camera	・Course change factor analysis ・Aggregation of inter-vehicular distance with a front vehicle ・Qualitative identification of risks caused by overtaking and course obstruction

2.3 Examination of a method of analyzing impacts of automated driving vehicles on traffic flow observed during the field operational test

Of the scenes in which impacts are assumed, draft field verification methods for the intersection part were identified.

State	Judgment target	Impacts on traffic flow (assumption)		Field verification		
		Conservative and low performance	Proactive and high performance	Analysis item	Analysis data	Analysis method
Straight traveling	Front vehicle	・Unable to judge on a front vehicle (stopped, accident congestion, waiting for entry into roadside parking, etc.) and continues to stop before an intersection, resulting in an decrease in the number of vehicles discharged. ・If a sufficient clearance is not secured on the side of a vehicle waiting for right turn, it continued to stop before an intersection , resulting in an decrease in the number of vehicles discharged. ・In the case of front vehicles with high height, the recognition of signal light delays, causing a vehicle to stop longer at an intersection, resulting in a decrease in the number of vehicles discharged.	・Increase in the number of vehicles discharged compared to the past due to earlier startup when the signal light changes ・Able to judge passing and others of front and right-turn waiting vehicles, allowing a vehicle to pass through without problem.	・Number of occurrences/frequency and duration of stops at a stop line	・Speed data (Number and duration of stops) ・Video from on-board cameras	・Aggregate calculation from the number of times and duration when the speed became 0 ・Visual cause analysis
				・Headway ・Number of vehicles discharged	・Roadside camera	・Headway in the order of passage through intersections ・Measurement of the number vehicles discharged
				[Evaluation of impacts on following vehicles] ・Speed of following vehicles ・Headway of following vehicles ※Hereafter such evaluation is referred to as [Evaluation of impacts on following vehicles].	・Roadside camera ・Simple vehicle detector ・Government and private probe	・Average speed ・Cross-section headway ・Identification of relationship between headway (flow rate) and accident occurrence probability)
	Other	・Decrease in the number of vehicles discharged due to early stopping of a vehicle when the signal light changes (it does not enter an intersection during yellow phase)	・Decrease in accidents as a result of appropriate stopping when the signal light changes			
Right turn	Front vehicle	・Because a vehicle judges the congestion situation of right turning destination after entering an intersection and stops therein, aggressive overtaking may occur which induces a contact accident.	・Appropriately judge the movement of front vehicles in the right-turn destination and pass through without problem.	・Number of occurrences/frequency and duration of stops in an intersection	・Speed data (Number and duration of stops) ・Video from on-board cameras	・Aggregate calculation from the number of times and duration when the speed became 0 ・Visual cause analysis
	On-coming vehicle	・Because a vehicle turns right after waiting for a sufficient gap, the time it is stopped in an intersection increases, resulting in a decrease in the number of right-turn vehicles discharged.	・Increase in the number of right-turn vehicles discharged due to a smooth right turn after judging the movement of oncoming straight and front (right-turn) vehicles	・Right-turn gap ・Number of right-turn vehicles discharged	・Roadside camera ・Simple vehicle detector	・Measurement of right-turn gap and the number vehicles discharged
				[Evaluation of impacts on following vehicles]		
	Other	・Delay in judgment on crossing pedestrians causes a vehicle to stop, resulting in a decrease in the number of right-turn vehicles discharged. ・Decrease in the number of right-turn vehicles discharged due to early stopping of a vehicle when the signal light changes	・Appropriately judge the movement of crossing pedestrians and pass through without problem. ・Decrease in accidents as a result of appropriate stopping when the signal light changes	(For the number of right-turn vehicles discharged, analysis data and method are the same as those of oncoming vehicles in the column above.) [Evaluation of impacts on following vehicles]		
Left turn	Front vehicle	・Because a vehicle judges the congestion situation of left turning destination after entering an intersection and stops therein, aggressive overtaking may occur which induces a contact accident.	・Appropriately judge the movement of front vehicles in the left-turn destination and pass through without problem.	・Number of occurrences/frequency and duration of stops in an intersection	・Speed data (Number and duration of stops) ・Video from on-board cameras	・Aggregate calculation from the number of times and duration when the speed became 0 ・Visual cause analysis
	Other	・Delay in judgment on crossing pedestrians causes a vehicle to stop, resulting in a decrease in the number of left-turn vehicles discharged. ・Decrease in the number of left-turn vehicles discharged due to early stopping of a vehicle when the signal light changes	・Appropriately judge the movement of crossing pedestrians and pass through without problem. ・Decrease in accidents as a result of appropriate stopping when the signal light changes	・Number of left-turn vehicles discharged	・Roadside camera	・Measurement of the number vehicles discharged
				[Evaluation of impacts on following vehicles]		

2.3 Examination of a method of analyzing impacts of automated driving vehicles on traffic flow observed during the field operational test

Of the scenes in which impacts are assumed, draft simulation verification methods for the basic road section were identified.

State	Judgment target	Impacts on traffic flow (assumption)		Simulation verification	
		Conservative and low performance	Proactive and high performance	Parameter setting method	Analysis method
Straight traveling	Front vehicle	・Low-speed driving in consideration of maintaining longer headway or the performance and safety of the vehicle causes light congestion in the following vehicles, resulting in the emergence of a new congestion area. ・The need to secure headway in preparation for a cutting-in vehicle that cuts in between a vehicle and a front vehicle causes light congestion in the following vehicles. ・Unable to judge the state of front vehicles (stopped, congestion due to accident, waiting for entry into roadside parking, etc.) and therefore stops behind a front vehicle.	・Headway becomes uniform and shorter, dissipating traffic congestion	・Setting of parameters relating to headway and desired speed.	・Analysis of changes in traffic volume and speeds
		・Aggressive overtaking occurs by a vehicle frustrated with an automated driving vehicle driving at a low speed in compliance with regulation speed or in consideration of vehicle performance and safety, resulting in increase in accident occurrence probability.	・Headway becomes uniform and shorter, lowering accident occurrence probability		
	Other	・The number of stops increases due to pedestrians and cyclists on the sidewalk area (particularly around crossings), causing light congestion in the following vehicles. ・Unable to detect obstacles and others early, causing stops to occur. ・Speed is maintained even in sag sections and others, dissipating congestion.	・Performs flexible route changes by obtaining information about fallen objects and obstacles on travel routes. ・Speed is maintained even in sag sections and others, dissipating congestion.	・Reproduction of the occurrence of stops ・Setting of parameters for the desired speed to be constant instead of setting them based on road structure	・Analysis of changes in traffic volume and speeds
		・Stops (rapid decelerations) and snaking caused by GPS communication disconnection may induce contact accidents			
Right turn	Oncoming vehicle	・Because the vehicles turn right by waiting for a sufficient gap, the time they are stopped in a lane increases, resulting in lower per-lane capacity than before.	・Startup delay decreases when right-turn vehicles are in a queue at the entrance of large-scale commercial facilities, etc., resulting in an increase in the number of right-turn vehicles discharged.	・Setting of parameters relating to headway, startup delay and right-turn gap	・Estimation of the number of right-turn vehicles discharged from traffic volume and comparison of the results
	Other	・Stops caused by delayed judgment for pedestrians on a sidewalk and resulting decrease in the number of right-turn vehicles discharged	・Increase in the number of right-turn vehicles discharged as a result of smooth right turns determined from the movement of crossing pedestrians	・If it is difficult to directly reproduce responses to pedestrians, indirect expression methods will be examined.	・Estimation of the number of right-turn vehicles discharged from traffic volume and comparison of the results
Left turn	Other	・Stops caused by delayed judgment for pedestrians on a sidewalk and resulting decrease in the number of left-turn vehicles discharged	・Increase in the number of vehicles discharged as a result of a quick judgment on the sidewalk situation following the judgment by a front vehicle.	・If it is difficult to directly reproduce responses to pedestrians, indirect expression methods will be examined.	・Estimation of the number of left-turn vehicles discharged from traffic volume and comparison of the results
Course change	Front and rear vehicle	・When a vehicle tried to change course, stopping or delay in changing the course occurred due to judgment on rear, front and oncoming vehicles, causing congestion in the following vehicles.	・Decrease in accidents with a front, rear and oncoming vehicle as a result of appropriate situation judgment when trying to change a course. ・Lower accident occurrence probability due to a decrease in unnecessary course changes	・Setting of parameters relating to course change judgment	・Analysis of changes in traffic volume and speeds
		・Dangerous overtaking occurs by a vehicle frustrated with an autonomous vehicle which is confused in making judgment, resulting in increase in accidents ・Cautious course change being made by an automated driving vehicle was blocked by a following vehicle, inducing a contact accident and causing subsequent congestion. ・Lower accident occurrence probability due to a decrease in unnecessary course changes			

(Grey shading) Impacts relating to safety

2.3 Examination of a method of analyzing impacts of automated driving vehicles on traffic flow observed during the field operational test

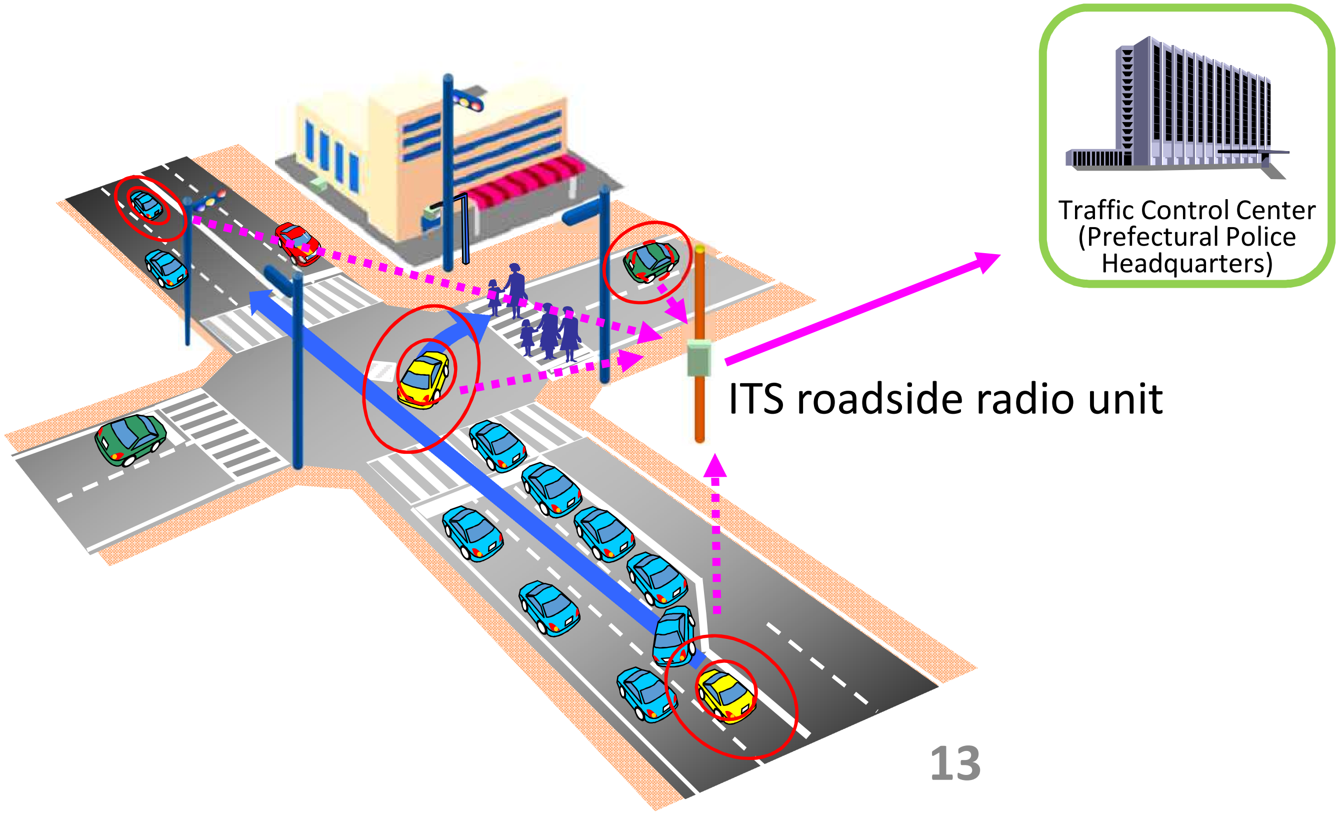
Of the scenes in which impacts are assumed, draft simulation verification methods for the intersection part were identified.

State	Judgment target	Impacts on traffic flow (assumption)		Simulation verification	
		Conservative and low performance	Proactive and high performance	Parameter setting method	Analysis method
Straight traveling	Front vehicle	・Unable to judge on a front vehicle (stopped, accident congestion, waiting for entry into roadside parking, etc.) and continues to stop before an intersection, resulting in an decrease in the number of vehicles discharged. ・If a sufficient clearance is not secured on the side of a vehicle waiting for right turn, it continued to stop before an intersection, resulting in an decrease in the number of vehicles discharged. ・In the case of front vehicles with high height, the recognition of signal light delays, causing a vehicle to stop longer at an intersection, resulting in a decrease in the number of vehicles discharged.	・Increase in the number of vehicles discharged compared to the past due to earlier startup when the signal light changes ・Able to judge passing and others of front and right-turn waiting vehicles, allowing a vehicle to pass through without problem.	・Setting of parameters relating to headway, startup delay and acceleration and deceleration ・If it is difficult to directly reproduce responses to a front vehicle and at the time of signal change, indirect expression methods will be examined.	・Comparison of the number of vehicles discharged after estimating them from through traffic volume at intersections
	Other	・Decrease in the number of vehicles discharged due to early stopping of a vehicle when the signal light changes (it does not enter an intersection during yellow phase)	・Decrease in accidents as a result of appropriate stopping when the signal light changes		
Right turn	Front vehicle	・Because a vehicle judges the congestion situation of right turning destination after entering an intersection and stops therein, aggressive overtaking may occur which induces a contact accident.	・Appropriately judge the movement of front vehicles in the right-turn destination and pass through without problem.	Only field verification is planned.	
	On-coming vehicle	・Because a vehicle turns right after waiting for a sufficient gap, the time it is stopped in an intersection increases, resulting in a decrease in the number of right-turn vehicles discharged.	・Increase in the number of right-turn vehicles discharged due to a smooth right turn after judging the movement of oncoming straight and front (right-turn) vehicles	・Setting of parameters relating to headway, startup delay, acceleration and deceleration and right-turn gap.	・Estimation of the number of right-turn vehicles discharged from through traffic volume at intersections and comparison of the results
	Other	・Delay in judgment on crossing pedestrians causes a vehicle to stop, resulting in a decrease in the number of right-turn vehicles discharged ・Decrease in the number of right-turn vehicles discharged due to early stopping of a vehicle when the signal light changes	・Appropriately judge the movement of crossing pedestrians and pass through without problem.	・Setting of parameters relating to headway, startup delay and acceleration and deceleration ・If it is difficult to directly reproduce responses to a front vehicle and at the time of signal change, indirect expression methods will be examined.	・Estimation of the number of left-turn vehicles discharged from through traffic volume at intersections and comparison of the results
			・Decrease in accidents as a result of appropriate stopping when the signal light changes		
Left turn	Front vehicle	・Because a vehicle judges the congestion situation of left turning destination after entering an intersection and stops therein, aggressive overtaking may occur which induces a contact accident.	・Appropriately judge the movement of front vehicles in the left-turn destination and pass through without problem.	Only field verification is planned.	
	Other	・Delay in judgment on crossing pedestrians causes a vehicle to stop, resulting in a decrease in the number of left-turn vehicles discharged. ・Decrease in the number of left-turn vehicles discharged due to early stopping of a vehicle when the signal light changes.	・Appropriately judge the movement of crossing pedestrians and pass through without problem.	・Setting of parameters relating to headway, startup delay and acceleration and deceleration ・If it is difficult to directly reproduce responses to a front vehicle and at the time of signal change, indirect expression methods will be examined.	・Estimation of the number of left-turn vehicles discharged from through traffic volume at intersections and comparison of the results
			・Decrease in accidents as a result of appropriate stopping when the signal light changes		

Impacts relating to safety (grey shading)

3. Overview of vehicle-to-vehicle communication information

Item	Specifications, etc. for radio waves used	Transmission cycle	Collection site/ communication area	Main items of information
Outline	755-765 MHz 1ch (shared by vehicle-to-vehicle, vehicle-to-infrastructure and infrastructure-to-infrastructure communication)	100 ms	A few hundred meters around intersection	Temporary vehicle ID Static attributes (by vehicle use category, by vehicle size category, etc.) Transmission time of vehicle-to-vehicle communication information Location of vehicle (longitude and latitude) State of vehicle (vehicle speed, forward and backward acceleration and deceleration rate, vehicle azimuth, etc.)



[Image of utilization]

Understanding of vehicle behavior

↓

Prediction of causes of congestion

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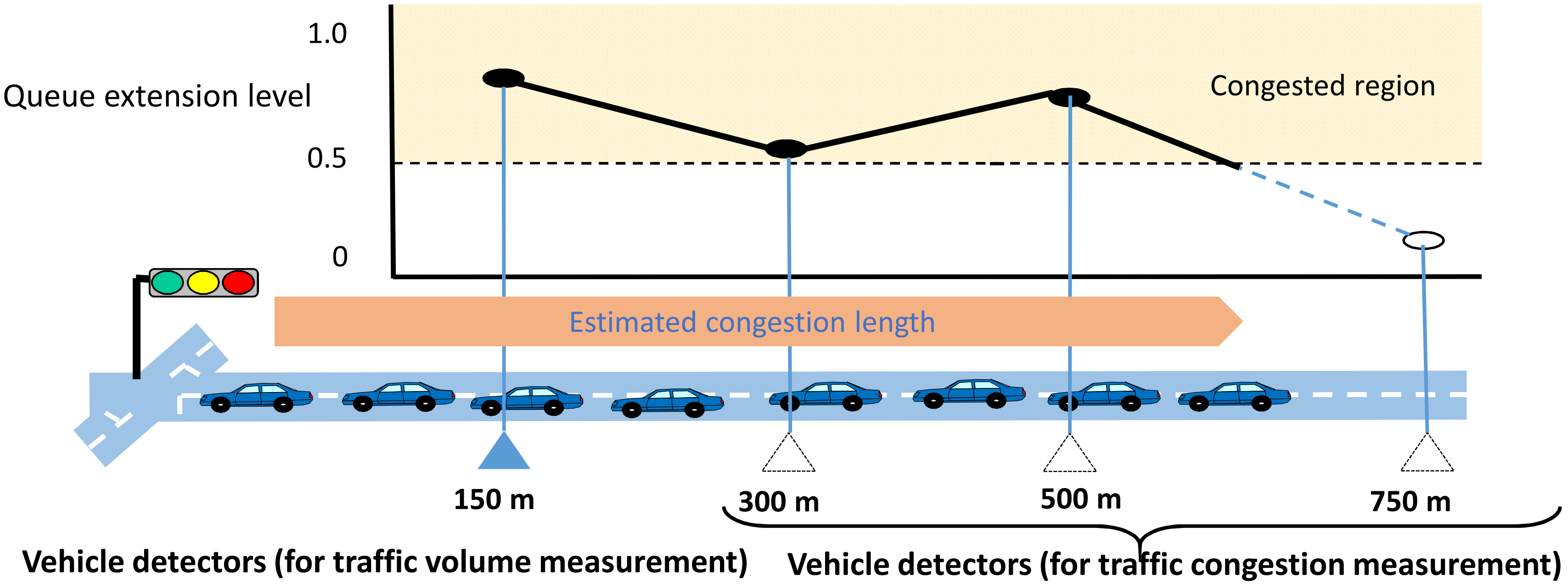
Control which responds to traffic situation, provision of new types of information, etc.

4. Draft use cases of traffic control utilizing vehicle-to-vehicle communication information

	Menu	Outline
Traffic control operations support	Calculation of indicators of intersection traffic dynamics	Branch traffic volume, percentage of large-sized vehicles, travel time by travel direction, stop positions, traffic congestion tail positions, etc. are calculated for intersections where ITS roadside radio units are installed.
	Calculation of indicators of network traffic dynamics	The number of vehicles traveling between multiple intersections where ITS roadside units are installed and their travel time between the intersections are calculated.
	Calculation of benefit indicators of traffic signal control	Benefit indicators at the time of introducing and upgrading the system and after aging of the system (number of vehicles x travel time) are calculated.
	Calculation of performance indicators of traffic signal control	indicators and others for the appropriateness of green time, drivability, safety are calculated from driving behavior and the number of seconds allocated to execute signal control, which are collected from vehicle-to-vehicle information.
Traffic control	**Control with fewer detectors**	**The number of vehicle detectors is reduced by substituting the congestion length measurement with vehicle-to-vehicle communication information (a simulation evaluation experiment will be conduced)**
	Traffic flow diagnosis	By analyzing vehicle behavior, causes of traffic congestion occurrence such as preceding jams and abnormal events such as malfunctioning vehicles are detected and utilized for notification to the traffic control centers, intervention to traffic control and others.
	Priority control for specific vehicles	Green time is adjusted to help ensure safe and smooth passage of buses and emergency vehicles through intersections.
Evaluation of impacts of automated driving vehicles	Calculation of safety indices of automated driving vehicles	An understanding on impacts of the travelling of automated driving vehicles on ordinary vehicles is obtained from vehicle behavior and safety indicators for automated driving vehicles such as situation confirmation are calculated after improving vehicle behavior.

5. Issues in traffic signal control and the purpose of reducing detectors by replacing them with the use of vehicle-to-vehicle communication information

- Basic idea of traffic signal control
  Green time is allocated in real time according to changes in the “demand rate” of each inflow route.
  (Demand rate = Traffic demand (Inflow traffic volume + Number of vehicles in congestion / Throughput volume)
- Congestion length (number of vehicles in congestion) calculation method
  Currently, the calculation is made by determining the extension of queue length from the vehicle existence time (occupancy time) beneath the detectors.
  → A number of detectors to measure traffic congestion are required on incoming roads to an intersection (substantial costs for deployment, operation and maintenance)



“Inflow traffic volume” and a congestion with “a wait time of one cycle or longer” are determined.

To be replaced by the use of vehicle-to-vehicle communication information
Reduction of deployment, operation and maintenance costs

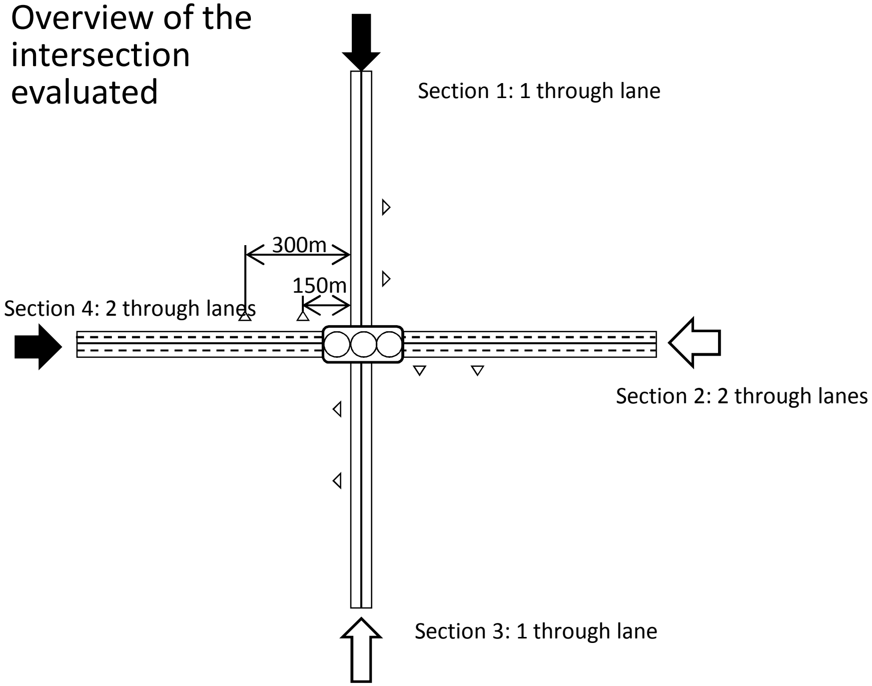
6-1. Conditions for the evaluation of simulated signal control using fewer detectors

- **Evaluation parameters**
  The "percentage of vehicles with on-board unit (the OBU inclusion rate)" and "longer data collection intervals" aimed at reducing the volume of communication data were used as evaluation parameters to evaluate the performance (total delay time) of traffic signal control with fewer detectors.
  ※Total delay time: Total wait time of all vehicles at traffic signals

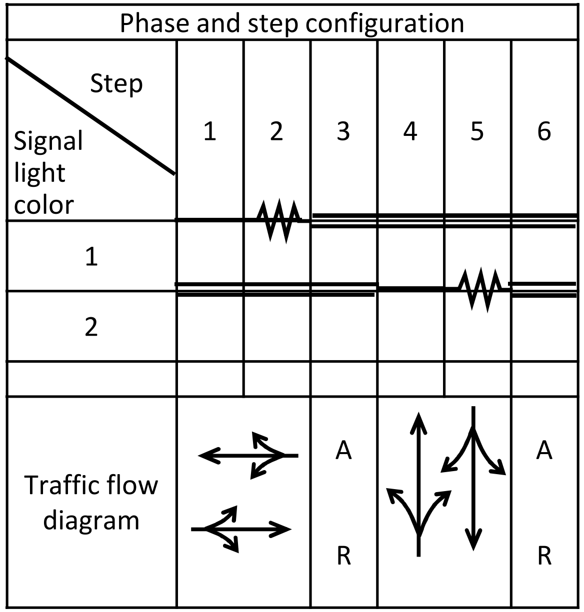
- **Traffic conditions employed**
  The simulated traffic conditions were set up such that the congestion lengths are about 400 m that falls within the vehicle-to-vehicle communication area.

- **Other simulation conditions**
  Simulator: VISSM, Runtime: 90 minutes, Number of times the simulation was performed: 10 times/case

Overview of the intersection evaluated



Traffic signal control (Phase and step diagram)



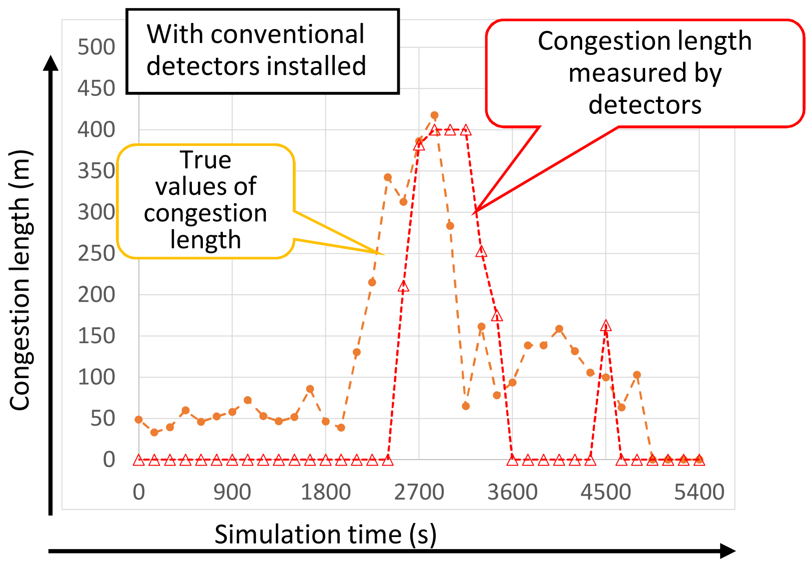
Minimum cycle length: 80 seconds
Maximum cycle length: 150 seconds

6-2. Evaluation of the accuracy of the estimated congestion length

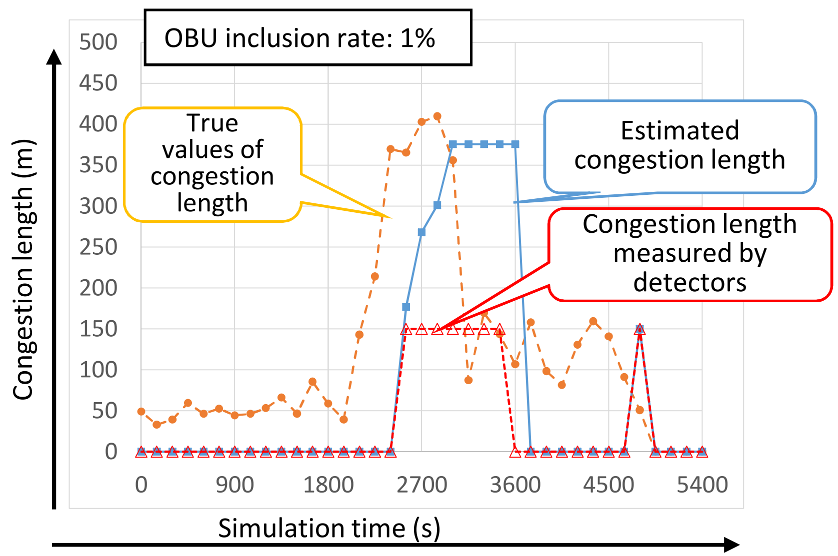
■ Summary of evaluation results

A comparison was made between the "true values of congestion lengths" output by the simulator, "congestion lengths measured by detectors" and "estimated congestion lengths" estimated from vehicle-to-vehicle communication information.

→ The traffic signal control without using the detectors located 300 m from the stop line (with the OBU inclusion rate of 1%) was, to a large extent, able to accurately estimate congestion lengths.



Results of the measurement of a congestion length on a main road (Section 1) with conventional detectors installed



Results of the measurement of a congestion length on a main road (Section 1) under traffic control using fewer detectors

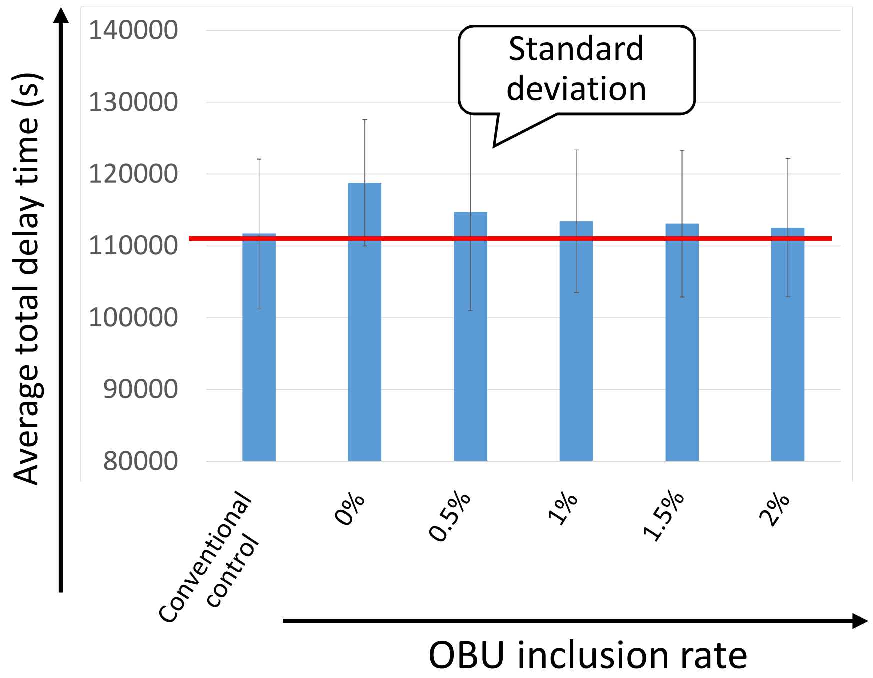
6-3. Results of the simulation experiment for the traffic signal control using fewer detectors

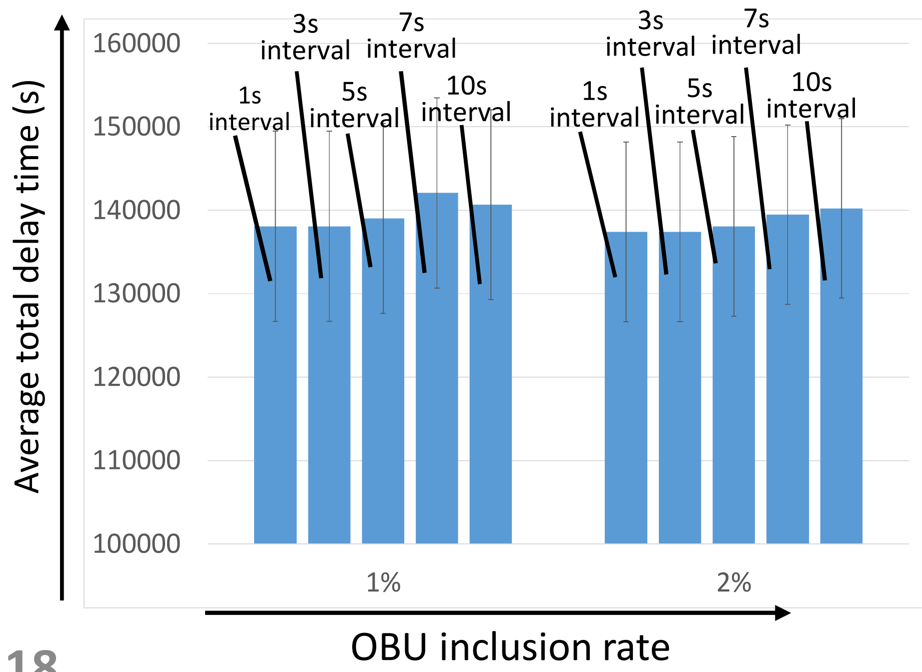
- Summary of evaluation results

- Effects of the OBU inclusion rate on the traffic signal performance of the "conventional signal control" that uses congestion measurement detectors and on the "signal control with fewer detectors" without installing detectors at 300 m from the stop line were evaluated.
  → **With an OBU inclusion rate of at least 1%, the traffic control performance is equal to that of the conventional control.**

  (Reference) OBU inclusion rate at the Kikukawa 2-chome intersection where the field survey was conducted: Around 0.7 to 1.0%

- Effects of longer data collection intervals during data collection were evaluated (with a OBU inclusion rate of 1% and 2%)
  → **Increasing the intervals to 5 seconds or longer increases performance degradation.**





7. Conclusion

- A method for evaluating the impacts of the coexistence with automated driving vehicles on existing traffic flow was developed.
  - It is desirable that the method be utilized in the simulation evaluation experiment and the Tokyo Waterfront City Area Field Operational Test which will bring together automobile and OEM manufacturers.

- Draft use cases for utilizing vehicle-to-vehicle communication information in traffic control operations were developed and the usability of traffic signal control with fewer detectors were verified.
  - Examination toward the implementation of a field verification experiment and practical application is desirable.