Cross-ministerial Strategic Innovation Promotion Program

「Cross-ministerial Strategic Innovation Promotion Program (SIP)/ Automated Driving for Universal Services/ Survey on Utilization Method of V2X Information for Ensuring Traffic Safety under Coexisting Traffic -Simulation of Evaluation of Impact of Autonomous Vehicles on Traffic Flow-」

FY 2019 Report

Pacific Consultants Co., Ltd.
UTMS Society of Japan

February, 2020

Purpose of Survey

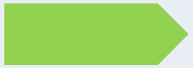
[Purpose of SIP Period 2: R&D Planning of Autonomous Driving]

- Put autonomous driving into practical use and expand its spread to contribute to solving social issues, such as **reducing traffic accidents, mitigating traffic congestion**, ensuring mobility of transportation-handicapped people, and improving driver shortages and reducing costs in logistics and mobility services, aiming to realize a society where everyone can live a high quality life.
- Establish **technologies in cooperative areas necessary for the realization of autonomous driving** by 2023, **confirm its effectiveness by demonstration experiments** involving various businesses and local governments, and enhance the prospect of social implementation by **creating multiple cases of practical application**.

[Purpose]

- Based on the results of the study conducted in FY2018, prepare and verify simulation and analyze traffic flow with the eyes focused on **utilization of data to be collected by demonstration experiments in the Tokyo waterfront area**, and accordingly **plan traffic safety measures and examine how to utilize data for traffic management operations**, taking into consideration the impact of autonomous vehicles on existing traffic flow **under traffic where ordinary and autonomous vehicles coexist**.

1. Positioning of This Project

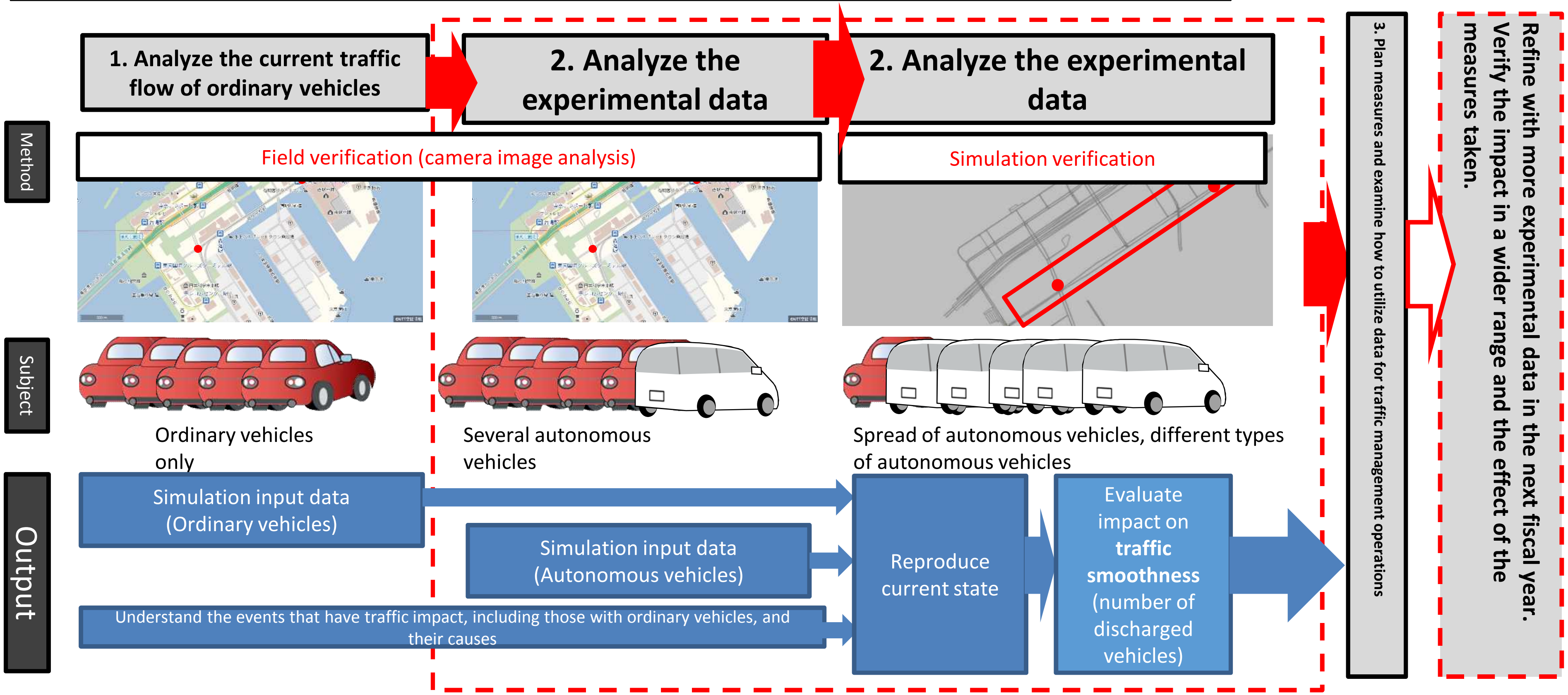
Business description		FY2018	FY2019
SIP business	• Examine the survey and analysis methods for the impact of the travel of autonomous vehicles on traffic flow. • Organize the inter-vehicle communication information that can be used for traffic control operations. • Investigate how to utilize inter-vehicle communication information for traffic control operations.		
	• Determine what to be evaluated about the impact of autonomous vehicles using the data obtained by demonstration experiments in the Tokyo waterfront area. • Analyze traffic flow by field verification and reproduce the current state in simulation verification. • Examine the analysis method using a simulator and perform analysis using actual data.		

2. Overview: Main Survey Items

1. **Analyze the current traffic flow at the target locations.**
2. **Analyze the data obtained by demonstration experiments in the Tokyo waterfront area (with autonomous vehicles traveling).**
3. **Plan traffic safety measures and examine how to utilize data for traffic management operations.**

Domestic and foreign literature and interview surveys

Committee



3－1. Field Verification (Ordinary Vehicles Only)

	Verification item	Verification method
Non-intersection roads	Overtaking other vehicles	• Extract the current speed from the speed distribution of all traveling vehicles. • Extract the percentage of vehicles that overtake a vehicle group traveling at a lower speed than the current speed.
	Congestion within a vehicle group	• Extract the number of vehicles in a vehicle group and the change in the speed of the last vehicle of the group.
	Preliminary deceleration when approaching an intersection	• Extract the distance to the stop position and speed at which deceleration starts.
Intersections	Discharge of vehicles when the traffic light changes (from red to green)	• Extract the most frequent value of the time until the first vehicle crosses the stop line. • Extract the time when the following vehicles cross the stop line to calculate the number of discharged vehicles.
	Discharge of vehicles turning right or left at an intersection	• Extract the critical gap time at which the probability of passing is equal. • Calculate the number of vehicles discharged per hour of green light.
		• Extract the relationship between the positions of pedestrians on the pedestrian crossing and the time required for the vehicle to pass.

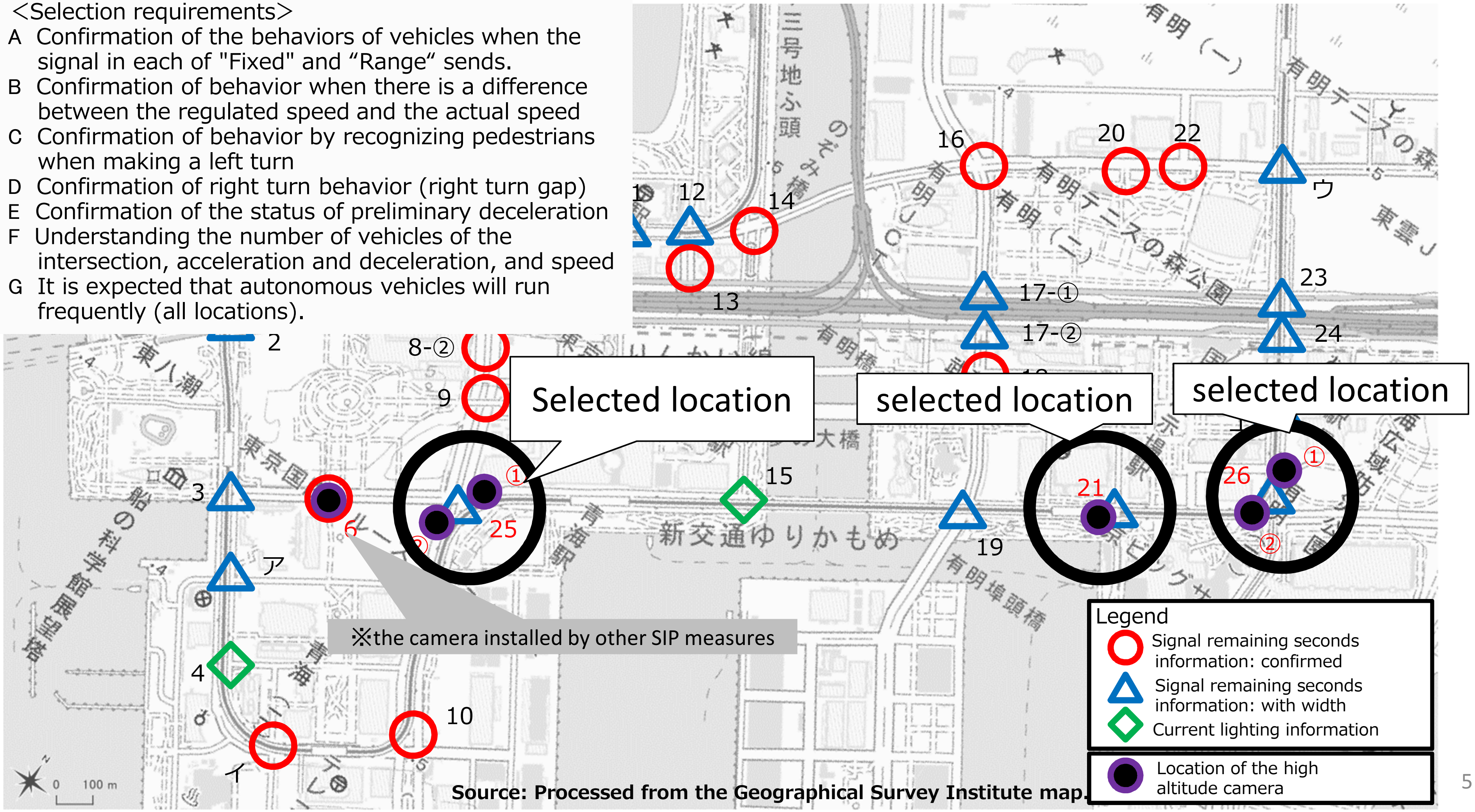
Used for checking input values to the simulation and the reproducibility of the current state.

3－2. Field Verification (selection of observation sites)

〇fixed-point cameras are necessary to obtain a bird's-eye view of the traffic volume and behavior of vehicles.
⇒Some observation sites were selected from the following point of view.

<Selection requirements>

- A Confirmation of the behaviors of vehicles when the signal in each of "Fixed" and “Range“ sends.
- B Confirmation of behavior when there is a difference between the regulated speed and the actual speed
- C Confirmation of behavior by recognizing pedestrians when making a left turn
- D Confirmation of right turn behavior (right turn gap)
- E Confirmation of the status of preliminary deceleration
- F Understanding the number of vehicles of the intersection, acceleration and deceleration, and speed
- G It is expected that autonomous vehicles will run frequently (all locations).

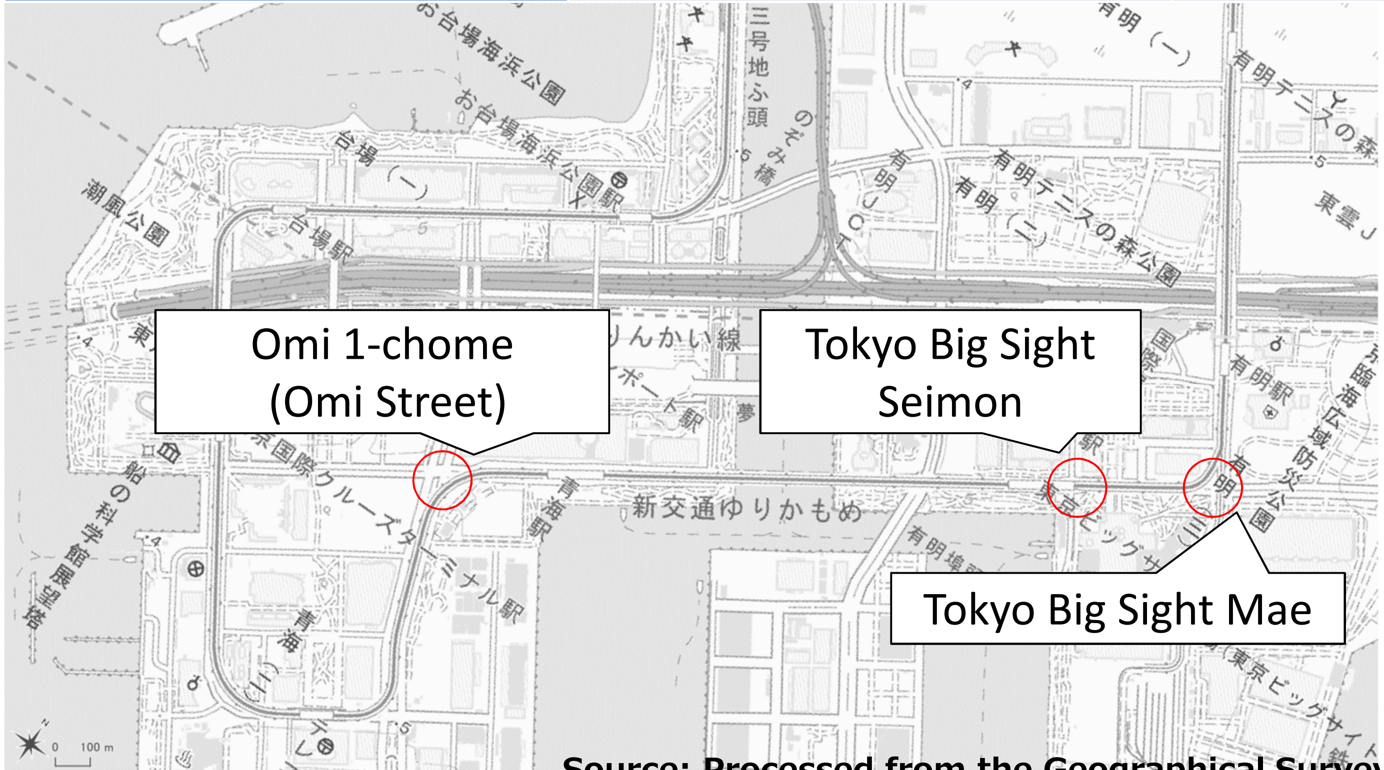


Source: Processed from the Geographical Survey Institute map.

3－3．Field Verification (observation with fixed-point cameras)

〇Installed fixed-point cameras to grasp the current traffic flow, and acquired the necessary data from the camera images.

Location name (intersection name)	Number of cameras observed in September (No autonomous cars mixed in.)	Number of cameras observed in November(Assuming that autonomous cars are mixed in.)
Tokyo Big Sight Seimon	4	4
Omi 1-chome (Omi Street)	2	2
Tokyo Big Sight Mae	2	2

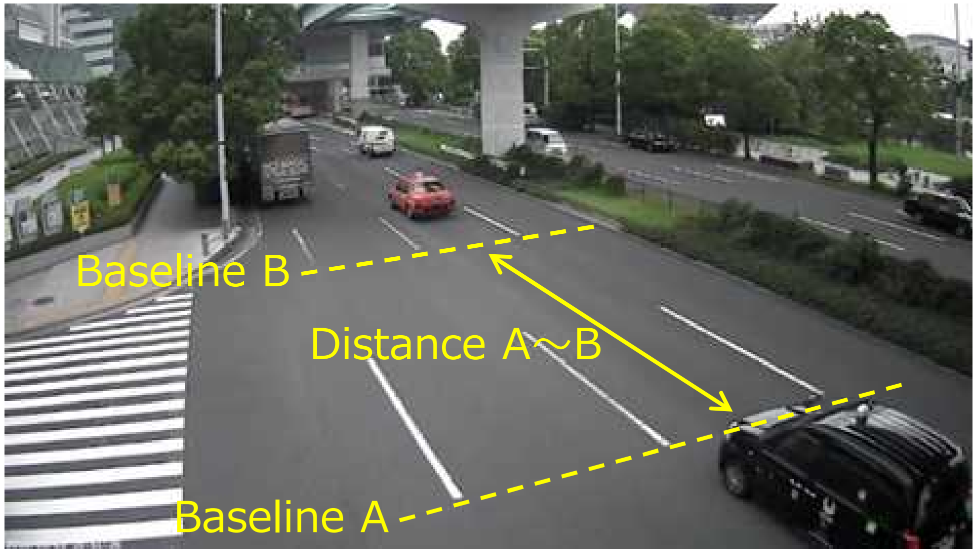


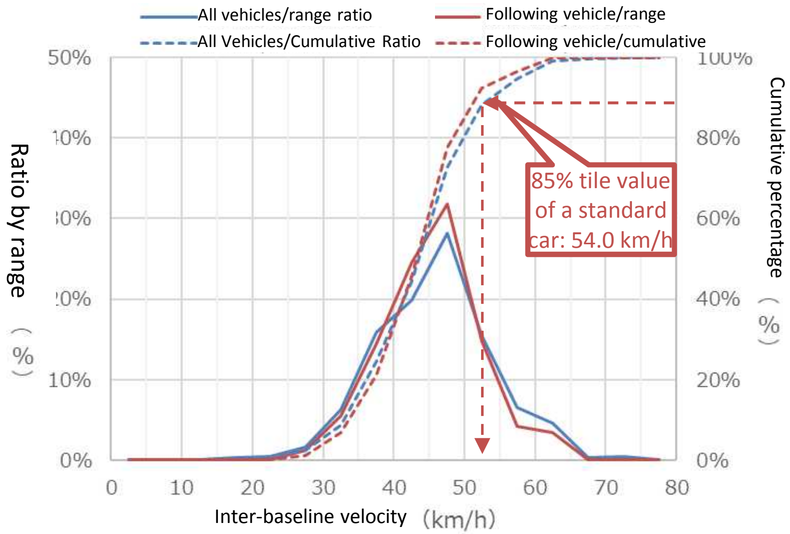
Source: Processed from the Geographical Survey Institute map.

3－4．Field Verification (data generation from a fixed-point camera)

〇Obtaining the necessary data from a fixed-point camera image
(example of velocity distribution)

① Set the reference line and measure the time when the reference line passes.
② The average speed for each interval is calculated from the distance between the baseline and the passing time of the interval.
※ Time of passage is measured in 1/30, distance is measured in 1m.
③Speed distribution is graphed and the actual speed (85% tile speed) is obtained.





4－1． Performing Simulation (selecting a simulator)

○ In this study, the micro model was judged to be suitable for setting the behavior specific to autonomous vehicles.
⇒Among them, Vissim, a micro-traffic flow simulator software, was used because of its basic functions, customizability, and thorough basic verification.

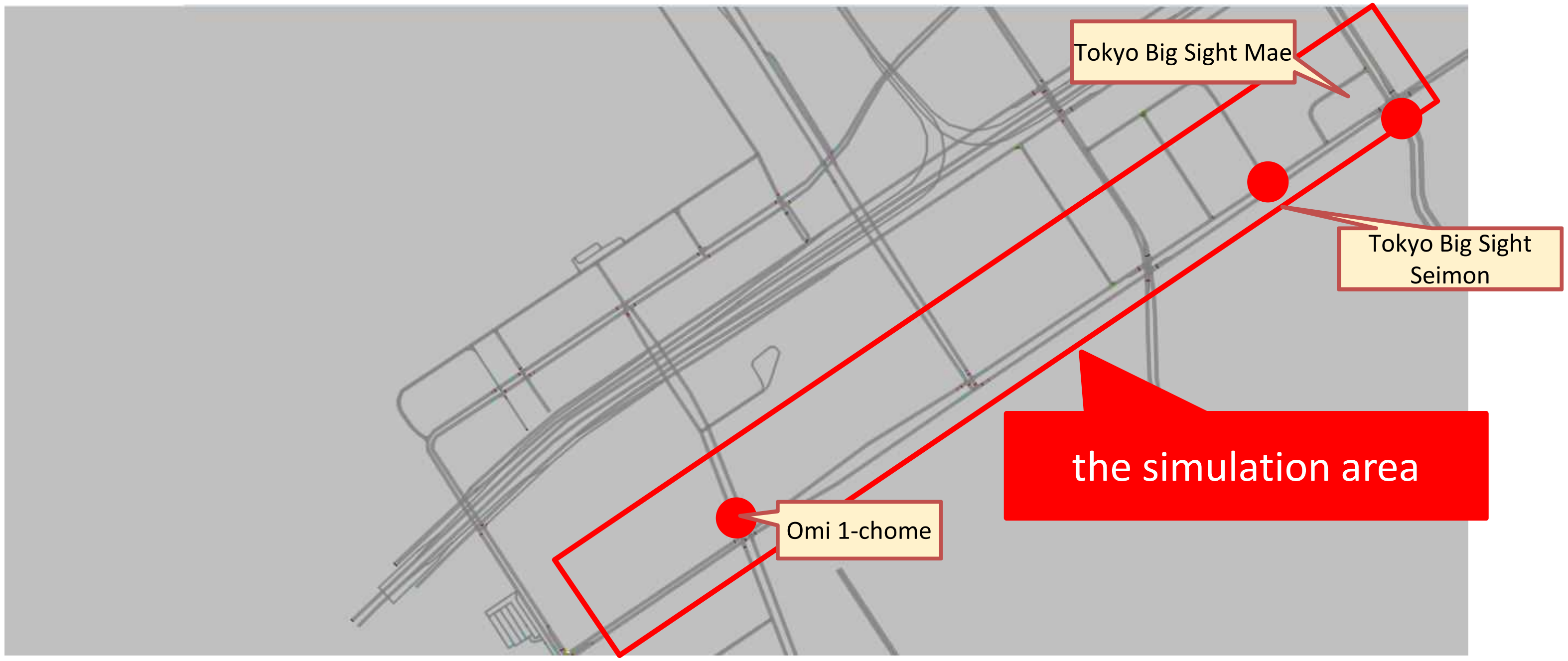
	macro model	hybrid model(Meso model.)	micro-model
Vehicle handling unit	Treating the vehicle as an aggregate.	Treating the vehicle as a vehicle group, a fluid.	Handling individual vehicles.
Model Overview	・QV is assigned to each link (road). ・The least cost (shortest time) path shall be used.	・Using QK	・Individual vehicles act according to the model formula (e.g., following theory)
Output	・Daily traffic indicators (daily traffic, congestion, speed, etc.) ※There's a time zone allocation, but it's not common.	・Traffic indicators in short time (minutes and hours) (Traffic volume, traffic length, speed, etc.)	・Traffic indicators in short time (minutes and hours) (Traffic volume, traffic length, speed, etc.)
Main software/system examples	・SOUND ・I/O method ・JICA STRADA ・Ministry of Land, Infrastructure, Transport and Tourism	・AVENUE ・DEBNetS ・MACSTRAN ・RISE ・TRANDMEX ・box model	・VISSIM ・AIMSUN ・PARAMICS ・NETSIM

Micro models are suitable for setting up behavior specific to autonomous vehicles.

4-2. Performing Simulation（Conditions）

〇Simulation Area

・Conducted a smoothness assessment as a road network that includes multiple intersections.(Includes three intersections (located fixed-point cameras) that have been performed field verification.



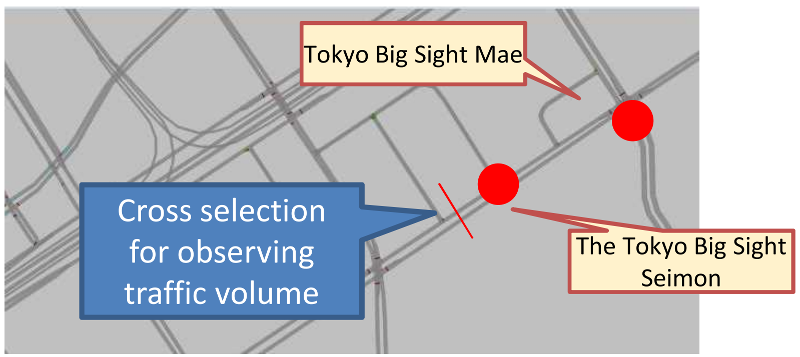
4－3　Setting simulation conditions

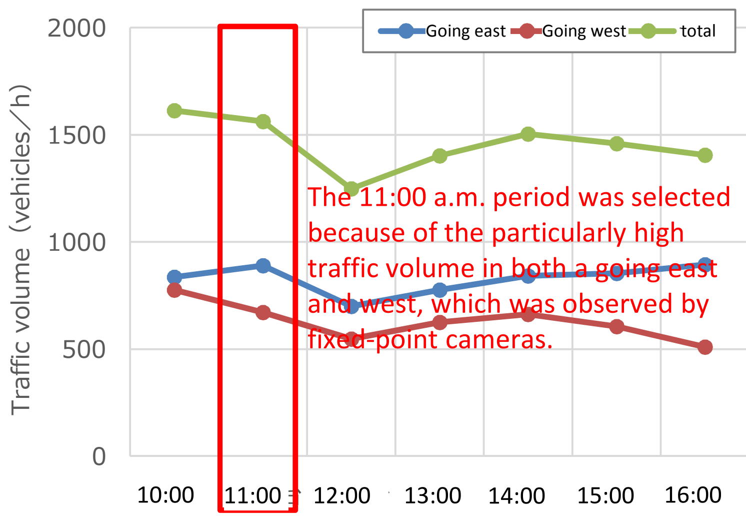
◯ Simulation time period

◯A weekday(Tuesday) was selected as the fixed-point observation day for the field verification, assuming a comparison with the case of including autonomous vehicles.

◯The 11:00 a.m. period was selected because of the particularly high traffic volume to evaluate impact on traffic smoothness.

Selected from the results of a traffic survey of fixed-point cameras





4-4. Performing Simulation (to Check Reproducibility of Current State)

- Compare the output values of the simulation with the values obtained by the field verification to check the reproducibility of the current state.

Index for checking reproducibility of current state	Result
Traffic volume	Check the reproducibility at each intersection (R^2=0.99).
Speed	Check the reproducibility from the distribution, average, and standard deviation of the speed.
Headway time	Check the reproducibility from the distribution, average, and standard deviation of the headway time.
Start of the first car	Check the reproducibility from the distribution, average, and standard deviation concerning the time from when the traffic light turns green to when the first vehicle crosses the stop line.
Number of lane changes	Check the reproducibility from the number of lane changes in a specific section.
Right turn gap	Check the reproducibility from the critical gap when turning right.
Deceleration in front of a traffic light	Check the reproducibility from deceleration before stopping at a red or yellow light.
Positions of pedestrians when turning right or left	Check the reproducibility from the start ratio when there are pedestrians on the pedestrian crossing.

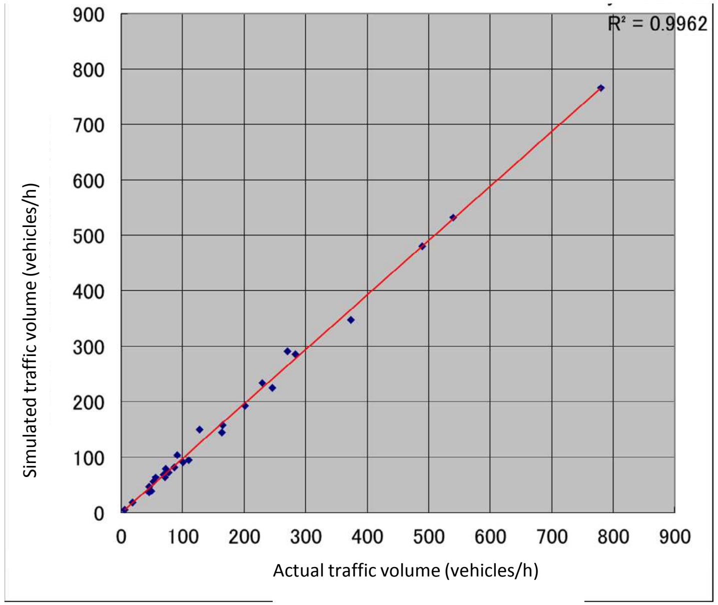
The above reproducibilities are checked after configuring settings so that vehicles parked on the street are reproduced in simulation at some places observed by fixed-point cameras.

4-5. Performing Simulation (to Check Reproducibility of Current State)

- Compare the output values of the simulation with the values obtained by the field verification to check the reproducibility of the current state.

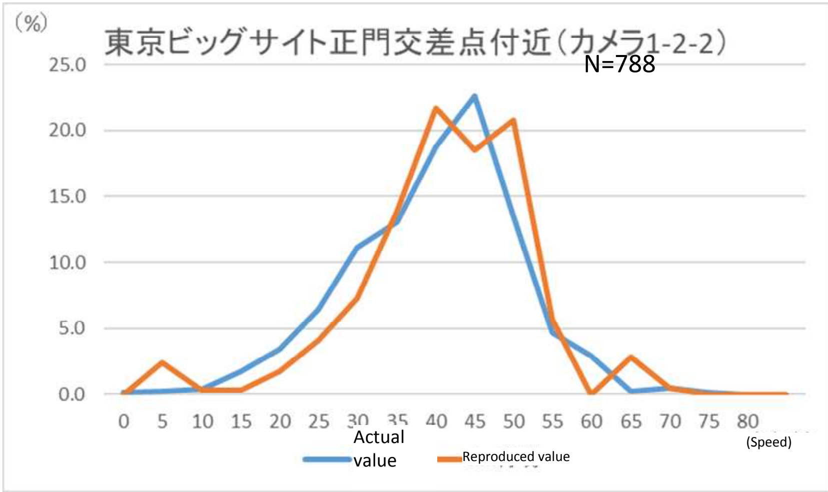
<Example of reproduction of current state>

Checking reproducibility of traffic volume by intersection, cross section, and direction*1



*1 The traffic volume by direction at each inflow point (4 points) is plotted with the ordinate as the measured value, and the abscissa, as the simulated value.

Speed distribution *2
(around the Tokyo Big Sight main gate intersection)



*2 Speed in the section from approx. 75 to 90 m from the intersection (Distribution in one hour)

4-6. Performing Simulation (to Set Parameters)

Data could not be obtained for the inclusion status of autonomous vehicles, and therefore the parameters were set based on information obtained from the Road Traffic Act, ISO, interviews and questionnaires to committee members, and literature.

Parameter	Description	Basic setting	Grounds	Reference: Setting for ordinary vehicles
Desired speed	Speed of a vehicle not following another and without a stop line ahead	Below the speed limit	Set based on the Road Traffic Act.	Distribution around 50 km/h
Maximum acceleration / desired acceleration	Vehicle performance acceleration and acceleration during normal driving	**2** to **4 m/s^2**	Set based on JIS D 0807: 2011 (ISO 22179: 2009).	0 to 3.5 / -7.5 to -5.1
Maximum deceleration / desired deceleration	Deceleration in the same case as above	**3.5 to 5 m/s^2**	Set based on JIS D 0807: 2011 (ISO 22179: 2009).	0 to 3.5 / -2.8
		(Desired deceleration) 0.2 G	* Set based on the questionnaire results.	
Stopping inter-vehicle distance CC0	Stopping distance between vehicles	**4.5 m**	* Set based on the questionnaire results.	1.5 m
Headway time CC1	Headway time to the vehicle ahead * In general, each driver has his/her own desired inter-vehicle time.	**3.0 sec. on average** **Standard deviation: 0**	Set by referring to Literature (1).	1.5 sec. on average Standard deviation: 0.5 sec.
Gap acceptance parameter when changing lanes	Minimum necessary gap to the following vehicle in the adjacent lane when changing lanes (sec.)	Complies with the Co-Exists Normal settings: MinHDwy: 0.5 [m] SafeDistFact: 0.6	Refer to the findings of Co-Exists (Efforts to evaluate traffic impact of autonomous vehicles in Europe).	MinHDwy: 0.5 [m] SafeDistFact: 1
Gap acceptance parameter when turning right	Parameter used to calculate the necessary gap to the straight-ahead oncoming vehicle when turning right	**Right-turnable gap equivalent to 5.0 seconds** FrontGap: 0.5 RearGap: 1.0	Set based on Literature (1) and hearing results.	Right-turnable gap equivalent to 4.5 seconds FrontGap: 0.5 RearGap: 0.5
Traffic light reaction time	The reaction time from when the traffic light changes from red to green to when the vehicle starts	**1 sec. (Standard deviation: 0)**	Set based on the questionnaire and hearing results.	2.5 sec. on average Standard deviation: 2 sec.

Literature (1): Right turn movements at signalized Intersections

4－7． Simulation Results

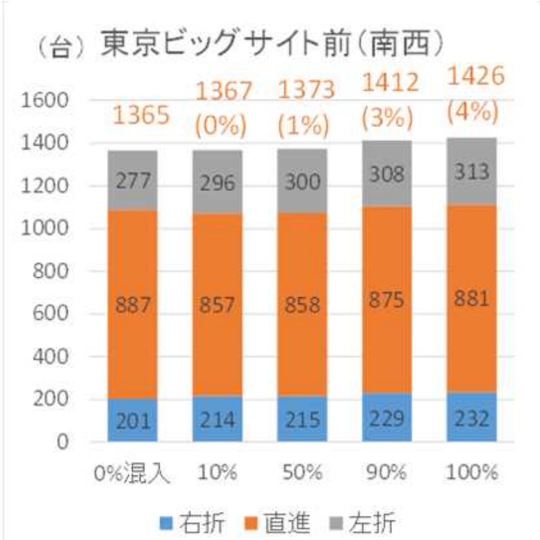
〇Comparative verification was performed for different **penetration rates** of autonomous vehicles of **0, 10, 50, 90, and 100%**.

〇Change in the number of discharged vehicles from an intersection

(Number of right-left turn and straight ahead in front of Tokyo Big Sight (southwest section) during an hour)

Basic setting pattern

Following behavior change pattern



When the vehicle head time is set to a value shorter than the basic setting pattern (equivalent to the setting for general vehicles)

Result	〇 In the Basic setting pattern, the number of vehicles discharged tends to decease with the penetration of autonomous vehicles. 〇 In the following behavior change pattern, if the headway time of autonomous vehicles is set shorter the number of discharged vehicles from an intersection tends to increase at the penetration rate of 50% or greater.
Consideration	〇 It will be necessary to take measures for traffic smoothness, such as the construction of a traffic environment that is easy to drive for both ordinary vehicles and autonomous vehicles.

4-8. Simulation Results

○In addition, **verification was also performed changing various parameters**.

Subject of verification	Vehicle	Parameter settings	Result
Reproduce current state	Ordinary vehicles	Ordinary vehicles	The actually measured current state was almost reproduced by simulation.
Coexistence of autonomous vehicles	Autonomous vehicles	Basic setting	With the modeling settings for autonomous vehicles (p6), traffic smoothness tends to decrease with the penetration rate of 50% or greater.
		Change in follow behavior (headway time)	If the headway time of autonomous vehicles is set as short as that of ordinary vehicles, traffic smoothness gradually improves at the penetration rate of 50% or greater.
		Change in start behavior (traffic light reaction time)	If the response time of autonomous vehicles to traffic lights is set shorter than that of ordinary vehicles, traffic smoothness improves at the penetration rate of 90% or greater.
		Change in lane change behavior (lane-changeable gap)	If the lane-changeable gap of autonomous vehicles increases, traffic smoothness improves at the penetration rate of 50% or greater.

5 – 1． Case Studies and Interviews (Summary)

1． Overseas Case Studies

- Case studies were collected at the TRB site, and the interview was conducted with PTV, which conducts traffic simulations around the world.

2． Expert Opinion Gathering

- Opinions were collected mainly from the following experts in Japan.

  Oneyama Research Laboratory, Tokyo Metropolitan University,

  Tanaka Research Office, Yokohama National University.

- An interview was also held with Kanazawa University, which participates in autonomous driving experiments in the Daiba area mainly and develops vehicles.

  Suganuma Laboratory, Kanazawa University

5－2．Case Studies and Interviews(Overseas)

１．Overseas case studies Main opinions

- It is possible that transportation demand will change as a result of future development and spread of various transportation, and taking these factors into account can also be an important finding.
- For example, it is assumed that the performance (behavioral characteristics) of widely used autonomous vehicles will differ between the 10% and 90% penetration stages. And CoEXIST* simulates the situation where advanced autonomous vehicles are used instead of BASE pattern autonomous vehicles in the 90% penetration stage.
- In CoEXIST, the parameters of autonomous vehicles were determined by predicting future performance (behavioral characteristics) in a meeting of experts.

※CoEXIT: An EU project, in which an evaluation is conducted based on differences in the penetration rate of autonomous vehicles and the performance (behavioral characteristics) of increasingly popular autonomous vehicles.

etc.

5 – 3．Case Studies and Interviews（Expert opinion）

２．Expert opinion collection Main opinions

〇Traffic Impact and Traffic Management Measures Assumed as a result of the mixture of auton omous Vehicles

- Intersections that do not require prudent decisions when making right and left turns should be operated, such as motion line separation and pedestrian separation that introduce directi onal signage.

- Rather than simply extending the blue hours for autonomous cars or asking other general dri vers to be careful, we should reexamine the way in which this information is displayed and h ow it is set.

- It is necessary to deal with areas where there is a discrepancy between the legal system and the actual, such as the regulated speed and actual speed, because autonomous vehicles can not deal with those.

- For example, the regulated speed is somewhat in line with actual conditions, while there is v ery strict speed control enforcement the regulated speeds are somewhat in line with the pre vailing conditions in Europe.

6－1． Application to Traffic Safety Policy Planning and Traffic Management

【Concept of the study】

issue

・It has existed in the past, and depending on the mixing rate of autonomous vehicles, the degree of the mixing will vary under mixed conditions.

method

① Traffic regulations (including traffic safety education, etc.)
② Road improvements.
③ Operation of traffic safety facilities (including the provision of traffic information).
※Basically, while focusing on ①and ③, we also mentioned what ② needs to be done.

policy

- In view of the scope of this study, it was limited to measures that prefectural police (traffic managers) and others can take on their own initiative. Specifically, the above measures ① and ③ were examined.

- **No changes to the current legal system are being considered for the means.**
- **The issue is limited to what is extracted from the analysis and is not comprehensiveness.**
- **A wide range of measures are described, including those obtained through questionnaires and interviews.**

6－2． Planning Traffic Safety Measures and Utilization for Traffic Management Operations

Area	Possible case (Excerpt)	Possible phenomena / issues	Examples of measures
Non-intersection roads	Congestion of following vehicles led by an autonomous vehicle	○ The field verification results show that if the speed of the first vehicle of a vehicle group is lower than the actual traffic speed, the speed of the following vehicles tends to decrease as the number of vehicles in the group increases. ○ The results of questionnaires and interviews show that there is a concern that minor collisions may occur due to unreasonable overtaking by following vehicles. ○ The simulation results show that if the headway time (inter-vehicle time) of autonomous vehicles is longer than that of ordinary vehicles, the number of vehicles discharged from an intersection tends to decrease.	• Education for general drivers and drivers of autonomous vehicles (enhanced safety education). • Mitigation of speed deviations in mixed traffic of autonomous vehicles • Indication and functions of consideration for following vehicles by autonomous vehicles • A Study on the Possibility of Signal Control Considering Vehicle Swarms • Driving support and upgrading of functions for general vehicles, etc. ※ It is necessary to consider and organize road and traffic conditions such as the number of lanes and the possibility of overtaking. ※ It is also noted that as the number of autonomous vehicles increases and the prevailing speed approaches the regulated speed, the occurrence of the phenomena/challenges described above may decrease.
	Preliminary deceleration when approaching an intersection	○ Based on the results of the questionnaire, it is assumed that the risk of rear-end collisions may occur or increase if the autonomous vehicle decelerates faster than the following driver assumes. ○ Based on the results of questionnaires and interviews, it is assumed that the preliminary deceleration of autonomous vehicles tends to be too fast compared to general vehicles, which may lead to congestion. ※ However, there is an opinion that this will not be an issue unless there is an extreme preliminary deceleration.	• Education for general drivers (enhanced safety education) • Optimization of signal control parameters based on the presence of autonomous vehicles • Optimizing pre-deceleration driving by providing signal information • Studying the possibility of a system that notifies following vehicles of preliminary deceleration

6－3． Planning Traffic Safety Measures and Utilization for Traffic Management Operations

Area	Possible case (Excerpt)	Possible phenomena / issues	Examples of measures
Non-intersection roads	Deceleration by recognizing pedestrians in the vicinity of the road	○ The results of the questionnaire show that if a pedestrian suddenly starts to cross, the possibility of a contact accident or sudden deceleration is assumed. ※ In this case, pedestrians are assumed to be on the carriageway side of a road with sidewalks and pedestrians on the shoulder of a road without sidewalks.	• Education for general drivers (enhanced safety education) • Consideration of the possibility of a display that can be recognized as a self-driving car even from the perspective of pedestrians • Detects pedestrians crossing by infrastructure-side sensors or crossing requests from pedestrians, and notifies surrounding vehicles
	Responding to emergency vehicles	○ Based on the results of the questionnaire, the possibility of delays in detecting the approach of emergency vehicles, delays in entering intersections, delays in responding to yielding the path is assumed.	• The combination of FAST and V2X will provide information on the arrival of emergency vehicles with time to spare.
No (signal) crosswalk	Prolonged stopping times due to the intermittent arrival of pedestrians	○ Based on the results of the questionnaires and interviews, the possibility of following congestion associated with the stopping of autonomous vehicles due to many pedestrian crossings and unpredictable pedestrian behavior is assumed. ※ However, there is an opinion that this is not an issue particularly because pedestrians are given priority based on legal compliance.	• Education for general drivers (enhanced safety education) • Consideration of intersections where right and left turns for autonomous vehicles are recommended/ not recommended • Detection and notification of pedestrians by such as infrastructure-side sensors.

6 – 4． Planning Traffic Safety Measures and Utilization for Traffic Management Operations

Area	Possible case (Excerpt)	Possible phenomena / issues	Examples of measures
Intersections	Change in the number of discharge of vehicles due to a traffic light reaction time when the traffic light changes (from red to green)	○ The field verification results show that if the speed of the first vehicle of a vehicle group is lower than the actual traffic speed, the speed of the following vehicles tends to decrease as the number of vehicles in the group increases. ○ The results of questionnaires and interviews show that there is a concern that minor collisions may occur due to unreasonable overtaking by following vehicles. ○ The simulation results show that if the headway time (inter-vehicle time) of autonomous vehicles is longer than that of ordinary vehicles, the number of vehicles discharged from an intersection tends to decrease.	•Education for general drivers and drivers of autonomous vehicles (enhanced safety education). •Mitigation of speed deviations in mixed traffic of autonomous vehicles •Indication and functions of consideration for following vehicles by autonomous vehicles •A Study on the Possibility of Signal Control Considering Vehicle Swarms •Driving support and upgrading of functions for general vehicles, etc. ※ It is necessary to consider and organize road and traffic conditions such as the number of lanes and the possibility of overtaking. ※ It is also noted that as the number of autonomous vehicles increases and the actual speed approaches the regulated speed, the occurrence of the phenomena/challenges described above may decrease.
	Change in the number of discharge of vehicles due to a careful judgment when turning right or left	○ The field verification results show that many vehicles wait at pedestrian crossings until all pedestrians have safely crossed. ○ The results of questionnaires and interviews show that if the gap acceptance of autonomous vehicles when turning right is expected to be larger than that of ordinary vehicles, the number of discharged vehicles may decrease.	•Reducing the burden of judgment by changing the traffic light control methods for pedestrian-vehicle separation, right-turn and straight separation, etc. •Reconsidering special controls that will affect the judgment of autonomous vehicles, such as traffic-actuated control. •Providing information on the critical gap of ordinary vehicles at each intersection.

7. Future Issues

- Observation based on the actual driving data obtained by autonomous driving demonstration experiments and reflection on simulation evaluation

  Due to the lack of data on autonomous vehicles, data was obtained mainly for ordinary vehicles and used for simulation.

  ⇒ It is necessary to perform **field verification and re-examination of simulation utilizing actual driving data of autonomous vehicles**.

- Expansion of simulation range

  Traffic smoothness was evaluated in limited sections, which confirmed certain trends in the effects of including automatic vehicles.

  ⇒ It is necessary to obtain data in a wider area in a more simple manner, and to evaluate **traffic smoothness in a wider road network** by simulation.

- Evaluation of the effects of the measures taken

  Measures were examined based on the evaluation of the impact of the inclusion of autonomous vehicles by simulation, as well as questionnaire surveys and interviews with experts.

  ⇒It is necessary to **evaluate the effect of the measures taken by simulation.**