STRATEGIC INNOVATION PROMOTION PROGRAM
(SIP)-AUTOMATED DRIVING SYSTEM

Feasibility study of more advanced automated driving for public bus under the traffic environment in Okinawa

March 16, 2018

OKINAWA Automated Driving Bus Consortium

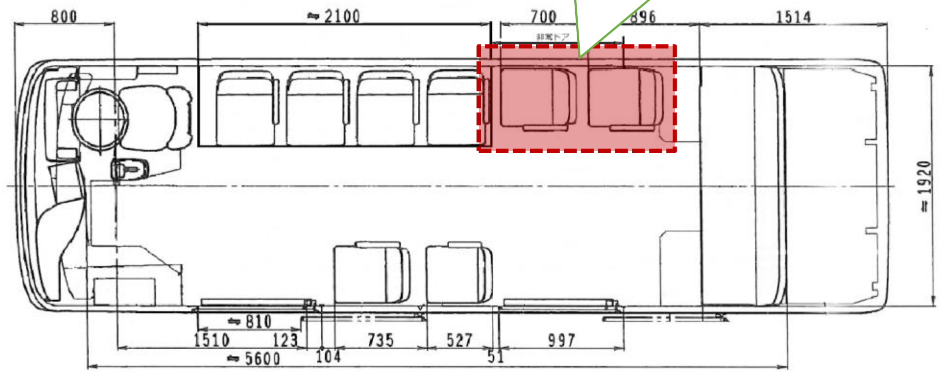
1. Apparatus of Automated Bus

Specification of bus

- Poncho; microbus by HINO
- Riding capacity of 22 passengers
- Length 6990mm, Width 2080mm
- 2 doors
- Without a step up entrance

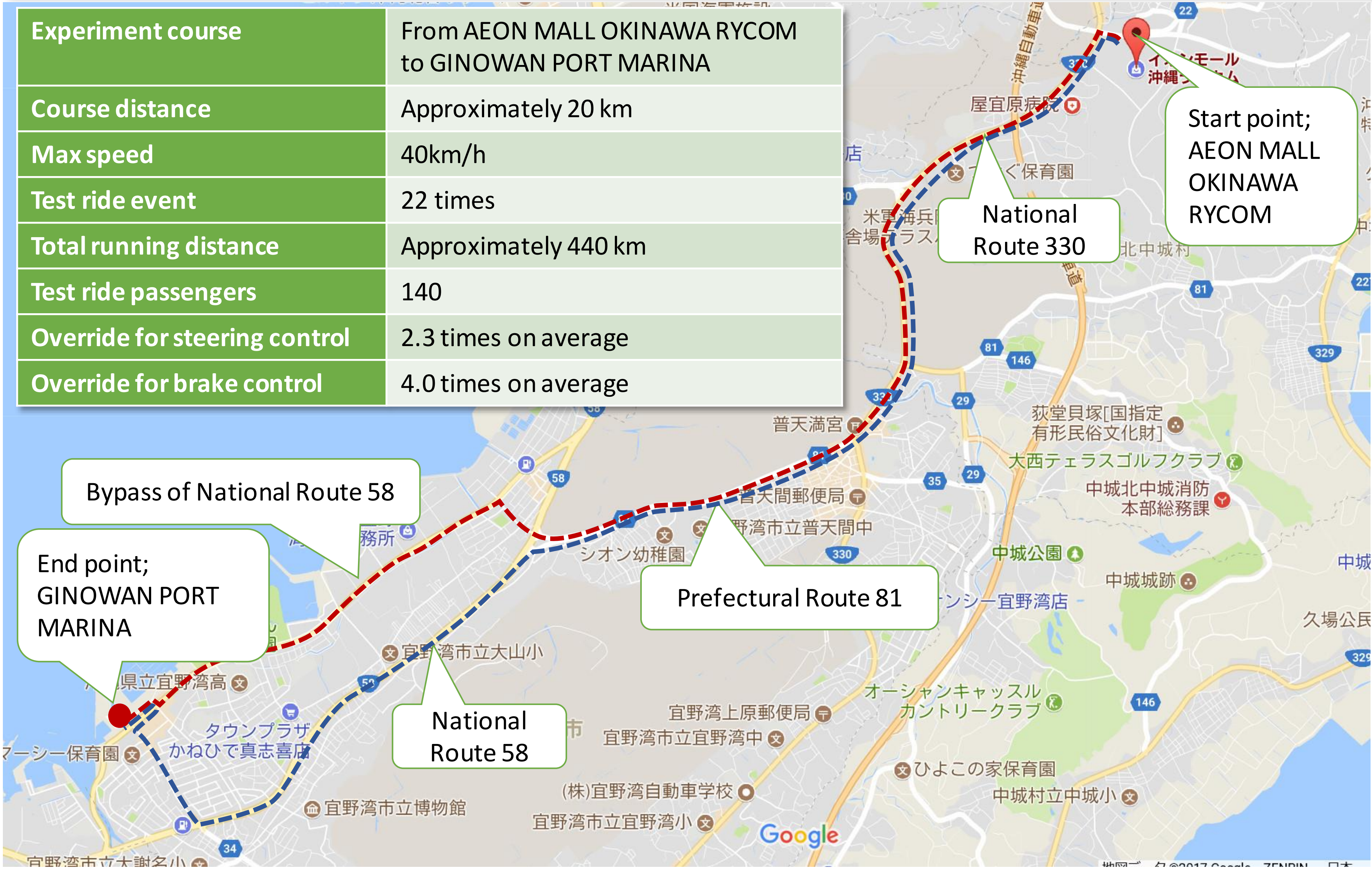
Apparatus

- Automatic steering system
- Automatic brake system
- Quasi-zenith satellite antenna
- 7LiDARs
- ECU



2. Travel Data of Feasibility Study

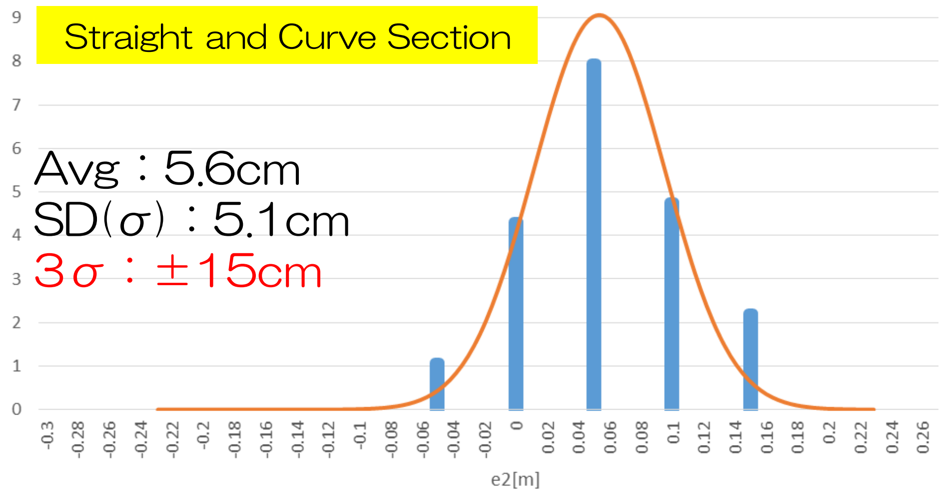
Experiment course	From AEON MALL OKINAWA RYCOM to GINOWAN PORT MARINA
Course distance	Approximately 20 km
Max speed	40km/h
Test ride event	22 times
Total running distance	Approximately 440 km
Test ride passengers	140
Override for steering control	2.3 times on average
Override for brake control	4.0 times on average

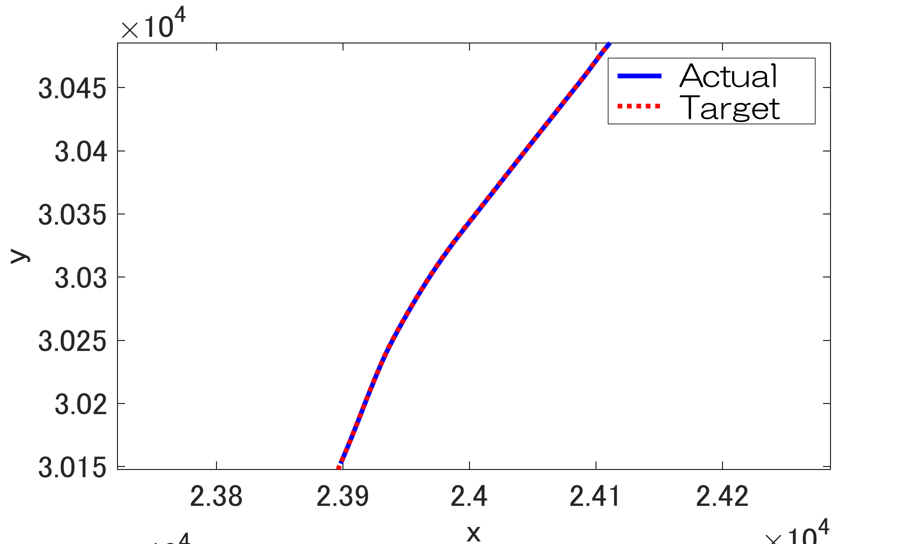


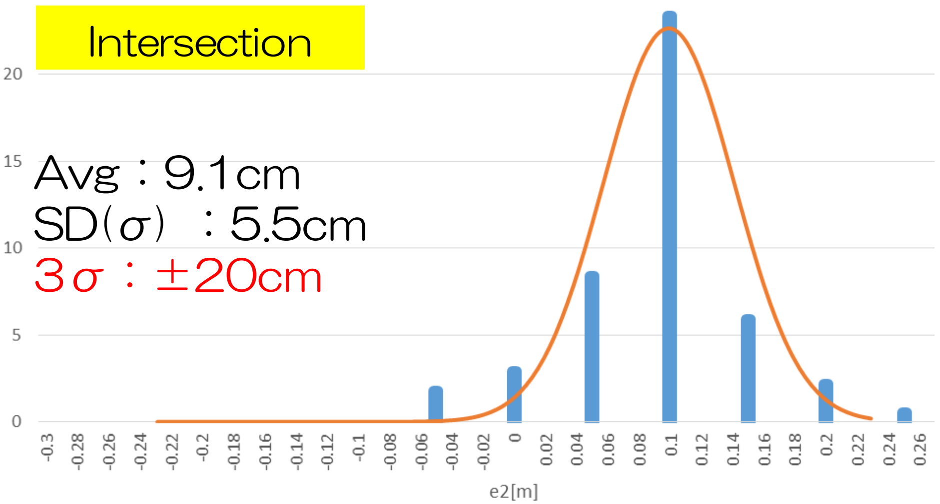
3. 3.1 Lane Keeping Control Evaluation

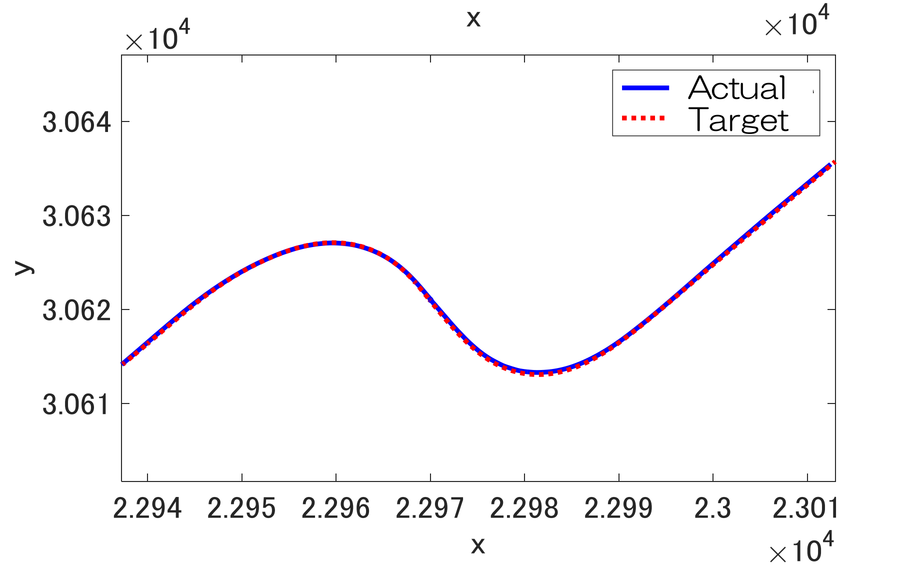
E2, the distance error between the target track and the actual position was evaluated.

→ Bus never deviated from its lane because max of 3σ was 20cm.



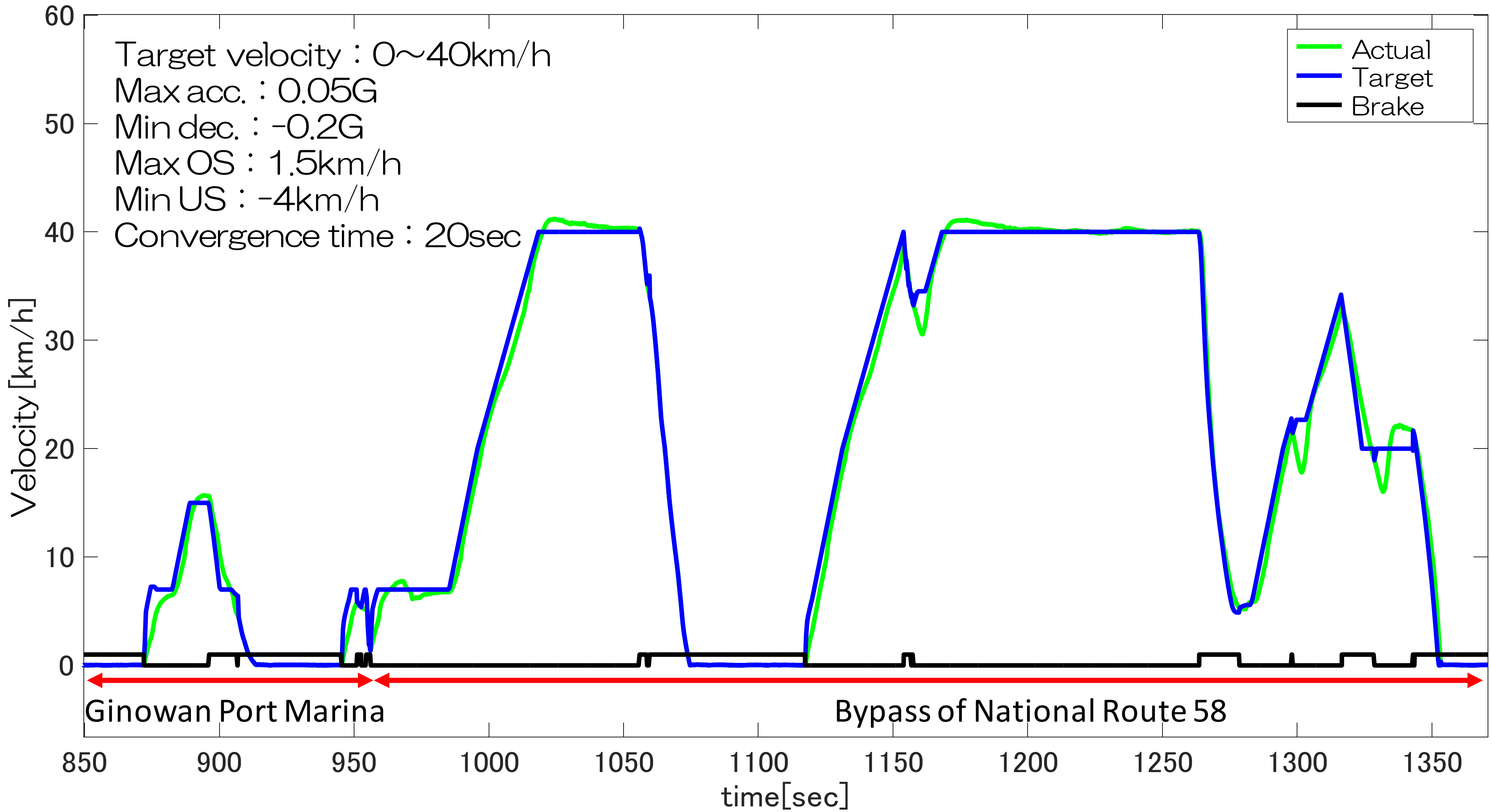






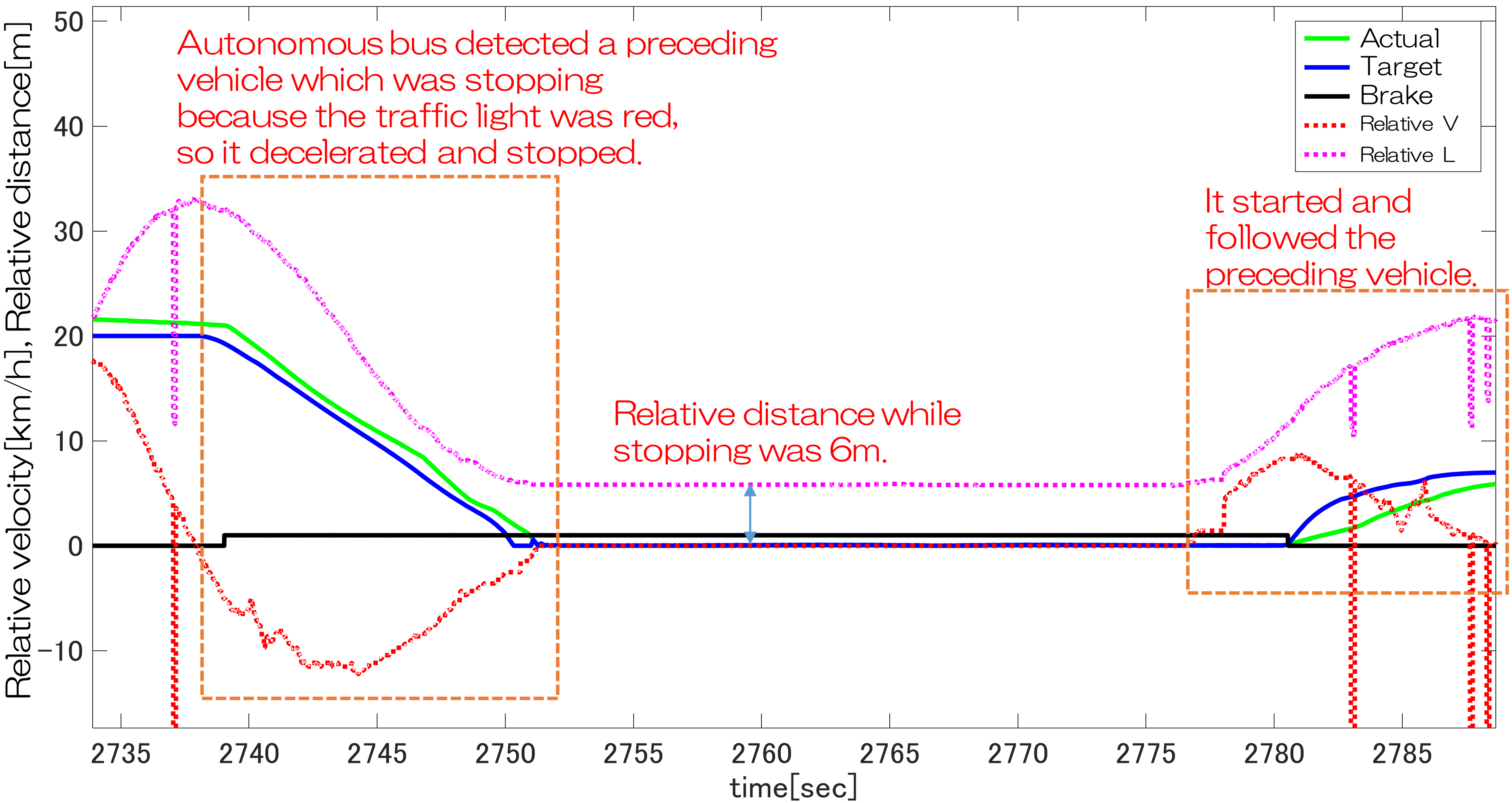
3.2 Velocity Control Evaluation

Target velocity was almost achieved at the speed from 0km/h to 40km/h, although there were some overshoots(OS) and undershoots(US).



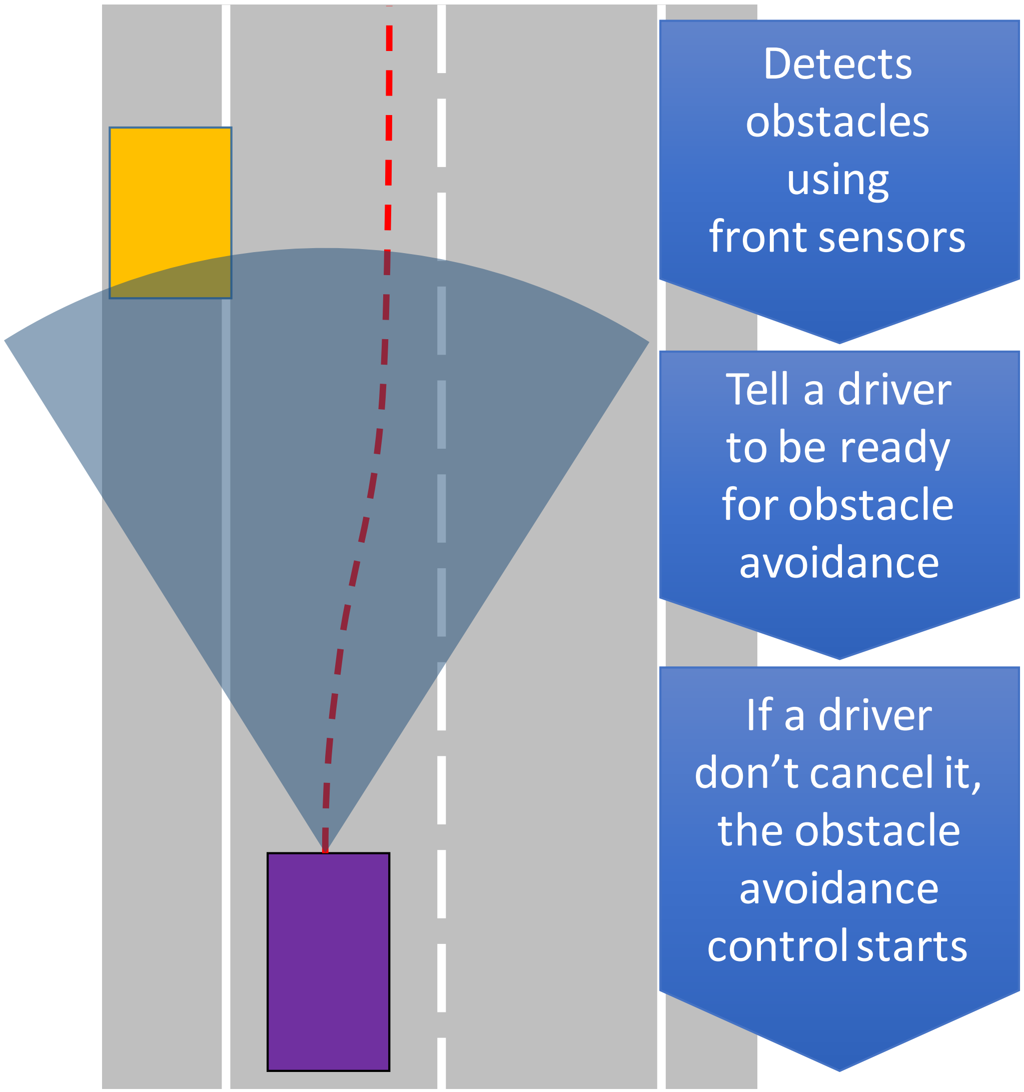
3. 3.3 ACC Control Evaluation

- In the case which a preceding vehicle is slower than the bus, it is decelerated.
- To prevent an emergency brake, it uses some kinds of sensors to detect a vehicle.

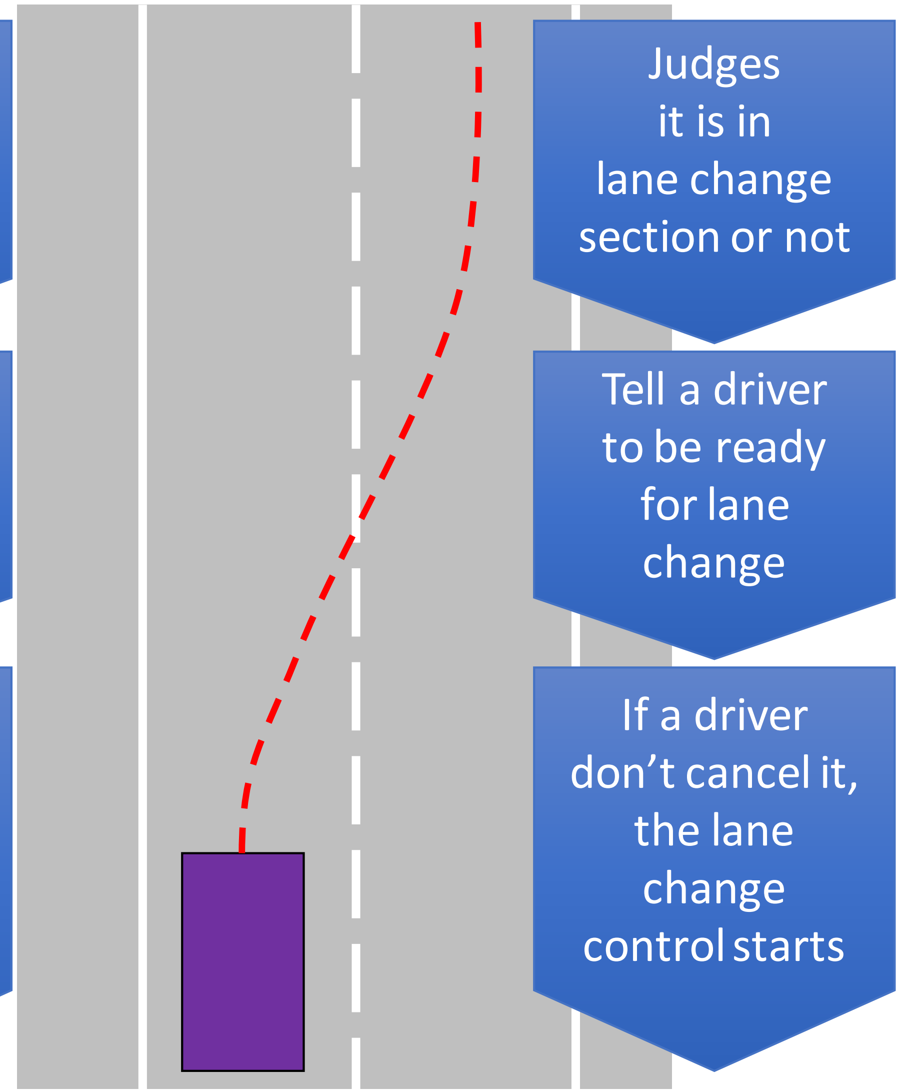


3.4.1 Obstacle Avoidance and Lane Change Control

Obstacle Avoidance Control

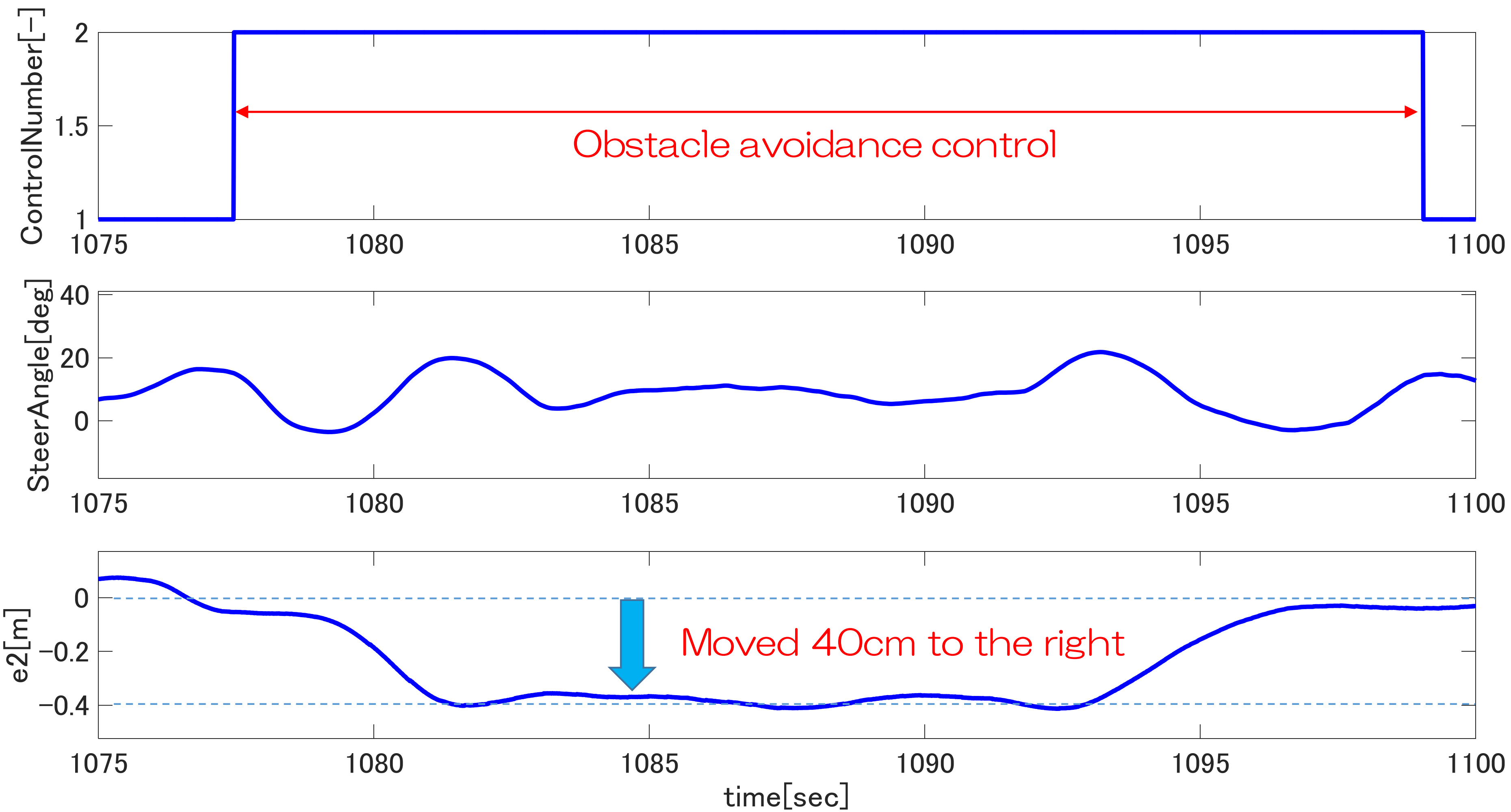


Lane Change Control



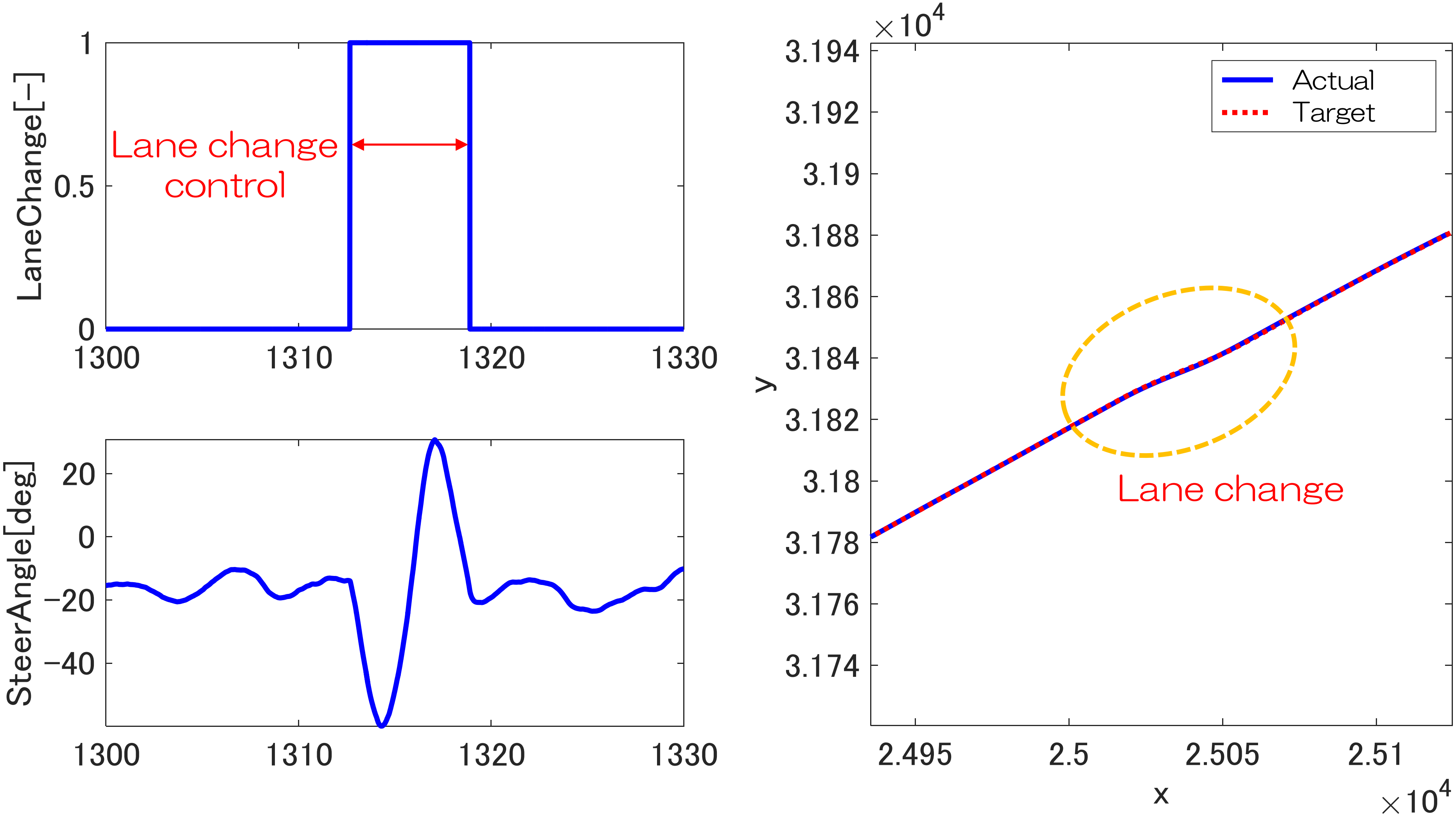
3.4.2 Obstacle Avoidance Control Evaluation

- When autonomous bus detected a vehicle parking on a road shoulder, it avoided the obstacle moving 40cm to the right.



3.4.3 Lane Change Control Evaluation

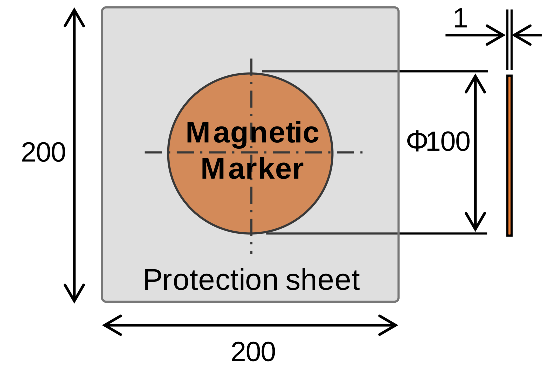
- Lane change control was mainly conducted before turning right at the end of bypass.
- The driver confirmed safety before the control would start in heavy traffic.



3.5.1 Accurate Arrival using Magnetic Marker

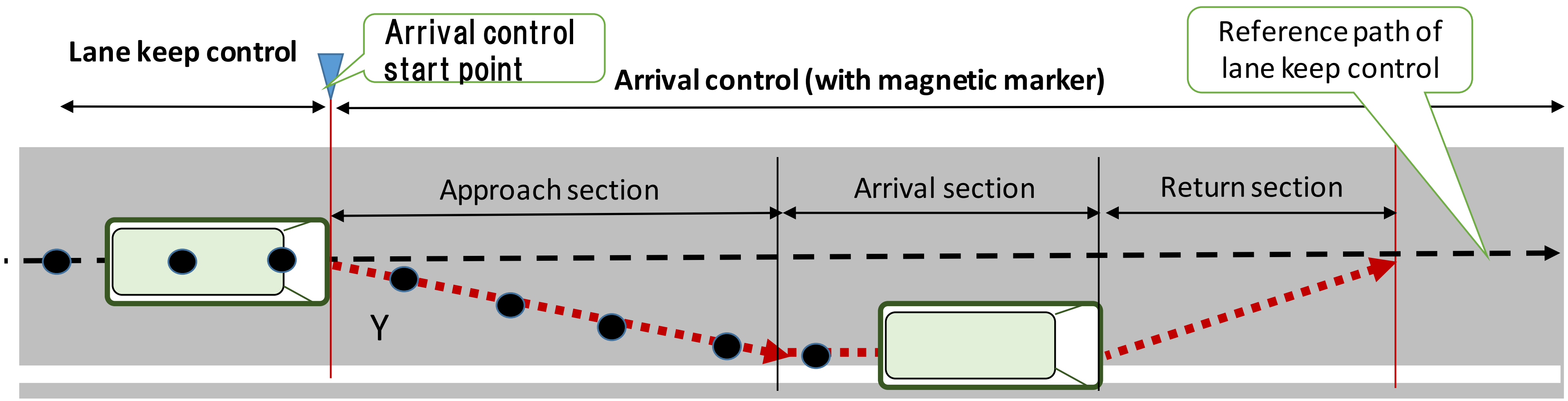
I have installed magnetic marker on non-public road of "Ginowan Port Marina". And, tried to control of accurate arrival to bus-stop using magnetic marker.

- Magnetic marker type : Plate type
- Setting method : Attach(glue)
- Setting interval : 50cm



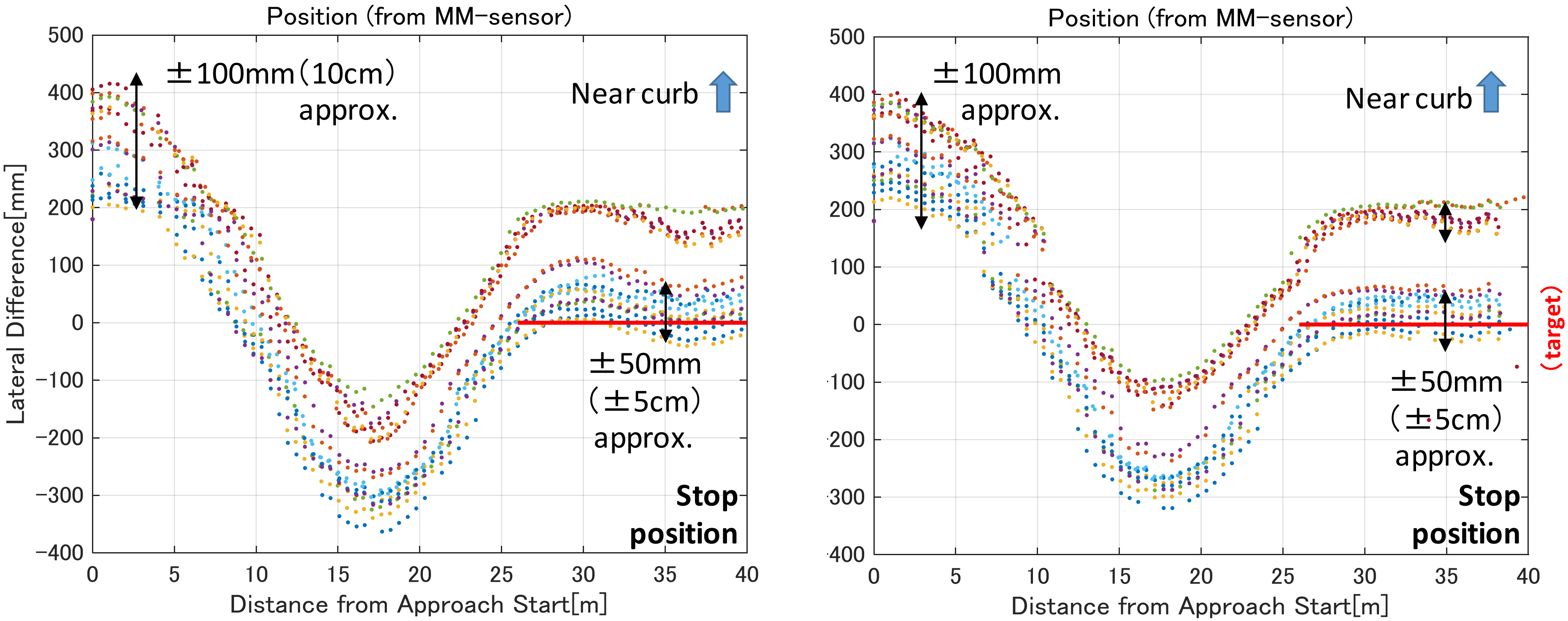
- **The target distance from body step to curb(walk road) is 20cm.**

  ＊ Considering margin for contact risk because of the curb is relatively high, and the doors are come out from body when opening.



3.5.2 Result of Approach Control with Magnetic Marker

- In this experiment, I have used combination of RTK-GPS and magnetic marker for control reference at arrival control section.
- The position estimate accuracy of RTK-GPS are about ±10cm (in general).
  In the case of magnetic marker system, the reference of position estimate have fixed on ground.
  Thus, that is example of compensatory function for GPS by magnetic marker.
- The variation in lateral difference are approx. ±10cm when arrival control started.
  But, the variation in lateral difference could be approx. ±5cm when arrival stop (at bus-stop).
  On the other hand, some cases had went to near the curb. It is considered influence by initial condition.

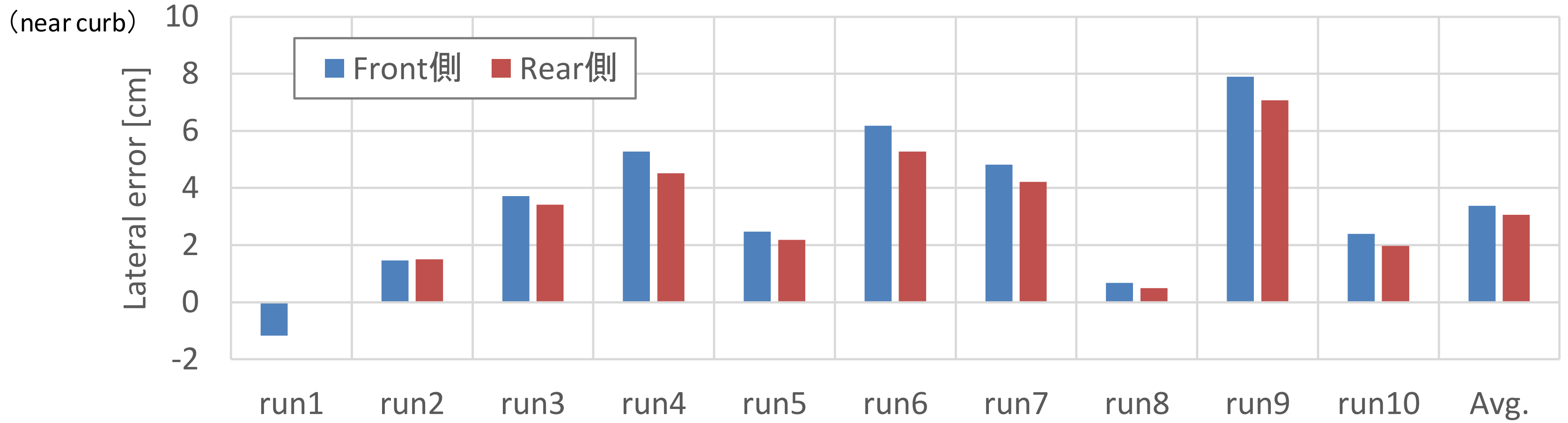


FrontAxle-side sensor log (18 runs) RearAxle-side sensor log (18 runs)

3.5.3 Accuracy Comparison by Arrival Control Method

■ Accuracy of arrival control using magnetic marker

- The actual accuracy of arrival control is evaluated approx. ±8cm.
  (That was evaluated without cases which strongly influenced by entry condition)



■ Accuracy Comparison by Arrival Control Method

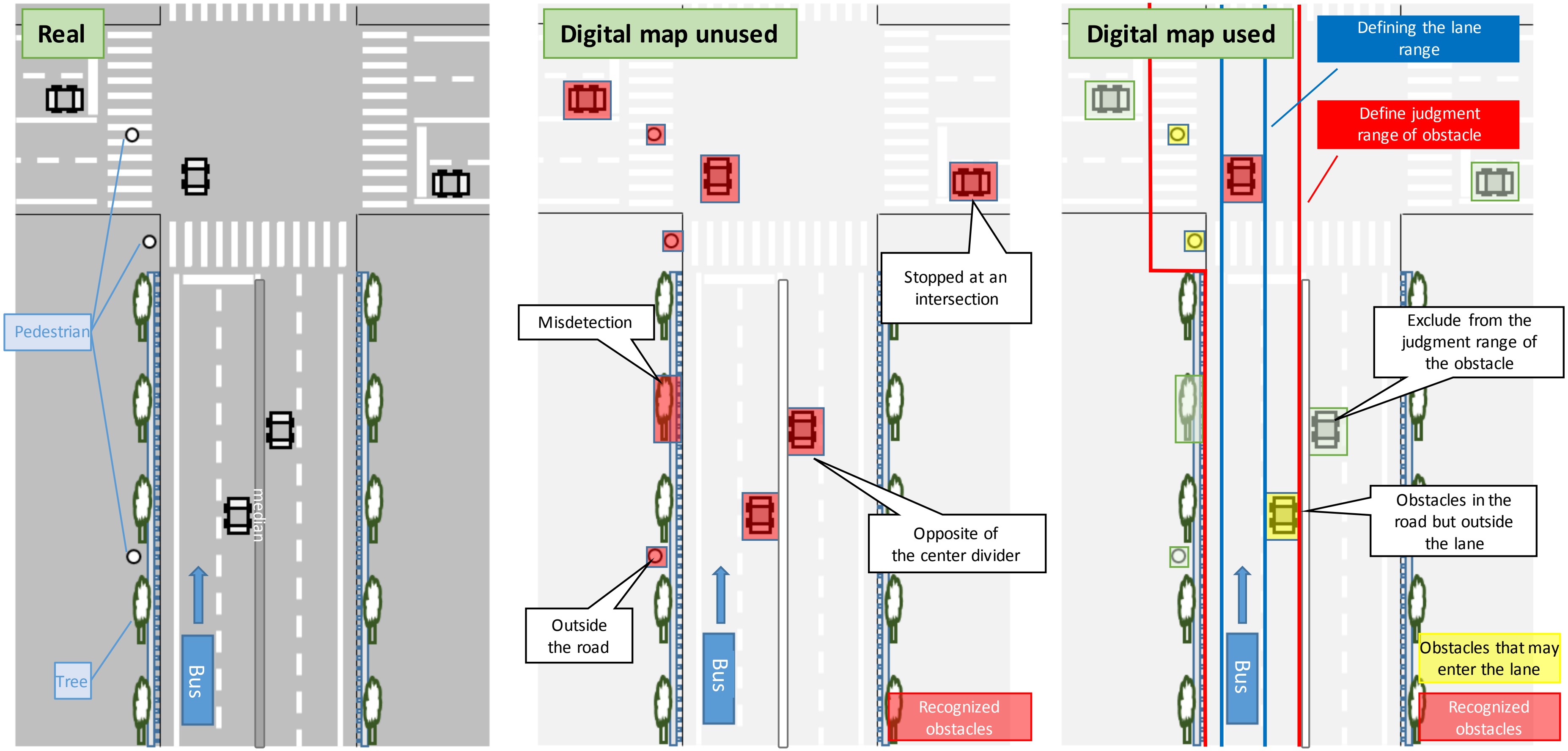
- The magnetic marker has discrete reference by its attachment interval.
  So the accuracy using magnetic marker is less than using while line or curve stone detection in principle.
- on the other hand, it is considered that the magnetic marker system have strong robustness for weather or the maintenance condition of while line, curbstone.
- The control accuracy using magnetic marker could be improved by adjust parameters.

method	GPS（RTK）	Magnetic Marker	White Line（Camera）	Curbstone（LiDAR）
Recognition	Continuously	discrete	Continuously	Continuously
Accuracy of arrival control	±10cm	±8cm	±5cm	±2cm

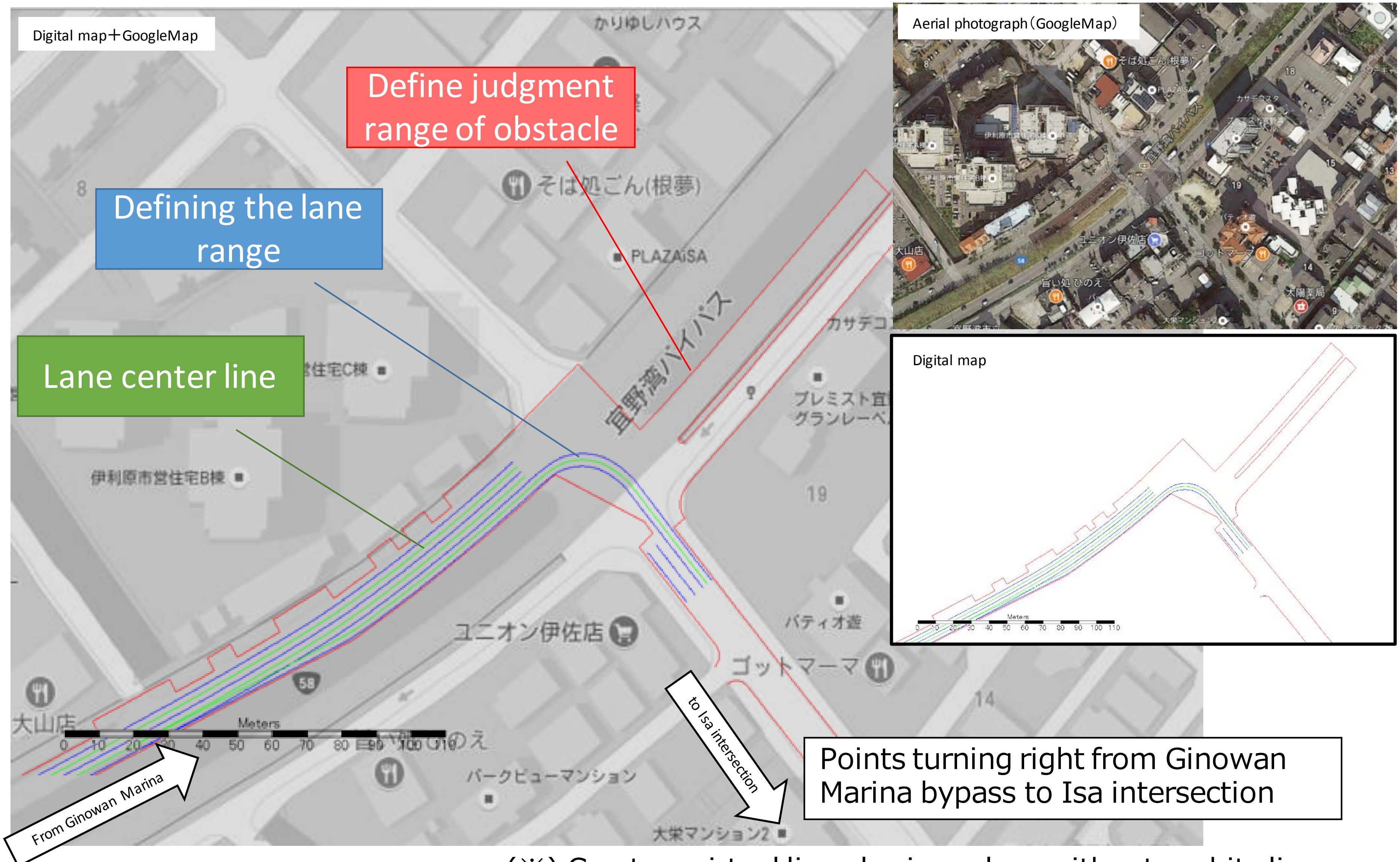
（Consideration : past record of ART evaluation）

3.6.1 Obstacle detection using digital map

Conventionally, objects detected by sensors (including misdetection) were regarded as obstacles regardless of inside or outside the road.
→ By using the digital map, only objects on the course of the bus are treated as obstacles.



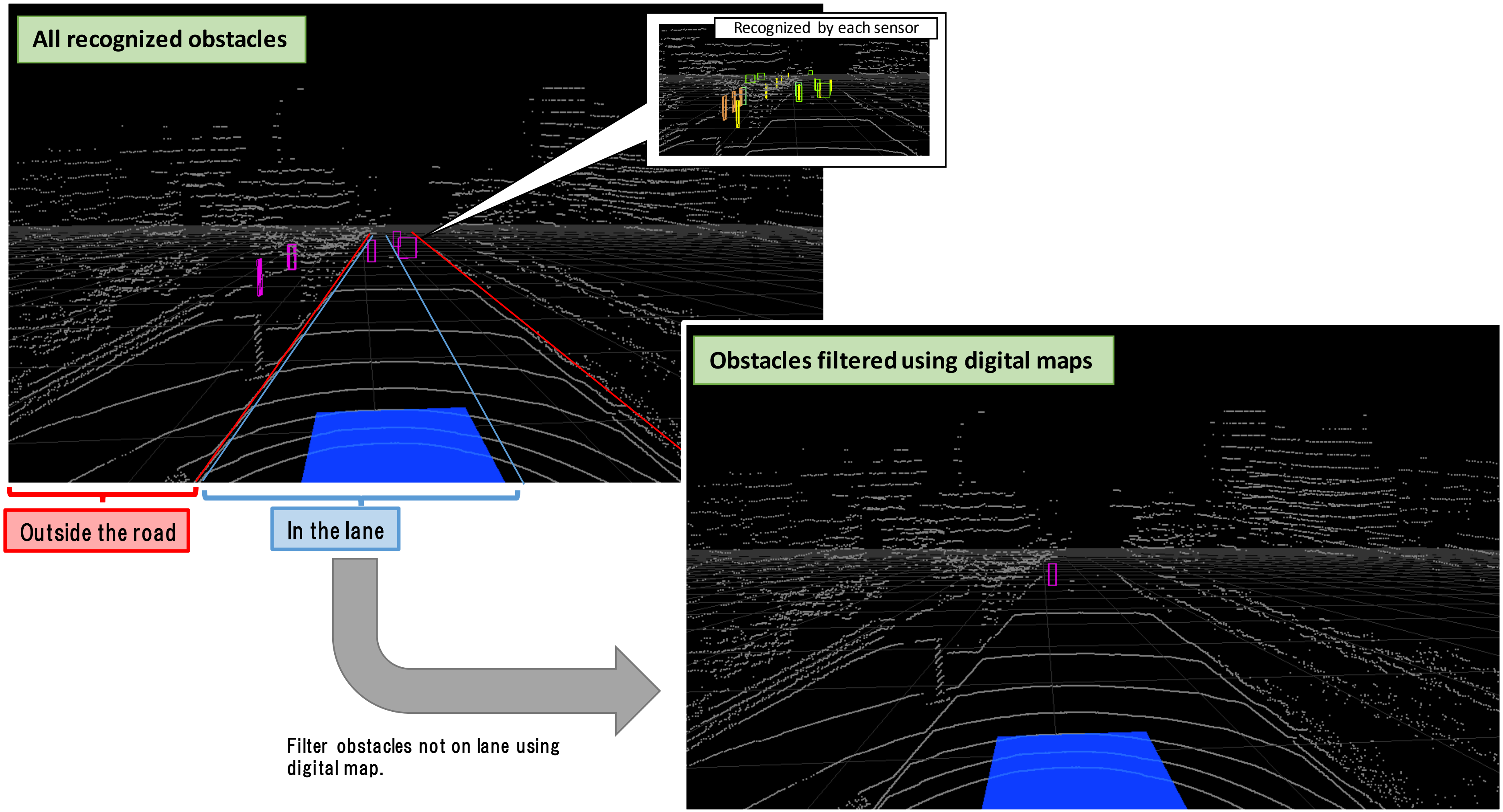
3. 3.6.2 Digital map used in Okinawa



(※) Create a virtual line also in a place without a white line

3.6.3 Obstacle detection by using digital map

Distinguish obstacles using digital maps at Inside and outside the road, inside and outside the lane.



3.6.4 Comparison with conventional methods

Comparison of obstacle determination results on lane compared with conventional method.

Log used for measurement

Route: Ginowan Marina → AEON MALL Okinawa Rycom(11/29/2017 12:33-13:16)

running time: about 43 minutes (about 25000 frame)

Count the number of obstacles (cars, pedestrians) judged to be on the lane.

	The number of obstacles (cars, pedestrians)
Conventional method	21793
Using digital map	18506

3. 3.7.1 The Number of Times of Override

- 3 round trips are randomly picked up.
- The number of times of unexpected steering override was 2.3 times per 20km on average.
  The number of times of unexpected brake override was 4.0 times per 20km on average.

The number of times of steering override

Total	Lane change	Others
3.3 times	1 time	2.3 times

Future task is how to lane change in heavy traffic.

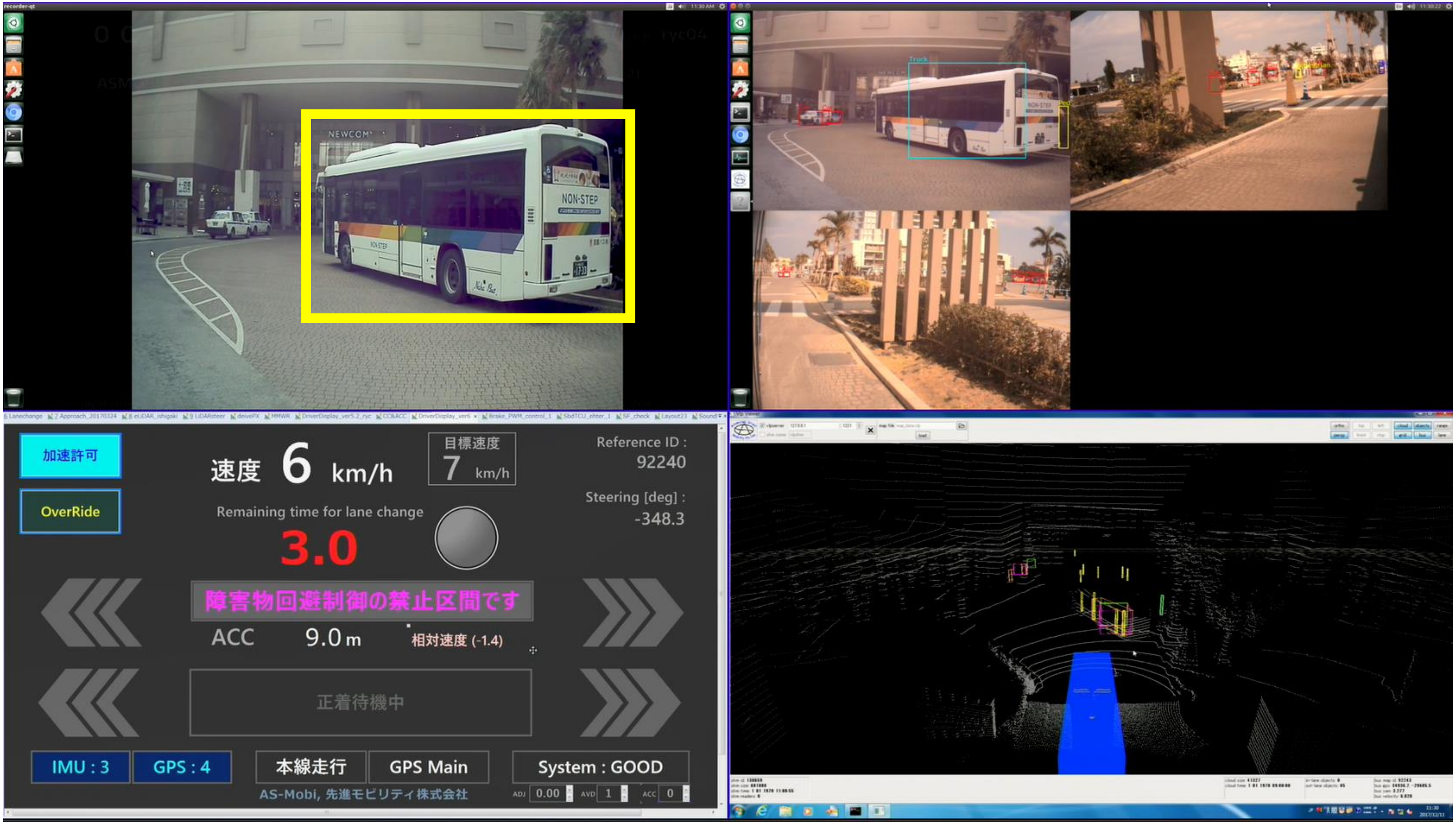
The number of times of brake override

Total	Red light	Turn right	Others
16.7 times	11 times	1.7 times	4 times

Future task is how to know the traffic light in advance.

Future task is how to turn right in the situation oncoming car is coming fast.

3.7.2 Situations of Steering Override

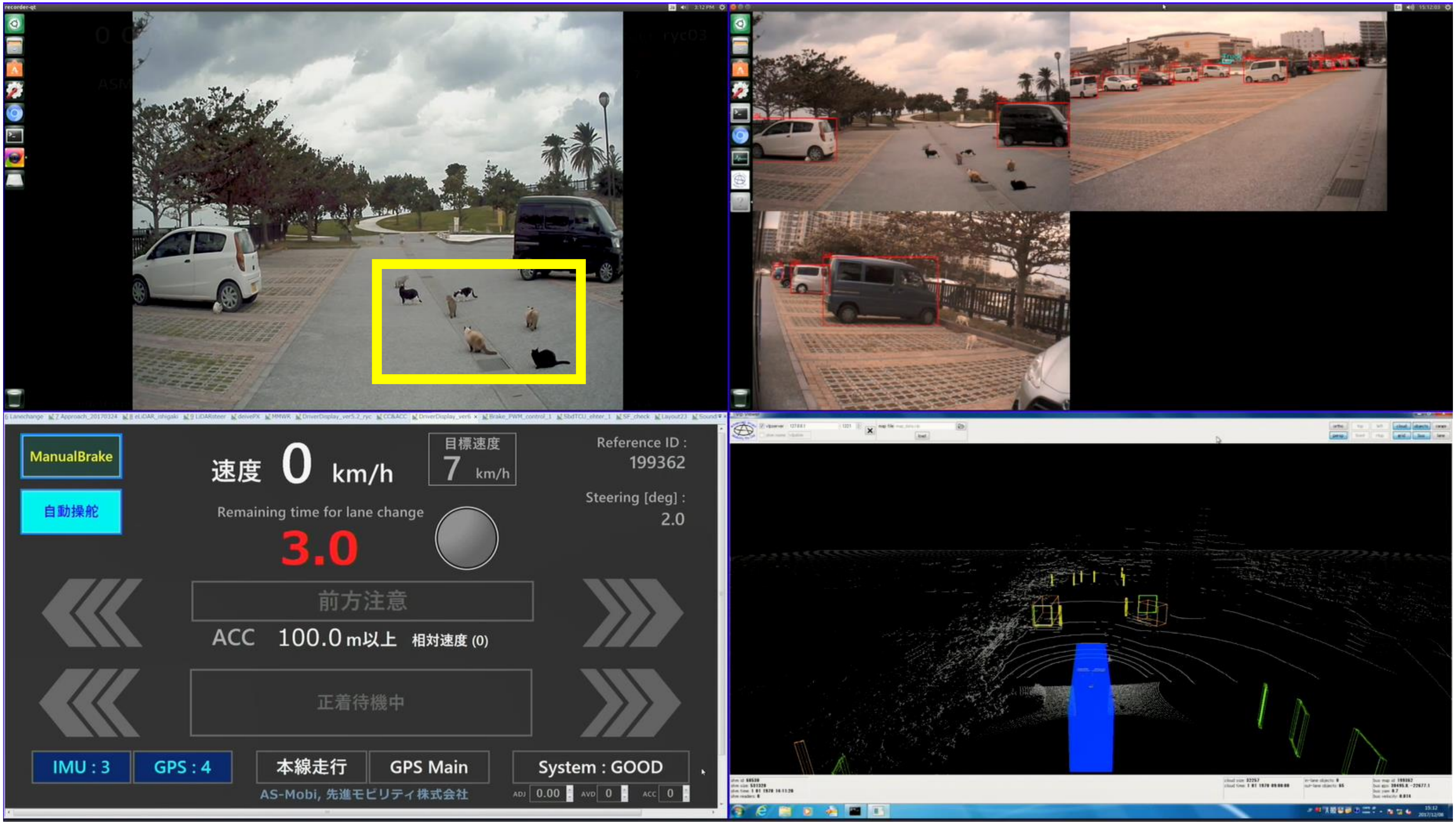


- It was difficult to avoid automatically in the case a large bus was blocking the path.
- It is needed to confirm high safety around the bus automatically.

3. 3.7.3.（1） Situations of Brake Override

- During obstacle avoidance, another vehicle passed by in the next right lane and the driver stepped on the brake for safety.
- It is needed to confirm high safety around the bus automatically.

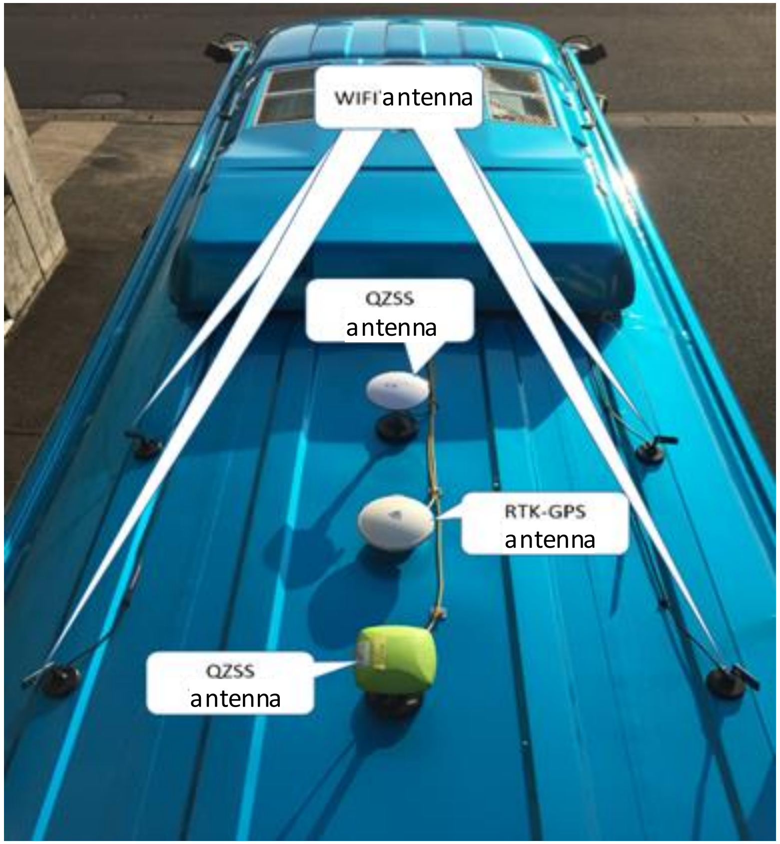
3. 3.7.3.（2） Situations of Brake Override



- The bus couldn’t detect cats and the driver stepped on the brake for safety.
- It is needed to detect small object.

3.8.1 Comparison between RTK-GPS and QZSS

- Experiment was conducted in Okinawa using the bus on which QZSS antenna and receiver had been mounted.
- RTK-GPS was used as reference.



◇ **RTK-GPS**

・**Trimble's VRS**

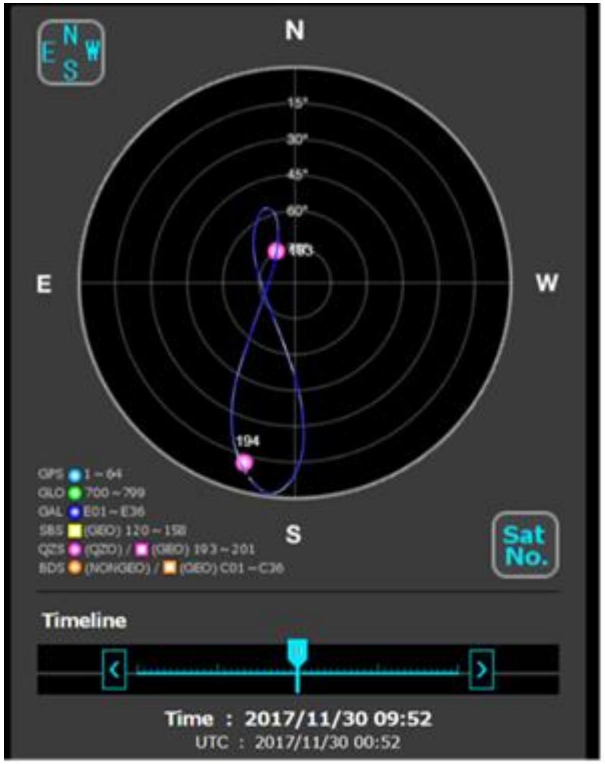
◇ **QZSS**

・**CLAS：**
Mitsubishi Electric

・**MADOCA：**
Magellan Systems Japan
（not related to this experiment）

3.8.2 QZSS Positioning System

During the experiment period, only #1 and #2 distributed the signal of CLASS, though #3 and #4 are also distributing it now.



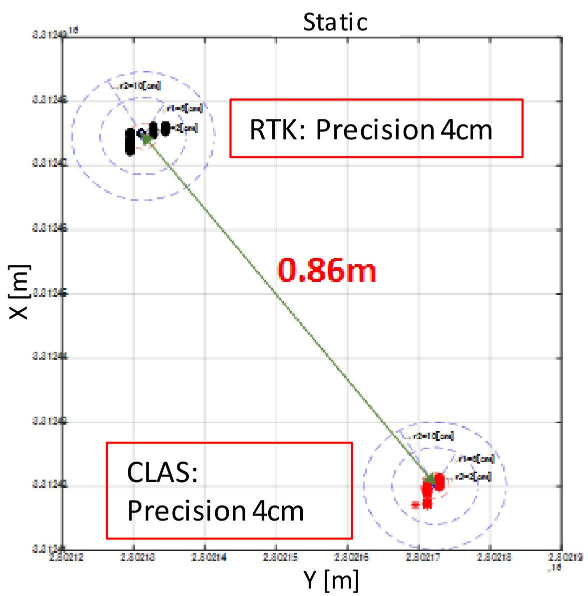
Cabinet Office GNSS View

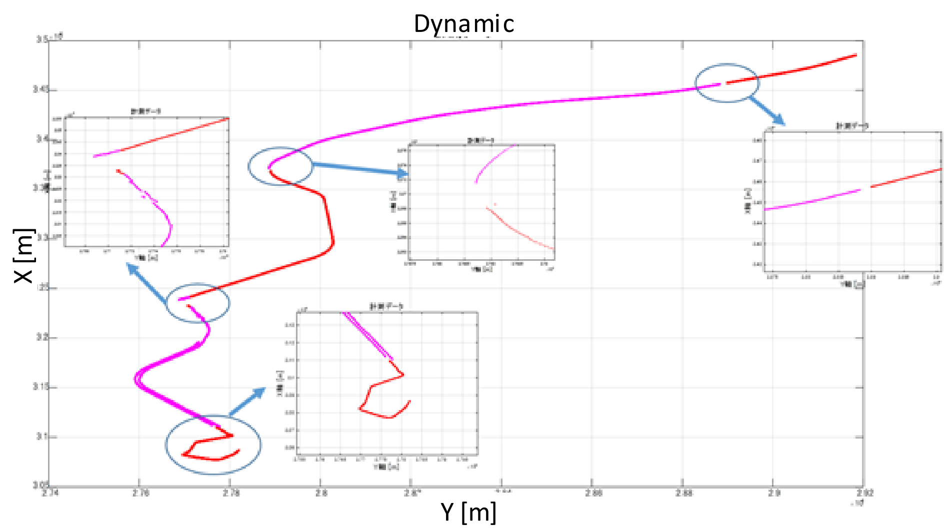
QZSS No.	Elevation angle	Distribution time
193(#1)	Over 60deg	02:00～14:00
	Over 70deg	03:00～12:30
194(#2)	Over 60deg	11:00～23:00
	Over 70deg	12:00～21:30

Definition of Fix Quality of QZSS			
Quality	Definition	Precision	Autonomous Vehicle
0	No Positioning	NaN	×
1	Single Positioning	3m～5m	×
2	DGPS	1m	×
4	CLAS/FKP (FIX)	～10cm	○
5	CLAS/FKP (Float)	50cm	×
6	Dead Reckoning	10cm～1m	△

3.8.3 Experimental Results

No.	Evaluation topic	Result	Comment
1	Precision during fixed	Static: 4cm, Dynamic: 10cm	No problems
2	Difference from RTK	0.86m	The difference was generated from the earth's crust used for calculating positions. It will be cancelled.
3	Rate of fixed time	32.8% （RTK 98%～）	Now it is improved up to 68.7% and the effort for application of autonomous vehicle is to be continued.
4	Restoring time	33.4sec （RTK 11.2sec）	Increasing the number of satellites will improve the restoring time but the algorism of the receiver also should be improved.

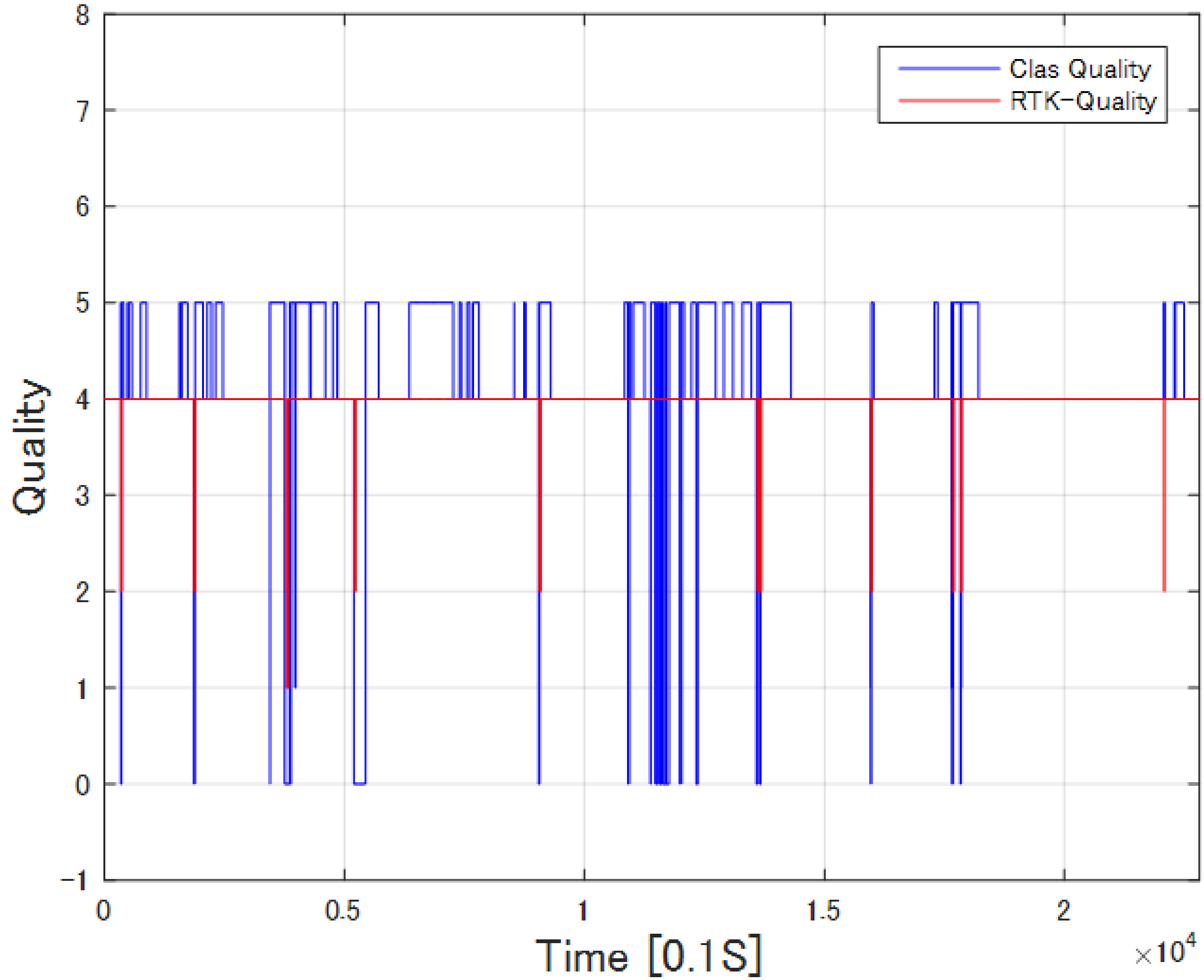




No.2 Difference from RTK was generated from the earth's crust （RTK: 1997, CLAS: current）

No.3 Rate of fixed time
No.4 Restoring Time

3.8.4 Degradation of Fix Quality



＜Result＞

- Fix quality of CLAS was often degraded from 4 to 5 or 0, though that of RTK wasn't frequently degraded from 4.

3.8.5 Long Restoring Time

<Result>

- After the bus went through sections where it was difficult to measure its position precisely, restoring time of CLAS was 33.4sec, on the other hand that of RTK was 11.2sec.

3.8.6 Summery of QZSS Evaluation

Experimental results

CLAS system is expected to be used for autonomous driving because precision of position was good while fix quality was 4. Although degradation of fix quality and long restoring time should be improved.

Issues and future measures

Tasks	Causes	Future measures
Degradation of Fix Quality Dec 2017 : 32.8% Feb 2019 : 68.7% Target : over 95%	(1) Multipath of reference satellite	Improve algorithm of receiver to select another reference satellite
	(2) Estimation error of ionosphere and atmosphere delay	Improve algorithm of receiver to calculate delay precisely
Long Restoring Time Dec 2017 : 33.4sec Target : under 30sec	(1) Shortage of satellites used for reinforcement of signal	Galileo will be launched then the number of satellites increase twofold
	(2) Updating cycle of reinforcement is 30sec	Shorten the restoring time by improving algorithm of receiver
		※ Combine IMU and output positions continuously

Conclusions

Improvement of algorithm of receiver and CLAS are expected to resolve issues such as degradation of fix quality and long restoring time. Additional study is to be continued.

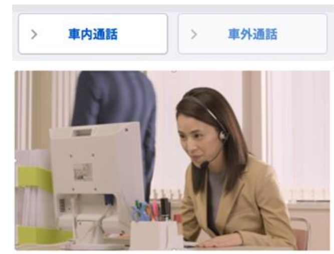
3.9 Automated Bus remote monitoring system

Remote monitoring system：Vehicle condition monitoring/Call Features

Vehicle speed, engine speed

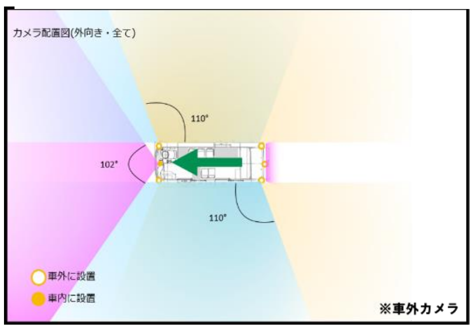
Vehicle position

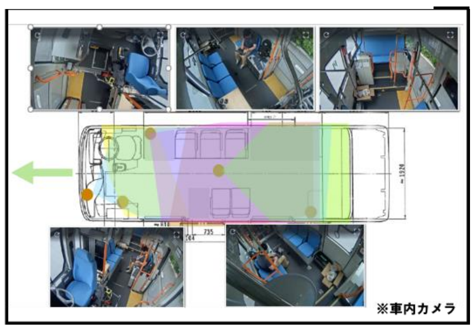
Call Features



The remote monitoring system monitors the position and speed, and tells the remote observer whether the car is running correctly. The remote monitor checks the screen of the vehicle posittion when an abnormality occurs in the state of the car,and when a remote observer needs to talk with passengers in the car,he / she makes a two-way call using the call features.

Automated Bus remote monitoring system: Video monitoring





In order to enable the remote monitoring system to remotely monitor the situation of the inside and outside of the bus, we installed multiple cameras.

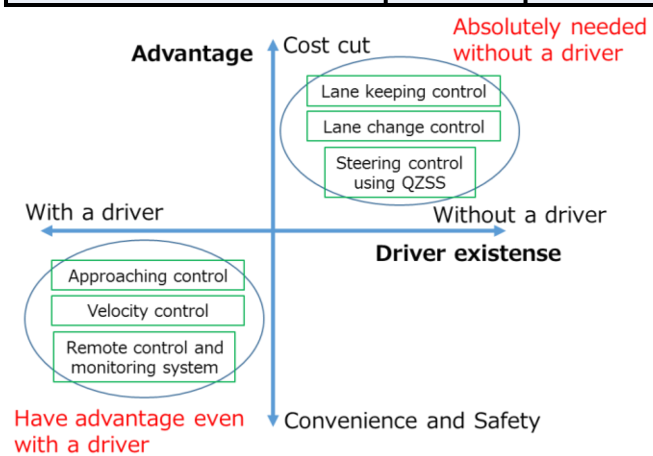
- ・Outdoor camera : 6
- ・In-car camera : 5

Automated Bus remote monitoring system:Stopping&Departure

The button on the upper right displays “stopping” while the bus is running, and displays “departure” while stopping.
The remote observer can press these buttons to stop or depart the car.

3. 3.10 Evaluation and Needs of Technical Items

Technical items	Feasibility		Advantages for transportation operators, government or users	Technical issues
	2020～	2023～		
Approaching control	○		Interest in not only convenience but also less getting on/off time was shown	It is difficult at bus bay to approach bus stop precisely because of short distance.
Lane keeping control	○		Increase of burden on drivers were worried about because they were not used to autonomous vehicle system.	It is not safe when fix quality of GPS degrades.
Lane change control		○		・It is difficult to lane change in heavy traffic. ・Recognition performance using AI should be improved.
Velocity control (with ACC)	○		It seemed to have advantage if human errors or accidents inside a bus decreases.	
Intersection control using current traffic signal	(○) split	○	It was effective to reduce problems of dilemma zone.	Centralized controlled traffic lights needs apparatus which send information.
Steering control using QZSS		○	It would contribute lower cost and more safety.	Improvement of algorithm of receiver and CLAS is needed for precise positioning.
Remote control and monitoring system	○		It should lighten burden on drivers besides safety.	Recognition ability inside a bus should be improved.



Drivers usually confirm safety inside buses but it' a problem that the burden on drivers is high and sometimes accidents happen while they can't see passengers.
Monitoring system is expected to decrease accidents inside buses by lightening the burden on drivers.

On the other hand, though ACC, Lane keeping control and Lane change control have advantage of safety and convenience, only each control can't replace a driver so they don't much contribute business challenges. Transportation operators are unwilling to introduce only each control.

4. Social Acceptability Study on Automated Driving Bus

Hearing result: current status & challenges for monetizing ①

Question 1	Do business operators (transportation operators, etc.) feel the needs of automated driving technologies (LV2-3)? Would they like to bring into automated driving technologies even though they cannot reduce labor costs by automation?
Consideration	**Many business operators have expected "securing drivers" from automated driving. However, there are many of them who expect improvement of safety by the vehicle monitoring system from automated driving buses. As a result of hearing, business operators are skeptical whether the automated driving technologies (LV2-3) can actually reduce the burden on drivers or not although there is a certain number of voices asking for it.** **As for the vehicle prices, many business operators are expecting around the existing vehicles + from 10 million to 20 million yen. However, it is hard to find business operators who can bear the same level of pricing (the existing vehicles + from 10 million to 20 million yen) under the situation where there are no labor cost reduction benefits since many of them have set the "reduction of labor costs" as the funds for automated driving vehicles to be introduced.** **In order to monetize automated driving vehicles, it is necessary to make the mechanism that is covered by personnel who can easily be employed due to low labor costs by the crew to be not the driver but the conductor, for instance. (equivalent to LV4 that the driver is absent)**
Comments excerpt from hearing (transportation operators)	• Enabling labor costs to be reduced for personnel who no longer need to be on board itself is desirable. • Functions to inform drivers the inside of vehicles by the front monitor & the remote monitoring system and also when dangerous situations occur such as passengers' sudden standing while on board are already available and appreciated by drivers. • Projects such as selling the car monitoring system separately and the system for safety solely are expected. • Crew members might feel stressed if the automated driving function requires them together. • There would be no advantage if 10 million yen were to be added with the crew on board. • New routes would make it profitable, however, even maintaining existing routes is hard enough currently. The cause is the lack of drivers. • We would expect human errors to be reduced by AI though the surroundings and the inside of vehicles are generally confirmed for safety by the drivers. • It would be enough if the burden on drivers could be reduced to solve the current problems. Around how much cost would be saved is the key by introducing the automated driving functions such as reduction of labor costs. • The funds acquisition by cost savings effect would be better than by earnings growth if the funds for automated driving needed to be raised. • It would be inexpensive if crew members became unnecessary and that could lead to reduction of labor costs although 20 million to 30 million yen needed to be added compared to regular buses. However, it would be expensive if crew members other than drivers were still needed. • Any functions to assist drivers would lead to fatigue reduction even if complete automation might not happen. It would also make it possible for drivers to concentrate on securing safety, for instance. • it is difficult to give an immediate answer for 10 million yen as the initial cost. We would like to see the total cost-effectiveness considering the running costs.

Hearing result: current status & challenges for monetizing ②

Question 2	To what degree are there interests and needs from the local government, business operators & users about this inspection technology (Approaching control, lane keeping & change, acceleration & deceleration control, remote monitoring, etc.)? Also, is the current technology level enough to fully meet the relevant needs?
Consideration	**From the hearing, there are a lot of needs relatively for Approaching control control and the technology level was considered to be enough. Also, as Question 1 showed, the needs for the vehicle monitoring can be expected from the viewpoint of safety. On the other hand, there were many voices to claim a sense of discomfort while the technology levels of lane keeping & change and acceleration & deceleration control were considered to be enough. Due to the hearing by transportation operators, there seem to be many cases to be compared with their own drivers. Needless to say, safety beyond professional drivers is required for automated driving buses. However, consideration is required whether the equivalent service to professional drivers is the sufficient condition.**
Comments excerpt from hearing (transportation operators)	• We felt uneasy about the lane change. It seemed dangerous that the speed was going down too much at the time of a lane change and could not fully match the speed around the traveling vehicles. • The lane keeping was smooth where there were no obstacles. • Public roads seem to be challenging, however, the technology has been advanced to the non-problem level in closed spaces. • The lane change was smooth and that should not be problematic. • In putting on the brake, it was so sudden that passengers' fall and contact with the following vehicles were feared to happen. • Frankly speaking, applying the brake for the override is still an issue. • Stop using a magnetic marker would enable customers to get on & off smoothly if it could pull off that much. That might even lead to wheelchairs' getting on & off. • Such as the moment of stopping, removal from the brake was quite weak. It would be better if that could come close to human behavior. • The purpose of "pulling off" for Approaching control should not limit users such as the elderly and children. That should be brought into any buses for all passengers' convenience. • It seems that even the current technology could enable the buses to run without human intervention.

Hearing result: current status & challenges for monetizing ③

Question 3	What are the issues and concerns for monetizing from the viewpoint of the local government & business operators? Also, what kinds of technical development & demonstration tests are expected to solve those?
Consideration	**For monetizing, there are voices to ask for where the responsibility lies at the time of accidents. Also, there are many concerned voices for collection of fares. As for collection of fares, consideration for the settlement means and the technology for remote monitoring & being linked with IDs is desired. The biggest issue seems to be the cost of introduction & operation. As Question 1 showed, many business operators expect the vehicle prices + from 10 million to 20 million yen and labor costs by reducing drivers as funds. However, the hurdles for introduction except for some transportation operators with ample funds are by no means low in the current situation as automated driving vehicles require running costs such as labor costs for remote monitoring, capital investment, and communication costs, etc. in addition to the initial cost for hardware. From now on, not only technology demonstration but consideration & verification on sustainable business models would be desired.**
Comments excerpt from hearing	• Who will be responsible? If there is a person in the driver's seat, will he/she be responsible? What happens to an unmanned case? • Would it be possible for loop buses in the housing complex with access to the nearby bus stops to be automated? • Occupancy is important for buses. All-day service by large-sized buses should not be a problem for urban local buses, however, there is little daytime use while there is a lot of commute use in the morning & evening in the linear area like our company. • In case of automated driving vehicles, collection of fares might become a problem. • How about the operation like BRT as arterial traffic – collecting fares outside, for example? • If there were a subsidy system for purchasing vehicles, the introduction would be easier. • Requirement for monitoring by those who own the large-sized motor vehicle 2nd-class license would be costly over monitoring investment since the drivers would be needed for the transition period. • Measures for cases like cats' jumping out onto roads and their staying on the traveling lines should be considered.