文書番号；08J3-F-93-002-001

“Strategic Innovation Promotion Program （ＳＩＰ）・Automated driving systems“

Investigation concerning automated driving bus in Okinawa

Report of 2018~2019 year

20th March 2019
JTEKT CORPORATION
R&D Headquarters

1) Investigation outline

- Contents of Investigation
- Vehicle for test
- System configuration

Contents of Investigation

Item／Problem	Target
Precise docking control 〔problem 〕 ・In the bus bay type bus stop, there is not enough distance for docking	・Robustness verification at various bus stops (cross-wind, Road condition, Approach route, etc.／4 cases) ・Verification of docking distance at bus bay type bus stop(2 cases) ・Investigate convenience and effectiveness(4 + 2 cases)
Braking control 〔problem 〕 ・Uncomfortable feeling because of rough control ・Not implemented at over 40km/h	・Verification by 2 types of deceleration charactaristics (Focus on quick-deliverability〔-0.15～-0.2G〕／ Focus on ride comfort〔-0.08～-0.1G〕) ・Verification on upper speed limit (50km/h)
Lane keeping control 〔problem 〕 ・Unstable control when GNSS condition is low ・Not implemented at over 40km/h	・Verification on upper speed limit (50km/h) (Including under various condition such as cross wind, road condition) ・Verification of accuracy of white line and curb detection with camera and LiDAR
QZSS 〔problem 〕 ・Achieving cm-class positioning accuracy	・Verification of accuracy as a positioning sensor (RTK-GNSS／CLAS／MADOCA)
Social acceptance 〔Bus service company／ Local government／ General public〕	・Holding a test ride event and discussion meeting 〔For bus service company, local government〕 ・Holding a trial ride for general public

Test vehicle・System configuration

GPS/GLONASS
QZSS※ (CLAS/MADOCA)

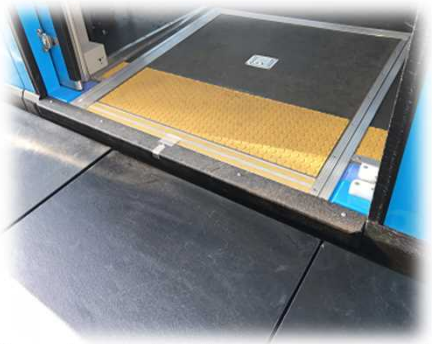
※ QZSS is a registered trademark of Quasi-Zenith Satellite System Services Inc.

Side view camera
〔White line/Curb detection〕

Front view camera
〔White line/Obstacle detection〕

Test vehicle

LiDAR
〔Curb detection〕



Precise docking control

Vehicle specifications

Model name :
Blue Ribbon City Hybrid, HINO Motors
Capacity : 20 passengers
Wheelchair fixing device
:Roller coaster type 1passenger
:Floor fixed type 1passenger
Size:L10.5m×W2.5m×H3.3m
Floor height : About 34cm Non-step
Main equipment : Surveillance camera, Steering actuator, Brake actuator, GNSS, QZSS, Camera(front, side and back view), LiDAR

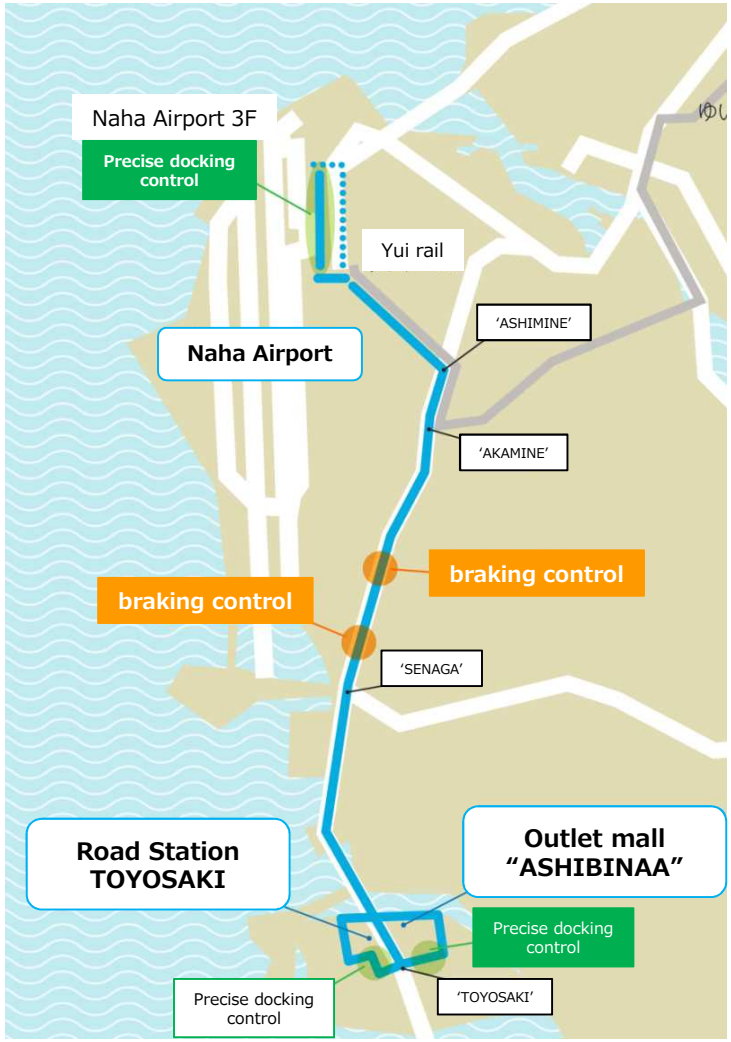
View in the car

Display monitor

2) Field operational test overview

- Test route
- Demonstration items

Field operational test overview



The duration of the experiment (for the public)

■ From 18, Feb to 7, Mar, 2019

※Excluding weekends

5 or 6 trips (round trip) /day

Route(about 18km round trip)

Outlet mall "ASHIBINAA" → Road Station TOYOSAKI → Naha Airport 3F (south/North)

Demonstration items

- **Automatic control of Steering and brake (Partially manual drive)**
- **Lane keep control in legal upper limit speed (50km/h)**
- **Precision docking control (Minimize gap between bus and platform)**

Opening ceremony 16,February

◇ **Attendees**

- Mr.Koda, Director General of Cabinet Office
- Mr.Kuzumaki, Program Director of SIP
- The mayor of Tomigusuku City
- Dean of Engineering,RYUKYU Univ.
- President of Bus service company in Okinawa

etc.

Press Coverage

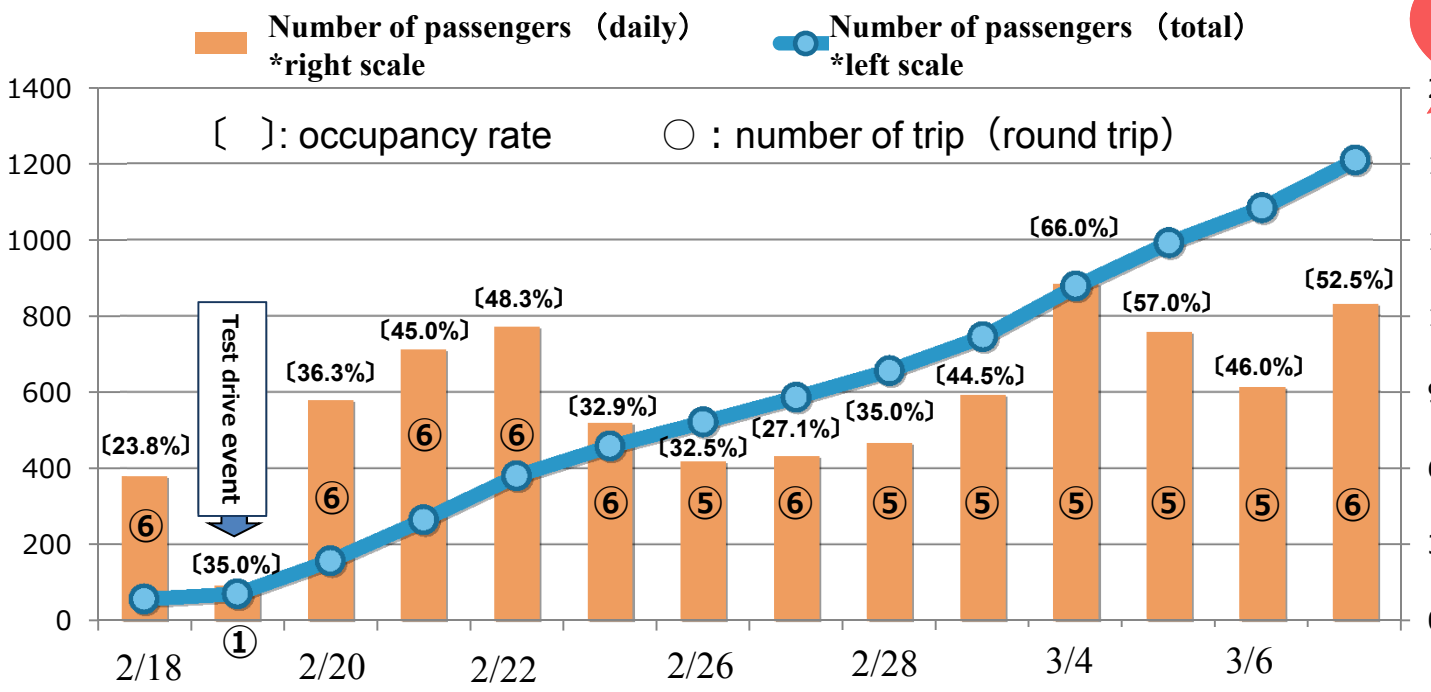
The main coverage

- TV : NHK, OTV, RBC, QAB
- Newspaper : Ryukyu Shimpo, Okinawa Times, YAEYAMANIPPO,
  Major newspaper company and web media
- Magazine : 「BUS GRAPHIC ®」© NEKO PUBLISHING CO.,LTD.
- Radio : FM-Okinawa（sh@reTIME）, FM-Toyomi, RBCi Radio（local station）

- **Extensive coverage in major news media contributed to an increase in number of rides.**
- **Leaflets were distributed to prefectural office, city hall, reception desk, etc.**

Number of passengers

Transition of total passengers



Final results 1210 passengers

- Number of trip 146trips (73round trips)
- Average occupancy rate 41.6%

- **More then 1200 passengers took a ride in 3 weeks. (total of general public and the people concerned)**
- **Passengers took a ride smoothly through both web reservation service and reception on spot.**

Stroller user

3) Result

- precise docking control
- braking control
- Lane keeping control
- Sensing
- Social acceptance

Precise docking control

- Road Station TOYOSAKI
- Outlet mall “ASHIBINAA”
- Naha Airport
- Bus bay

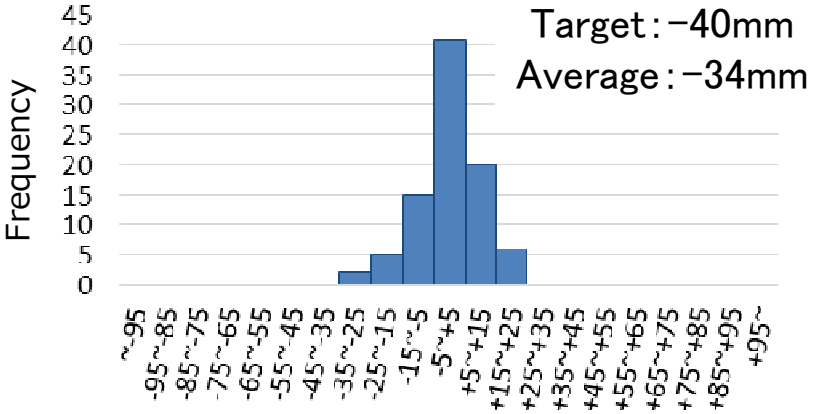
Road Station TOYOSAKI

◆**Docking with high repeatability**

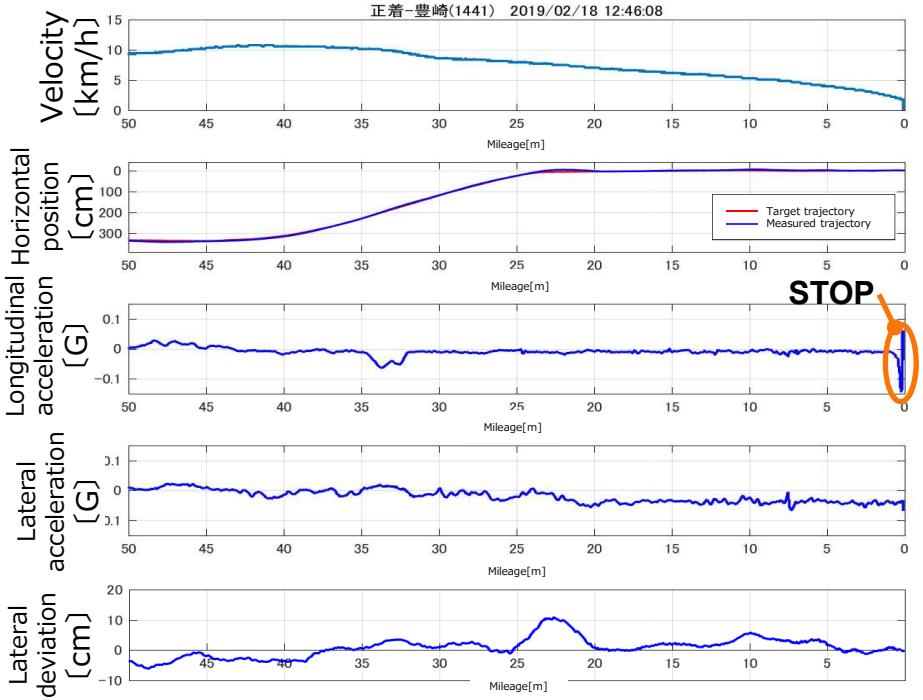
Docking trajectory

Platform

Precise docking at Road Station TOYOSAKI



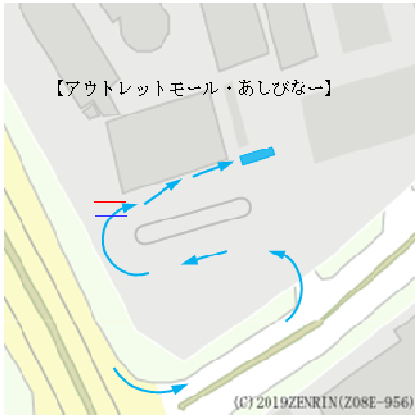
Distribution of distance to curb measured by LiDAR



Vehicle behavior

Outlet mall “ASHIBINAA”

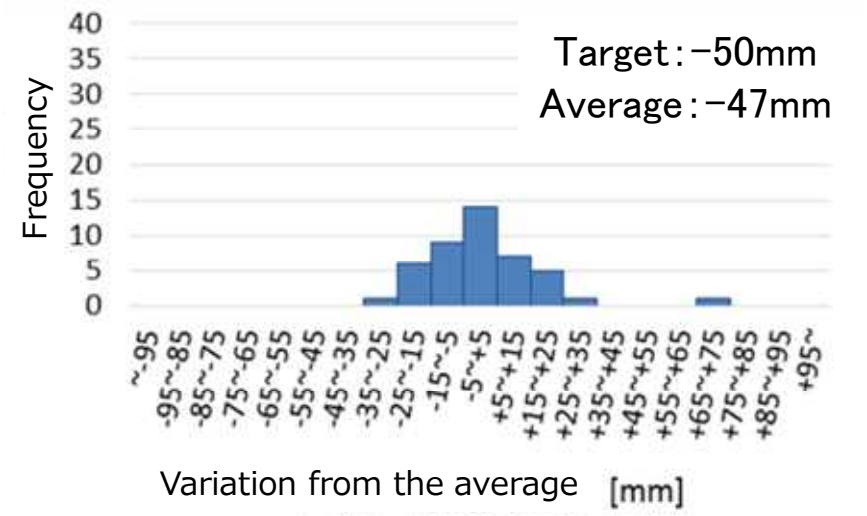
- High repeatability is realized in case of good RTK-GNSS sensitivity.
- In some case, oscillated rolling motion was occurred at large steering angle operation.



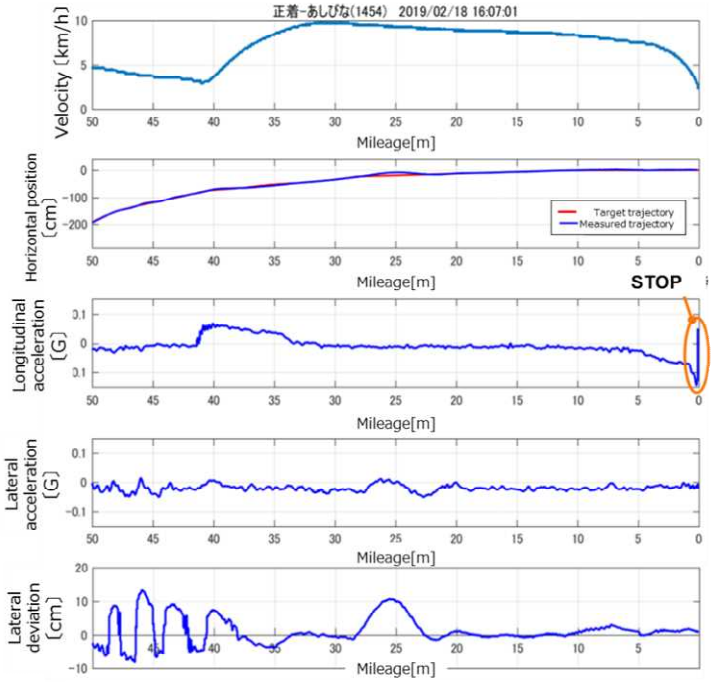
Docking trajectory

Platform

Precise docking at Outlet mall “ASHIBINAA”



Distribution of distance to curb measured by LiDAR

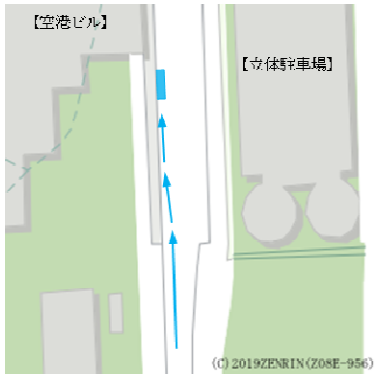


Vehicle behavior

Naha Airport

◆If RTK-GNSS condition is good, stable docking is achieved in spite of body movement came from rough road surface.

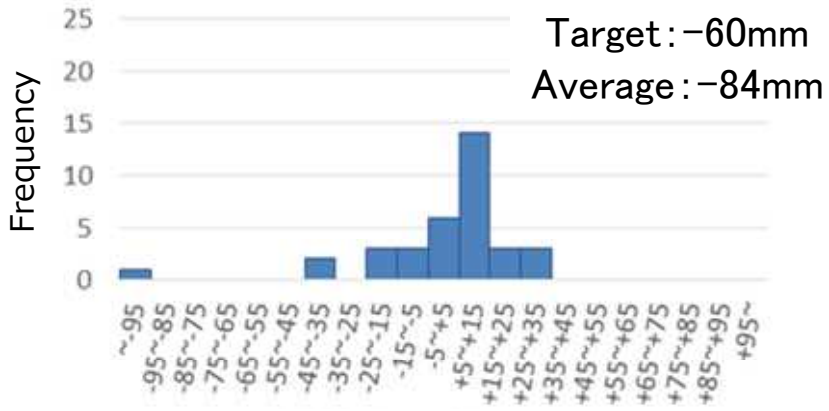
※GNSS signal isolation by signboards or monorail above the road affected to the control.



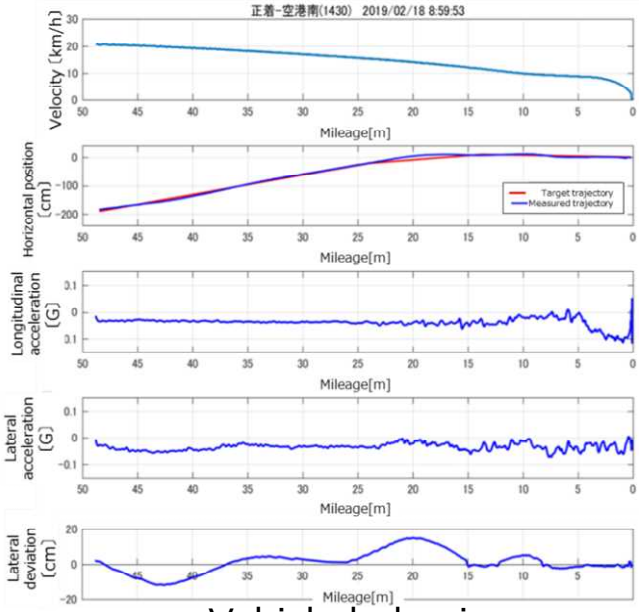
Docking trajectory

Platform

Precise docking at Naha Airport



Distribution of distance to curb measured by LiDAR

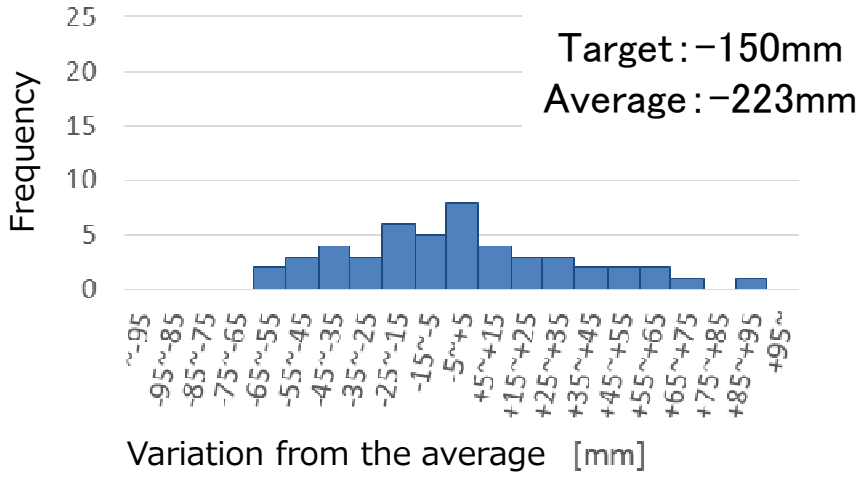


Vehicle behavior

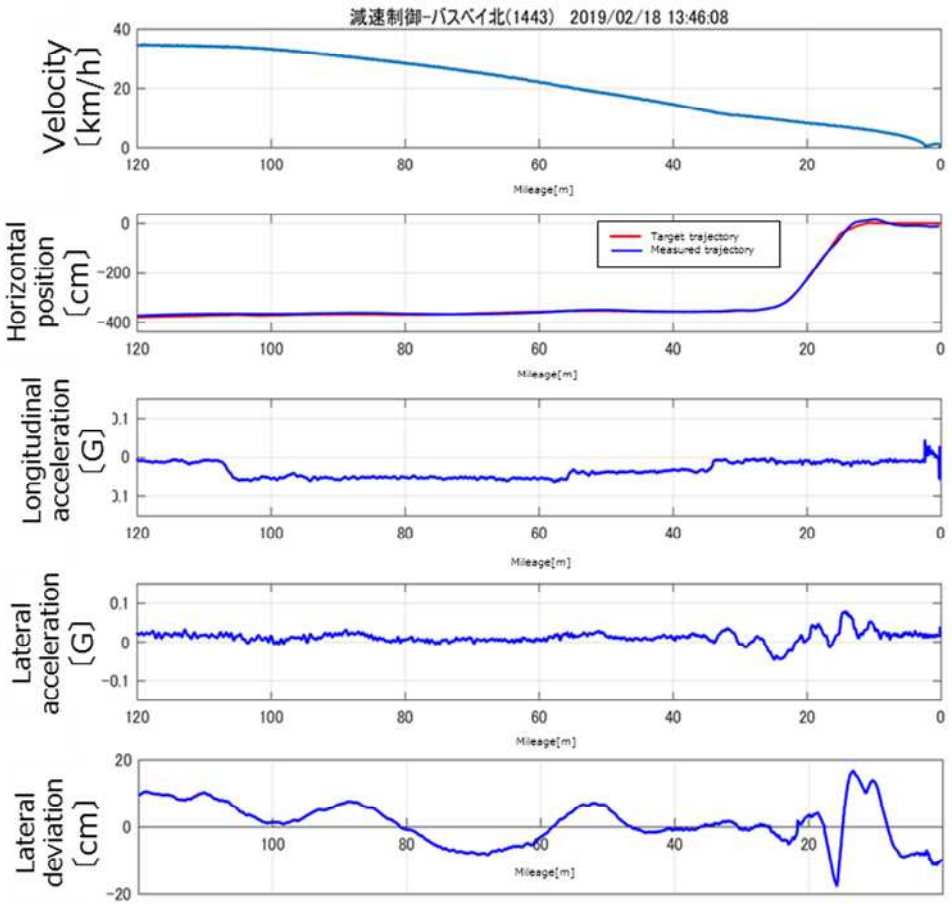
Bus bay〔Bound for North〕

◆Target distance was set 150 mm considering streetlights, curbs and bus stop shape. Distance to the platform was 100 to 300 mm.

Docking to bus bay



Distribution of distance to curb measured by LiDAR

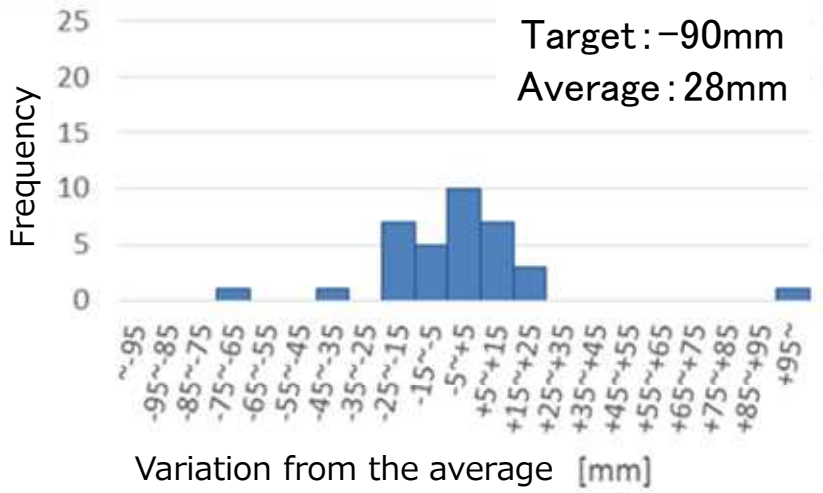


Vehicle behavior

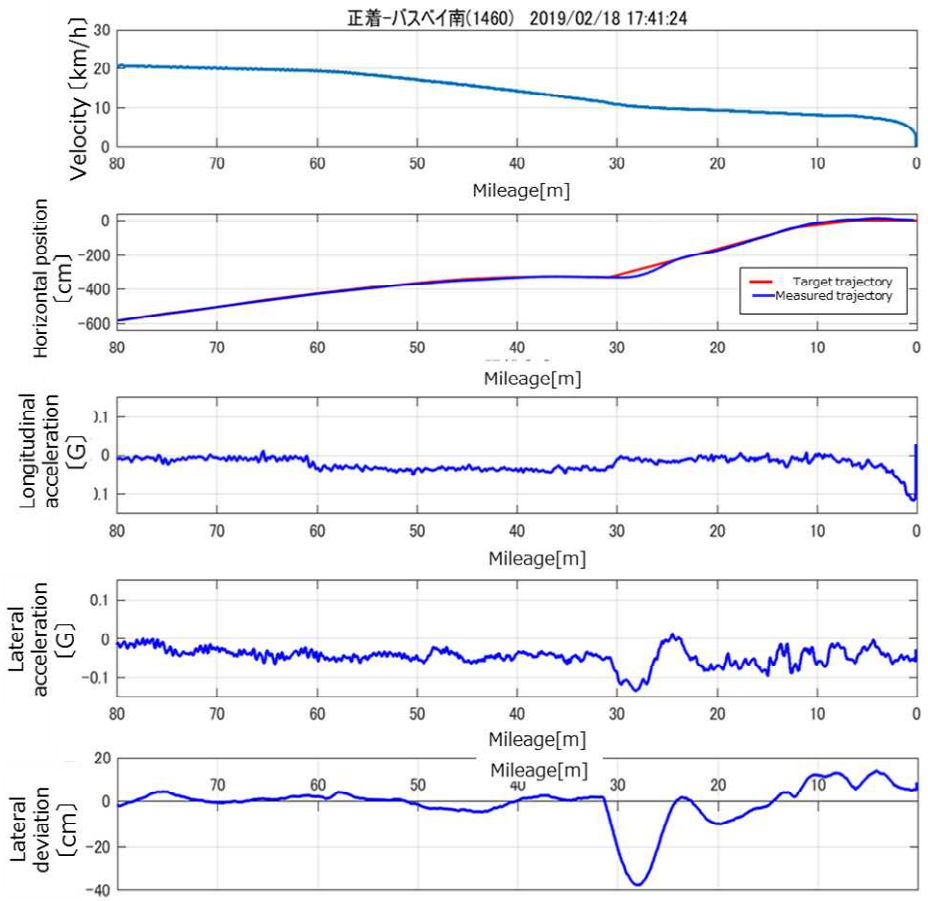
Bus bay〔Bound for South〕

◆Distance to the platform was within 200 mm.
Lower curbs during approach contributed to minimize the distance compared to north bound.

Docking to bus bay



Distribution of distance to curb measured by LiDAR

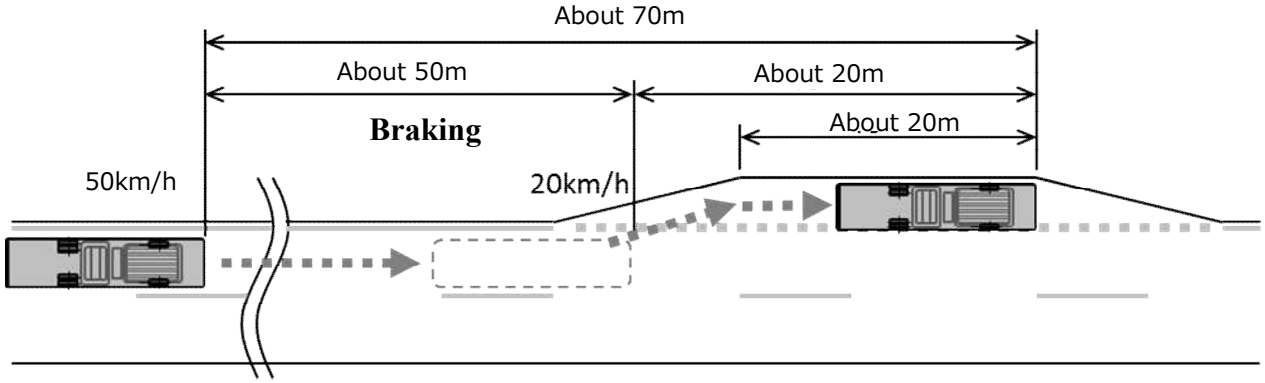


Vehicle behavior

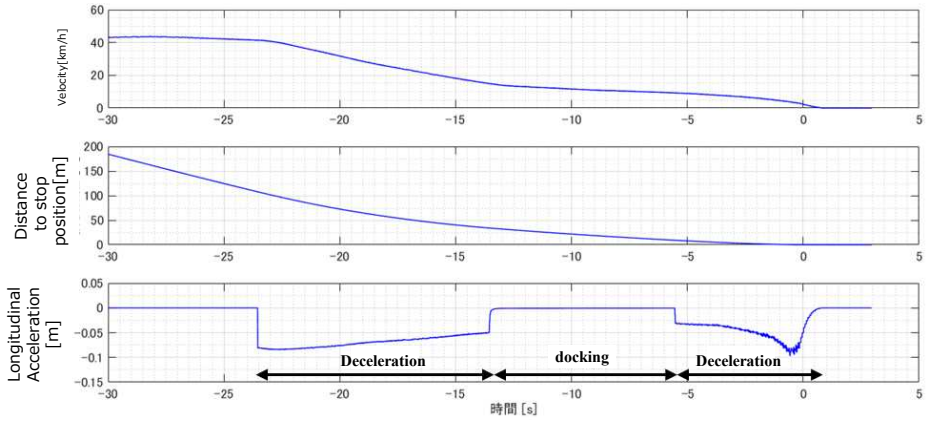
Braking Control

Braking control

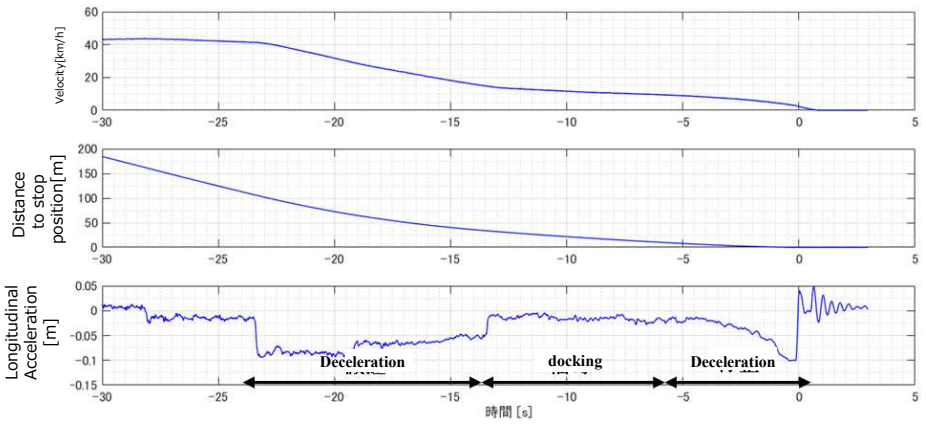
- **Implement brake control from over 40km / h and confirm deceleration almost as commanded.**
- **Evaluation at high deceleration was not satisfied enough performance due to short period for tuning and severe traffic condition.**



Braking control procedure



Command



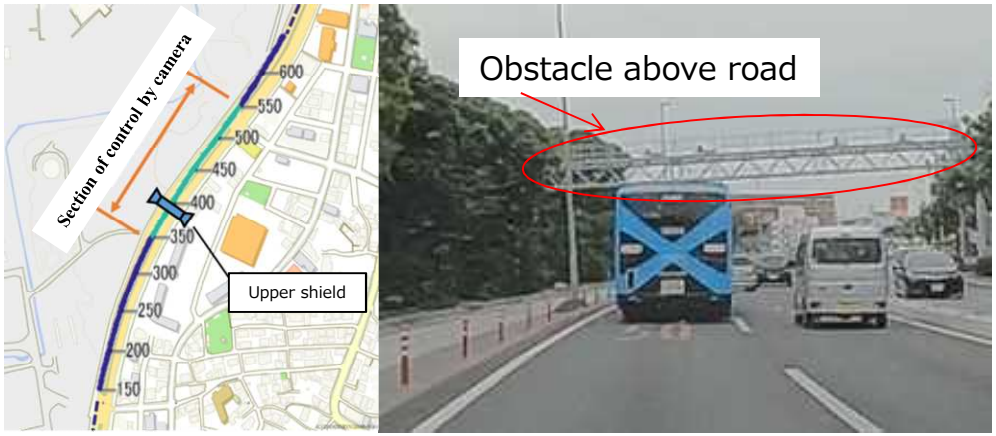
Vehicle behavior

Lane keeping control

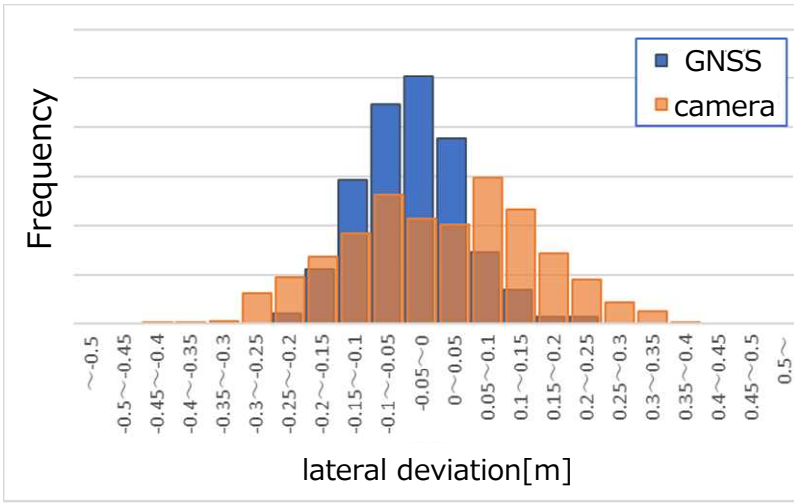
- Switching GNSS/Camera
- Driving over 40km/h
- S-curve

Switching GNSS/Camera

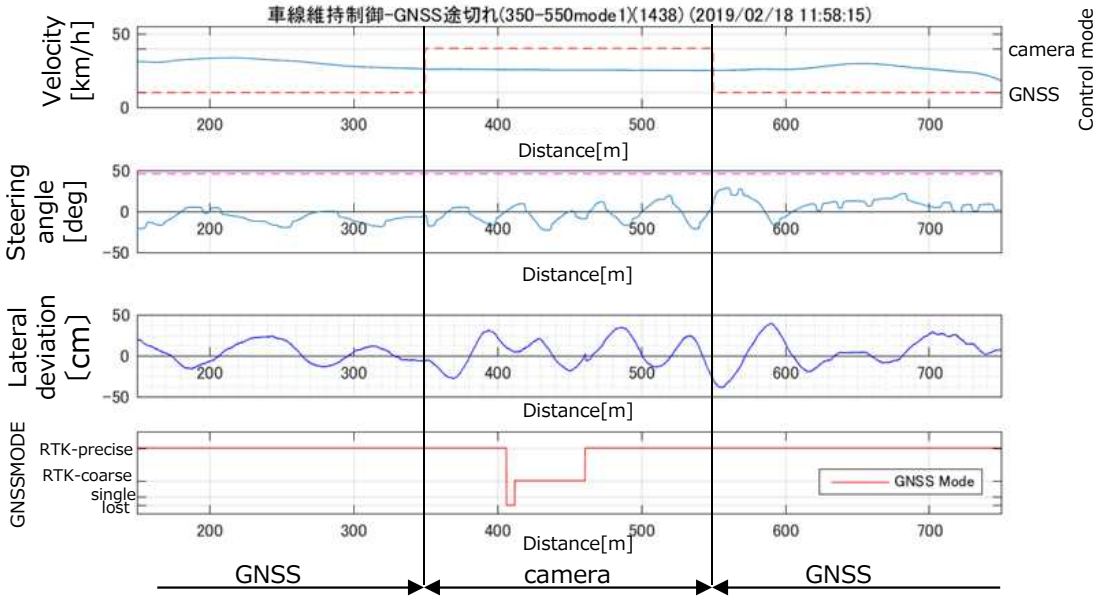
- **In order to avoid the effect of GNSS signal isolation due to the obstacles above the road, sensing device for lane keeping control was changed from GNSS to camera.**
- **Lateral deviation is increased in camera control compared to GNSS control. Bus could travel within the lane in both cases.**



Traveling section overview



Histogram of lateral deviation

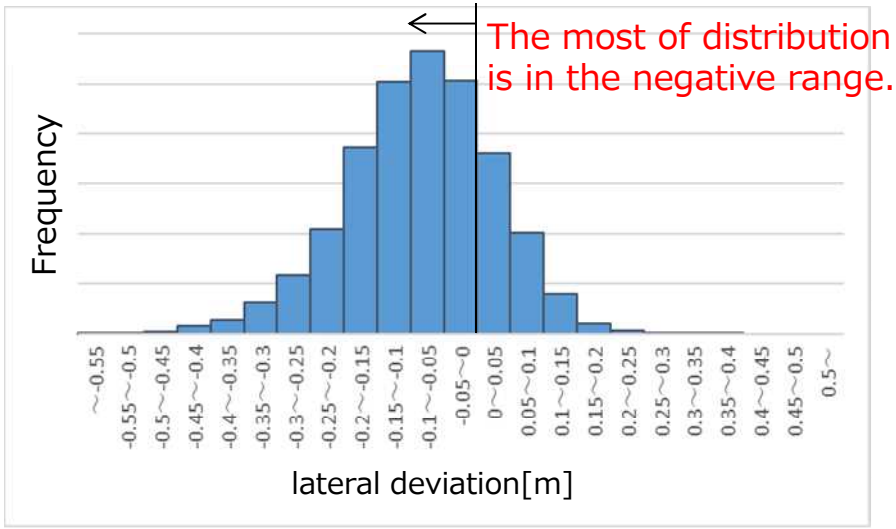


Vehicle behavior

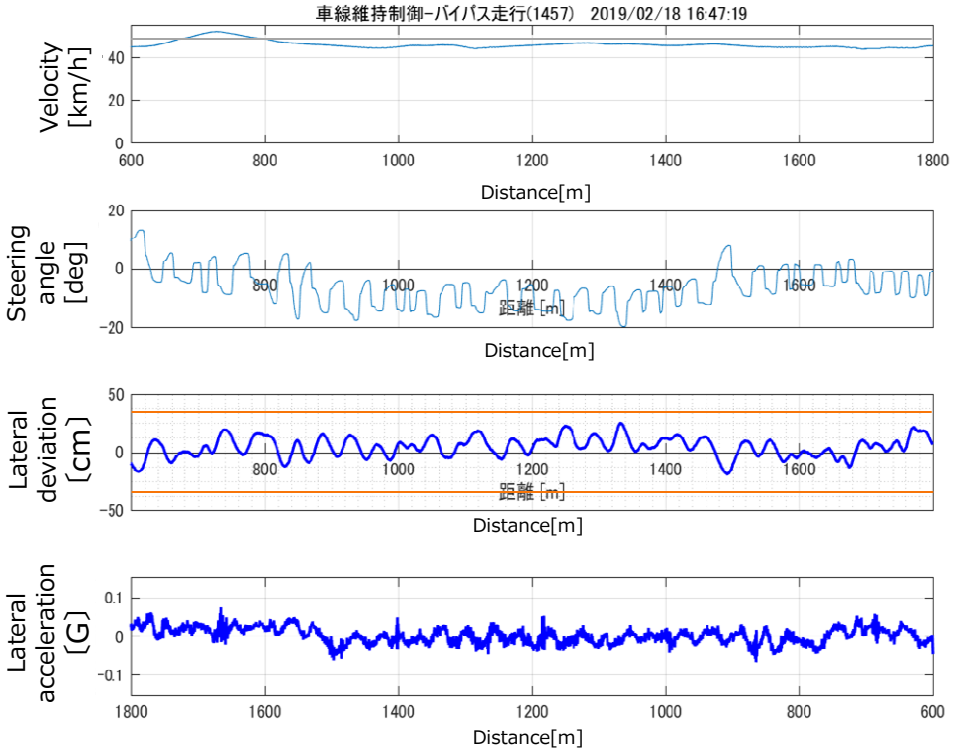
Lane keeping over 40km/h

- Lane keeping control at the range of over 40km/h (Maximum speed 50km/h)
- Trajectory was affected by crosswind but could travel within the lane.

Section traveling over 40 km/h



Histogram of lateral deviation

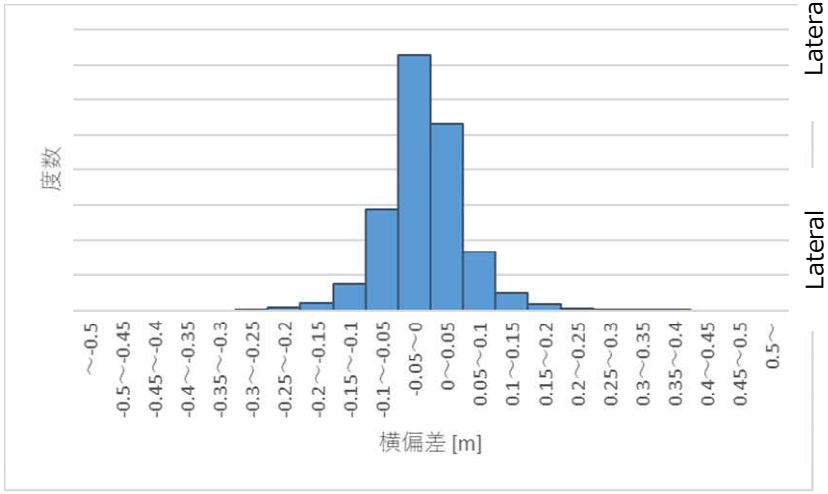


Vehicle behavior

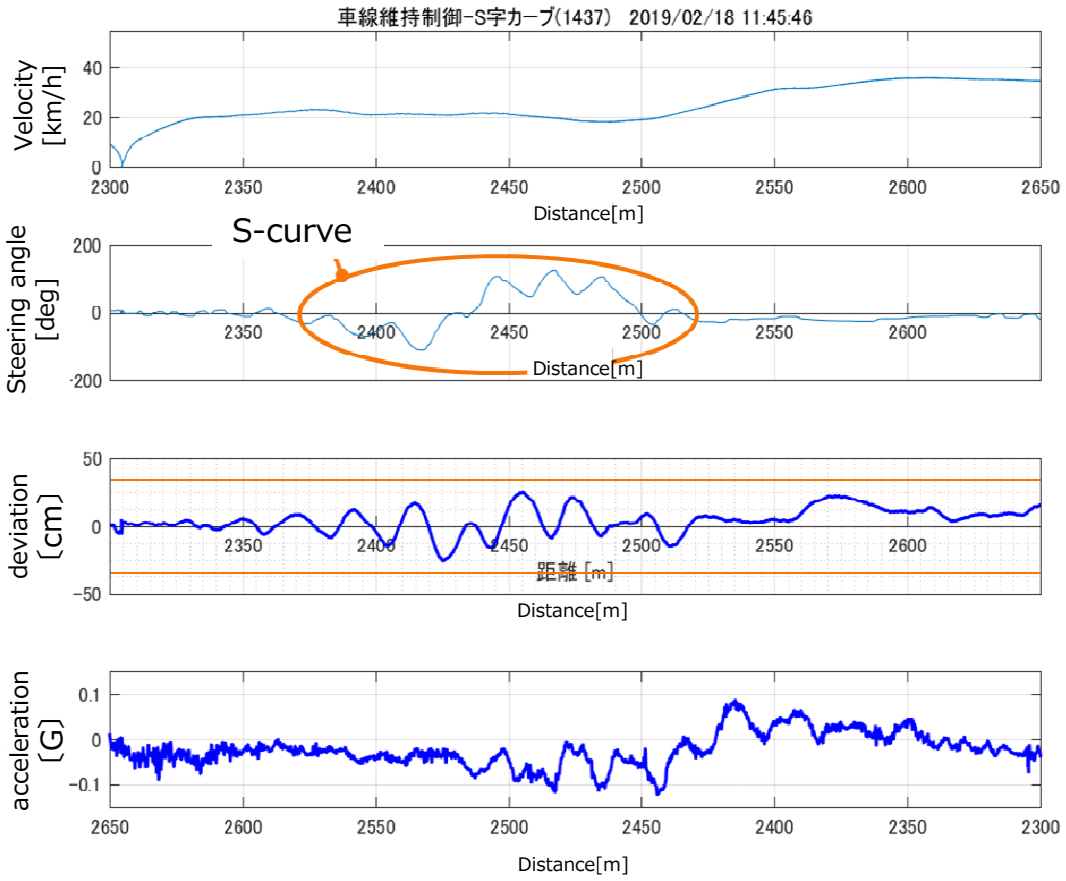
S-shape curve

◆ **Successfully keeping the lane of S-shape curve at ±30cm of lateral deviation (20～25km/h)**

S-curve



Histogram of lateral deviation



Vehicle behavior

Sensing technology

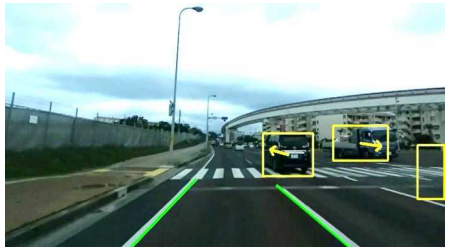
- Ranging with camera
- Ranging with LiDAR
- QZSS
- Sensor-fusion

Ranging with camera

Front stereo camera

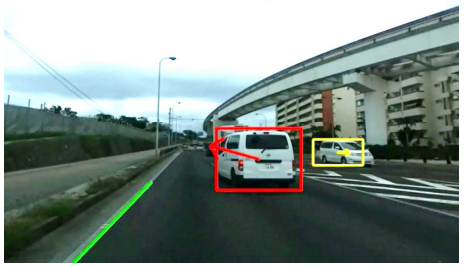
Test vehicle

Side stereo camera



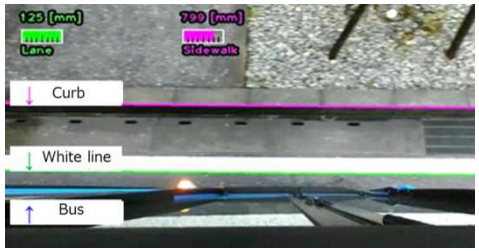
Vehicle

Human

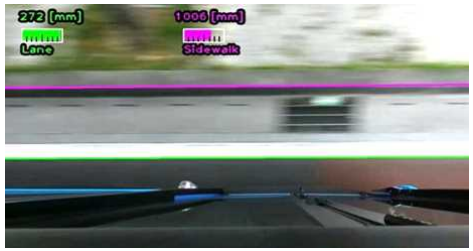


Obstacles at risk of collision

- Detect obstacles
- Improvement of detection performance is necessary.



Detect white line and curb



Fast vehicle condition

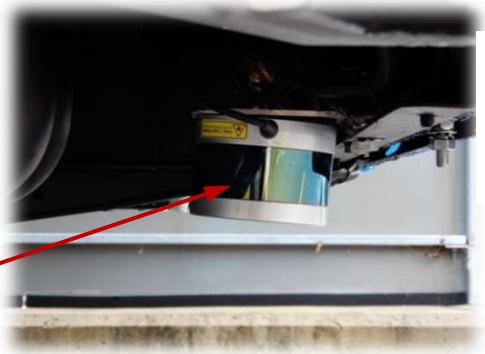
Undetected example(Under the influence of vegetation)

- Detect white line and curb
- Reduction of effects from roadside plantation or puddles are necessary.

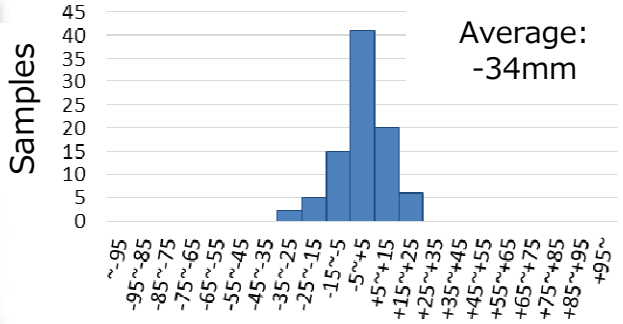
Ranging with LiDAR

◆ **Detect the distance and angle to the curb during precise docking**

Test vehicle



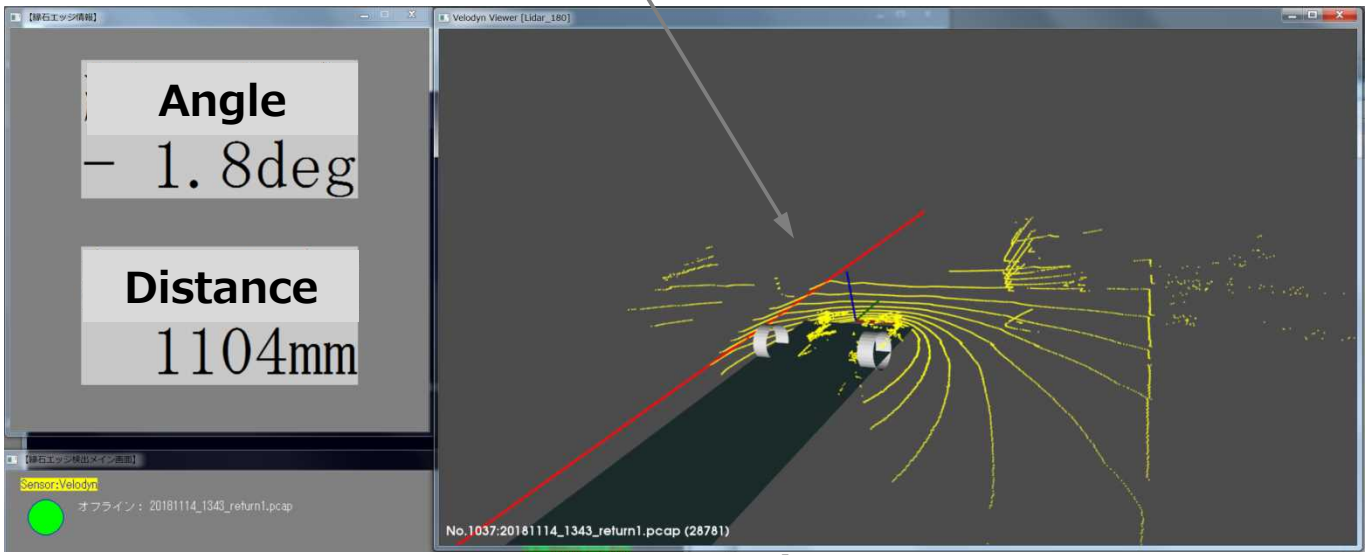
LiDAR（VLP-16）



Variation from the average [mm]

Result of distance at precise docking

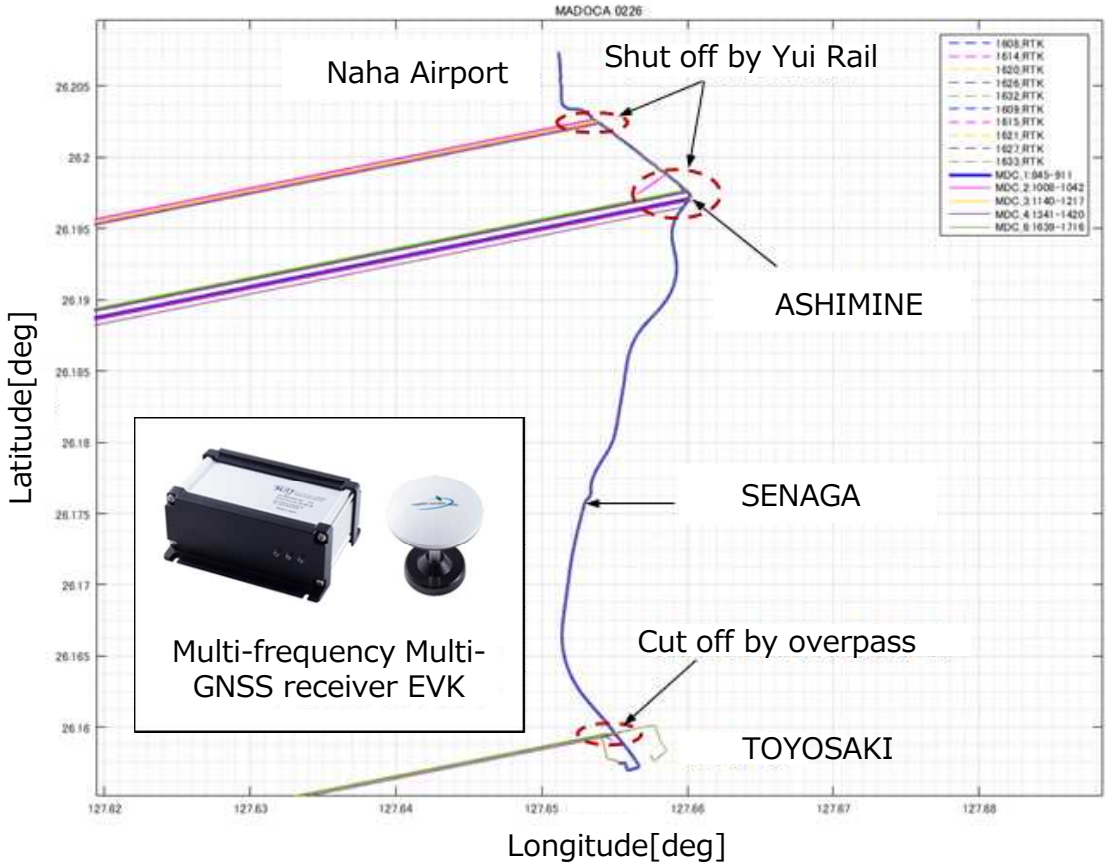
Detected edge of the road



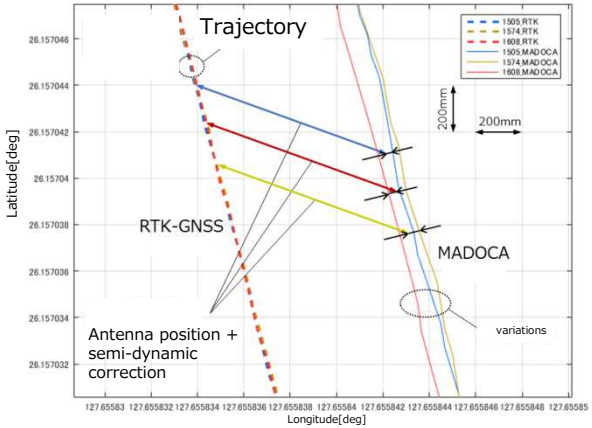
State to detect

QZSS

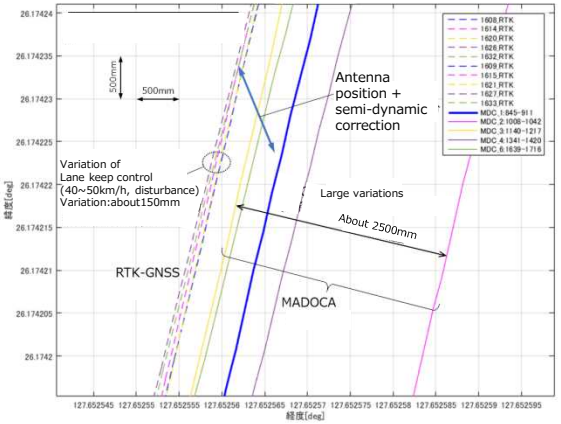
- Only MADOCA mode was evaluated due to specification changes in CLAS mode
- In case that signal is blocked by obstacles above the road, it took about 30 minutes to recover the high precision positioning state for secured precise control.
- Accuracy of less than 10 cm was confirmed while high precision positioning state is continuing stably.



QZSS reception status in the demonstration course



High precision positioning status



High precision positioning status not recovered

Sensor-fusion

◆Detects the vehicle position on 99.8% of the travel route

In case of north bound

In case of south bound

Detection status（GNSS+Fr Camera+LiDAR）

Detection rate

Trip distance[m]	15126	
	Detected distance[m]	Detection rate[%]
RTK-GNSS	13791	91.2
Fr Camera	12438	82.2
LiDAR	9150	60.5
RTK-GNSS＋Fr Camera	15024	99.3
RTK-GNSS＋LiDAR	13791	91.2
Fr Camera+LiDAR	13566	89.7
RTK-GNSS＋Fr Camera＋LiDAR	15102	99.8

・Position detection is not satisfied the requirement at intersection while RTK-GNSS state is bad due to obstacle above the road.

・One of the major issues is position detection in intersections without lines on the road or curbs.

Social acceptance

- Questionnaire results
- Test drive event for bus drivers

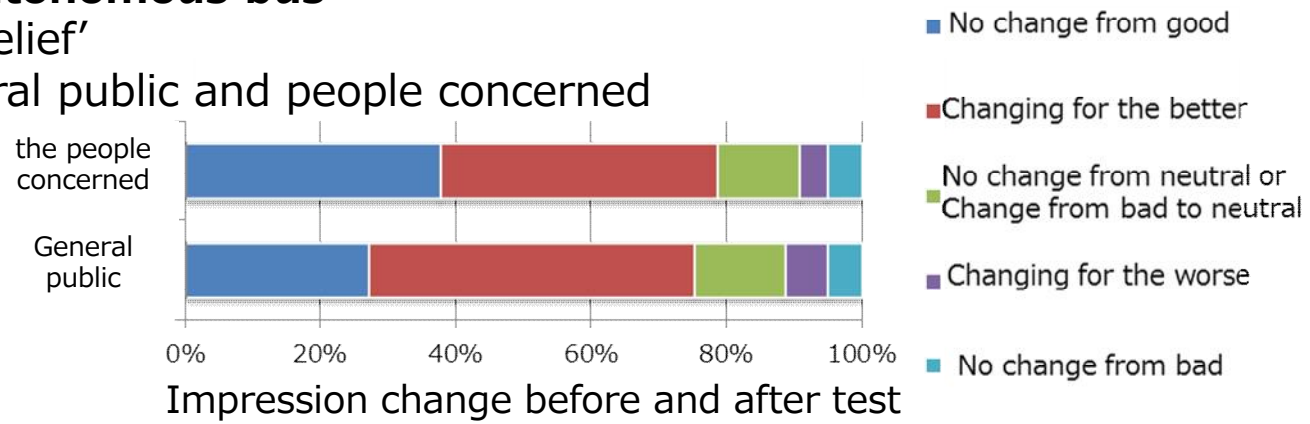
Results of questionnaire（1）

■Effect on social acceptance improvement

1．Impressions for an autonomous bus

'Neutral'・'Anxiety' ⇒ 'Relief'
; about 70% both general public and people concerned

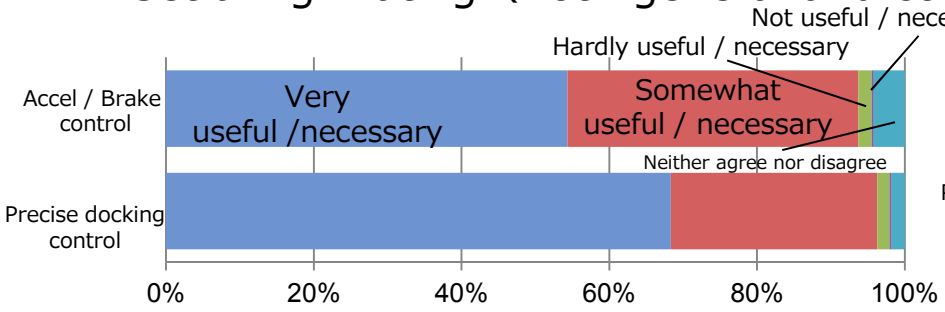
●「Neither」「A little anxiety」「Anxiety」
⇒「Relief」「A little relief」
・concerned 40／58people＝**69%**
・general 300／434people＝**69%**



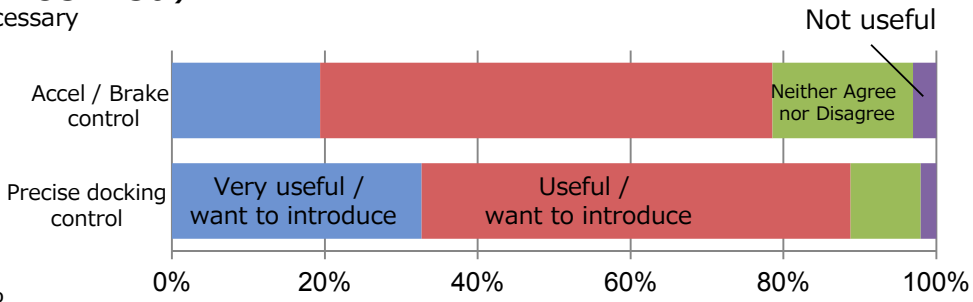
Impression change before and after test

2．Impression of technology（Acceleration/Braking, Precise docking control）

・Get a high rating（Both general and concerned）



①General



②Concerned

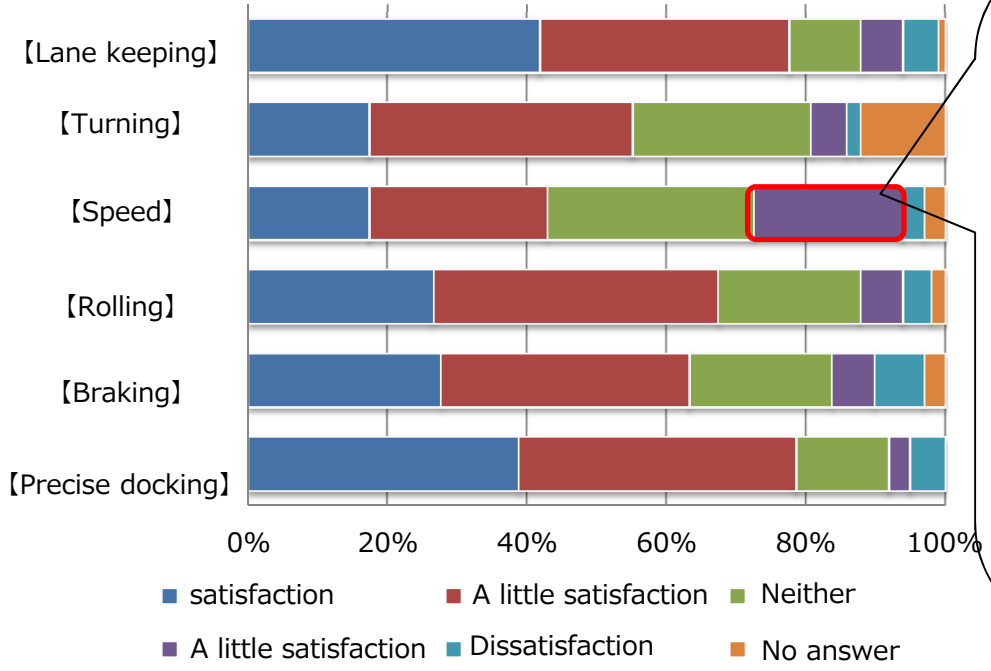
⇒Social acceptance of autonomous driving was successfully promoted through the field operational test

Results of questionnaire (2)

■The evaluation of ride comfort

Both general public and the people concerned are highly rated.

General public : Highly rated, No correlation between ride quality and frequency of use
The people concerned : about 80% of people reply good.



Think about many complaints about "speed"

①Verification of speed and early arrival is required.
⇒It seems that important thing for the passengers is early arrival. Verification about the effect of increasing the speed is important.

②The speed difference with the surrounding traffic and between GPS area and camera area
⇒Route selection, legal regulation and improvement of sensing technology are required.

③Waiting time to launch is long at the bus bay in the middle of the course.
⇒We had to wait in bus bay until the signal changes for safety. It is effective to reduce waiting time with Public Transportation Priority System.

Satisfaction level of each verification item of concerned

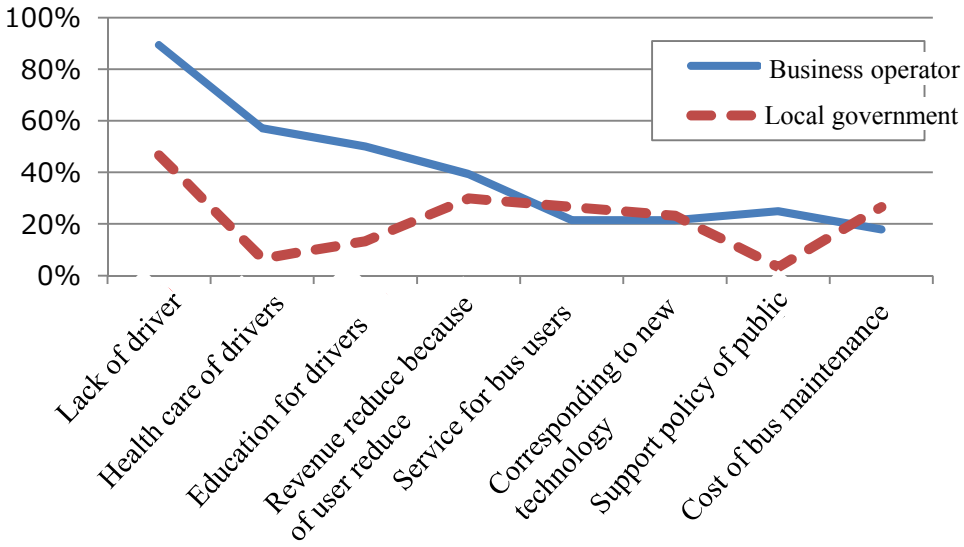
⇒Our autonomous bus is equal to or better than the general bus in the evaluation of ride comfort.

Results of questionnaire (3)

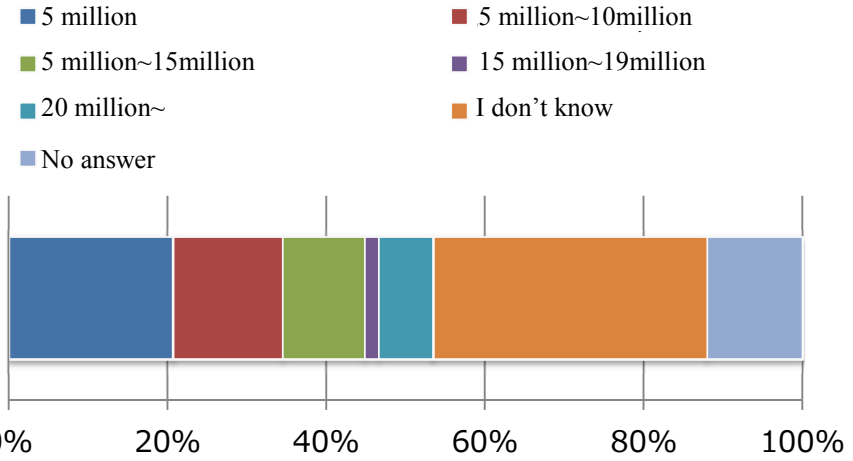
■ **The verification of the intention about introduce the autonomous driving bus (for business operator)**

- Current management issues: cost/revenue issues, driver shortage etc.
- The benefit of introducing Lv.2: Many of the answers are traffic accidents reduction, reduction of driver's stress and driving assistance.
- The price for introduction :The answers are at variance from "5 million" to "20 million". The most answer is "I don't know".

1. The issues of bus business operation



2. The image of price for introduction (bus business operator, local government)



⇒The advantages of Lv.2. were recognized.
However it's necessary to clarify the cost effectiveness.

Test drive event for bus drivers

Contents（Feb,19）

- 700m route for experience of autonomous driving.
- 5 professional drivers working for NAHABUS, OKINAWABUS and TOYOBUS experienced autonomous driving.

autonomous driving (steering, acceleration and deceleration)

autonomous driving (steering, deceleration and braking)

manual driving

Result

- Bus drivers understood the technology of autonomous driving and experienced the switching between automatic and manual mode driving.
- First impression was uncomfortable, but opinion was improved to positive due to the understanding of autonomous driving technology.
- An example of comments : “It’s hard to stop in the right position for an immature driver, but I was surprised that the autonomous bus could achieve this operation easily.”

- **Towards the social implementation, it contribute to promote the acceptance and understanding of business operators.**
- **Level 2 technology has potential to contribute to the homogenization of operating quality and the safety operation by inexperienced drivers.**

4) Subject about implement

Issues of technology subject

◆ Precise Docking

・The precise docking accuracy is affected by body movement due to road surface roughness.
→The improvement of sensing, accuracy and the improvement of road surface condition.

◆ Ride comfort related to Steering/Braking Control

・The impression about ride comfort was good.
→Pitching behaviors at complete stop and sway motion at small turning radius should be improved.

・Passenger's evaluation of braking control at strong deceleration（0.15G～0.2G）and from high speed were not carried out due to the time limitation for the tuning.

◆ Lane keeping control

・Under control with RTK-GNSS, it is possible to keep the lane in the case of upper speed limit(50km/h), cross wind and S-shaped curve
→Smooth sensor switching procedure and robustness against surrounding condition should be improved.

◆ Sensing Technology

・It should be considered advantage and disadvantage for each sensor performance specified by environmental conditions. Single sensor's capability for conditions is limited.
→The sensor fusion technology using different multiple sensing technologies is necessary.

◆ Tuning in advance to the Field operational test

・Tuning process is important to achieve the good result effectively in field operational test. In this case, it took long time compared to the plan because of traffic condition mainly.
→Implementing of regional temporary traffic limitation should be considered.
→Plan of road construction, traffic restriction and special event on the test route should be managed.

Toward implement

As a result of investigating opinions from various people including bus operators, these two kinds of proposals are considered.

(1) Promoting level 2 driver-assistance technology installation at low cost

- Accelerate the equipment of driver-assistance technology carried over from mass production technology for passenger cars
- Prevention of minor accidents caused by the mistakes of drivers

(2) Field operational test for level 4 autonomous driving (Specified area)

- Operation by crew without specified license for public bus or unmanned operation by central control system
- Discuss driver shortage and profitability continuously

⇒ **It is desirable that new model bus is equipped level 2 driver-assistance technology and have the potential to add the function for level 4 in the future.**

5) Summary

Summary

◆“Investigation concerning automated driving bus in Okinawa, SIP” was operated.

◆ Total travel distance is over 1300 km and more than 1200 passengers experienced.
We could evaluate the needs and issues both of the business side and general public toward social implementation by the questionnaire.

◆ This field operational test including mass media like TV or radio programs was contributed to the improvement of understanding and interest of local residents.

◆ In severe traffic environment, various kinds of evaluation including lane keeping control, deceleration control, precise docking control, various sensing technologies and traffic signal information transfer system have carried out for a long period. Many technical issues and usefulness that are difficult to verify in a test site was investigated.

◆ Towards the social implementation, technological improvement, infrastructure maintenance for introduction, understanding both of local residents and the business side and legal developments are important.
Continuous progress for these issues will be necessary.