Cross-ministerial Strategic Innovation Promotion Program (SIP) Phase Two/
Automated Driving (System and Service Expansion)

Survey for Introducing Precise Docking Technology by Automatic Driving to BRT(Bus Rapid Transit)

Interim Report

March 2021

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1. Outline of the Study 1-1 Significance and Aim of the Study

The precise docking of buses at the bus stops is recognized its importance as an element of barrier-free accessibility. Which enables wheelchair users, the elderly, baby stroller users and others to get on/off the bus smoothly by decreasing the gaps and steps between the vehicles and the bus stops.

There are cases introducing manual precise docking by using curbs for the system in European countries. However, it is concerning to introduce the system in Japan, because it may cause tires to wear and passengers to feel uncnfortable quake when the vehicle stops, due to hit against the curbs.

However, precise docking technology is one of the elements of the next-generation urban transportation systems which has been developing in resent years, and expected to be introduced as automatic driving technology.

Although there are some types for precise docking technology, which has been developed, we investigate the introduction of a method that uses a camera to perceive guidance lines (hereinafter referred to as the "guidance line method"), which has been introduced overseas and is expected to be put to practical use in 2020.

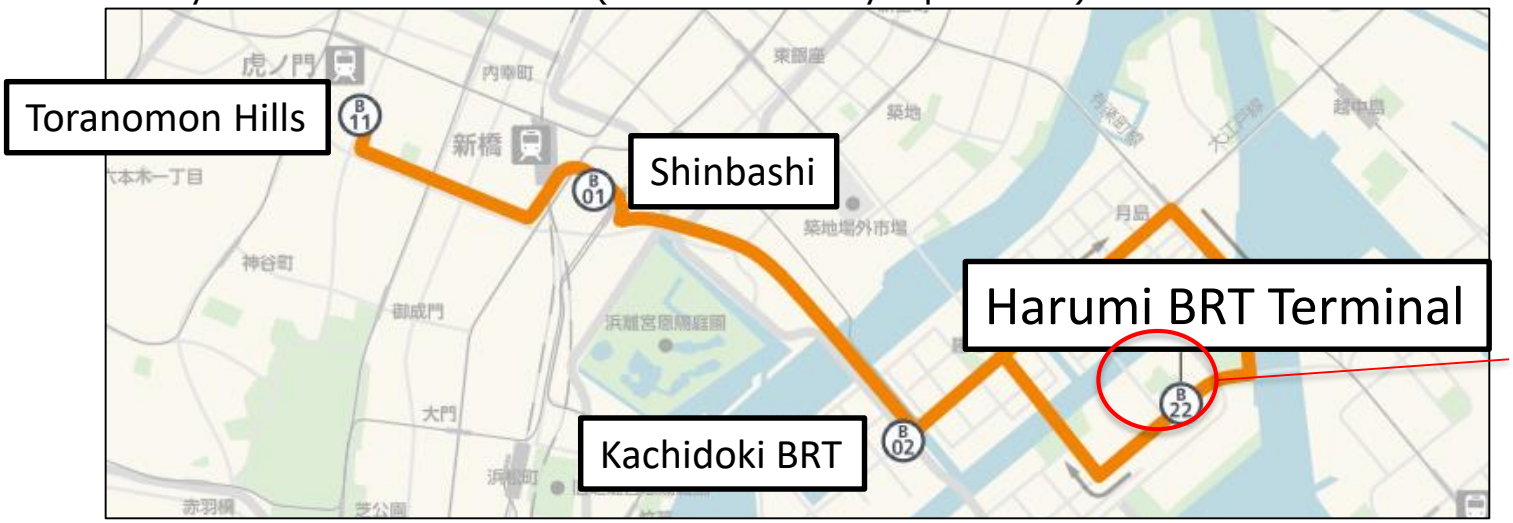
1. Outline of the Study 1-2 Objectives of the Study

The following issues remain at present, because it has not yet been decided whether or not to adopt the precise docking control system using guidance line methodcontrol system for BRT and other applications in society.

1) Durability, maintenance frequency and methods of guidance lines are unknown.
2) The robustness of the system in bad weather (rain and snow) and night-time has not yet been confirmed.
3) The social effects of the system have not yet been examined.
4)The construction and management entity (road manager or operator) of the guide line are not yet coordinated.
5) Response and responsibility in case of system abnormality are unclear.
6) Since whether or not to adopt the new system has not yet been decided, the coordination between the parties involved about whether installing guide lines on the bus operated section in the public road has not yet been carried out.

The purpose of this study is to conduct a demonstration experiment during the first preliminary operation of the Tokyo BRT started in October 2020, and to verify issues from (1) to (3) in order to pave the way for solving issues (4) to (6) in the future.

■Tokyo BRT Service Route (1st Preliminary Operation)



Tokyo BRT has been operated between Toranomon Hills and Harumi BRT terminal since October 1 .

Operational guidance lines for precise docking and bus stop are installed at Harumi BRT Terminal.

Outline of the Study 1-3 Study Items

(1) Verification of technical problems about control of precise docking using guidance line method.

1) Clarification of the system usage conditions

Grasping the relationship between conditions, for the system usage such as during night-time, illumination, rain and snow, and so on.

2) The Guidance lines durability check

Organizing the maintenance frequency of the lines by grasping the painting status of the the lines and how well the system can recognize the lines and reviewing the deterioration status of the lines and the results of existing surveys.

(2) Verification of the social effects about the precise docking control technology using guidance line method.

1) Verification of the barrier-free effects on precise docking

Grasping specific effects through questionnaire surveys to passengers and interviews with drivers of the buses.

2) Time saving effect of precise docking at boarding and alighting.

Grasping the individual effects, which is obtained by each person, such as time saving by precise docking and the ones for the entire route.

3) Verification of the effects for preventing falls of passengers during boarding and alighting

Grasping the effect to prevent passenger from falls when getting on and off the buses by understanding the stumbling status of users during the actions

4) Verification of the effect of preventing falls of passengers when the bus starts and stops

Grasping the effects to prevent passengers from falls when the bus starts and stops by understanding the effects of vehicle swaying (due to steering angle and acceleration/deceleration) and the effects for passengers at the time in the both case of the bus with/without the system.

Status of the Study 2-1 Outline of the Study

The status of this year's verification is as follows:
Due to the declaration of the state of emergency and other reasons, we were not able to conduct some of the surveys using monitoring recruitment, so they will be implemented next year.

■ Review status

classification	verification item	Verification Status
(1) Verification of Technical problems	i) Clarification of the system usage conditions	Verification of system usage conditions for evenings and snowfalls Conditions for using the system during rainwill be verified in the next fiscal year
	ii)The Guidance lines durability check	Confirming how well the cameras recognize the guidance lines when they are deteriorated Grasping the deterioration of the guidance lines after installation → In the next fiscal year, check the chronological deterioration status twice and estimating the maintenance frequency
(2) Social verification of the efficacy of a project	(i) Verification of the barrier-free effect on precise docking	Conducting questionnaire survey for the 30 monitors recruited in (2)(ii) (target 150) implementing an interview survey with drivers → Carrying out additional surveys by recruiting monitors in the next fiscal year
	(ii) Time saving effect of precise docking at boarding and alighting	Monitors were recruited to measure when they getting on/off the bus by their attribute → In the next fiscal year, measuring the number of BRT users to understand the effect of overall time reduction
	(iii) Verification of the effect for preventing falls during getting on and off the bus	Observation of falls of the passengers when boarding and alighting by cameras → In the next fiscal year, we will use cameras to observe passengers and measure the number of falls by passenger.
	(iv) Verification of the effect of preventing falls when stopping and starting a vehicle	Observation of falls of the passengers during when the bus starts and stops by cameras → In the next fiscal year, cameras inside the buses will be used to observe to measure the number of people who fall over when vehicle starts and stops

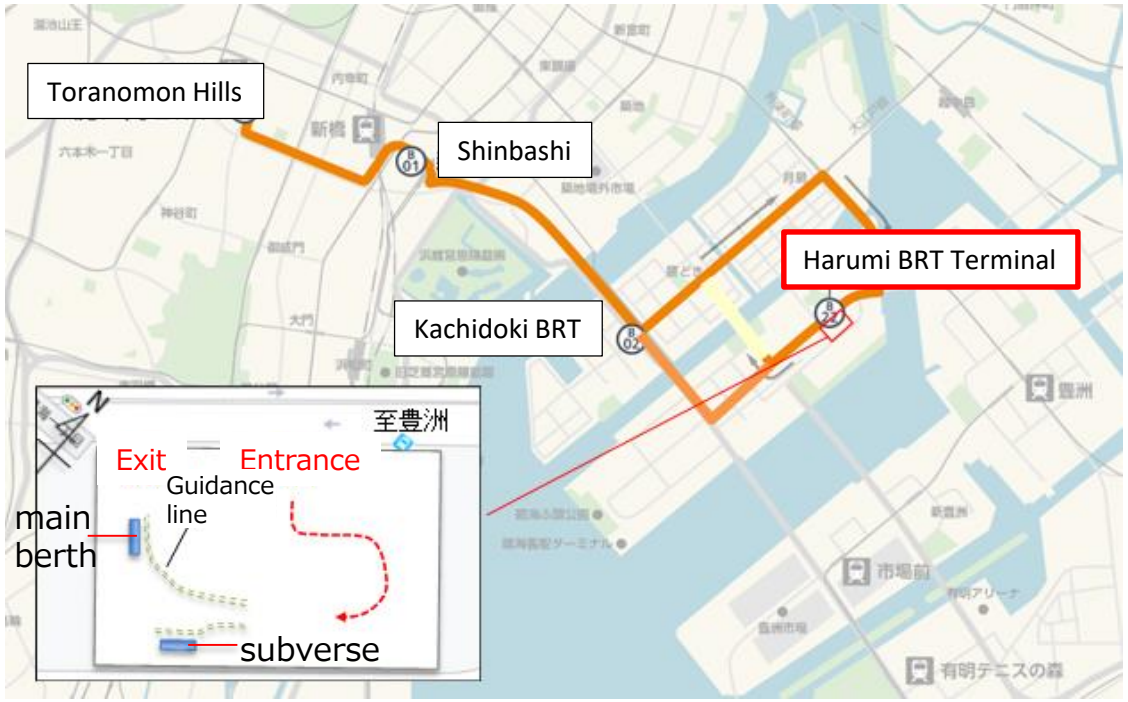
2.2 Status of study 2-2 Location of verification

A demonstration experiment was conducted at the Harumi BRT Terminal for six days from November 17 to 22, 2020.

The Harumi BRT Terminal has two bus berths, a main berth (for boarding) and a sub-berth (for alighting), and the latter was used for this time.

Since the sub-berth was not raised at the boarding/unloading section, a platform to ease the actions was installed when the test was conducted.

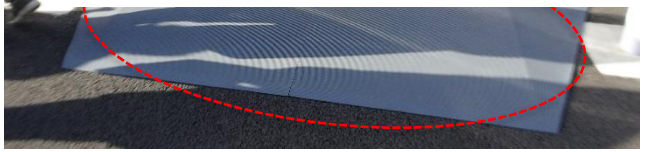
■ Tokyo BRT route map and demonstration sites



■ Vehicle (TOYOTA: SORA)

■ Platforms

Platform for boarding and alighting



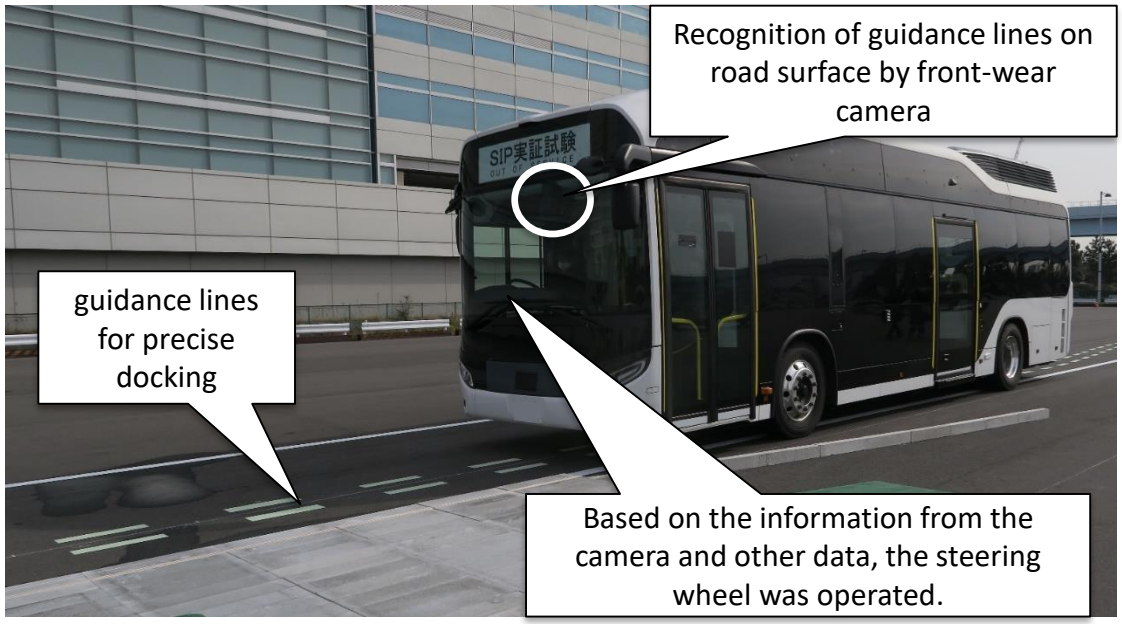
(1) Verification of technical issues (i) Clarification of system usage conditions

■Outline

In the case of precise docking using guideline method, a camera put on the bus vehicle recognizes the guidance lines on the road surface. Based on the information from the camera, the bus automatically steers itself along the guidance and dock precisely at bus stops.
Since performance of the camera is influenced on external cause, we will clarify which condition it can be used to recognize guidance lines for precise docking under various conditions, such as night-time (early evening), rainy or stormy weather, and snow, in preparation for full-scale introduction.
As for rainy and stormy weather, it was decided to implement the project in 2021 because rainy weather did not occur during the demonstrable period in 2020.

[Verification Item 1]
Whether or not precise docking is possible in the evening and night-time.
[Verification Item 2]
The condition of whether precise docking is possible or not in the case of rain or stormy weather.
[Verification Item 3]
The condition of whether precise docking is possible or not in the case of snowfall.

■The concept of control of precise docking using guidance lines



(1) Verification of technical issues (i) Clarification of system usage conditions

By carrying out precise docking control repeat with measuring the illuminance repeatedly before sunset, we confirmed the threshold of the measurement at which the camera no longer recognized the guidance lines.
Generally, the **camera stopped recognizing the guidance lines 15 minutes after sunrset at 30lux illumination.**

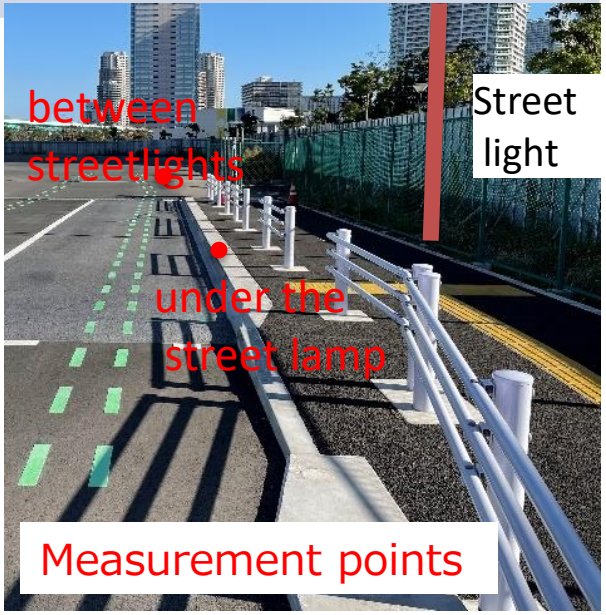
■Verification 1: Night-time

verification item	measurement item	Outline of Implementation
[Verification 1] Early Evening / Night-time	1) Whether the camera for precise docking perceive the guidance lines 2) Illuminance 3) How the road surface was wet/dry	Carrying out precise docking control repeatedly before sunset (About 2 minutes interval) Check the condition which the camera succeeded in precise docking by measuring illuminance meter and visual check. →this process was conducted for 4 days

■Summary of Measurement Results

	Sun-set	Illuminance Under the light (Lux)	Time	Illuminance(Lux) guidance recognized		Time	Illuminance(Lux) guidance NOT recognized	
				Under Light	Middle of Light		Under Light	Middle of Light
11/18	16:33	495	16:47	108	68	16:50	80	41
11/19	16:33	534	16:49	76	35	16:51	78	19
11/20	16:32	315	16:46	90	47	16:48	72	32
11/21	16:32	480	16:48	66	34	16:51	59	26

All the times, road surface were dry.



■Verification 3: Snowfall

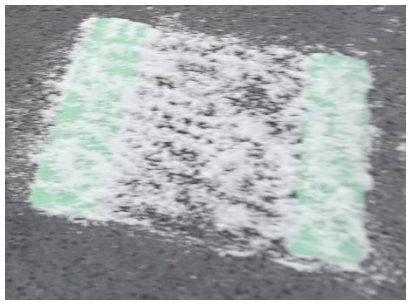
Snow powders were spread on the guidance lines to check whether they were recognized by the camera.
Even at a snowfall depth of 0.025 cm, the accuracy of recognizing them was greatly decreased (2 out of 5 regognization).
It was confirmed that the **system does not recognize when even a small amount of snowfall occurs.**

verification item	measurement item	Outline of Implementation
[Verification 3] snowfall	(1) With or without recognition of the positive wearing camera 2) Illuminance 3) Snowfall conditions	Verification was carried out in one day before the pre-operation period. Snow powder is used to reproduce snowfall conditions step by step and verify the reading status.

■Depth of snowfall

Depth of snowfall	0.5cm	0.3cm	0.2cm	0.1cm	0.05cm	0.025cm
Reading Status (5 test)	0	0	0	0	0	2

0.5 cm 0.1cm 0.025cm

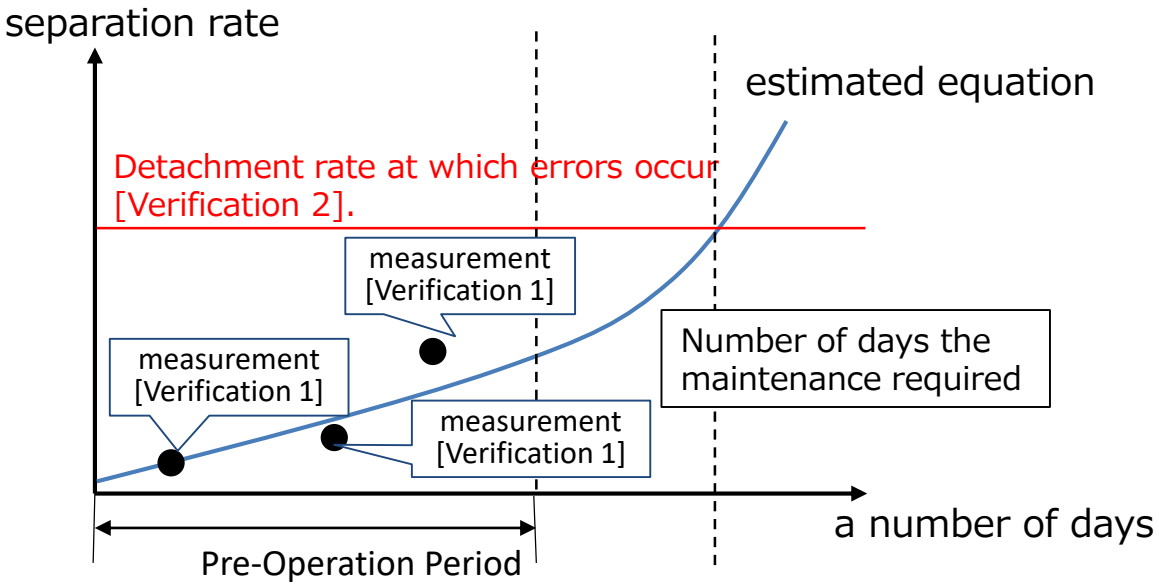




Grasping average depth of snowfall by measuring the amount of powder with a measuring cup and spreading over a predetermined area

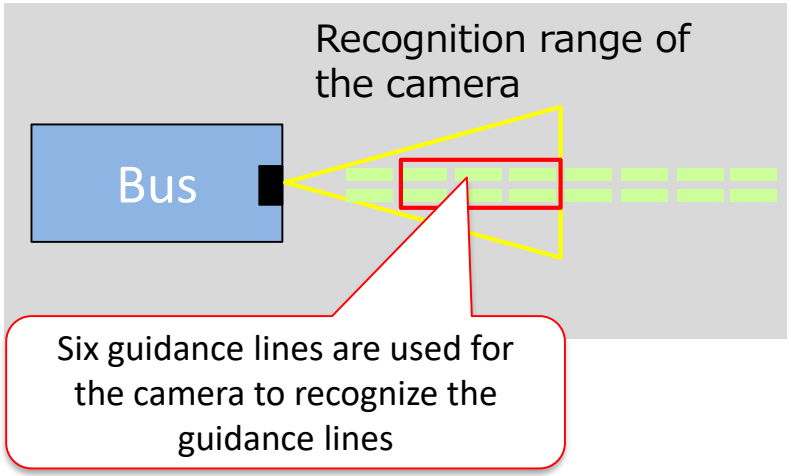
(1) Verification of technical issues (ii) Induction line durability check

Measureing the trend of deterioration of the guidance lines and estimating the maintenance frequency of the lines based on the state of deterioration over time (paint peeling rate, etc.).
In estimating the maintenance frequency of the guidance lines, the following two points will be verified.
Verification Item 1: Measurement of the degradation status of guidance line (detachment rate) during preoperational period
Verification item 2: Measurement of the degradation status of guidance lines (detachment rate) that causes errors
In this fiscal year, we measured a part of the verification item 1 and conduct the verification item 2.
In the next fiscal year, we will measure the detachment rate twice and estimate the number of days when the rate exceeds the threshold.

■ Image of maintenance frequency estimation of guidance lines



■ Recognition image of guidance lines by the camera



(1) Verification of technical issues (ii) Induction line durability check

The threshold of the degradation status of the guidance line where the errors occur was verified.
The degraded condition was reproduced using a glacial sheet. Specifically, the edge of the glanshall sheet, which was the same color as the guide line, was made black, and the state of the delamination rate from 40 to 80% was reproduced according to the black area (see the figure below).
This glancing sheet was pasted on the guide lines to reproduce the situation where a part of the actual guide line was detached, and checked whether the camera recognize the lines.
The camera no longer recognized the guidance lines when the detachment rate exceeded 50%.

■Reproduction of deteriorated condition of guidance lines

separation rate： 40% 50% 60% 70% 80%

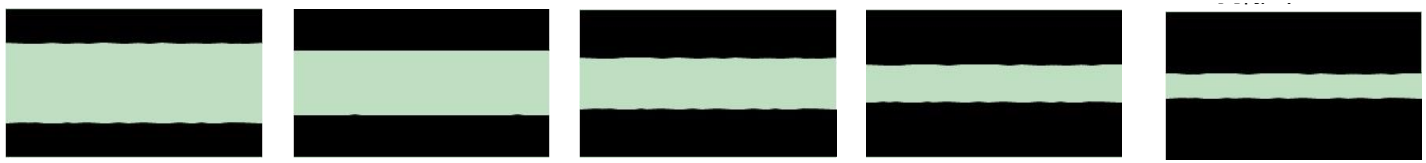


Table: Measurement results

		Test 1	Test 2	Test 3
separation rate 40% glanshall sheet	Illuminance(lx)	7,500	7,100	7,000
	Road Conditions	Dry	Dry	Dry
	Precise Docking	○	○	○
separation rate 50% glanshall sheet	Illuminance(lx)	7,200	7,000	7,000
	Road Conditions	Dry	Dry	Dry
	Precise Docking	○	○	○
separation rate 60% glanshall sheet	Illuminance(lx)	7,800	7,800	7,600
	Road Conditions	Dry	Dry	Dry
	Precise Docking	×	×	×

(2) Verification of social effects (i) Verification of barrier-free effects

We will conduct questionnaires and interviews to BRT users and its drivers, and clarify the barrier-free effects of precise docking as perceived by users and drivers.
In this fiscal year, we conducted a user questionnaire survey targeting the monitors recruited for "(2) Boarding and Alighting Time Survey" and an interview survey with the drivers of the buses at that time.
We plan to increase the number of monitors in the next fiscal year and finally compile the results with about 150 samples.

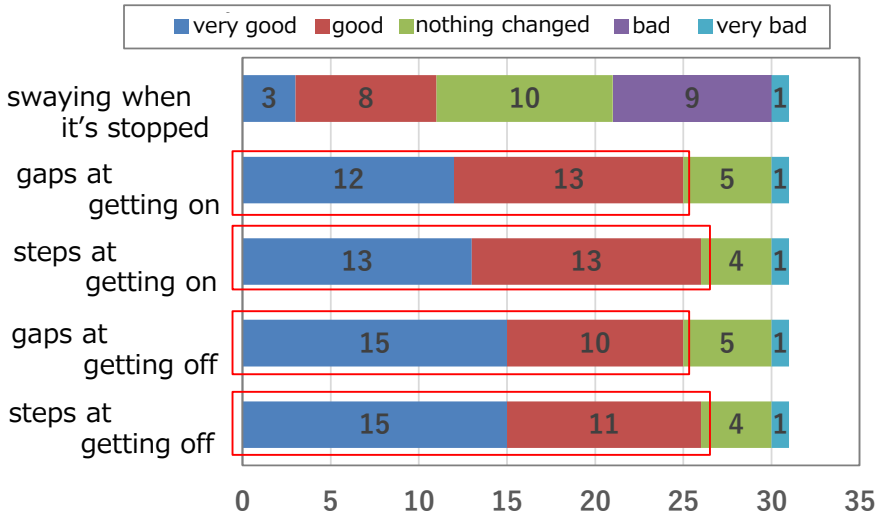
■Contents of the survey (this year)

classification	Method (draft)	Target / Sample	research item
User questionnaire survey	Conducted a questionnaire survey of 30 monitors of "(2) Boarding time survey" With the investigation of the boarding and alighting time, the monitors were asked to answer a questionnaire after experiencing the precise docking system	General : 10 people Elderly: 10 people Wheelchair: 5 people Strollers: 5 people Total 30 people	Sex, age, occupation, and awareness of positive clothing Usual use of public transportation Effect and influence of precise docking control Intention to use or introduce, improvements, and requests
Driver hearing survey	Conducted for bus drivers in the boarding and alighting time survey	Bus drivers having experience to drive the ones with precise docking control	Gender, age group, and driving history Burden and hassle of driving, etc., and sense of security Effect and influence of positive landing control (distance, step, sway, etc. during positive landing) Intention to introduce, improvements, and requests

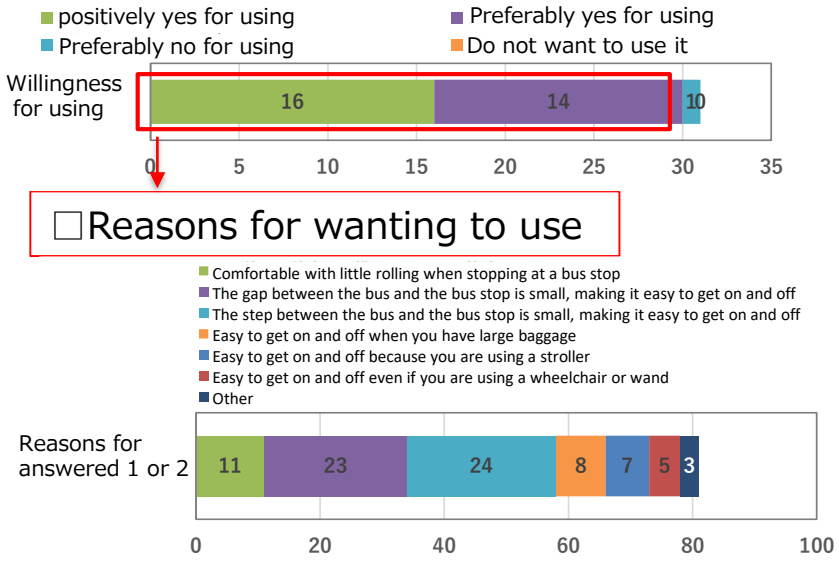
(2) Verification of social effects (i) Verification of barrier-free effects

Regarding the evaluation of stopping at bus stops when working automatic precise docking, most of the respondents answered “good” for gaps and bumps both when getting on and off. One-third of them answered that horizontal swaying was bad.
Most of the respondents answered that they would like to use the buses if the buses with automatic precise docking were introduced. As for the reasons, 80% of the respondents answered that "the gap is small and easy to get on and off" and "the step is small and easy to get on and off.
All of the respondents answered that they hope the buses to get spread in the future.

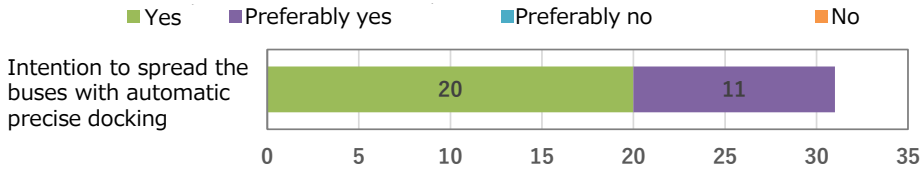
■Evaluation when stopping at bus stops with working automatic precise docking



■Willingness to use buses with automatic precise docking



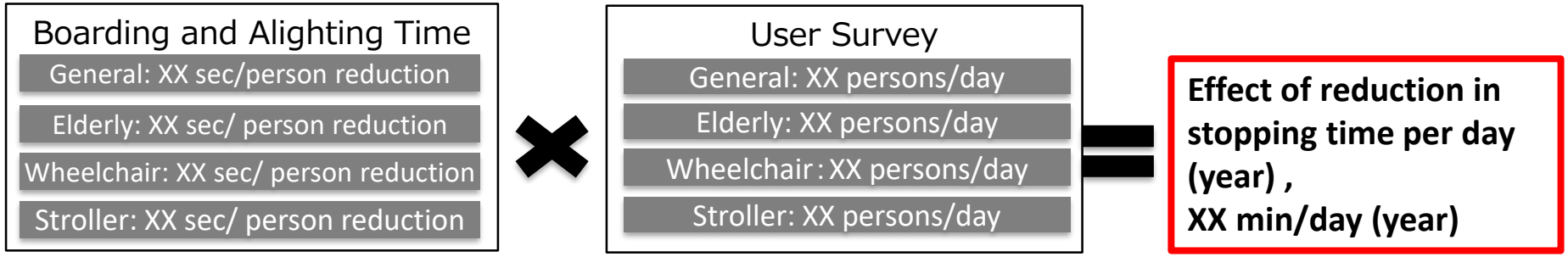
■Intention to spread the buses with automatic precise docking



(2) Verification of social effects (ii) Boarding time survey

We estimate the time saving effect of introducing the Inductive Line Type of Precise Docking Technology for Tokyo BRT.
The following will be verified for the effect of reducing the stopping time. In this fiscal year, only verification 1 will be conducted. [Verification 1] Boarding and alighting time survey (monitor survey). Comparison of three stopping patterns: 1) Precise Docking Technology 2) manual Precise Docking Technology (barrierless curb) 3) normal
[Verification 2] Survey of the number of users

■ Approach to Evaluation

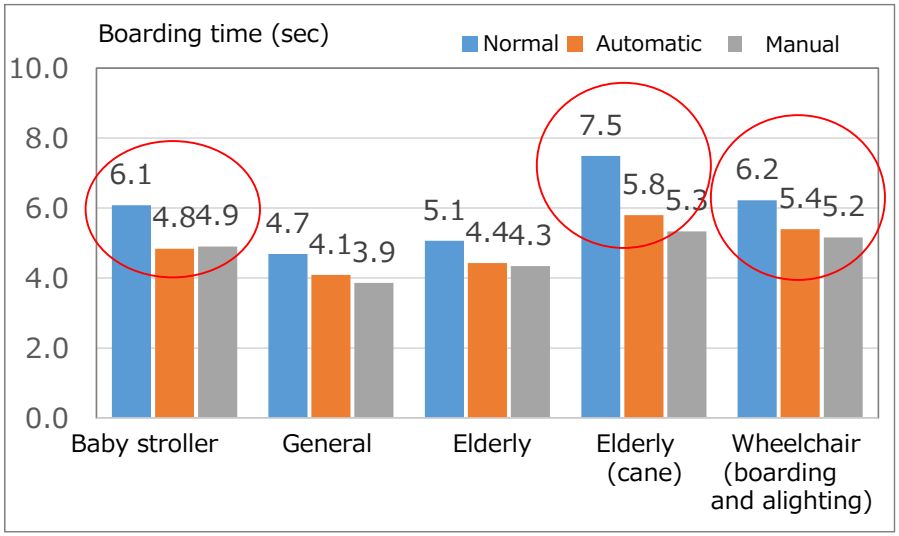


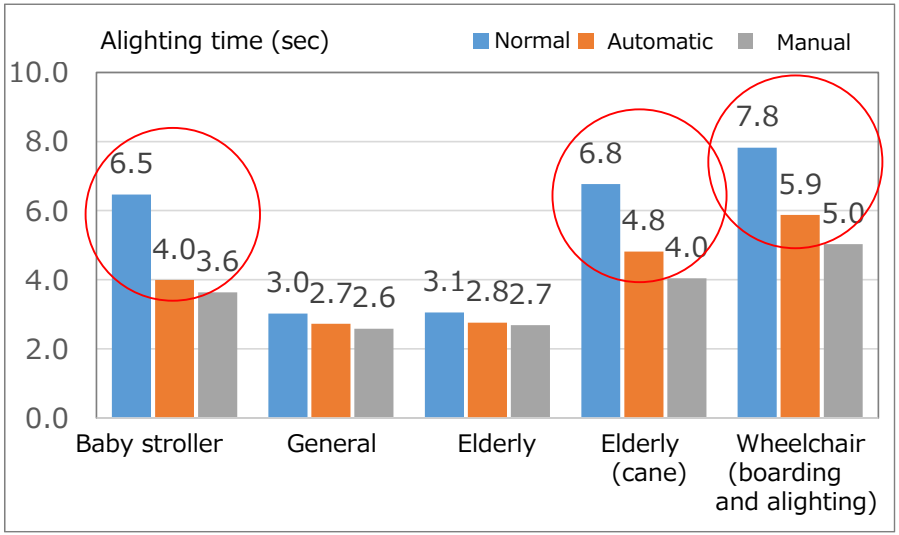
■ Survey details

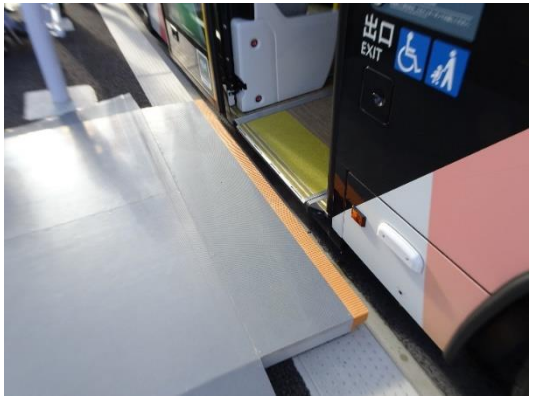
	Verification Method	Verification Period
[Verification 1] Boarding and Alighting Time survey	Monitors: **10 general applicant, 10 elderly people, 5 wheelchair users, and 5 baby stroller users.** The time required for each person to get on and off the bus was measured five times each under three different stopping conditions.	November 19-22, 2020
[Verification 2] The number of users Survey	The number of bus passengers were counted by installing video cameras at the entrances and exits of the buses, and visually checking the images afterwards to count the number of users by attribute.	Next fiscal year, video observation

(2) Verification of social effects (ii) Boarding time survey

There is no significant difference in boarding and alighting time between automatic and manual precise docking technology , but the difference is particularly large for stroller users, the elderly, and wheelchair users when compared to regular buses.
If the time for the wheelchair user's driver to set up the ramp and secure the wheelchair with a belt is included, the difference can be 15~20 seconds.



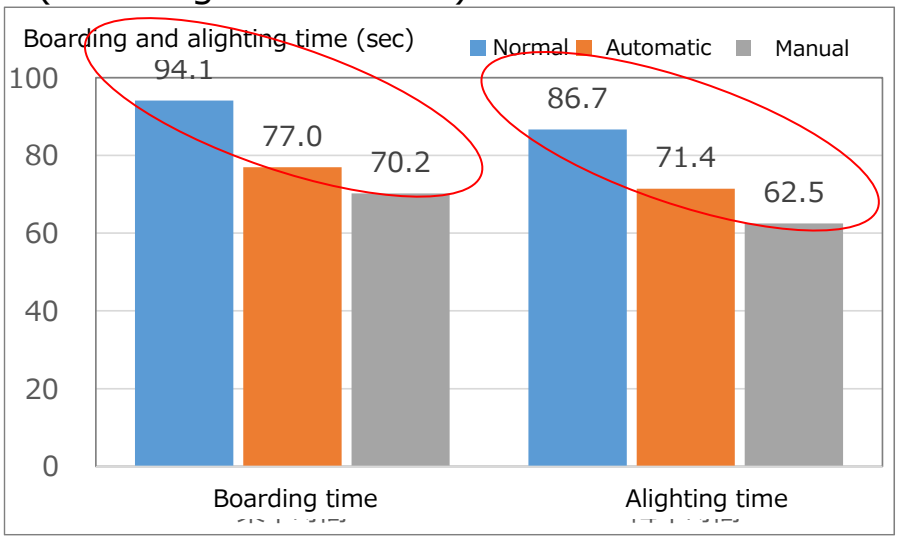




■ Precise Docking status (average value)

Normal : 25.0cm
Auto Precise Docking : 5.3cm
Manual Docking: 1.3cm

■ Wheelchair Boarding and Alighting Time (including driver's time)



The effect of preventing falls when getting on and off the buses and when it is stopped will be verified during the monitoring survey to be conducted in the next fiscal year for the barrier-free effect.
However, it is difficult to collect a large number of samples, and it is difficult to evaluate quantitatively. Therefore, "people who seem to have difficulty getting in and out of the vehicle" and "people who seem to stumble" were checked from the video, and "status of body sway" and "acceleration" were checked when the vehicle stopped and started, and the effect of fall prevention would be organized by qualitative consideration.

■Approach to Evaluation

Classification	Method	Measuring Instrument
When getting on /off the buses tumbling prevention Effect	At the time of the monitoring survey, we took pictures of users getting on and off the bus, and afterwards measured the stumbling conditions (the percentage of people who seemed to have difficulty getting on and off the bus, fell, or tripped) to qualitatively evaluate the results.	Drive recorder for capturing the scene at the entrance and exit
When stopping and starting the vehicle tumbling prevention effect	In the monitoring survey, we filmed the passengers when the bus started and stopped, and measured their body swaying and acceleration when the bus stopped and started afterwards to qualitatively evaluate the results.	Speedometer/accelerometer (smartphone, etc.) to measure the vibration of the car body Drive recorder for capturing images inside the car

4. Summary

The status of the verification for FY2020 is as follows.
Due to a state of emergency, the verification of social effects could not proceed as initially planned. The remaining verification items will be verified in the next fiscal year.

classification	verification item	Verification Status
(1) Technical problem-solving	(1) System conditions of use clarification	Verification of system usage conditions for evening and snowfall. In case of rainfall, verification will be done in the next year.
	Induction line durability check	Grasping the recognition status of the camera when the guidance lines are deteriorated and the deteriorated status of the guidance lines at Harumi Bus Terminal. In the next fiscal year, the chronological deterioration status will be checked twice to estimate the maintenance frequency.
(2) Social verification of the efficacy of a project	(1) Verification of the barrier-free effect of Precise Docking Technology	A questionnaire survey was sent to 30 monitors and an interview survey was conducted with drivers. Additional surveys will be conducted in the next fiscal year by recruiting monitors.
	(2) When boarding and alighting due to Precise Docking Technology time saving effect	Monitors were recruited to measure boarding and alighting times by attribute. In the next fiscal year, the number of BRT users will be measured to determine the effect of the overall time reduction.
	(3) Verification of the effect of preventing falls when getting in and out of a vehicle	Observation of falls during boarding/unboarding by camera In the next fiscal year, we will use cameras to observe passengers and measure the number of falls by passenger.
	4) Verification of the effect of preventing falls when stopping and starting a vehicle	Stopping and starting tipping situation observed by camera. In the next fiscal year, we will use cameras to observe the interior of vehicles and measure the number of people who fall over when stopping and starting.