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)

Final Report

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1. Overview of the study 1-1. Significance and aim of the study

○ The precise docking of buses at bus stops has been recognized as an important element of barrier-free accessibility by reducing the gaps and steps between bus vehicles and bus stops so that wheelchair users, the elderly, baby carriage users, and others can get on and off smoothly.

○ In European countries, there are some examples of manual precise docking using special curbs, but when introducing it in Japan, there are concerns about tire wear and swaying caused by contact between the tires and the curb when stopping.

○ On the other hand, precise docking control technology is positioned as an element of the next-generation urban transportation system that has been developed in recent years, and is expected to be introduced as an automated driving technology.

○ There are several methods of precise docking technology, and each method is being developed, but in this study, we examined the possibility of introducing the “method of reading guidance lines with a camera (hereinafter referred to as the ‘guidance line method’),” which has been introduced overseas.

1. Overview of the study 1-2. Purpose of the study

○ The following issues remain to be resolved as of now, and the adoption or rejection of the guidance line type precise docking control system for social implementation in BRT, etc. has not yet been decided.

(1) Durability of guidance lines, and maintenance frequency and methods are unknown.
(2) The robustness of the system in weather conditions (rain, snow) and at night-time has not yet been confirmed.
(3) Consideration of the social effects of the system is incomplete.
(4) The construction/management entity (road manager/operator) of guidance lines is not yet determined.
(5) The response and where the responsibility lies in the event of a system error are unclear.
(6) Since the adoption or rejection of the introduction has not yet been decided, the parties concerned have not yet coordinated on whether or not to install guidance lines at bus stop sections on public roads.

○ In this study, a demonstration experiment will be conducted during the first preliminary operation of the Tokyo BRT, which started in October 2020, and by examining the issues (1) through (3), we aim to create a roadmap for solving issues (4) through (6).

■ Tokyo BRT service route (first preliminary operation)

In operation between Toranomon Hills and Harumi BRT Terminal from October 1.

Installed guidance lines and bus stops with precise docking at Harumi BRT Terminal.

1. Overview of the study 1-3. Items to be examined

(1) Verification of technical issues for guidance line type precise docking

[1] Clarification of system usage conditions

- Understand the relationship between system usage conditions (illumination, rainfall, snowfall) at night-time, in the rain and during snowfall.

[2] The guidance line durability confirmation

- Understand the status of the painted guidance lines and the system's recognition of the guidance lines and organize the maintenance frequency based on the deterioration status of the guidance lines and the results of existing surveys.

(2) Verification of the social effects of guidance line type precise docking control technology

[1] Verification of the barrier-free effects of precise docking

- Understand specific effects through questionnaire surveys of users and interviews with drivers.

[2] Time-saving effects of precise docking when getting on and off the bus

- Identify individual benefits (benefits gained by each person), such as time savings due to precise docking, and benefits for the entire route.

[3] Verification of the effects of preventing falls during boarding and alighting

- Grasp the stumbling status of passengers during boarding and alighting with and without precise docking, and grasp the effects of preventing falls during boarding and alighting.

[4] Verification of the effects of preventing falls when the bus stops and starts

- Determine the effects of vehicle swaying (lateral acceleration) and the effects on passengers when the bus stops and starts, with and without precise docking, to prevent falls when the bus stops and starts.

2. Examination status 2-1. Overview of the study

○ Due to the declaration of a state of emergency, some surveys, such as the questionnaire survey of monitors, could not be conducted last fiscal year.
○ Therefore, the following items in blue were verified this fiscal year.

■ Examination status

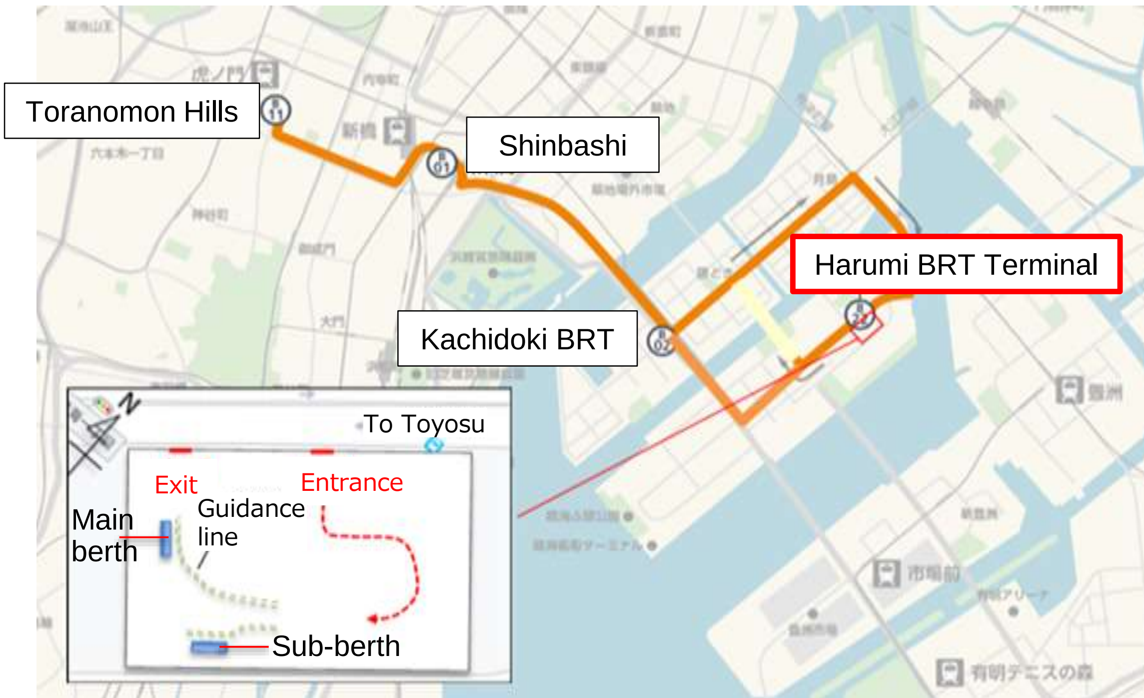
Classification	Verification items	Verification status
(1) Verification of technical issues	[1] Clarification of system usage conditions	○ Verified system usage conditions for snowfall in the evening (last fiscal year). ○ Verified system usage conditions for rainfall (this fiscal year).
	[2] Guidance line durability confirmation	○ Confirmed the recognition status of the camera when the guidance line deteriorates, using a glanshall sheet (last fiscal year). ○ Grasped the deterioration status of guidance lines after installation (from last fiscal year to this fiscal year) . → This fiscal year, we checked the deterioration status twice at different times and estimated the maintenance frequency.
(2) Verification of social effects	[1] Verification of the barrier-free effects of precise docking	○ Questionnaires were sent to 149 monitors (31 last fiscal year, 118 this fiscal year). ○ Conducted interviews with drivers (One last fiscal year, three this fiscal year).
	[2] Time-saving effects of precise docking when getting on and off the bus	○ Measured boarding and alighting time by attribute of 31 monitors by stopping pattern* (last fiscal year). ○ Surveyed the number of passengers by attribute and identified time differences by stopping pattern (this fiscal year).
	[3] Verification of the effects of preventing falls during boarding and alighting	○ Cameras were used to observe conditions during boarding and alighting, and to measure the presence or absence of falls and the risk of falls by boarding and alighting according to stopping patterns (this fiscal year).
	[4] Verification of the effects of preventing falls when the bus stops and starts	○ Cameras were used to observe the interior of the bus while driving, and the presence or absence of falls and the risk of falls was measured for each stopping pattern (this fiscal year).

* The three stopping patterns are automatic precise docking, manual precise docking, and normal stopping.

2. Examination status 2-2. Location of verification implementation

○ A demonstration experiment was conducted at the Harumi BRT Terminal for six days from November 17 to 22, 2020, and for three days from October 22 to 24, 2021.
○ The Harumi BRT Terminal has two bus berths, a main berth (for embarking passengers) and a sub-berth (for disembarking passengers), and the sub-berth was used for this demonstration experiment.
○ Since the sub-berth is not raised at the boarding/alighting section, a boarding/alighting platform was installed and a demonstration test was conducted.

■ Tokyo BRT route map and locations of demonstration tests



■ Vehicle (Toyota: SORA)

■ Platforms

■ Overview

○ With the guidance line type precise docking control, a camera mounted on the bus vehicle reads the guidance lines on the road surface and automatically steers the vehicle along the guidance lines based on the information from the camera to arrive at the bus stop correctly.

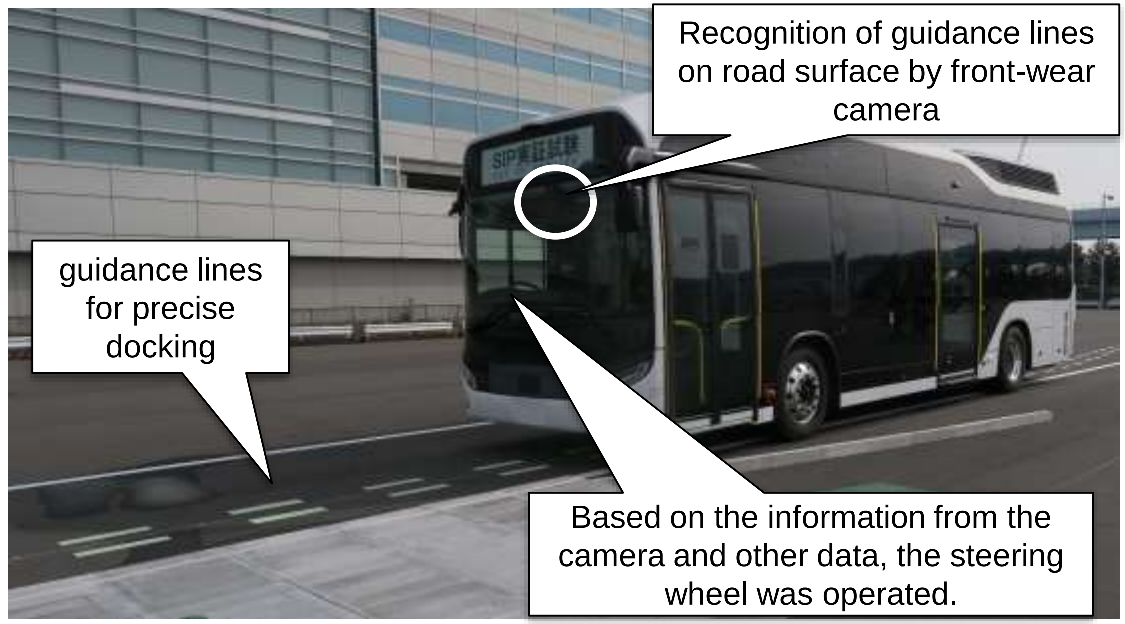
○ Since the accuracy of camera readings varies depending on external factors, clarify the operating conditions under which the guidance lines of the precise docking control system can be recognized in various conditions, such as during night-time (evening), rainy or stormy weather, and snowfall, in preparation for full-scale introduction.

(Verification item 1)
- Whether or not to use precise docking in the evening or at night

(Verification item 2)
- Conditions for precise docking in case of rain or stormy weather

(Verification item 3)
- Conditions for precise docking during snowfall

■ The concept of control of precise docking using guidance lines



■ Verification 1: Night

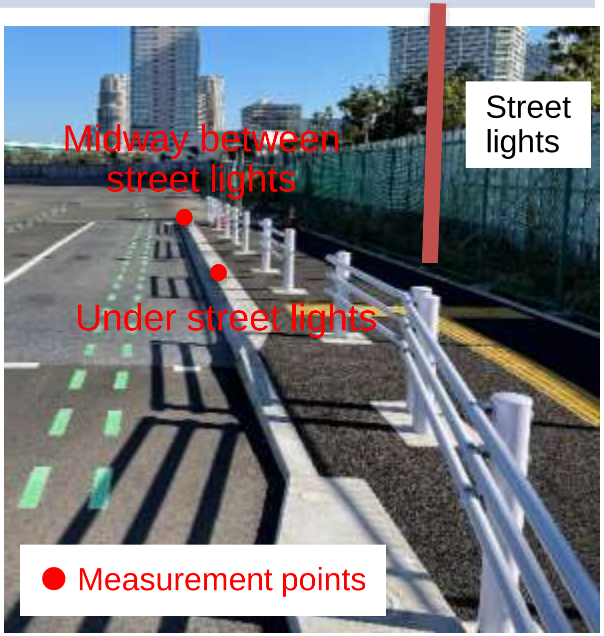
○ Starting before sunset, the precise docking control was repeatedly carried out while measuring the illuminance, and the threshold of illuminance at which the camera no longer recognized the guidance line was confirmed.
○ Roughly **15 minutes after sunset, the camera stopped recognizing the line at 30 lux.**

Verification items	Measurement items	Implementation overview
[Verification(1)] Early Evening / Night-time	(1) Whether the camera for precise docking recognizes the guidance line or not (2) Illuminance (3) Dry and wet conditions of the road surface	• Repeated precise docking control from before sunset (about every two minutes). • Checking the conditions under precise docking control with an illuminance meter and visual confirmation → Implemented for four days.

■ Overview 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 road surfaces were dry.



■ Verification 2: During rainy weather

○ During rainy weather, the precise docking control was repeatedly carried out while measuring the rainfall and illuminance, and the rainfall and illuminance threshold at which the camera no longer recognized the guidance lines were confirmed.
○ On that day, rainfall of less than 1mm/h fell intermittently from the morning and the road surface was wet to flooded, but the precise docking control operated normally during the day.
○ However, when the illumination started to drop before sunset, the guidance lines were no longer recognized earlier than was the case in clear weather.

Verification items	Measurement items	Implementation overview
[Verification (2)] During rainy weather	(1) Whether the camera for precise docking recognizes the line or not (2) Amount of rainfall (3) Illuminance	• Repeat precise docking control in rainy weather. • Use a rain gauge and an illuminance meter to confirm the rainfall and sunshine in case of no precise docking control. Also confirm the wetness of the road (dry, wet, flooded).

■ Rainfall conditions at the time of the experiment

■ Illuminance measurement points

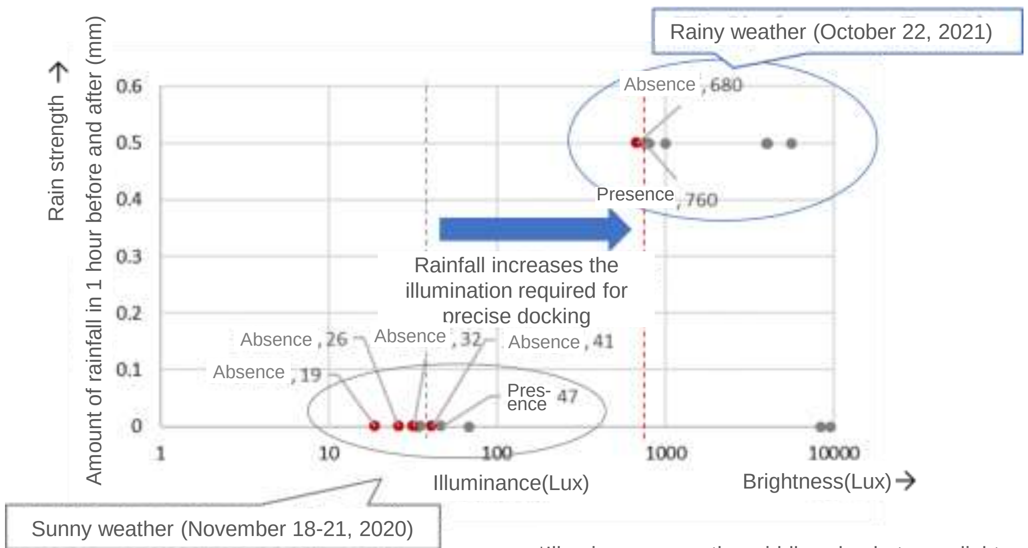
■ Installed rain gauges

- ○ The rainfall within an hour before and after the time of no precise docking was 0.5 mm (0.25 mm/h), and the illumination was 680 lux.
- ○ Compared to the illuminance (30 lux) of the nighttime survey conducted on a clear day, the illuminance threshold increased from 30 lux to 680 lux during rainy weather, indicating that the **illuminance required for guidance line recognition increases during rainy weather.**
- ○ This is thought to be due to the fact that the asphalt becomes wet and reflects light more easily, reducing the contrast difference between the road surface and the guidance lines, and making it difficult to recognize even in highly illuminated conditions.

■ Measurement results of system usage conditions in rainy weather

id	Road surface conditions	Time	Absence or presence of precise docking	Illuminance(Lux)		Amount of rainfall in 1 hour before and after (mm)
				Lower	Mid	
1	Warm	10:31	Presence	4080	4080	0.5
2	Warm	10:34	Presence	5600	5600	0.5
3	Warm	11:24	Presence	6550	8390	0
4	Warm	13:30	Presence	7700	9600	0
5	Warm	15:28	Presence	4000	4000	0.5
6	Warm	16:32	Presence	780	780	0.5
7	Warm	16:14	Presence	1000	1000	0.5
8	Warm	16:24	Presence	760	760	0.5
9	Warm	16:29	Presence	800	800	0.5
10	Warm	16:40	Absence	680	680	0.5

■ Difference in illuminance between rainy day survey and night survey (clear day)



*Illuminance uses the middle value between lights

■ Verification 3: During snowfall

○ Snow powder was spread on the guidance lines to check whether the lines were recognized by the camera for precise docking.
○ Even at a snow depth of 0.025 cm, the accuracy of the guidance line readings decreased significantly (two out of five readings).
○ **It was confirmed that the system does not recognize the lines when even small amounts of snowfall occur.**

Verification items	Measurement items	Implementation overview
[Verification (3)] During snowfall	(1) Whether the camera for precise docking recognizes the line or not (2) Illuminance (3) Snowfall conditions	• Conducted verification on a day before the pre-operation period. • Snow powder was used to reproduce snowfall conditions in stages and verify the reading conditions.

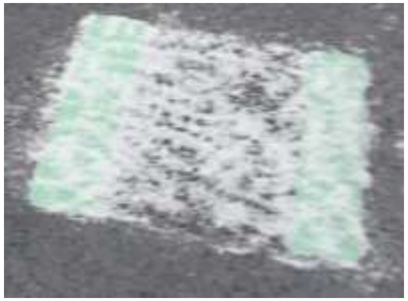
■ Depth of snowfall

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

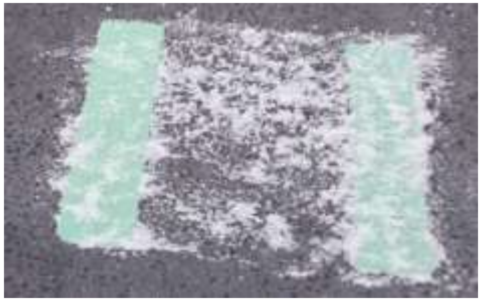
The amount of powder was measured with a measuring cup and the powder was spread over a predetermined area to determine the average depth of snowfall.

0.5 cm

0.1 cm



0.025 cm



(1) Verification of technical issues [2] guidance line durability confirmation

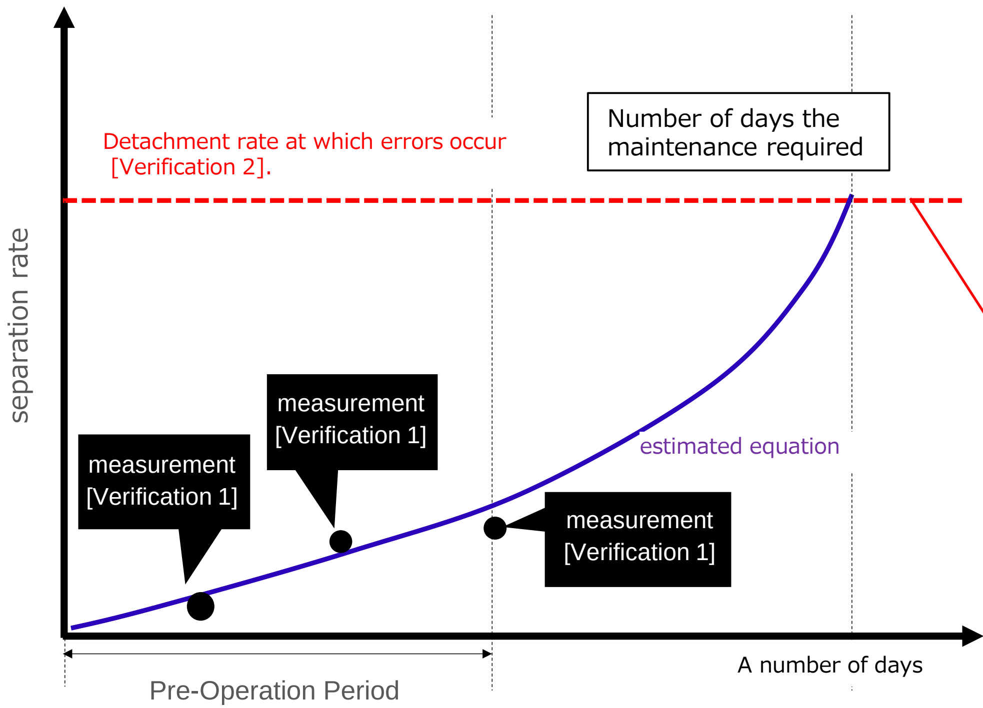
○ Measure the trend of deterioration of the guidance lines and estimate the maintenance frequency of the guidance lines based on the state of deterioration over time (e.g., rate of peeling of the paint).

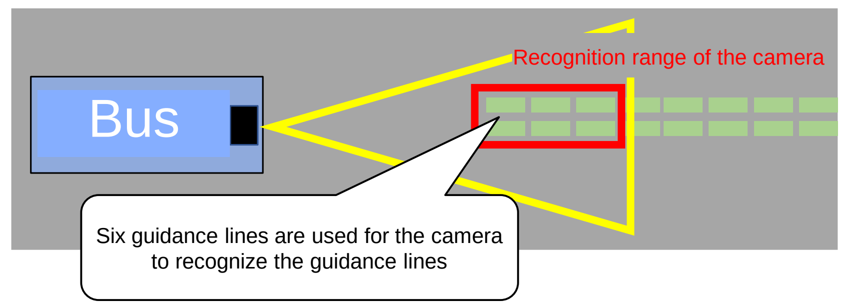
○ In estimating the maintenance frequency of the guidance lines, the following two points will be verified.

Verification item 1: Measurement of guidance line deterioration (rate of peeling) during preoperational period

Verification item 2: Measurement of guidance line deterioration (rate of peeling) that causes errors

■ Image of estimation of maintenance frequency of guidance lines





A granular sheet that mimics a degraded guidance line was placed on the guidance line, and a camera was used to perform a reading test. The rate of peeling at which errors occur was confirmed as the threshold.

Actual deterioration (rate of peeling: 11.3%)

Deterioration reproduction (rate of peeling: 40.0%)

■ **Verification item 1**

○ The state of deterioration was measured at three points. Four locations were photographed for each point.

○ The rate of peeling of all the guidance lines increased with time, although there were variations.

■ **Verification item 2**

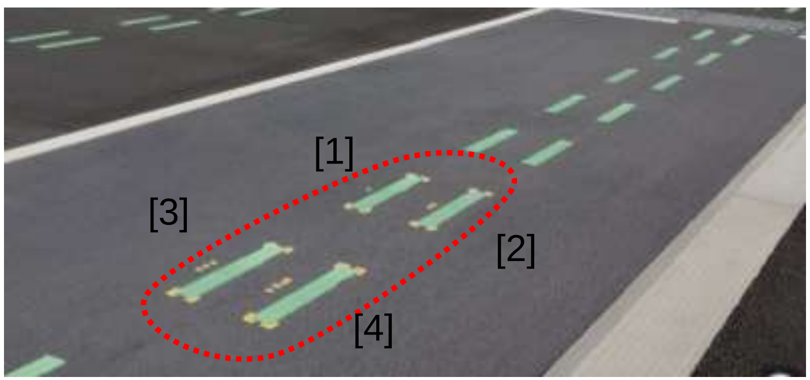
○ The threshold of the deterioration condition of the guidance lines where the error occurs was verified.

○ The deterioration conditions were reproduced using a granular sheet. Specifically, the edge of the granular sheet, which is the same color as the guidance line, was made black, and the rate of peeling of 40–80% was reproduced according to the black area (see the figure below).

○ This granular sheet was pasted on the guidance line to reproduce the situation where a part of the actual guidance line was peeled off, and the recognition of the camera was checked.

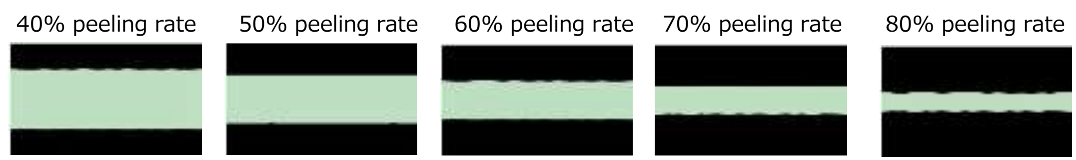
○ When the rate of peeling exceeded 50%, the camera stopped recognizing the guidance lines.

■ Results of verification item 1



No.	November 2020	April 2021	October 2021
1	2.5%	7.0%	11.3%
2	2.0%	4.7%	10.8%
3	1.9%	4.2%	6.6%
4	2.6%	5.0%	7.5%

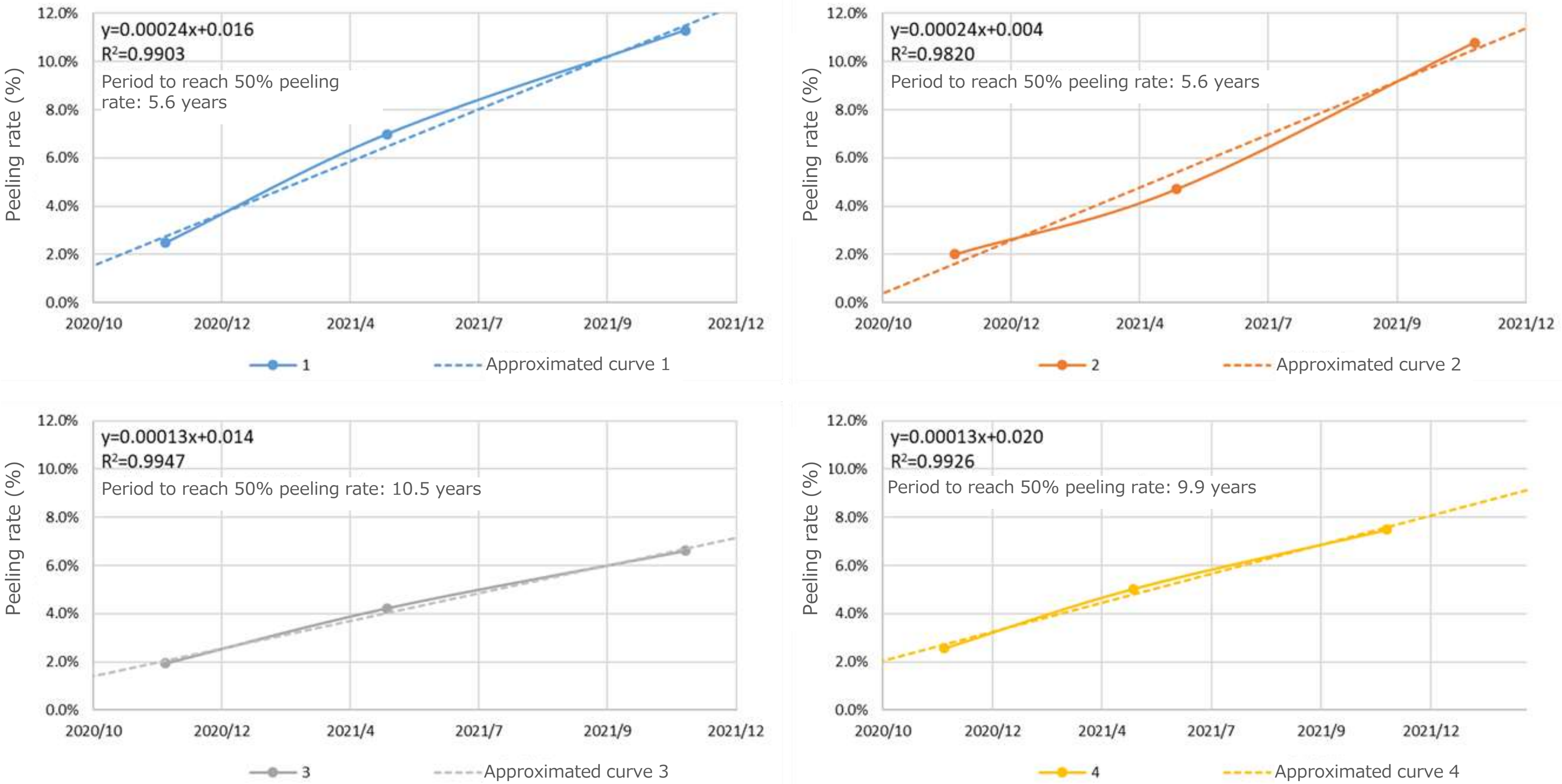
■ Results of verification item 2



		1st measurement	2nd measurement	3rd measurement
Grouncial sheet with 40% peeling rate (Chipped on sides)	Brightness (lx)	7,500	7,100	7,000
	Drying temperature of the road surface	Dry	Dry	Dry
	Absence or presence of precise docking	Yes	Yes	Yes
Grouncial sheet with 50% peeling rate (Chipped on sides)	Brightness (lx)	7,200	7,000	7,000
	Drying temperature of the road surface	Dry	Dry	Dry
	Absence or presence of precise docking	Yes	Yes	Yes
Grouncial sheet with 60% peeling rate (Chipped on sides)	Brightness (lx)	7,800	7,800	7,600
	Drying temperature of the road surface	Dry	Dry	Dry
	Absence or presence of precise docking	No	No	No

(1) Verification of technical issues [2] guidance line durability confirmation

- ○ The regression equation between the rate of peeling and the number of years elapsed was estimated based on the changes in the deterioration condition identified in verification item 1, and the number of years that the rate of peeling reaches 50% was estimated based on the regression equation.
- ○ As a result, it was found that the guidance lines reach a 50% rate of peeling in a minimum of about five years and a maximum of about 10 years.
- ○ At bus stops on public roads, where more vehicles are likely to pass over the guidance lines than at the Harumi Terminal, the subject of this verification, the deterioration rate is expected to be faster than the above results.



Deterioration curve of guidance line (approximation by guidance line)

y: Rate of peeling,
x: Number of days

(2) Verification of social effects [1] Verification of barrier-free effects

○ Questionnaires and interviews were conducted with BRT users and drivers to investigate and verify the barrier-free effects of precise docking from their perspective.
○ Specifically, we rented out a BRT bus for a few days, had the recruited monitors experience the ride, and conducted a questionnaire survey on the effects of precise docking. In addition, an interview survey was conducted with the drivers who cooperated in the operation of the BRT during the experiment.
○ The number of monitors was 118 in the 2021 experiment and 31 in the 2020 experiment (149 in total).

■ Survey contents

Classification	Method	Target/sample	Main survey items
User questionnaire survey	• Recruited monitors and conducted questionnaire surveys after riding the BRT. • The ride experience includes three different stopping patterns including normal stopping, automatic precise docking technology, and manual precise docking technology.	149 monitors (Breakdown) Survey conducted in 2021: 118 passengers (12 wheelchair users, five baby stroller users, 101 general passengers) Survey conducted in 2020: 31 passengers (Five wheelchair users, six baby stroller users, 20 general passengers)	(Personal attributes) Gender, age, occupation, frequency of bus use, etc. (Barrier-free effects) Horizontal swaying when stopping Ease of getting on and off at bus stops (Intention to use/introduce) Intention to use/introduce automatic precise docking, reasons, and requests
Driver interview survey	• Conducted with bus drivers who cooperated during the user survey.	Drivers with experience in driving buses equipped with precise docking control: four	(Personal attributes) Gender, age, driving experience (Effects and effectiveness of precise docking control) Burden, hassle, and peace of mind of the driver Gaps, horizontal swaying, etc. when stopping (Intention to use/introduce) Intention to use/introduce automatic precise docking, reasons, and requests

Note: Survey period: 2021: Friday, October 22 to Sunday, October 24, 2021; 2020: Thursday, November 19 to Sunday, November 22, 2020

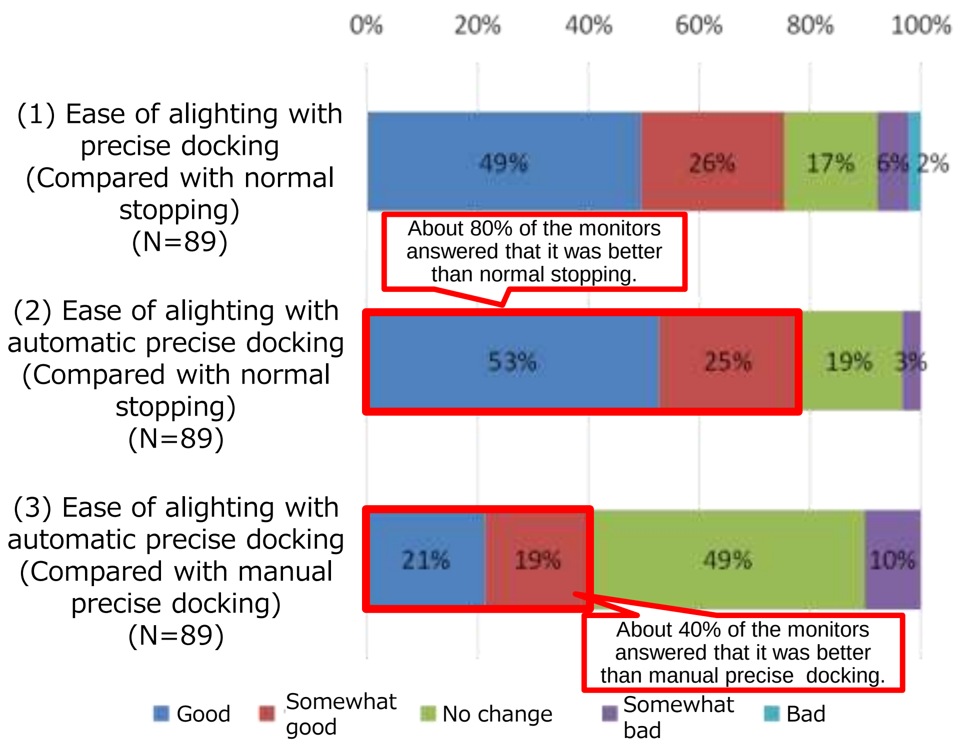
(2) Verification of social effects [1] Verification of barrier-free effects

○ Many monitors answered that it is easier to get off the bus with automatic precise docking than normal stopping and manual precise docking because the gap between the bus and the bus stop is smaller.

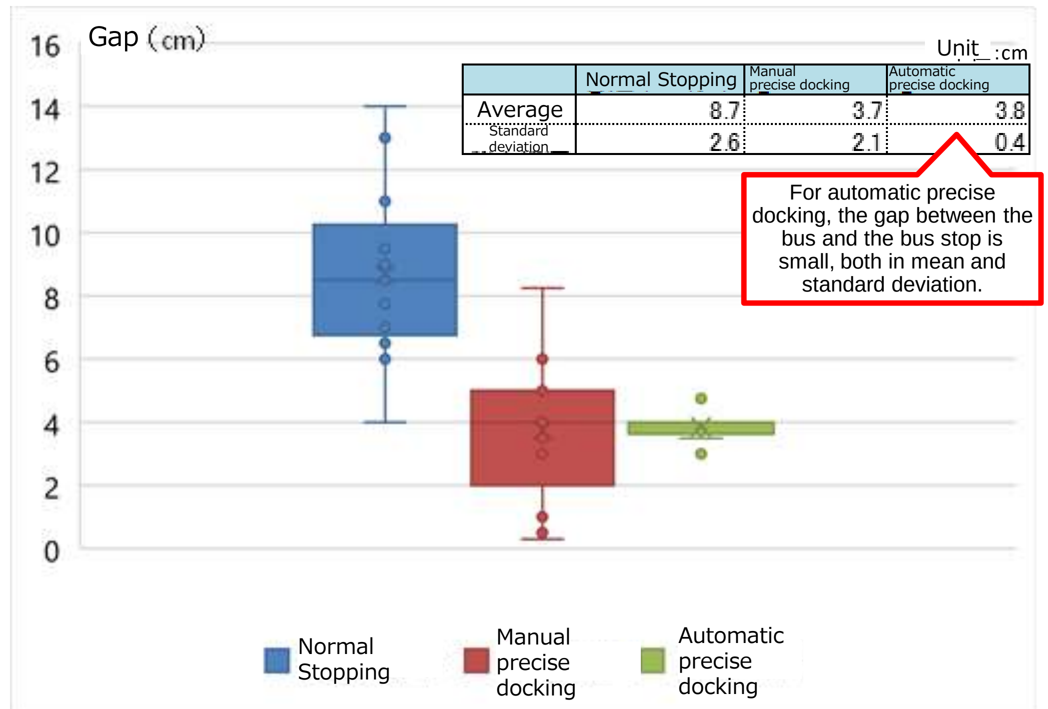
○ The gap between the bus and the bus stop is smaller with automatic precise docking than with normal stopping and manual precise docking, and the width is stable regardless of the driver's experience and skill. This is thought to have led to the evaluation that it was easy to get off the bus.

■ Results of evaluation by bus users for each stopping pattern

(Evaluation of the ease of getting off at a bus stop)



(Measurement results of the gap between the bus and the bus stop for different stopping patterns)



Note 1: To show the results of the experiment under the same conditions, the display is limited to the survey results of the samples acquired in the 2021 experiment.
Note 2: The gap between the bus and the bus stop was measured at the middle door of the bus used for alighting in each experimental session.

(2) Verification of social effects [1] Verification of barrier-free effects

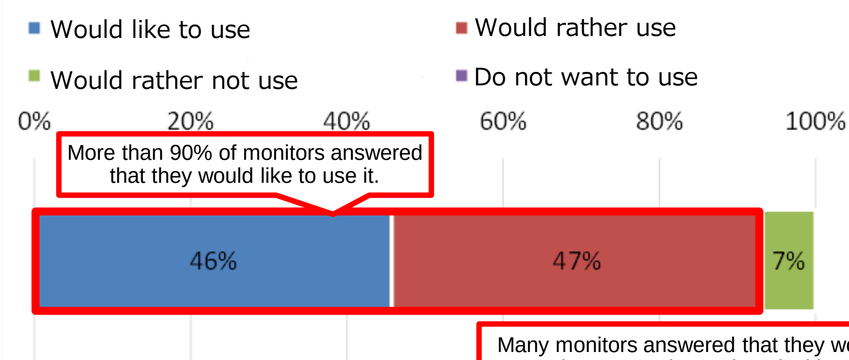
○ More than 90% of the monitors answered that they would like to use a bus that allows automatic precise docking. Many of them cited the small gaps and steps between the bus and the bus stop as reasons for this, making it easy to get on and off the bus. These results indicate that the barrier-free effects of automatic precise docking is high.

○ On the other hand, because of the horizontal swaying that occurs when entering the guidance line and while traveling on the guidance line, the automatic precise docking was rated lower than the normal stopping and manual precise docking for horizontal swaying during stopping. Addressing this point is an issue for the future.*

* For horizontal swaying when entering the guidance line, it is effective to have drivers get used to automatic driving, and for horizontal swaying when passing through the S-shaped curve in the guidance line, it is effective to ease the curvature of the S-shaped curve by introducing a completely dedicated lane closer to the center line.

■ Willingness of bus users to use automatic precise docking

(Intention to use)



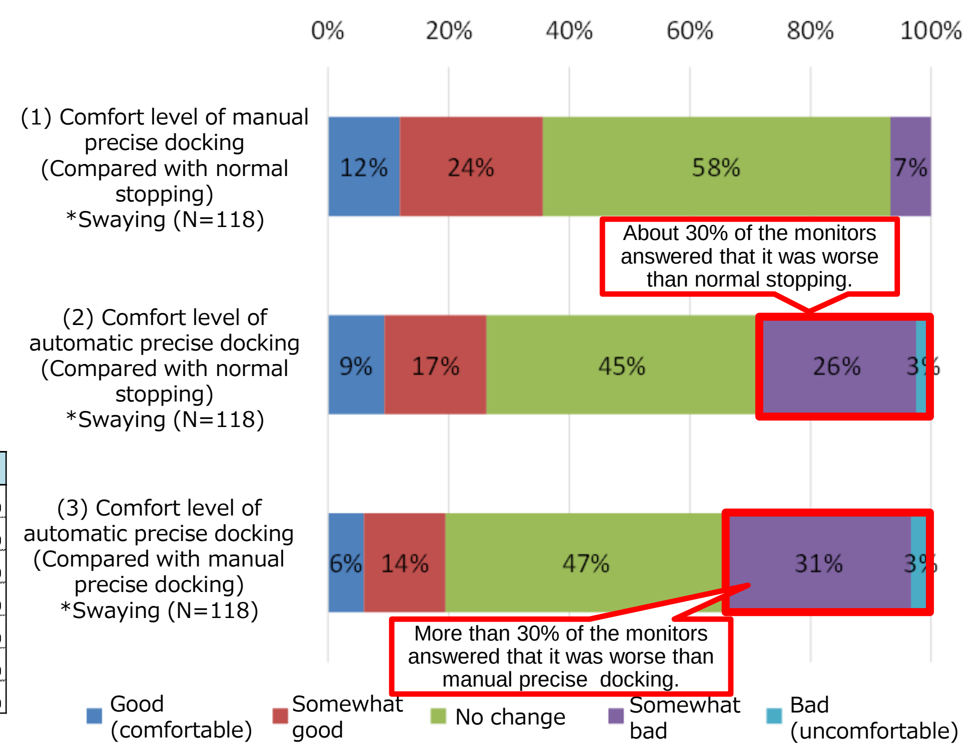
(Reason for wanting to use)

Many monitors answered that they would like to use the automatic precise docking because of the small gap/step between the bus and the bus stop.

Reasons for wanting to use	Number of subject	Compostion Ratio
①It's more comfortable and there's less swaying when stopping at a bus stop.	18	16.4%
②Because the gap between the bus and the bus stop is small and easy to get on and off.	75	68.2%
③Because the step between the bus and the bus stop is small and easy to get on and off.	69	62.7%
④Because it is easy to get on and off the train when you have large baggage.	44	40.0%
⑤Because I use a baby stroller and it is easy to get on and off.	20	18.2%
⑥Because I use a wheelchair or walking aid (cane, etc.) and it is easy to get on and off.	19	17.3%
⑦Other	25	22.7%

■ Results of evaluation by bus users for each stopping pattern

(Evaluation of horizontal sway when the vehicle is stopping)



Note: To show the results of the experiment under the same conditions, the display is limited to the survey results of the samples acquired in the 2021 experiment.

(2) Verification of social effects [1] Verification of barrier-free effects

○ From the interview survey with the bus drivers, it was pointed out that the advantages and effects of the automatic precise docking include "improved safety for passengers when getting on and off the bus" due to the smaller gap between the bus and the bus stop, and "reduced workload" for wheelchair users when getting on and off the bus, such as loading and unloading the ramp.

○ On the other hand, "the horizontal swaying that occurs when buses enter the guidance lines" and "the need for countermeasures against parking on the street at bus stops" were cited as issues and points to be considered for the introduction of automatic precise docking.

■ Main opinions of bus drivers on automatic precise docking

	Contents of opinions
Advantages and benefits of automatic precise docking	• The gap between the bus and the bus stop will be reduced so that passengers can get on and off the bus safely. • For wheelchair users, it eliminates the need for a ramp to get on and off the bus. • Although the front wheels will need to be locked and secured, it will be more convenient for getting on and off the bus with a wheelchair. • It takes a certain amount of time to get used to it, but passengers will get used to it after a few times. • If the technology improves and there is no more horizontal swaying, there will be no problem in introducing it.
Issues and points to keep in mind for automatic precise docking	• The horizontal swaying that occurs when the bus reads the guidance lines is a concern. • Horizontal swaying occurs when entering the guidance line. • It would be better if it were possible to enter the guidance line from various angles and still be able to conduct precise docking. • The movement of the bus seems to be a little choppy. • Some bus stops have a great deal of on-street parking, so parking countermeasures will be necessary when fully guidance this. • It doesn't function if there is on-street parking at the bus stop. • It's easier to stop with normal stopping. • It's going to take some time to get used to it.

(2) Verification of social effects [2] Verification of time-saving effects during boarding and alighting

○ We estimated the time-saving effects of introducing the guidance line type precise docking control technology to the Tokyo BRT.

○ In order to estimate the time-saving effects, the following two experiments and surveys were conducted.

(1) Boarding and alighting time survey (monitor survey)

Measured boarding and alighting times for three stopping patterns, including 1) automatic precise docking (guidance line method), 2) manual precise docking (barrier-free curb), and 3) normal stopping.

(2) Survey of the number of users

A video camera was installed inside one of the Tokyo BRT buses in actual operation, and the passengers were filmed as they got on and off the bus. We surveyed the number of bus users and their attributes (age group, wheelchair/baby stroller use) from the video footage.

■ Image of the method for estimating the time-saving effects

Boarding and alighting time survey (monitor survey)
- General passengers: XX seconds reduced/person
- Elderly passengers: XX seconds reduced/person
- Wheelchair users: XX seconds reduced/person
- Baby stroller users: XX seconds reduced/person

×

Survey of the number of users, etc.
- General passengers: XX people/day
- Elderly passengers: XX people/day
- Wheelchair users: XX people/day
- Baby stroller users: XX people/day

=

XX min/day reduction in stopping time per day

■ Survey contents

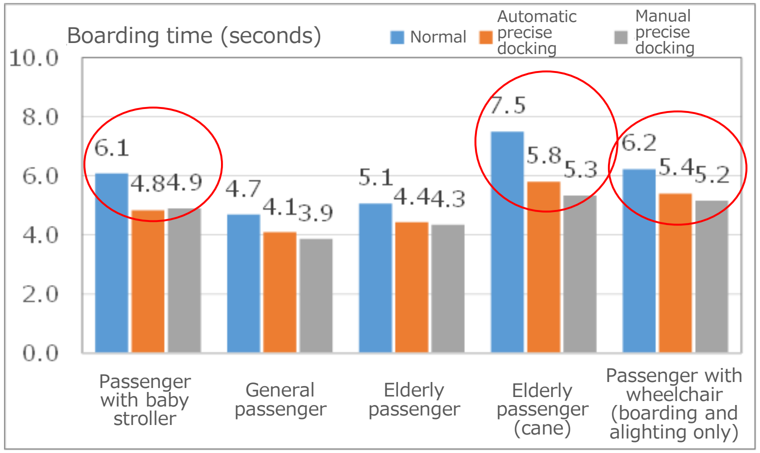
	Survey method	Implementation period
(1) Boarding and alighting time survey	• Monitors* were recruited to experience getting on and off the bus in three different stopping patterns: automatic precise docking, manual precise docking and normal stopping. • Measured the time it takes to get on and off the bus. * There were 31 monitors in total. (Five wheelchair users, six baby stroller users, 20 general passengers [including 10 elderly passengers])	Thursday, November 19 to Sunday, November 22, 2020
(2) Survey of the number of users	• A video camera was installed inside one of the Tokyo BRT buses in actual operation, and the passengers were filmed as they got on and off the bus. Visually confirmed the video footage and counted the number of passengers by attribute*. * Attributes: Age group, wheelchair use, baby stroller use	Thursday, November 25, to Thursday, December 2, 2021

(2) Verification of social effects [2] Verification of time-saving effects during boarding and alighting

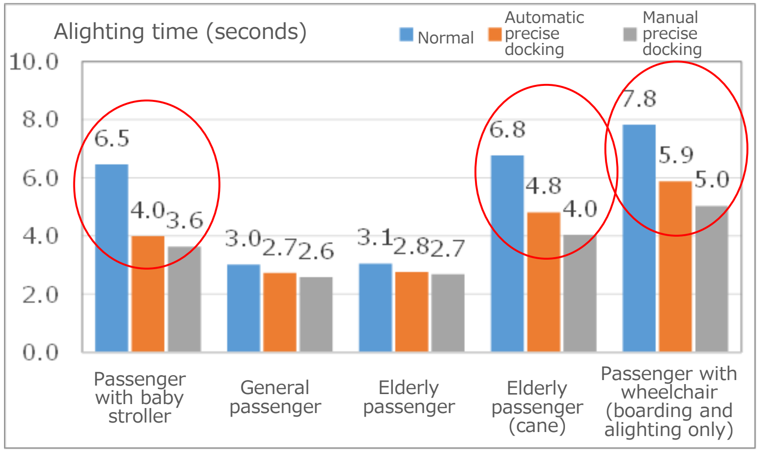
○ Although there is no significant difference in boarding and alighting time between automatic and manual precise docking, when compared to normal stopping, the difference is especially large for baby stroller users, elderly people with canes, and wheelchair users.
○ For wheelchair users, the difference is 15 to 20 seconds, including the time taken by the driver to set up the ramp and secure the wheelchair with a belt.

■ Results of the boarding and alighting time survey

(Boarding time)



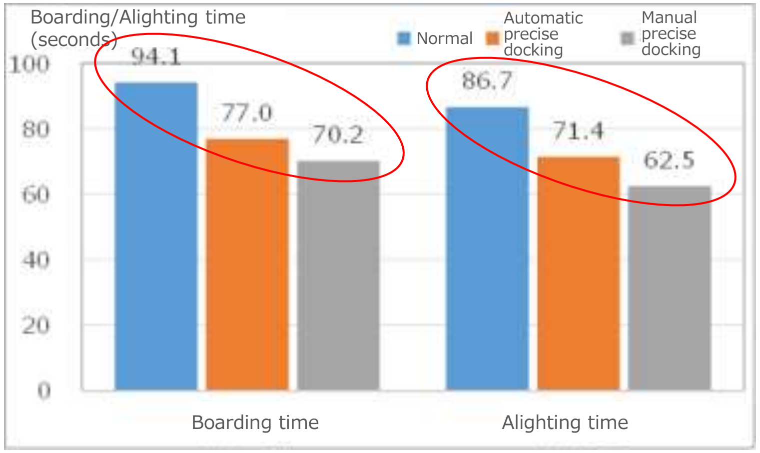
(Alighting time)



■ precise docking status (mean value)

Normal: 25.0 cm
Automatic precise docking: 5.3 cm
Manual precise docking: 1.3 cm

■ Boarding/alighting time of wheelchair users (Including driver’s work time.)

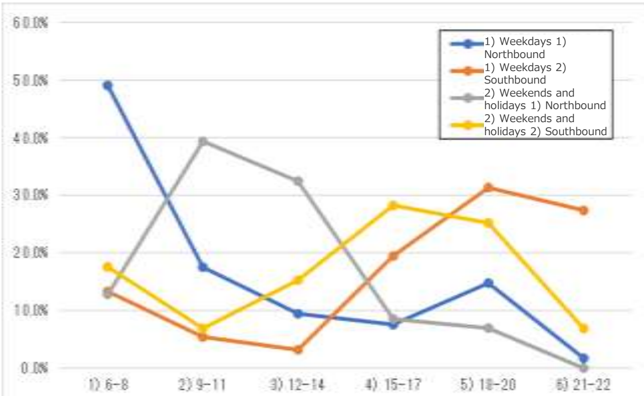


○ A video camera was installed inside one of the Tokyo BRT buses for eight days from Thursday, November 25, to Thursday, December 2, 2021, to film bus passengers and count the number of passengers by individual attribute (wheelchair user, baby stroller user, age group) from the video footage. The following figure shows the ratio of personal attributes of the passengers calculated from the survey results.

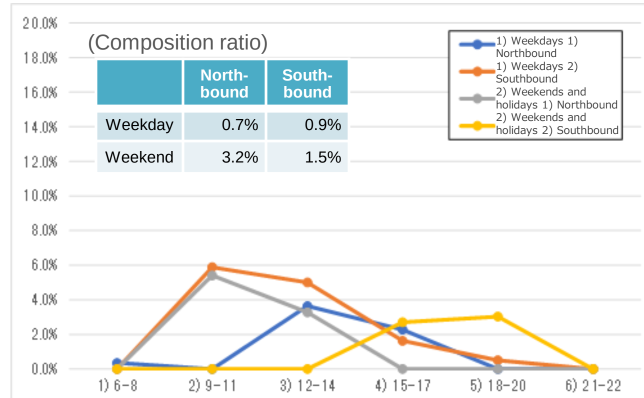
○ There was only one wheelchair user in the survey period. On a daily basis, baby stroller users account for less than 1% of both northbound and southbound users on weekdays, and 3.2% northbound and 1.5% southbound users on weekends. For elderly passengers (70 and older), the rate is around 2% both on weekdays and weekends, both northbound and southbound.

■ Results of the survey on the number of passengers

(Composition ratio of users for each time of day)

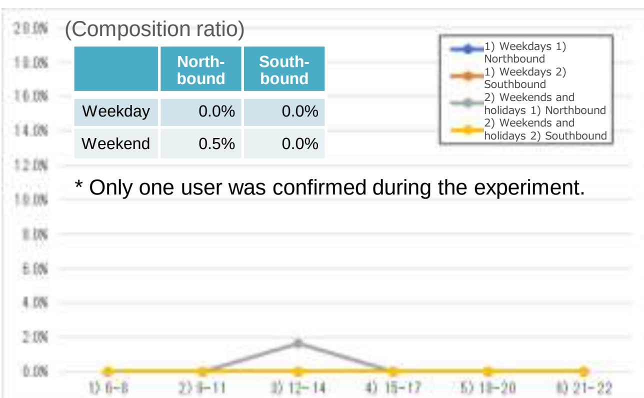


(Ratio of baby stroller users to total passengers)



	North-bound	South-bound
Weekday	0.7%	0.9%
Weekend	3.2%	1.5%

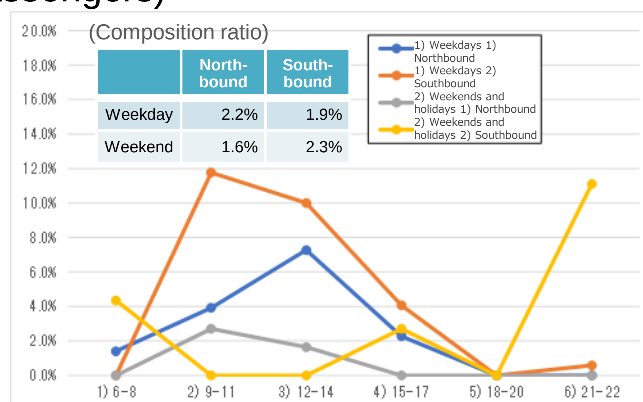
(Ratio of wheelchair users to total passengers)



	North-bound	South-bound
Weekday	0.0%	0.0%
Weekend	0.5%	0.0%

* Only one user was confirmed during the experiment.

(Ratio of elderly passengers (70 and older) to total passengers)

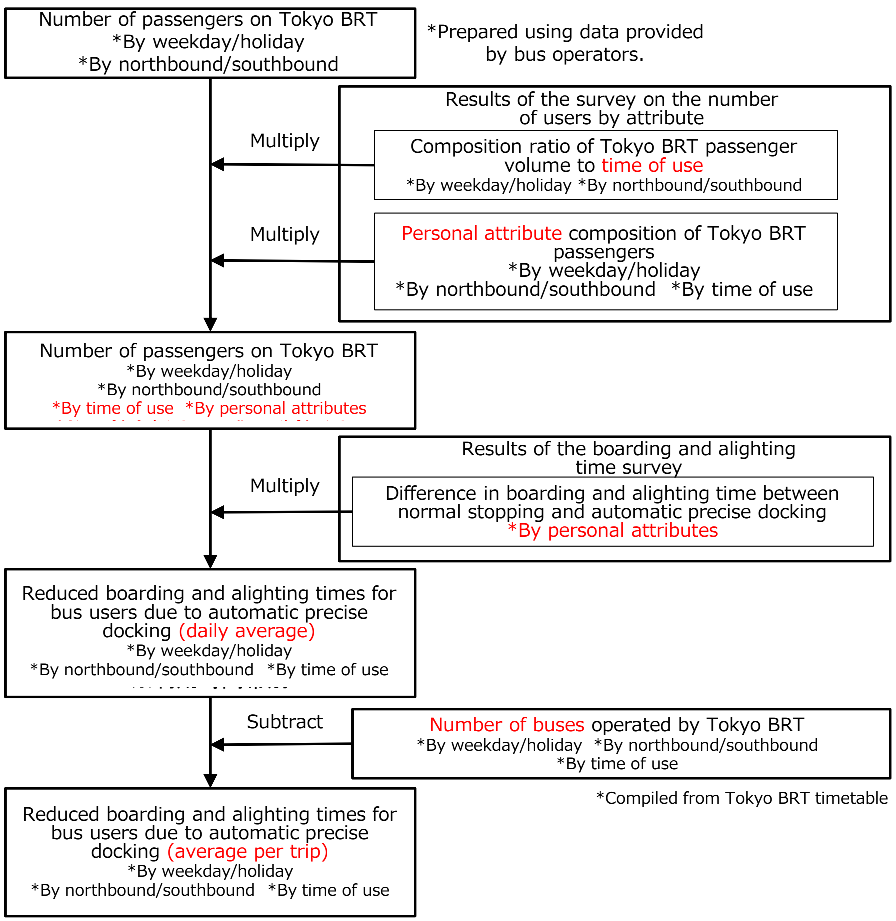


	North-bound	South-bound
Weekday	2.2%	1.9%
Weekend	1.6%	2.3%

(2) Verification of social effects [2] Verification of time-saving effects during boarding and alighting

○ The effects of reducing boarding and alighting time were estimated assuming that automatic precise docking is introduced at all bus stops of the Tokyo BRT.
○ The number of passengers by attribute was obtained by multiplying the daily number of passengers on the Tokyo BRT, which was calculated based on data obtained from bus operators, by the ratio of the composition of the attributes of the passengers, which was determined through a survey of the number of passengers. The number of passengers by attribute was multiplied by the time saved by attribute, as determined by the boarding and alighting time survey, to estimate the effects of time savings per day and per trip.
*The estimation flow is shown in the figure below.

■ Method for estimating time-saving effects



■ Prerequisites for estimation

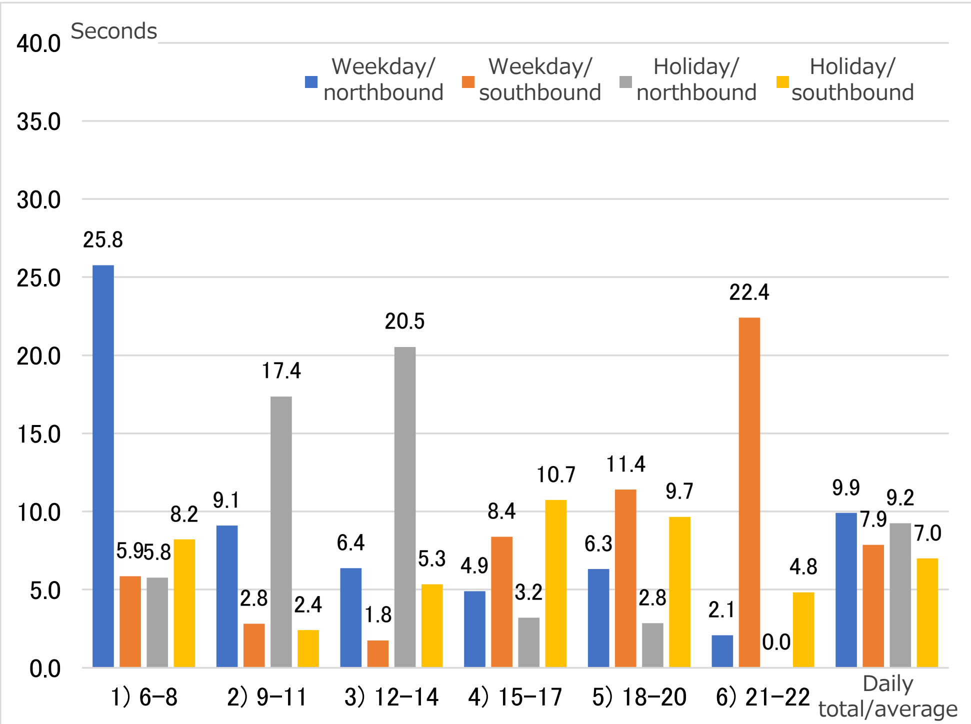
(1) Assuming that automatic precise docking is introduced at all bus stops on the Tokyo BRT
(2) The total number of users of the Tokyo BRT is assumed to be the average number of users by weekday or weekend from Thursday, November 25 to Sunday, November 28, 2021, based on data provided by bus operators.
(3) The percentage of wheelchair users, baby stroller users, and elderly passengers (70 and older) in the total number of users is based on the results of the user survey.
(4) The number of Tokyo BRT services by time zone and the time required for each service are based on the timetable as of November 2021.

(2) Verification of social effects [2] Verification of time-saving effects during boarding and alighting

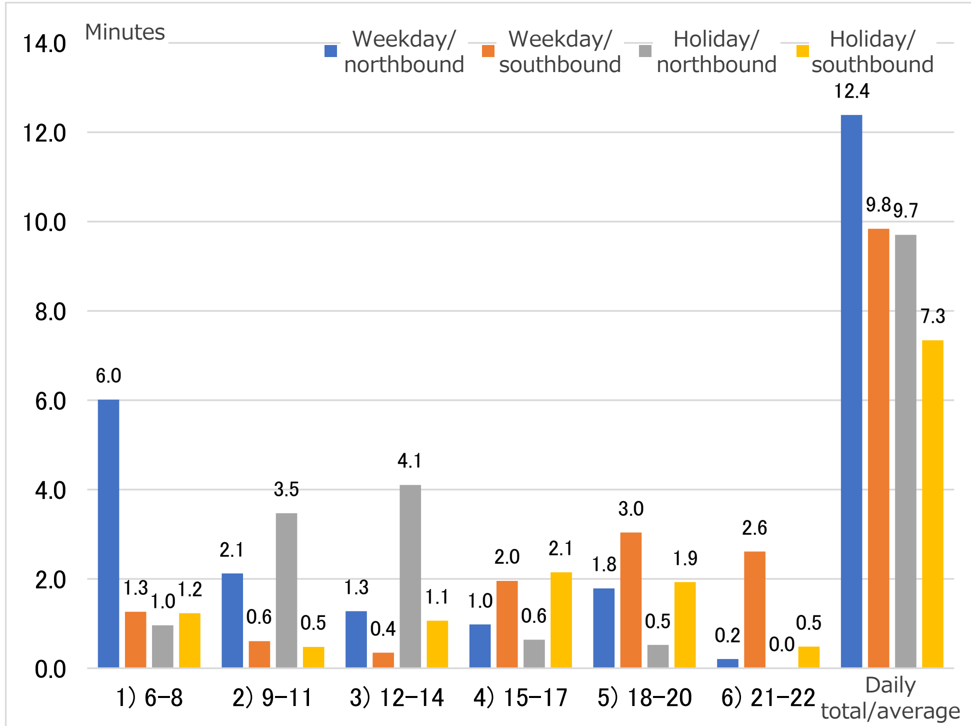
- ○ The greatest reduction per trip was seen in the early-morning weekday northbound direction (25.8 seconds), followed by the nighttime weekday southbound direction (22.4 seconds).
- ○ On a daily basis, the northbound direction on weekdays resulted in a time saving of 12.4 minutes.

■ Results of time-saving effect estimation

(Per trip)



(Per day; total of all trips)



(2) Verification of social effects [2] Verification of time-saving effects during boarding and alighting

○ With the above case for calculating the time-saving effects as the base case (0), a sensitivity analysis of the time-saving effects was conducted assuming the following cases: The number of users of the Tokyo BRT increases (1-1 to 1-3), the ratio of wheelchair/baby stroller users increases (2), and the number of Tokyo BRT users increases and the ratio of wheelchair/baby stroller users increases (3-1 to 3-3).

■ Sensitivity analysis case of time-saving effects

Estimated case		Assumed number of passengers				
		Total number of passengers	Number of wheelchair users	Number of baby stroller users	Number of elderly passengers	Number of other general passengers
0	Basic case	Current status	Current status	Current status	Current status	Current status
1-1	Increase in total number of passengers (However, the percentage of user attributes is fixed)	1.5x increase for all time periods	1.5x increase for all time periods	1.5x increase for all time periods	1.5x increase for all time periods	1.5x increase for all time periods
1-2		2x increase for all time periods	2x increase for all time periods	2x increase for all time periods	2x increase for all time periods	2x increase for all time periods
1-3		2.5x increase for all time periods	2.5x increase for all time periods	2.5x increase for all time periods	2.5x increase for all time periods	2.5x increase for all time periods
2	Increase in the number of wheelchair and baby stroller users	Current status *Same as case 0	Assuming that the ratio of wheelchair users to the total number of passengers is equal to the ratio of people with disabilities with limb disabilities to the total national population (1.4%)	Assuming that the ratio of stroller users to the total number of passengers is equal to the ratio of infants (0-3 years old) to the total national population (2.8%).	Current status *Same as case 0	Decrease only by the increase in the number of wheelchair users and stroller users from case 0
3-1	Increase in total number of passengers + Increase in the percentage of wheelchair and baby stroller users	1.5x increase for all time periods *Same as case 1-1	Assuming that the ratio of wheelchair users to the total number of passengers is equal to the ratio of people with disabilities with limb disabilities to the total national population (1.4%) ※1	Assuming that the ratio of stroller users to the total number of passengers is equal to the ratio of infants (0-3 years old) to the total national population (2.8%). ※2	1.5x increase for all time periods *Same as case 1-1	Decrease only by the increase in the number of wheelchair users and stroller users from case 1-1
3-2		2x increase for all time periods *Same as case 1-2	〃	〃	2x increase for all time periods *Same as case 1-2	Decrease only by the increase in the number of wheelchair users and stroller users from case 1-2
3-3		2.5x increase for all time periods *Same as case 1-3	〃	〃	2.5x increase for all time periods *Same as case 1-3	Decrease only by the increase in the number of wheelchair users and stroller users from case 1-3

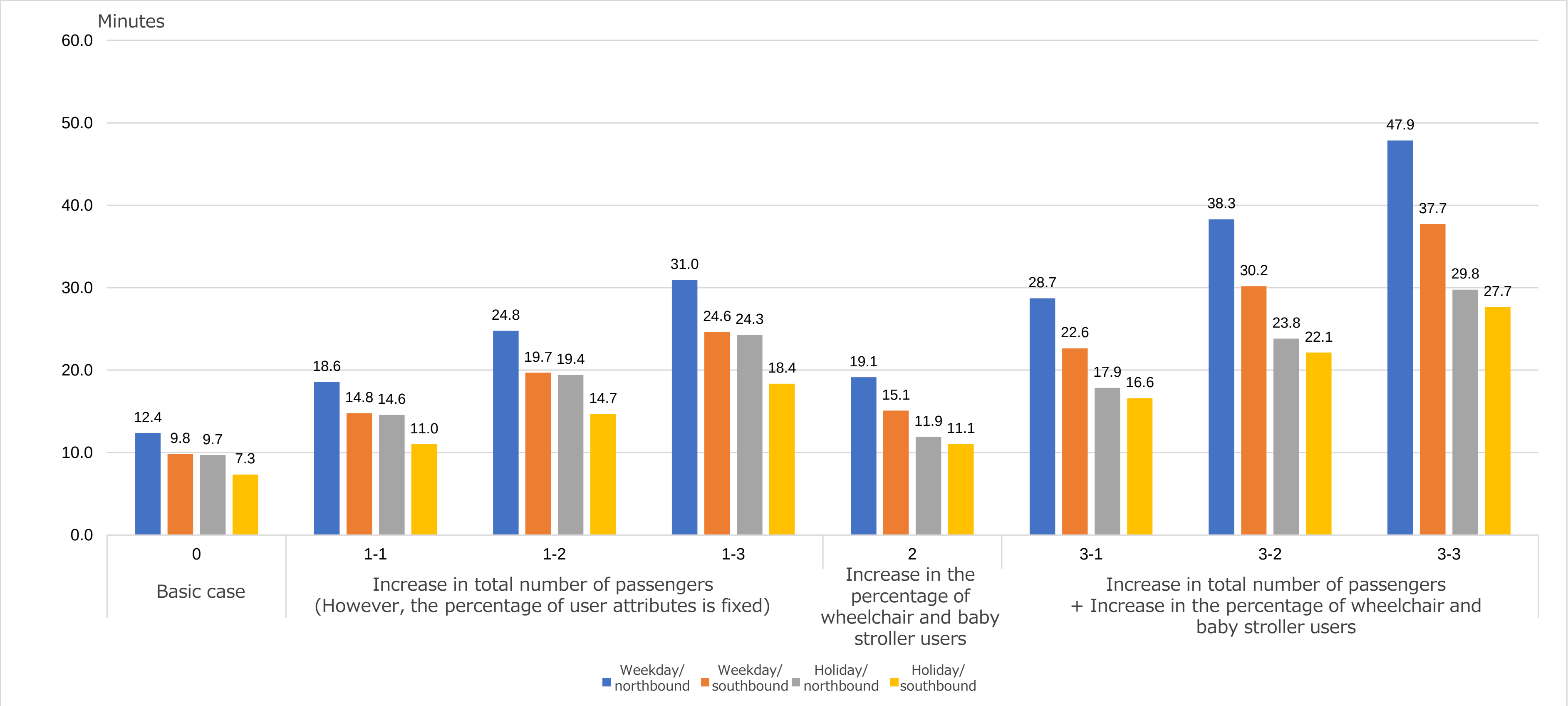
*1: The number of physically handicapped persons is 1,810,000 based on the survey on persons with physical disabilities (2006; Ministry of Health, Labour and Welfare), and the total national population is 127,901,000 based on the population census (2006; Ministry of Internal Affairs and Communications). Dividing the former by the latter, it is calculated to be 1.4%.
*2: Based on the national census (2020; Ministry of Internal Affairs and Communications), calculated by dividing the population aged 0-3 by the total population.

○ In cases 1-1 to 1-3, the time saving effect increased in proportion to the increase in the number of users to 1.5, 2.0, and 2.5 times that of the basic case 0, resulting in a time-saving effect of 31.0 minutes per day in the northbound direction on weekdays in case 1-3.
○ In case 2, the time-saving effects increased by 1.2 to 1.6 times compared to the basic case 0, resulting in a time-saving effect of 19.1 minutes per day in the northbound direction on weekdays.
○ In cases 3-1 to 3-3, the time-saving effects increased by 1.5, 2.0, and 2.5 times compared to case 2, resulting in a time-saving effect of 47.9 minutes per day in the northbound direction on weekdays in case 3-3.

* However, in cases 1-2 to 1-3 and 3-1 to 3-3, there would be a lack of capacity and insufficient space for wheelchairs and baby strollers in some time slots and buses, so measures such as increasing the number of buses and expanding the space for installation are necessary.

■ Results of sensitivity analysis of time-saving effects

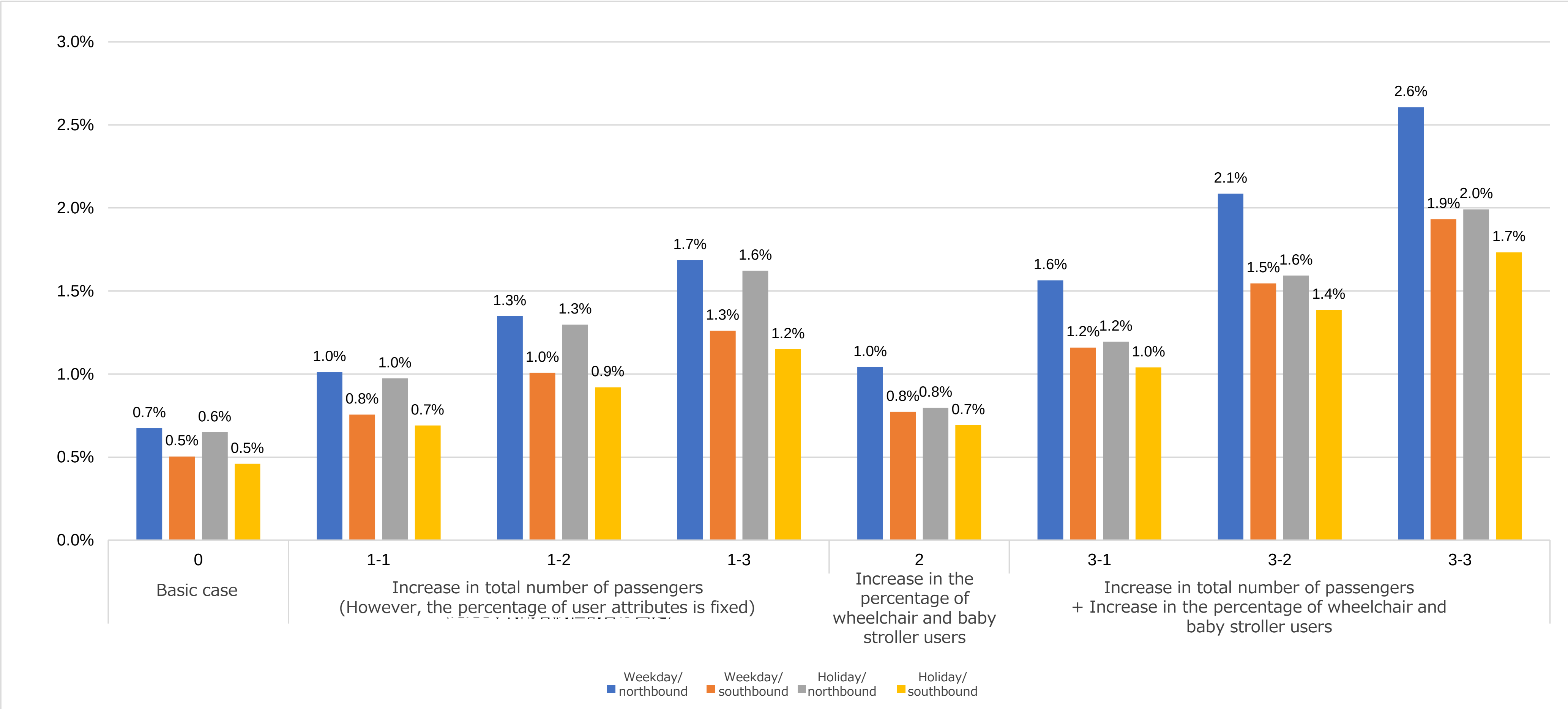
(Time-saving effects per day)



○ The percentage of time reduction in boarding and alighting time due to the introduction of automatic precise docking was 1.0% to 1.7% of bus travel time in cases 1-1 to 1-3, 1.0% in case 2, and 1.6% to 2.6% in cases 3-1 to 3-3 in the northbound direction on weekdays.

■ Results of sensitivity analysis of time-saving effects

(Ratio of reduced time to operating time)



○ We recorded the monitor's falls and stumbles caused by the difference between the bus step and the platform for each stop pattern (normal stopping, manual precise docking, and automatic precise docking) to verify the effectiveness of the precise docking control in preventing falls during boarding and alighting.
○ During the survey, no falls or trips were observed when getting on or off the bus.
○ While manual and automatic precise docking allows wheelchairs to get on and off the bus without a ramp, the front wheels of the wheelchair sometimes got caught in the gap between the platform and the entrance.

■ Overview of the survey

We surveyed how the monitors boarded and exited the bus during normal stopping, manual precise docking and automatic precise docking. We recorded the presence or absence of falls or tripping and the risk of falling. The platform was used only for manual and automatic precise docking.

Ramp used for wheelchairs (no steps or gaps)

No ramp for non-wheelchair users (with steps and gaps)

All used platforms
(No steps)
(Gaps existed in some cases)

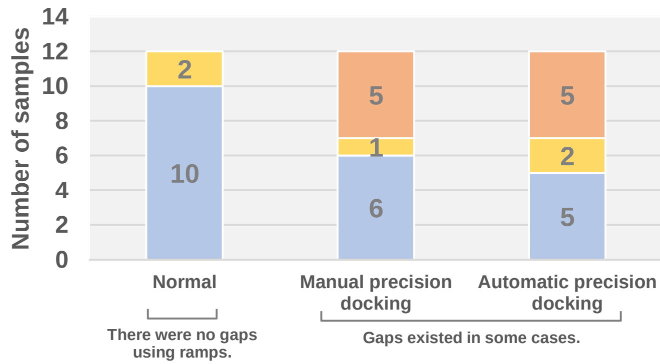
■ Whether or not passengers fell or tripped while getting on or off the bus

No one was observed to fall or trip while getting on or off the bus.

■ Risk of falling when baby stroller users get on or off the bus

When there were steps as with normal stopping, baby stroller users lifted the baby stroller to get on and off the bus, but we did not observe any problems such as the lifted baby stroller getting caught in the boarding/exiting door.

■ Risk of falling when wheelchair users get on or off the bus at the middle door



Snagging

➡ As a result of observation, it was confirmed that the front wheels of the wheelchair get caught when slowly passing over the gap.

Lifting of the front wheels

➡ As a result of observation, it was confirmed that users who are familiar with wheelchairs lift the front wheels to prevent them from getting caught.

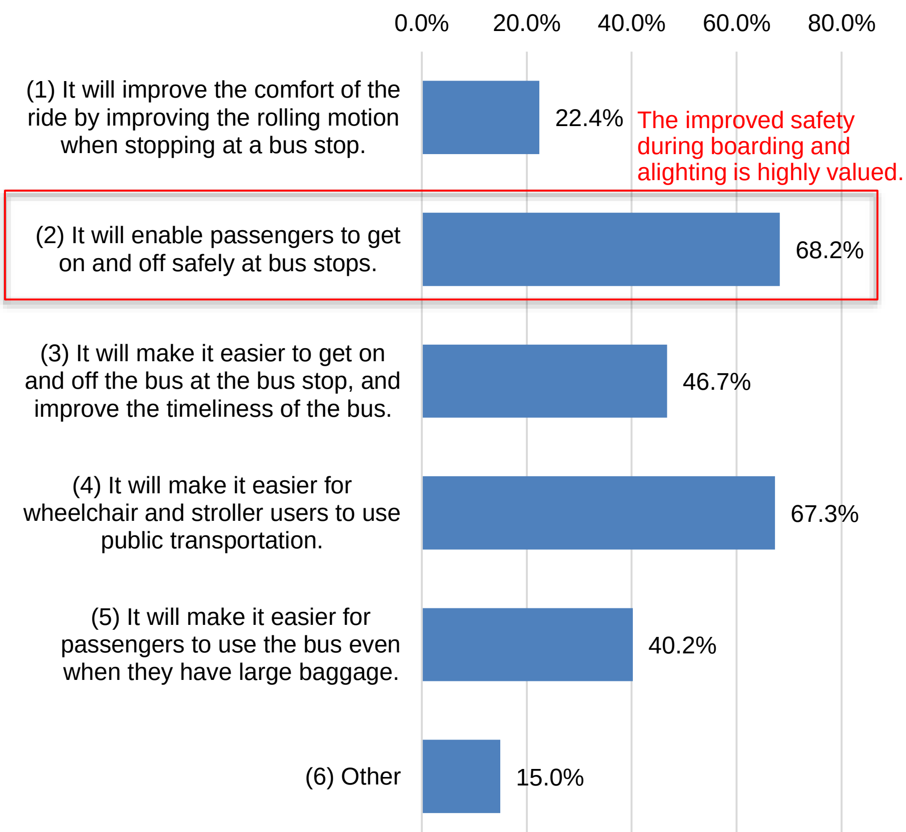
No problems

➡ As a result of observation, it was confirmed that if the gap is narrow enough or the passing speed through the gap is fast enough, the front wheels do not need to be lifted to avoid being caught.

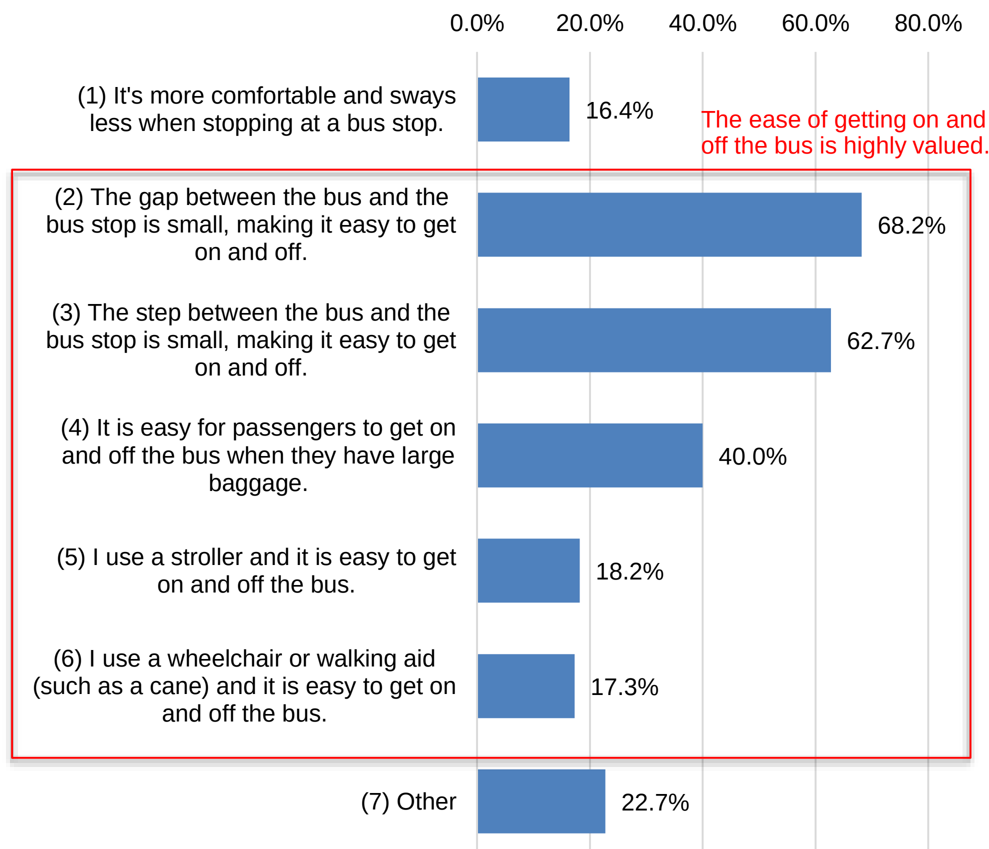
○ Looking at the results of the questionnaire survey of the monitors, 70% of the respondents thought that automatic precise docking which eliminates gaps* and steps would improve safety when getting on and off the bus, and improved safety when getting on and off the bus was highly evaluated.

* For monitors other than wheelchair users, the gap between the bus and the bus stop will also be smaller due to the automatic precise docking.

■ Reasons for wanting buses that enable automatic precise docking to become widely used



■ Reasons for wanting to use buses that enable automatic precise docking



Source: Compiled based on the results of the survey of monitors

○ The swaying of the bus caused by steering and acceleration/deceleration when the bus stopped was measured in each of the following stopping patterns: normal stop, manual precise docking, and automatic precise docking, and the effect of preventing the passengers from falling over when the bus stops and starts was verified.

○ The left/right acceleration was the highest for the automatic precise docking. The two possible reasons for this are the automatic steering at the start of reading the guidance lines and the steep curvature of the S-shaped curve due to the short guidance line setting.

■ Overview of the survey

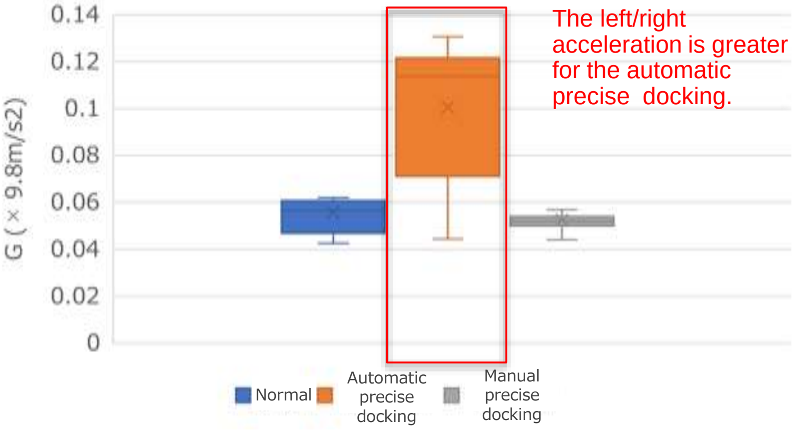
Maximum left/right acceleration on October 23
Driver's proficiency in automated driving **(None)**

- ○ **Acceleration recording**
  Using a smartphone to record acceleration when driving on the guidance line.
- ○ **Recording whether the monitor has fallen**
  Have the monitor stand in the bus and observe if they fall over.
- ○ **Recording the monitor's risk of falling**
  Questionnaire survey to see if monitors made to stand in the bus almost fell over.

* All of the above were conducted on October 23 and 24, 2021, after the monitoring survey.
* Only on October 24, 2021, test runs were repeated in between experiments to learn how to operate the automatic precise docking.

■ Maximum left/right acceleration by stopping pattern

Maximum left/right acceleration on October 23 and 24



■ Factors that increase the left/right acceleration of automatic precise docking

Factor (1) Automatic steering at the start of guidance line reading
When the guidance line is far from the center of the vehicle at the start of reading the guidance line, a relatively steep automatic steering occurs.
➡ It may be possible to suppress the left/right acceleration by learning to keep the guidance line at the center of the vehicle.

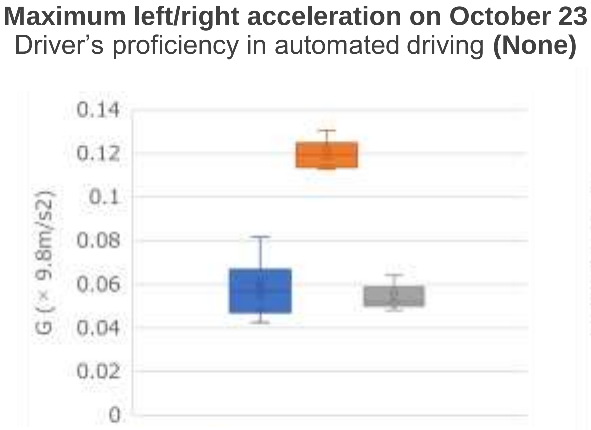
Factor (2) Curvature of the S-shaped curve, which was made steeper by the shortening of the guidance line
The guidance lines are not allowed to interfere with the legal lines, and in order to install them at many bus stops, it is necessary to make the guidance lines as short as possible, so this time, we followed this idea when we installed the guidance lines, which resulted in a steep curvature.
➡ It is effective to avoid interference with the legal lines by adopting a completely dedicated lane closer to the center line.

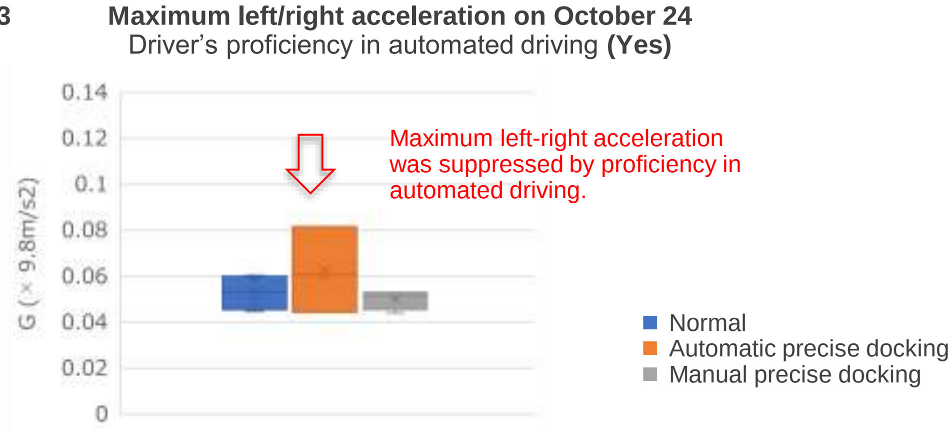
Note: Since this survey was conducted in a closed space with careful driving, the horizontal swaying during stopping and starting may not have reproduced that during normal operation.

○ As the driver becomes more proficient* in automatic precise docking, the left/right acceleration in automatic precise docking can be reduced to the same level as in other stopping patterns.
○ It was found that when the driver is proficient in automatic precise docking, left/right acceleration is unlikely to cause a fall risk for people standing in the bus.

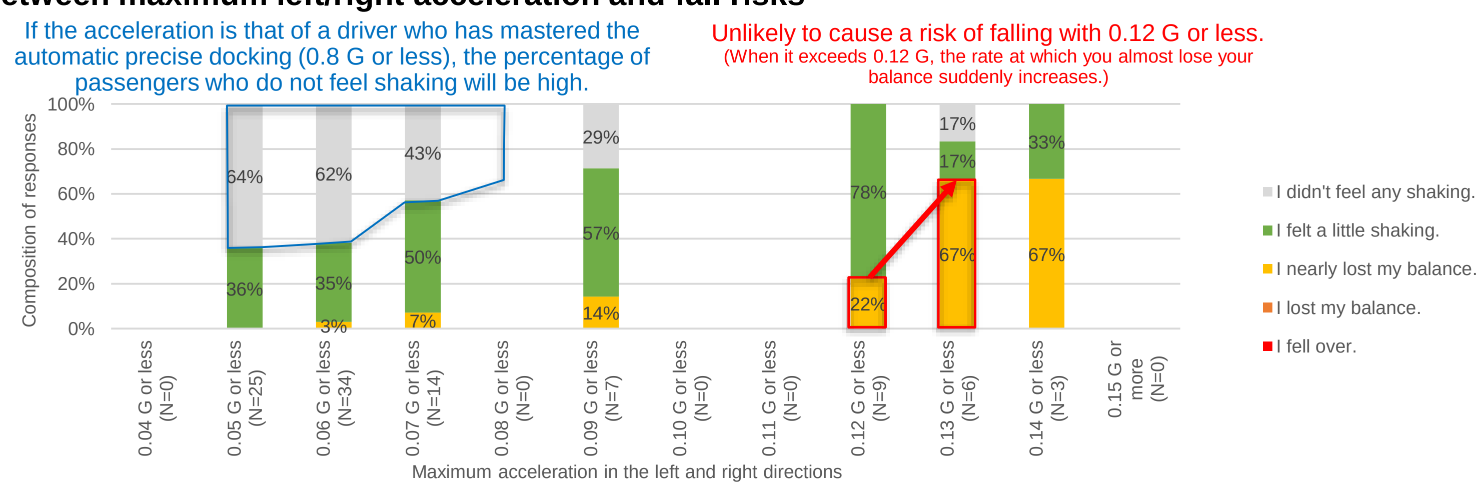
* However, some operators point out that it is easier for the driver to move the left edge of the vehicle closer to the curb while looking at the mirror than to align the guidance line with the center of the vehicle, so if the same amount of time is to be spent, it is more effective for the driver to become proficient in manual precise docking than in automatic precise docking.

■ Maximum left/right acceleration by driver's proficiency in automated driving





■ Relationship between maximum left/right acceleration and fall risks



Clarification of system usage conditions

- We confirmed that the illuminance condition at night to recognize the guidance lines is 30 lux or more, and that the guidance lines are not recognized when there is light snowfall on the road surface.
- During rainfall, the illuminance level at which the guidance lines were not recognized was 680 lux, indicating that the illuminance level required to recognize the guidance lines increased during rainfall compared to clear weather.
- One possible response to the lack of illumination is to extend the usable time by installing lighting.

Guidance line durability confirmation

- We confirmed the rate of peeling of the coating and the recognition performance of the camera, and confirmed that maintenance is required when the rate of peeling exceeds 50% because positive adhesion control does not occur when the rate of peeling reaches 60%.
- The deterioration of the four guidance lines was checked at three points, and the rate of peeling increased over time. From this data, the pace of deterioration of the guidance lines was linearly approximated, and the point at which the rate of peeling exceeds 50% was estimated, and it became clear that the rate of peeling reaches 50% in about five years at the shortest and about 10 years at the longest.
- However, at bus stops on public roads, where more vehicles pass over the guidance lines, the deterioration rate may be faster than the above, so it is desirable to install dedicated lanes.

Verification of the barrier-free effects of precise docking

- As a result of the questionnaire survey, more than 70% of the monitors answered that automatic precise docking made it easier to get off the bus because there were fewer gaps and steps between the bus and the bus stop compared to normal stopping. On the other hand, although the average value of the gap for manual precise docking was not much different from that of automatic precise docking, it was evaluated poorly when the gap was wide open, because the dispersion of the gap increased depending on the driver's skill.
- More than 90% of the monitors answered that they would "like to" or "somewhat like to" use automatic precise docking buses in the future. More than 60% of the monitors cited that "the gap between the bus and the bus stop is small, making it easy to get on and off" and "the step between the bus and the bus stop is small, making it easy to get on and off" as reasons why, indicating that automatic precise docking is highly effective for barrier-free access.

Time-saving effects of precise docking when getting on and off the bus

- Comparing the boarding and alighting time of automatic precise docking with normal stopping, it was reduced by 3.7 seconds for baby stroller users, 32.4 seconds for wheelchair users, and 0.9 seconds for elderly and general passengers.
- As for the user attributes of the Tokyo BRT, baby stroller users accounted for less than 1% of both northbound and southbound users on the weekdays, 3.2% northbound and 1.5% southbound users on the weekend, and there was one wheelchair user during the daytime on the weekend.
- If automatic precise docking were to be used at all bus stops on the current Tokyo BRT route, the amount of time saved would be up to 25.8 seconds per trip, or up to 12.4 minutes per day (the ratio of the time saved to the total travel time is 0.7%).
- The current Tokyo BRT is not in full operation, and the number of users is low due to COVID-19. However, in the future, the number of users is likely to increase from the current level, and the proportion of wheelchair users and baby stroller users is also likely to increase. Therefore, we conducted a sensitivity analysis assuming these factors. If the number of users increases to 2.5 times the current level, and the proportion of wheelchair users and baby stroller users increases to the proportion of wheelchair users and baby stroller users in the total population, the maximum time saved per day was 47.9 minutes (2.6% of the total driving time).

Verification of the effects of preventing falls during boarding and alighting

- No one fell or tripped when getting on or off the bus during normal stopping, manual precise docking or automatic precise docking.

(Risk of falling: Wheelchair users)

- With normal stopping, wheelchair users cannot get on and off the bus by themselves due to the large gap between the bus and the bus stop, and need to use a ramp to get on and off. This eliminates the gap when getting on and off the bus, but increases the boarding and alighting time.
- Compared to using the ramp with normal stopping, automatic and manual precise docking creates a small gap between the bus and the bus stop, and the front wheels sometimes got caught in the gap as the wheelchair slowly passed through the gap.
- However, we also confirmed that the risk of falling is low because users who are accustomed to wheelchairs do not get caught because they raise their front wheels when getting on or off the bus, and if the gap is narrow and the passing speed is fast enough, the front wheels will not get caught.

(Risk of falling: Non-wheelchair users)

- Since automatic precise docking eliminates gaps and bumps compared to normal stopping, 70% of the monitors answered that “automatic precise docking improves safety when getting on and off the bus,” confirming that automatic precise docking increases the effectiveness in preventing falls when getting on and off the bus.

Verification of the effects of preventing falls when the bus stops and starts

- The maximum acceleration in the left/right direction was greater in the automatic precise docking than in the normal stopping or manual precise docking, but in all cases, no one fell.
- Automatic precise docking causes horizontal swaying when entering the guidance line and when passing through the S-shaped curve of the guidance line, but this can be improved by increasing the driver’s proficiency in automatic precise docking and by setting a longer guidance line to ease the curvature of the S-shaped curve.
- Guidance lines are not allowed to interfere with legal lines, and in order to install them at many bus stops, it is necessary to set the guidance lines as short as possible. When we installed the guidance lines this time, we followed this idea and set the guidance lines shorter, so the curvature of the S-shaped curve was steep. In the future, it will be necessary to consider the installation of dedicated lanes in order to reduce the curvature of the guidance lines.

Issues other than verification items

(1) Liability in the event of an accident

- Since the guidance line type precise docking control is a Level 2 driver assistance system, the driver is responsible for any accidents (including accidents where the passenger falls over due to acceleration/deceleration in the front/rear or left/right directions), and the hurdle for businesses to adopt this system is high.
- At least with regard to accidents involving falls in vehicles, consideration should be given to holding the person who fell responsible for their own actions by having the operator or driver adequately remind passengers to hold on to the straps to prevent falling while standing.

(2) Who will maintain the guidance lines

- Currently, there is no clarification on who will be the entity responsible for the maintenance of the guidance lines, and the hurdle to adoption will be high if operators are required to maintain the guidance lines.
- Therefore, it is desirable to clarify that guidance lines should be maintained by the road manager as part of the road structure.

(3) Installation of dedicated lanes

- In order to ensure the speed and punctuality of BRT, it is preferable to have a completely dedicated lane near the center line, which is the case in many BRTs in other countries.
- This is expected to improve the durability of the guidance lines used for precise docking control, increase the number of bus stops where guidance lines can be installed, and reduce lateral acceleration by relaxing the curvature of the guidance lines.

This report documents the results of Cross-ministerial Strategic Innovation Promotion Program (SIP) 2nd Phase, Automated Driving for Universal Services (SIP-adus, NEDO management number: JPNP18012) that was implemented by the Cabinet Office and was served by the New Energy and Industrial Technology Development Organization (NEDO) as a secretariat.