“Strategic Innovation Program (SIP)/Automated Driving System/
Large-scale Field Operational Tests/Advanced Rapid Transit”

Research and Development on Infrastructure Requirements for Precise Docking of Advanced Rapid Transit

Report

- Summary -

February 2019

The Institute of Behavioral Sciences

Contents

1. Overview of This Study 1.1 Purpose

- Among control methods being studied for precisely docking a bus at a bus stop (“precise docking”) of ART, or Advanced Rapid Transit, the method of following guidelines on a road surface has the advantage of less control errors and can be implemented in the near future. On the other hand, **before the installation of guidelines and platforms on public roads**, **it is necessary to broaden proper understanding of functions and roles of guidelines and to ensure safety and robustness against various external factors under actual environments**.

- In this project, **we installed guidelines and platforms under actual environments, conducted FoTs for technologies, and appealed to stakeholders in order to clarify the system of installation, maintenance, and management, and identify definitive issues for early field implementation**.

1. Overview of This Study 1-2. Study Flow

a. Preliminary study for installing guidelines on public roads

- (1) Selecting locations to install guidelines and bus stops
- (2) Investigating installation positions and shapes of guidelines and platforms

b. Construction of traffic facilities necessary for FoTs

- i. Guidelines for precise docking
- ii. Platforms for buses

d. Evaluation of needs for precise docking and its effects

- i. Holding a test drive event for stakeholders
  - SIP members, the Tokyo Metropolitan Government
  - Transportation operating companies, municipalities, local residents
  - Wheelchair users, stroller users, seniors
- ii. Evaluation of needs and effects

c. Conducting FoTs for technologies

1) Preliminary evaluation
- i. Recognizability evaluation of guidelines at night
- ii. Safety evaluation of precise docking platform structures
- iii. Promoting regular drivers' recognition and understanding of guidelines

2) FoTs under actual environments
- i. Recognizability evaluation of guidelines at night
- ii. Safety evaluation of precise docking platform structure
- iii. Promoting regular drivers' recognition and understanding of guidelines

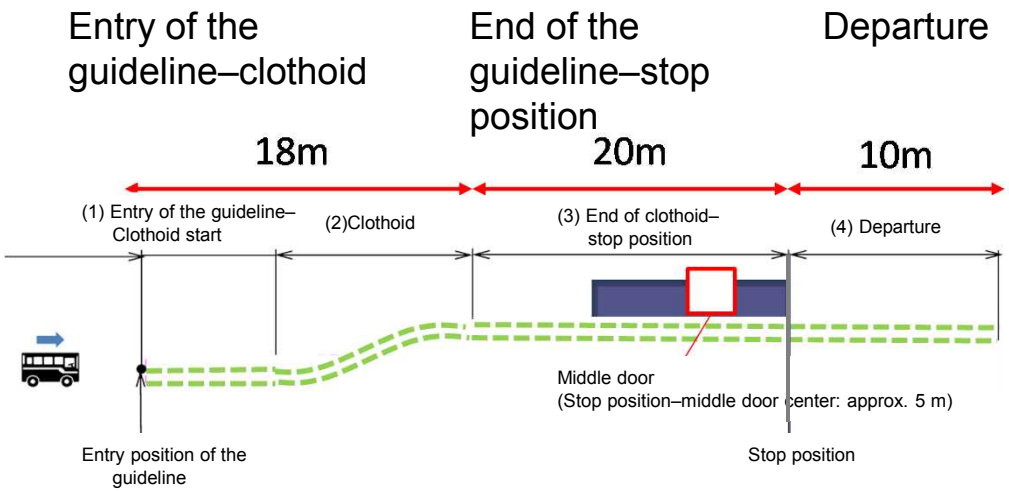
Conclusion

2. Preliminary Study for Installing Guidelines on Public Roads

2-1. Organizing Prerequisites for Infrastructure

- Guidelines were constructed as follows.
- The structure of platforms was constructed to satisfy the following requirements (from the view of both users and operators).

■ Components of the guideline



■ Structure of the platform

(1) Users' view

- Height: the same as the bus floor for boarding/discharging
- Width: enough for two wheelchairs to pass each other
- Approx. 5% slope

(2) Operators' view

- Safe structure for both a bus and platform in case of collision
  - Plan 1) Installing protectors on the surface
  - Plan 2) Curb that contacts tires
- Structure preventing contact of tire volts that most protrude from the body

2. Preliminary Study for Installing Guidelines on Public Roads

2-3. Selecting a Location for Public Road FoTs

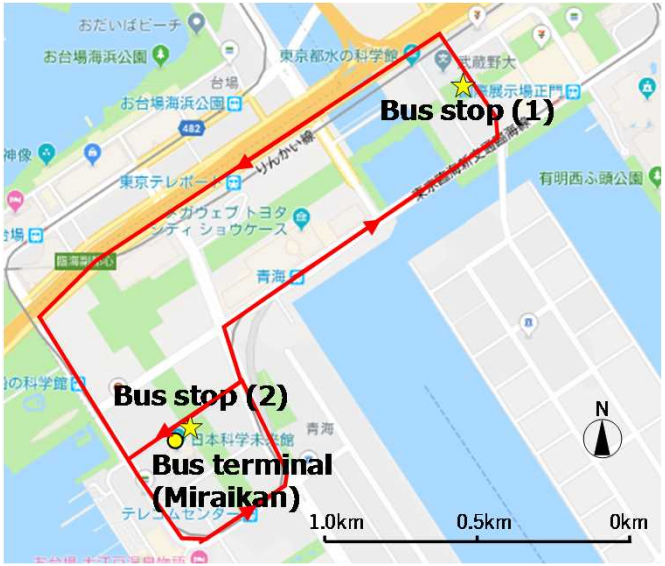
- After consultations with agencies concerned, a location for FoTs was selected in the southern district of the Tokyo Waterfront Area based on the following viewpoints.
- Considering sidewalk condition and road structure, installation positions of guidelines and platforms were examined.

■ Viewpoints on the selection of a location for FoTs

Ease of installation		Points to be considered or prioritized
Ease of installation	Minimizing time and cost for installation	(1) No guardrail or roadside tree
	Minimizing effects on surrounding traffic	(2) Sufficient number and width of lanes
		(3) No bicycle lane or bus stop
Ease of FoTs	General	(4) Securing a 48 m straight line
	Safety evaluation of structures of precise docking platforms	(5) Accessibility for a test drive event (for those including wheelchair users)
		(6) Neighboring space for a certain number of people waiting for buses
	Promoting regular drivers' recognition and understanding of guidelines	(7) Certain amount of regular drivers' traffic

■ Selected location for FoTs

Bus stop (1): Musashino Daigaku-Mae
Bus stop (2): Miraikan-Mae



3. Construction of Traffic Facilities Necessary for FoTs

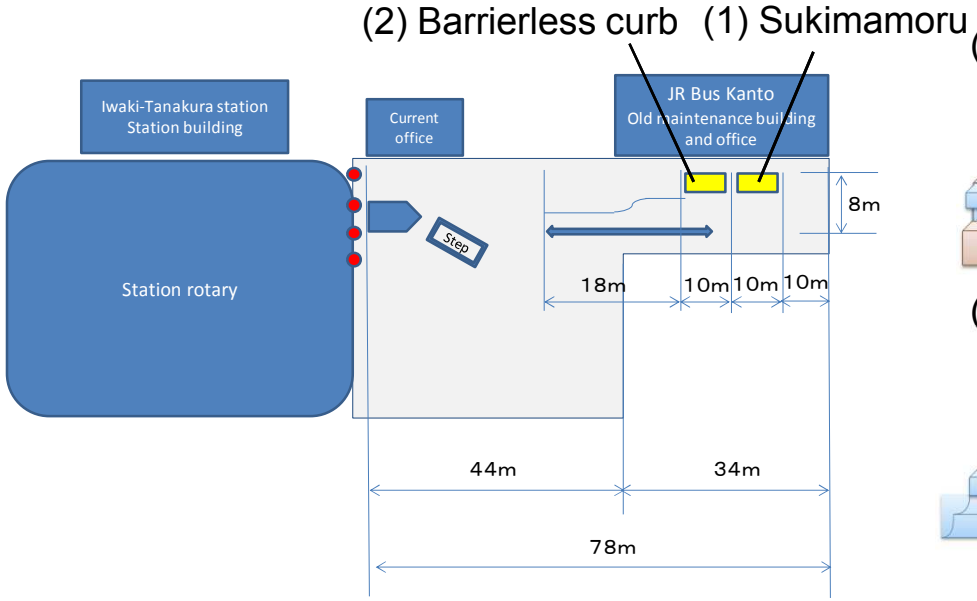
- We examined the structures of traffic facilities (guidelines and platforms) used for FoTs at a test course and public roads.
- We examined the structures for installation, considering the purpose of each FoT and site conditions.
- We also examined portable sheds for FoTs on public roads and determined not to use them since pillars of a specific length must be rammed into the ground for safety reasons with regard to wind.

* Refer to pp. 7 and 8 for an overview of the installed traffic facilities.

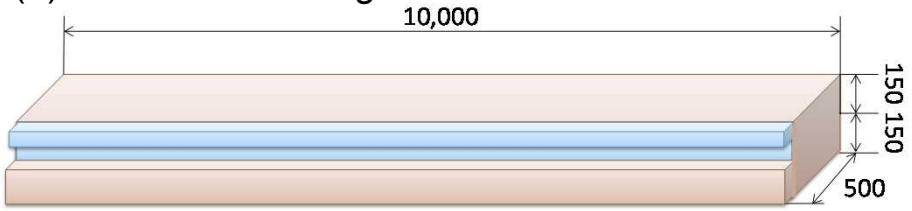
3. Construction of Traffic Facilities Necessary for FoTs
3-1. FoTs on the Test Course

- A preliminary evaluation on the test course was conducted at the site of a bus company in Tanagura Town, Fukushima Prefecture.
- Two platforms for guidelines and barrierless curbs were prepared. The platforms and guidelines were installed and FoTs for technologies were conducted.

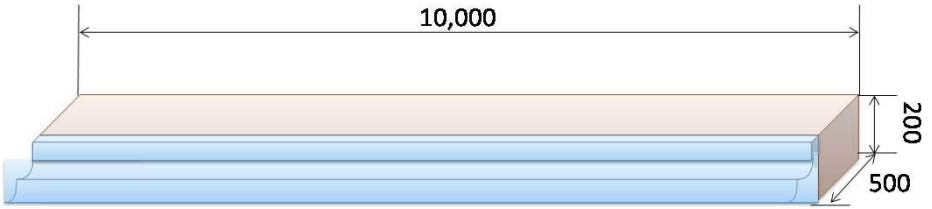
* Guidelines were shown earlier.



(1) Sukimamoru: Height: 30 cm



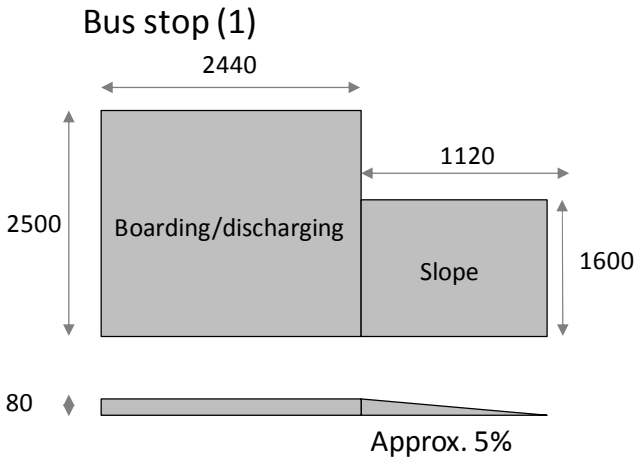
(2) Barrierless curb: Height: 20 cm

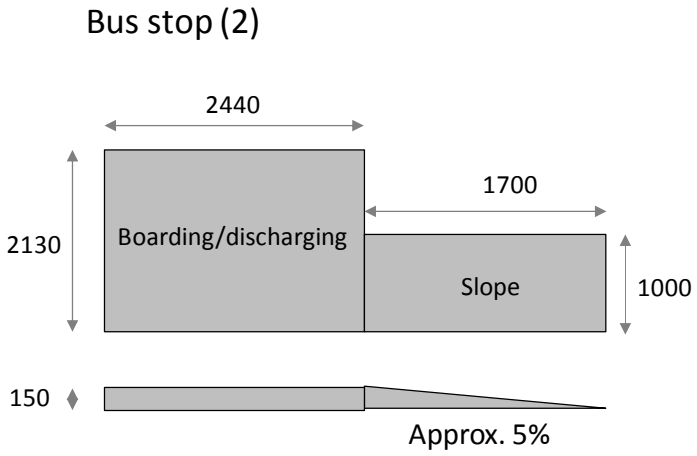


3. Construction of Traffic Facilities Necessary for FoTs
3-2. Public Road FoT and the Test Drive Event

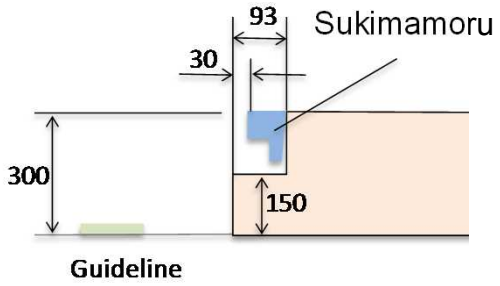
- A public road FoT and test drive event were conducted in the southern district of the Tokyo Waterfront Area.
- Platforms installed at the two bus stops contained the structures shown below.
- For safety reasons, Sukimamoru was installed as a protector on the surface that comes into contact with vehicles. To prevent tire hub bolts from coming into contact, the Sukimamoru-installed portion featured a setback structure.

■ Structure of the platforms





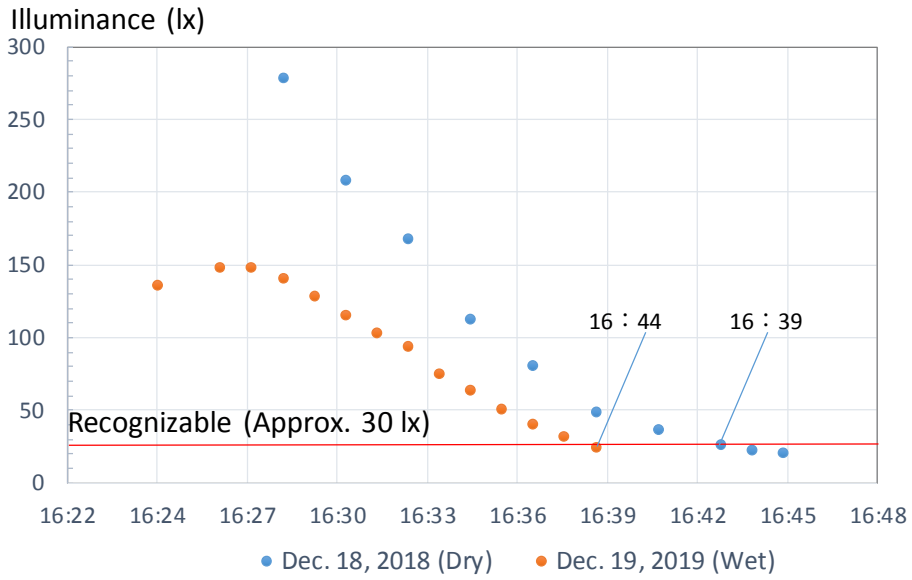
■ Cross-section of the platform



4. FoTs for Technologies
4-1. Recognizability Evaluation of Guidelines at Night (1) Preliminary evaluation

- Recognizability of guidelines was checked with a camera at sunset under dry and wet conditions.
- The minimum illuminance for the camera to be able to recognize guidelines on dry and wet roads was 22 lx and 24 lx respectively, suggesting that 30 lx is required for a camera to recognize the guidelines.

Evaluation purposes	● Recognition limit at sunset was identified using a camera. ● Precise docking was conducted on dry and wet roads to check the effects of these conditions.
Evaluation methods	● Precise docking was conducted at sunset while illuminance was measured and headlights turned on in order to identify the relationship between illuminance and precise docking. ● Precise docking was conducted under dry and wet conditions to check the effects of these conditions.
Evaluation items	● Illuminance during evaluation ● Distance of precise docking

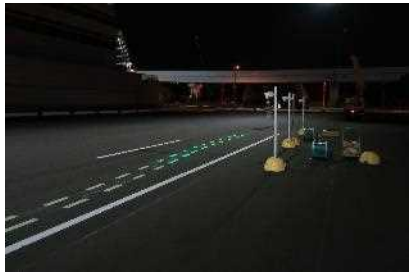


4. FoTs for Technologies
4-1. Recognizability Evaluation of Guidelines at Night (2) Actual Environment

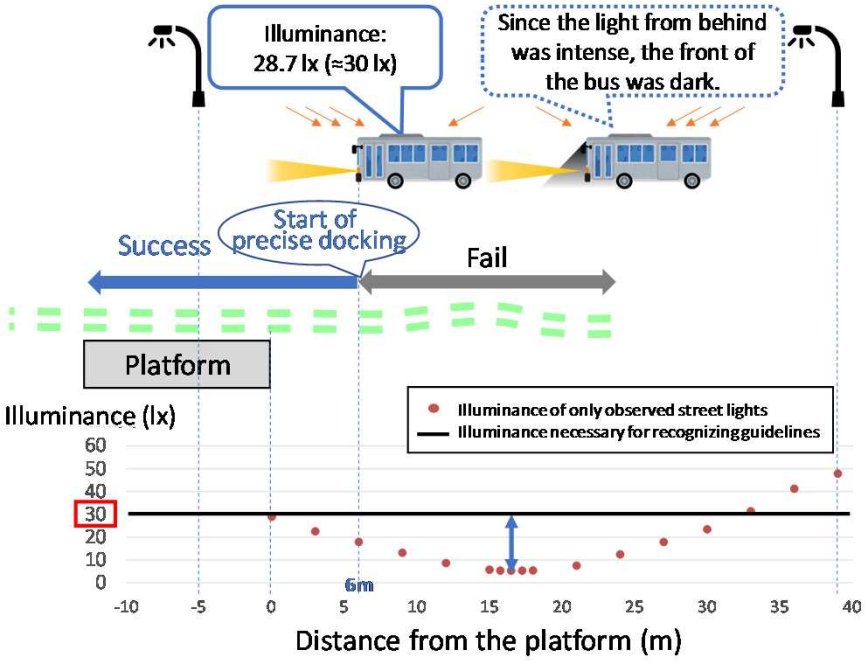
- Precise docking FoTs were conducted using several lighting patterns on the test course for the test drive event.
- The camera failed to recognize guidelines using pattern (1), the most intense illuminance.
- The illuminance under which the camera was able to recognize the guidelines was 30 lx using headlights and 20 lx without headlights. Since headlights turn on at sunset, the necessary illuminance is 30 lx.

■ Street light patterns representing actual environments

Pattern (1): Sodium lamps or their equivalent
(Reproducing illuminance around a bus stop at Toyosu)
Pattern (2): LED lamps or their equivalent
(Tokyo Metropolitan standards: two lanes in each direction, with a sidewalk)
Pattern (3): LED lamps or their equivalent
(Tokyo Metropolitan standards: three lanes in each direction, with a sidewalk)
Pattern (4): Using materials that illuminate under a black light for guidelines



■ Overview of the evaluation results



4. FoTs for Technologies

4-2. Safety Evaluation of Precise Docking Platform Structures (1) Preliminary Evaluation

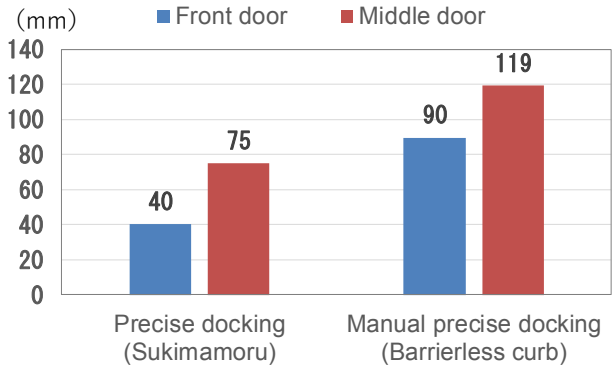
• The purpose and method of evaluating safety of the precise docking platform structures in the test course are shown below.

Evaluation purpose	(1) Normal operation of precise docking was confirmed. (Precise docking was confirmed to be better than barrierless curbs.) (2) Effects on vehicles, platforms, and passengers in vehicles were checked when precise docking failed. (3) Manual movement of a bus to a bus stop was checked when a vehicle was parked around the bus stop. (Stop) (4) Physical departure possibility was checked when a vehicle was parked around the bus stop. (Departure) (5) Effects of protrusions and grooves of barrier curbs on the camera were checked.
Evaluation methods	(1) Measuring precise docking distance after conducting normal precise docking (2) Measuring acceleration after bringing the bus into contact with the platform by turning the steering during low-speed driving just before precise docking to the bus stop (3) Measuring precise docking distance when manually stopping the bus after avoiding a road cone placed at a certain distance short (4) Measuring physical distance from a front vehicle to be avoided in departure from the precise docking status (5) Checking camera output when conducting precise docking to a barrierless curb
Evaluation items	● Speed, steering angle, acceleration in the forward/backward and right/left direction ● Precise docking distance

4. FoTs for Technologies
4-2. Safety Evaluation of Precise Docking Platform Structures (1) Preliminary Evaluation

- In normal precise docking and manual precise docking to a barrierless curb, the distance to the front door was approx. 4 cm and 12 cm, respectively. Precise docking using the guidelines was better.
- When the failure of precise docking was reproduced, damage to the body, tires, and functions of Sukimamoru were not observed. Effects on the passengers in the bus were confirmed to be minimum.
- How to drive a bus when making contact is an issue that should be addressed in the future.

(1) Distance comparison between precise docking and manual driving
(Precise docking: 11 times, manual precise docking: 3 times)



* Likelihood of the middle door not being sufficiently close to the platform

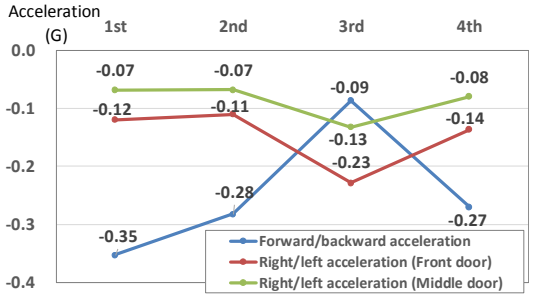
(2) Effects of failure in precise docking

■ Sukimamoru

■ Tires and body

- No damage to the functions of Sukimamoru was observed.
- Concrete contact marks were observed on the tires, but no damage to the body and tires was observed.
- An observer in the bus did not feel significant swinging, which is the criterion for a near miss.
- Since the driver braked hard just after collision to minimize damage to the body during the experiment, the forward/backward acceleration was around 0.1 G.

■ Maximum forward/backward and right/left acceleration during experiments

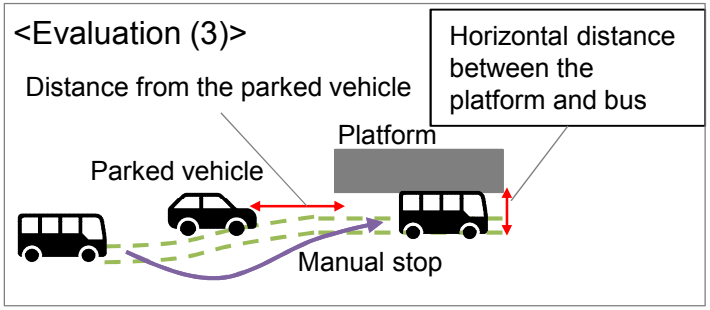


4. FoTs for Technologies
4-2. Safety Evaluation of Precise Docking Platform Structures (1) Preliminary Evaluation

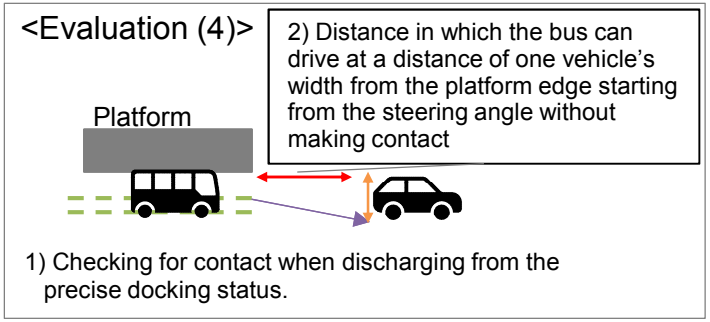
- When a vehicle was parked at the near side of the bus stop and manual precise docking to the platform was conducted, horizontal distance decreased as the distance between the platform and the parked vehicle increased; however, it was difficult to stop the bus at a position that was sufficiently near.
- When a vehicle was parked at the far side of the bus stop, the distance to the vehicle required was approx. 10 m for a bus to pull out successfully.

■ Evaluation methods

<Evaluation (3)>

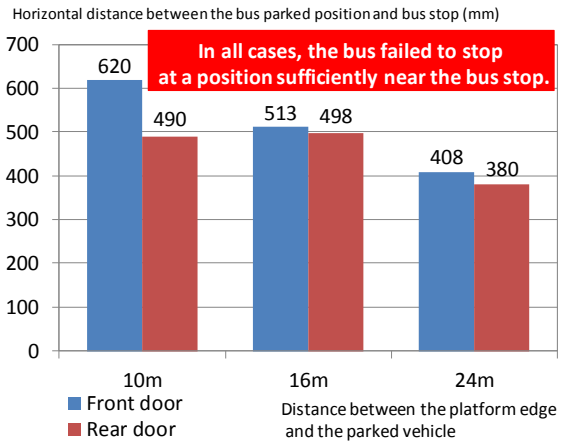


<Evaluation (4)>

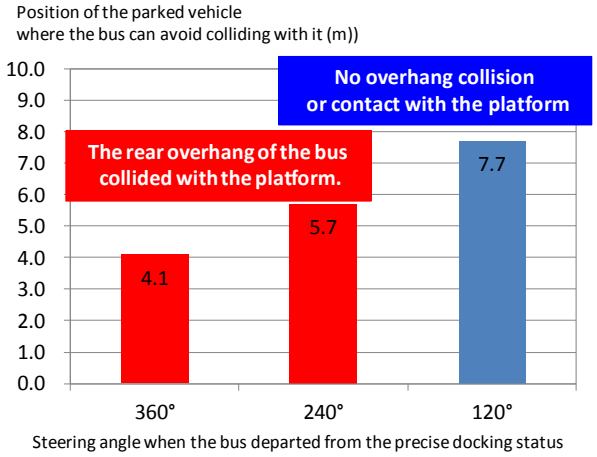


■ Evaluation results

(3) Evaluating the effects of a parked vehicle at the near side of the bus stop



(4) Evaluating the possibility of avoiding a parked vehicle at the far side of the bus stop



4. FoTs for Technologies

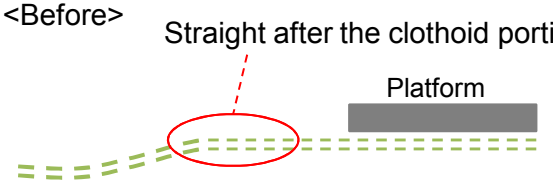
4-2. Safety Evaluation of Precise Docking Platform Structures (2) Actual Environment

- FoTs on public roads were conducted for the following purposes:
  (1) Checking for precise docking on public roads and identifying issues
  (2) Checking the effect of improved guidelines that will reduce the space between the middle door and the platform, which was a problem identified on the test course
  (3) Checking for effects of the public-road guidelines on ordinary vehicles

Evaluation purposes	(1) Checking for precise docking operations on public roads (2) Checking improved guidelines that will reduce time to move vehicles close to the platform; the middle door had a space on the test course (3) Checking the effects of public-road guidelines on ordinary vehicles
Evaluation methods	(1), (2) Improving guidelines, checking for precise docking accuracy, and comparing the accuracy with that on the test course (3) Checking the behavior of ordinary vehicles around the bus stop (Slowdown, lane change, etc.)
Evaluation items	● Speed, steering angle, forward/backward acceleration, and right/left acceleration ● Precise docking distance

■ Improvement of guidelines

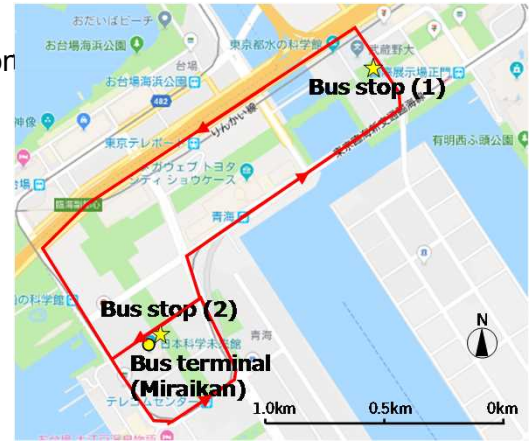
<Before>



<After>

Curving outward after the clothoid portion and then going straight

■ Location of the public road FoT



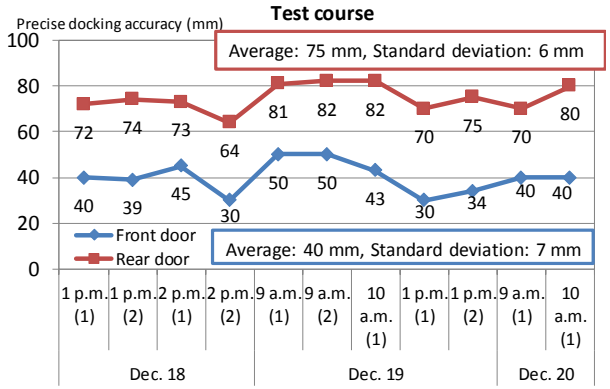
* The middle door was closer to the platform when the vehicle stopped.

4. FoTs for Technologies
4-2. Safety Evaluation of Precise Docking Platform Structures (2) Actual Environment

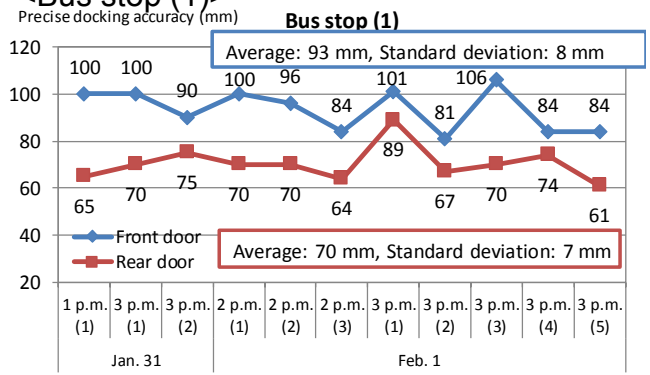
- Precise docking using improved guidelines was checked.
- Precise docking on public roads was mostly stable.
- In a comparison of the precise docking status with that on the test course (Tanagura), the distance from the front and middle door for the precise docking was reduced, indicating the effects of the improved guidelines.

■ Evaluation results

<Test course>



<Bus stop (1)>



<Bus stop (2)>

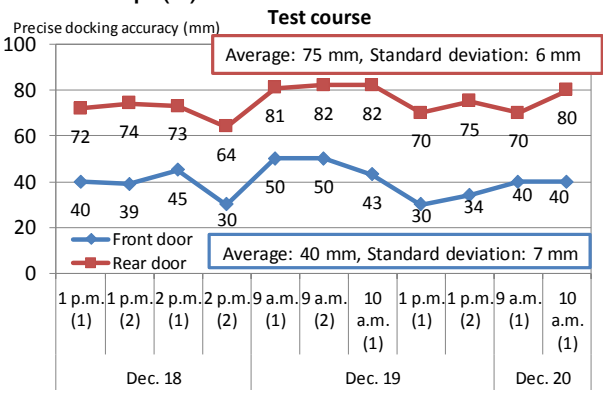


Table: Summary of evaluation results

		Front door	Rear door	Difference (rear door - front door)
Public road	Bus stop (1)	93	70	−23
	Bus stop (2)	81	66	−15
Preliminary evaluation	Test course (Tanagura)	40	75	35

4. FoTs for Technologies
4-2. Safety Evaluation of Precise Docking Platform Structures (2) Actual Environment

- During each of the 20-minute observation windows of the behavior of vehicles passing on guidelines near bus stops (1) and (2) in the morning and afternoon, some vehicles passed near the centerline to avoid the guideline altogether.
- No abrupt steering or braking that could lead to accidents was observed.
- Branches from roadside trees that grow toward the roadway should be trimmed.

■ Evaluation results

<Vehicles passing nearby>

Bus stop (1)

Bus stop (2)

<Vehicle behavior that seemed to be affected by the guidelines>

No.	Vehicle type	Behavior
1	Light car, passenger car, truck	Passing near the centerline to avoid the guideline
2	Truck	Passing near the centerline to avoid the guideline
3	Truck	Passing near the centerline to avoid the guideline
4	Passenger car	Changing lanes before the guideline and returning to the previous lane after passing through the guideline
5	Passenger car	Passing near the centerline to avoid the guideline

■ Others

4. FoTs for Technologies

4-3. Promoting Regular Drivers' Recognition and Understanding of the Guidelines (1) Preliminary Evaluation

- Measures and surveys below were developed to promote recognition and understanding of the guidelines. Choosing among these ideas, we informed the public through leaflets or signboards and then conducted a web survey to confirm the results.

Evaluation purposes	(1) Promoting regular drivers' recognition and understanding of the guidelines and precise docking through public relations activities (2) Checking the results and effects
Evaluation methods	(1) PR activities such as developing a website, distributing leaflets, and installing signboards along the road (2) Checking through a web survey
Evaluation items	● Understanding of the guidelines (known/unknown, purpose, effect) ● Understanding of the public road FoTs

Measures (draft)	Scope	Details	Survey method (draft)	
			Recognition of the guidelines	Understanding of the guidelines
PR through television and newspapers	General	Having a wide range of people recognize the guidelines through introduction via mass media and posts on the website concerning FoTs and guidelines installation	Web survey [Survey (1)]	Web survey [Survey (1)]
Posts on a website				
Distribution of leaflets	Residents along the road	Having people deepen their understanding by installing signboards and distributing leaflets along the road, trying to encourage people to view the actual guidelines on the site (and attaining recognition)		Web survey [Survey (1)] + Questionnaire on facilities along the road
	Operators along the road			
Installation of signboards (Guideline-installed zone)	Pedestrians along the guideline installation zone			Web survey for residents in the 23 wards [Survey (1)]

<Details>
- Posting reports from the SIP results report meeting on a website
- Distributing leaflets
- Installing signboards

<Details>
- Web survey
  * 1,000 samples

4. FoTs for Technologies

4-3. Promoting Regular Drivers' Recognition and Understanding of the Guidelines (2) Actual Environment

- Measures and surveys below were developed to promote recognition and understanding of the guidelines.
- 14.5% of respondents have seen the guidelines, but only 9.7% correctly understood them.
- No large differences were observed among age groups.

■ Survey items from the web questionnaire

○ Attributes
- Gender, age, residence, employment

○ Guidelines
- Seen/not seen on public roads
- Purpose of the guidelines

○ Precise docking
- Known/unknown
- Social advantages/disadvantages

○ FoTs at the waterfront area

○ Use of a wheelchair, stroller, and bus

■ Have you ever seen the guidelines?

	n=	Yes	No
Total	(1,030)	14.5	85.5
20s	(206)	20.9	79.1
30s	(206)	15.0	85.0
40s	(206)	15.0	85.0
50s	(206)	9.2	90.8
Over 60	(206)	12.1	87.9

(%)

■ Purpose of the guidelines (Check-all-that-apply)

	n=	For road construction	For a bicycle lane	For a bike lane	For a left-turn lane	For guiding buses	Others	No idea
Total	(935)	0.9	43.6	13.3	18.5	9.7	0.32	23.4
20s	(183)	2.2	47.5	16.9	19.1	12.0	0.55	18.0
30s	(187)	–	49.7	18.2	19.8	11.2	–	12.8
40s	(185)	1.1	41.6	11.9	19.5	9.7	0.54	23.8
50s	(192)	1.0	48.4	10.4	15.6	7.3	–	25.5
Over 60	(188)	–	30.9	9.0	18.6	8.5	0.53	36.7

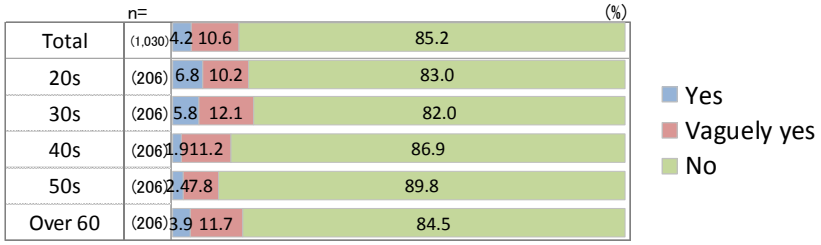
(%)

4. FoTs for Technologies

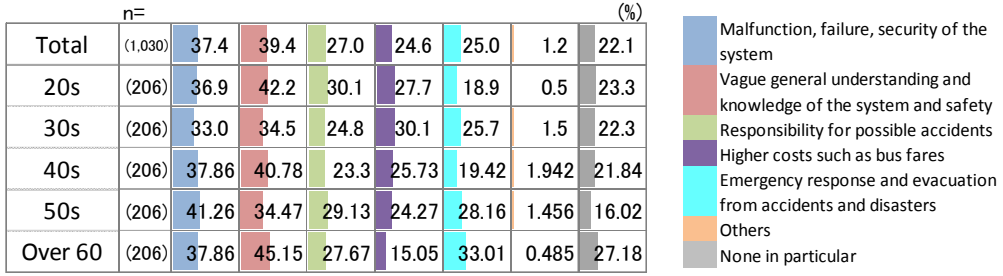
4-3. Promoting Regular Drivers' Recognition and Understanding of the Guidelines (2) Actual Environment

- 4.2% of respondents knew about precise docking technology and 85.2% did not.
- Major answers to social advantages were Transportation assistance for the elderly and Contributing to a barrier-free society.
- Major answers to concerns about precise docking were the General understanding of system safety and Malfunction of the system.
- More than 70% of the total respondents answered Very useful or Somewhat Useful.

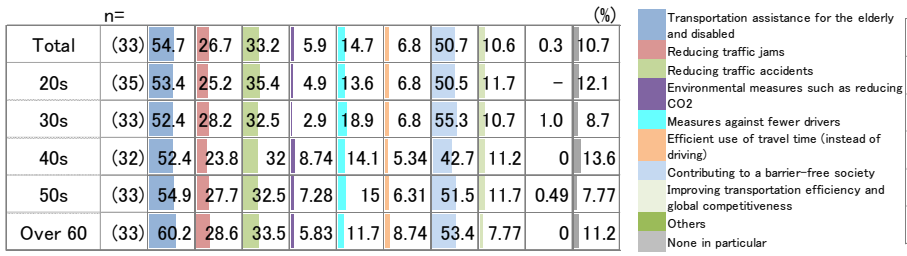
■ Do you know about precise docking?



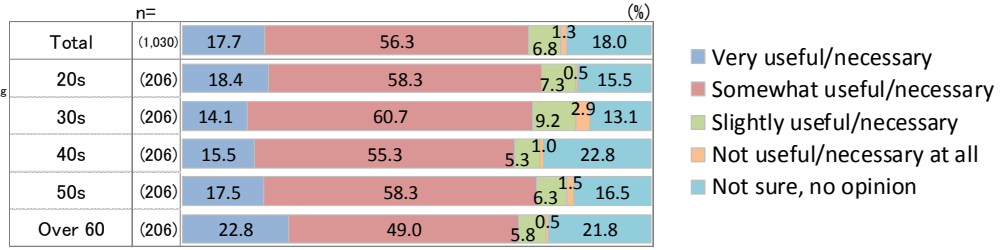
■ Concerns about precise docking (Check-all-that-apply)



■ Important social advantages of precise docking (Check-all-that-apply)



■ Evaluation of precise docking



* In the web survey, respondents answered the questions after receiving an explanation on the meaning of precise docking.

5. Evaluation of Needs for Precise Docking and Its Effects

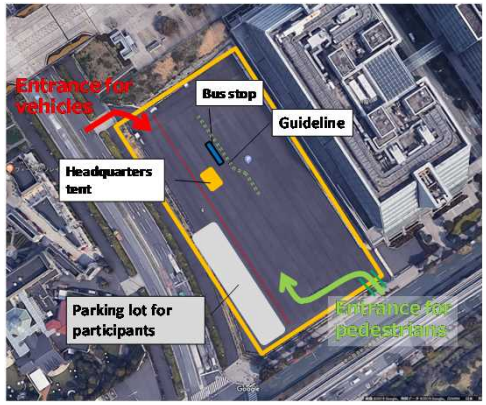
- To evaluate needs for precise docking and its effects, we held a test drive event and an SIP results report meeting for stakeholders.
- In the test drive event, stakeholders and trial users took a bus for a precise docking test ride and saw models of a bus stop and bus body so they could check for the presence of gaps in height and width.

■ Event overview

Section	Date	Place	Target
Test drive	Tue., Jan. 29, 2019 Wed., Jan. 30, 2019 Two weekdays	Ariake G1 parking lot	Stakeholders and trial users → Evaluating needs for precise docking and its effects after a test ride
			Bus drivers → Identifying needs from a bus driver's viewpoint
SIP results report meeting	Wed., Feb. 6, 2019 Thur., Feb. 7, 2019 Two weekdays	Indoor exhibit hall in the TFT building	Participants in the SIP results report meeting → Identifying detailed needs for spatial gaps between the bus body and bus stop
		Ariake G1 parking lot	Participants in the SIP results report meeting → Evaluating needs for precise docking and its effects after a test ride

■ Location

■ Layout (test drive venue)



5. Evaluation of Needs for Precise Docking and Its Effects
5-1. Holding a Test Drive Event for Stakeholders

- In the test drive event, after receiving an explanation about the overview of precise docking technologies and effects, stakeholders and test users experienced actual precise docking and then answered a questionnaire.

■ Flow of the test drive event

Overview of precise docking technologies and effects
↓
Experiencing precise docking (ride)
↓
Experiencing precise docking (outside)
↓
Answering a questionnaire

■ Participants

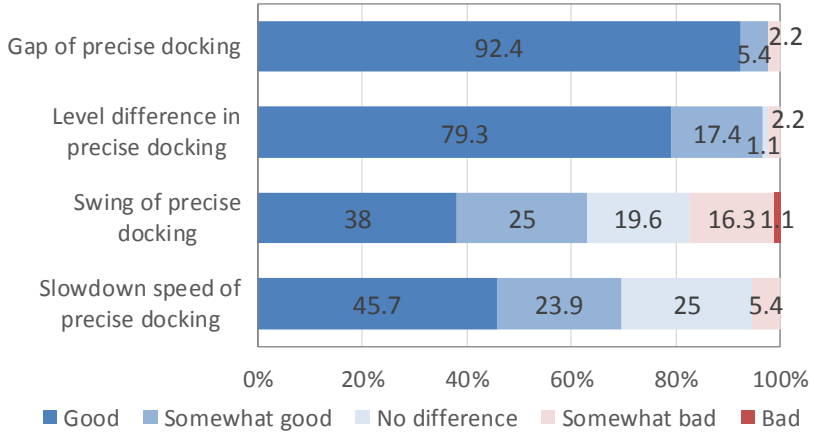
○ From 20 to 75 (92 people)
  • Including wheelchair and stroller users
○ Tokyo Metropolitan Government
○ Traffic controllers
○ Transportation operating companies
○ Municipalities
○ Automobile manufacturers, etc.

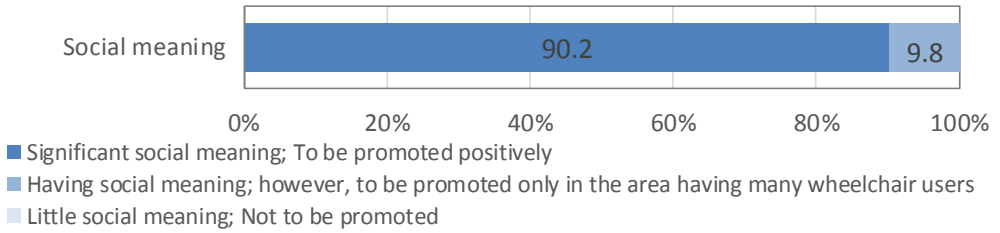
■ Questionnaire

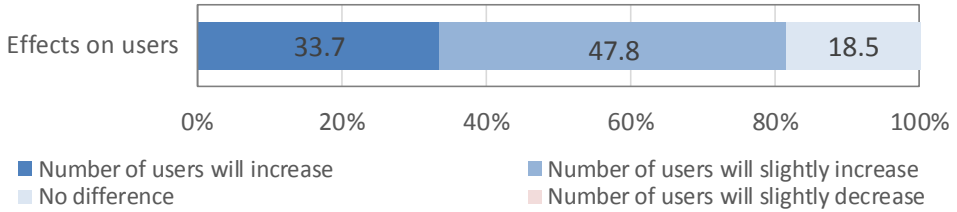
○ Attributes
  • Gender, age, employment
  • Use of wheelchairs, strollers, or buses
○ Evaluation by bus boarding/discharge height and precise docking gap
  • Gap and level difference between the bus and platform
  • Swing when the bus moved close to the platform
  • Slowdown speed when the bus moved close to the platform
○ Future installation of guidelines for bus routes
  • Social meaning, etc.

5. Evaluation of Needs for Precise Docking and Its Effects
5-1. Holding a Test Drive Event for Stakeholders

- Compared to conventional buses, more than 95% of respondents answered Good or Somewhat Good for the precise docking Gap and Level difference in precise docking.
- Most respondents answered No difference or Somewhat Good for Swing of precise docking and Slowdown speed of precise docking.
- All respondents recognized social meaning, with more than 90% answering To be promoted positively.





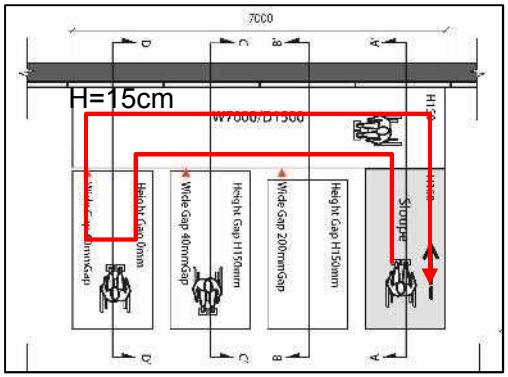


5. Evaluation of Needs for Precise Docking and Its Effects
5-2. SIP Results Report Meeting

- Participants experienced the ease of boarding/discharging after precise docking at various heights and gaps using wheelchairs.
- Thereafter, a questionnaire survey was conducted to evaluate the needs for precise docking and its effects.

■ Overview of the booth for experiencing precise docking

- Experiencing the ease of boarding/discharging after precise docking with various heights and gaps using wheelchairs
- Experiencing the ease of boarding/discharging using a platform with a height of 15 cm, and a slope, and stages measuring H30 cm and W20 cm, H15 cm and W 4cm, and H30 cm and W20 cm



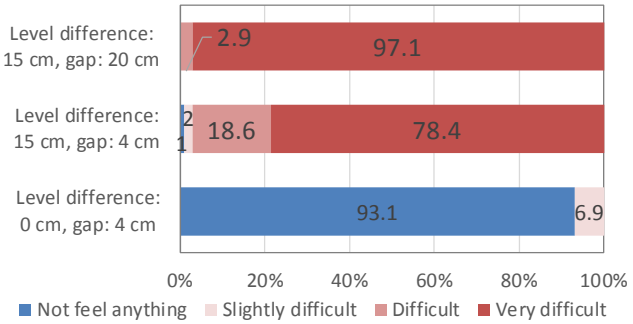
H=15cmH=30cmH=30cm
W=4cm W=4cm W=20cm

■ Questionnaire overview

○ Attributes
- Gender, age
- Typical use of buses
- Use of wheelchairs or strollers

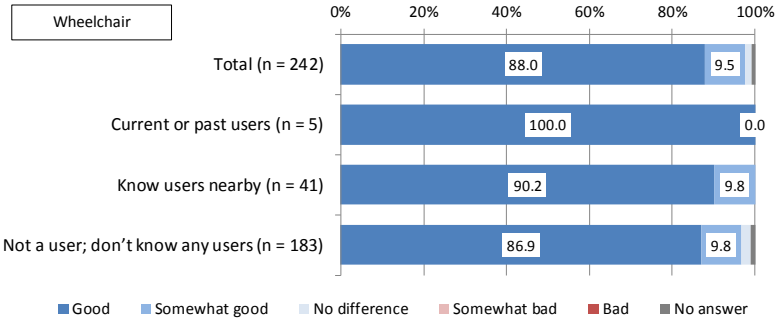
○ Evaluation by bus boarding/discharging height and precise docking gap
- Ease of use of the platform (Normal/with a wheelchair)
- Free comments

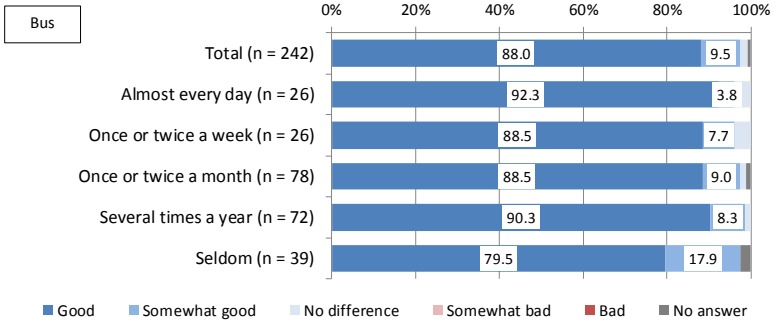
■ Results of the questionnaire

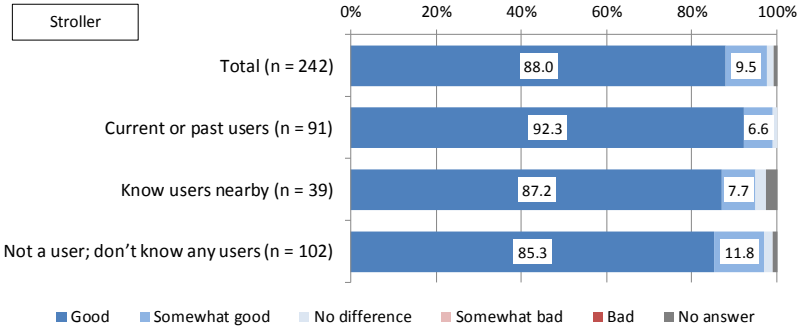


5. Evaluation of Needs for Precise Docking and Its Effects
5-2. SIP Results Report Meeting

- In the parking lot next to the results report meeting venue, participants took a bus for a precise docking test ride and then answered a questionnaire.
- Most participants answered that the gap was sufficient. Users of wheelchairs, strollers, and buses highly evaluated the precise docking.



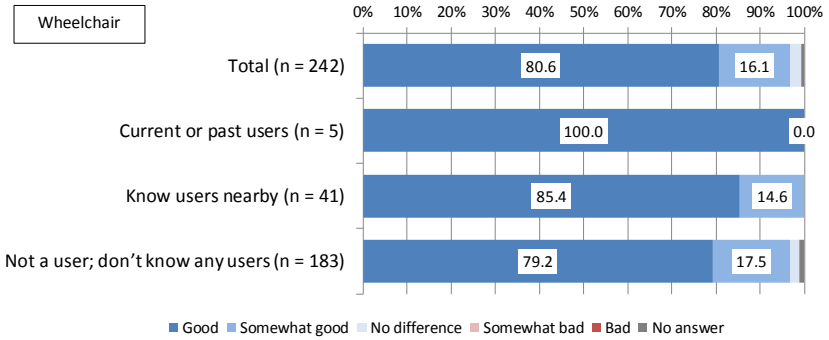




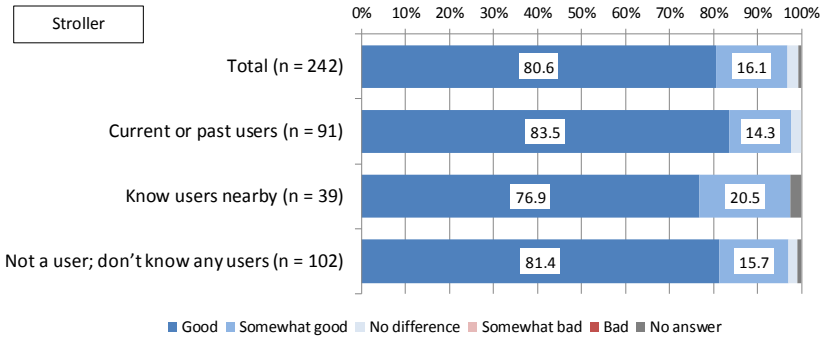
5. Evaluation of Needs for Precise Docking and Its Effects
5-2. SIP Results Report Meeting

- A high percentage of respondents answered Good or Somewhat good for evaluation of the level difference.
- A higher percentage of wheelchair users and frequent users of buses tended to answer Good.

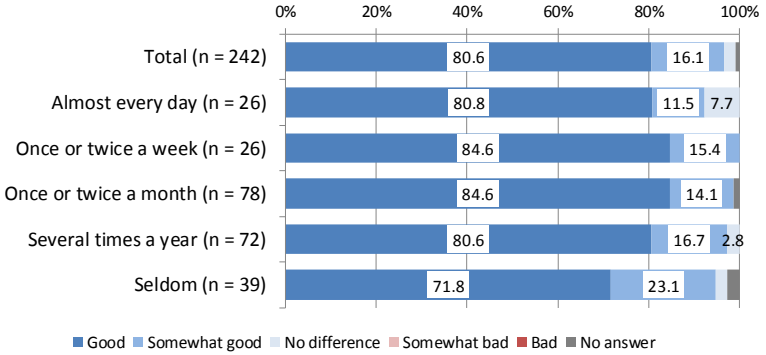
Wheelchair



Stroller



Bus



6. Conclusion

■ **Recognizability evaluation at night**

- At night, an illuminance of approx. 30 lx with headlights and approx. 30 lx only with street lights are required. When ensuring illuminance, shady areas that are made by shadows should be considered.

■ **Safety evaluation**

- Precise docking using guidelines is superior to precise docking to a barrierless curb because it is more stable and enables shorter distance docking.
- If precise docking fails, a setback structure and cushioning material in the top of the platform ensure safety of the body, platform, and passengers. However, how to drive the bus after collision is a remaining issue.
- Parking must be prohibited in the zone between the area where the guideline is installed in the near side of the bus stop and 10 m far from the bus stop because vehicles parked in the zone will make manual stopping and discharge difficult. Or rather, the zone must be for exclusive use if possible. When a vehicle parks at the near side of the bus stop and manual precise docking is conducted, how to board/discharge passengers is a remaining issue.

■ **Promoting regular drivers' recognition and understanding of the guidelines**

- Ten percent of drivers recognize the purpose of the guidelines, with attributes making no difference. Around 15% of drivers know (or somewhat know) about precise docking technologies.
- After explaining the meaning of the guidelines and precise docking, respondents came to understand the meaning of precise docking, with more than half answering that social advantages consist of transportation assistance for the elderly and contribution to a barrier-free society, and more than 70% answering that precise docking is useful.
- It is important to promote further recognition and understanding of the meaning of precise docking.

■ **Evaluation of needs for precise docking and its effects**

- Almost all respondents understand about social meaning, with more than 95% answering that a 4 cm gap and 0 cm level difference in precise docking is better or slightly better than that seen with conventional buses.