Next Generation Transport

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ABSTRACT: As Japan's society ages, the percentage of traffic accident fatalities involving elderly people is increasing. For this reason, it is necessary to develop more flexible, efficient, and useful public transport systems. With this background, the SIP-adus Next Generation Transport Working Group decided to develop a partially automated driving system, in addition to the related services and advanced infrastructure applications for public transport. These services and applications include a precise docking system, an advanced public transportation priority system (PTPS) application, an Advanced Rapid Transit (ART) information center, and a walking assistance service system for vulnerable road users. We set the 2020 Tokyo Olympic and Paralympic Games as the milestone for the initial implementation of these systems.

Fundamental needs of Public Transport

More than half of traffic accident fatalities are people aged 65 years and older, and about 70% of those are pedestrians and bicycle users. Furthermore, more than 50% of elderly traffic accident victims lose their life within 500 meters from their home. To reduce the overall number of traffic accident fatalities, countermeasures are required from the standpoint of both vehicles and pedestrians.

Advanced driver support systems that assist elderly drivers whose driving skills have decreased with age have been proposed. However, since these systems include several controversial points, the best way to help elderly or handicapped people lead active lives through mobility is to promote more flexible transport systems with advanced accessibility characteristics.

Public transport systems are becoming more and more important. However, the limitations of public transportation, such as the relatively lower fares that can be earned from these systems and the necessity of making them available to all, make them hard to operate in depopulated areas. Although a fully automated bus service has the potential to reduce driver costs, high initial costs make these systems difficult to deploy. One potential solution is a combination of new technologies with a completely evolutional business model that has yet to be practically realized.

Advanced Rapid Transit (ART)

The initial objectives of this project were to improve the quality of urban public transport and to resolve the shortage of highly skilled bus drivers. One of the first working items was to develop an automated precise docking system for buses. This is a control technology that enables a bus to come alongside a bus stop precisely, without any large gap between the bus entrance and the edge of the bus stop. This will help wheelchair users and visual impaired persons to get on and off the bus without missing their step. Even skilled drivers need this system because it is a hard task to perform every time, especially when it is dark. Of course, this system will also help less experienced bus drivers as well. Buses using this system were given the name Advanced Rapid Transit (ART).

Development of Precise Docking System

SIP-adus was requested to implement some of items from our activity by the 2020 Tokyo Olympic and Paralympic Games. However, we realized that it would be too difficult to complete and transfer the specifications to a potential manufacturer within a year (considering that vehicle man-

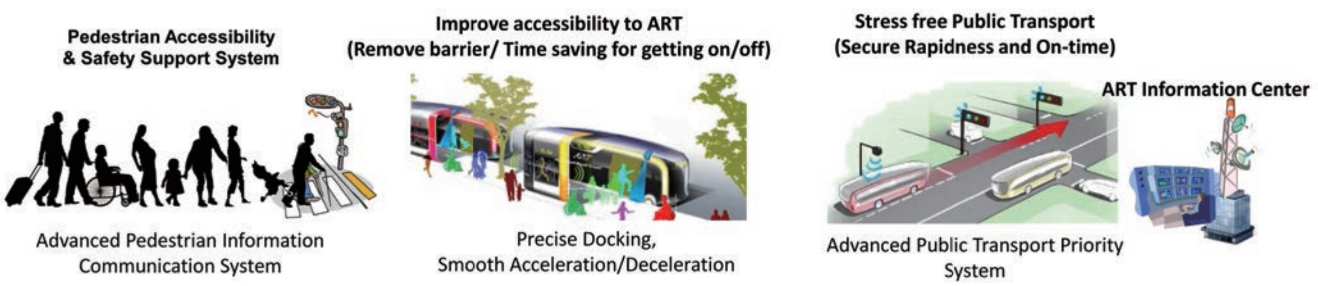

Fig.1 SIP-adus Next Generation Transport WG activity

ufacturers usually require a further three years for their work). Although we decided to utilize our basic specifications as much as possible, more reliable sensor hardware was needed to achieve production level quality, which meant that we had to use an existing product already on the market.

This tentative solution uses a dedicated optical guideway on the road surface. One concern about this solution was the possibility that general road users might misunderstand the meaning of this visible guidance line (unlike some examples in Europe, we planned to put this line on general roads).

To evaluate this concern, two types of experiments were conducted. One involved selecting the color of the guidance line to reduce the impact on general road users while also allowing robust detection by the precise docking system. Another involved proving ground testing with a variety of test subjects to see whether they misunderstand the line. According to these test results, road authorities were approved to use this system within limited locations. The authorities also asked us to develop a new system that does not use dedicated visible markers instead of this short term solution.

New System Development for Precise Docking

Two different approaches were conducted.

One used an invisible guidance line created by infra-red (IR) reflective paint that only IR cameras can detect and cannot be confused by general road users. One issue of this system is heat radiation from the road surface during sunny days in summer. Although some potential countermeasures were identified, we needed to give up this approach at the end of the fiscal year for several reasons.

The other approach involved a sensor fusion system that uses existing roadside objects, including road signs and structures around the bus stop, to detect the precise location. This system does not require any dedicated infrastructure. As some experiments have found very positive results, ensuring robustness would be a final key to reach the goal.

Advanced PTPS

Lack of speed and chronic operational delays are major reasons why bus transit loses value and service quality. Advanced public transportation priority systems (PTPS) can help to resolve these issues. These systems have a wide range and can cover large numbers of buses simultaneously around a targeted intersection using radio wave beacons. This feature provides the new capability of coordinating which bus of several approaching the same intersection should be prioritized. Flexible prioritization factors can be adopted, such as the number of passengers in the bus, or whether the bus is critically delayed or classified as an express. These factors and the priority threshold values can be controlled as required at the ART information center.

ART Information Center

From the standpoint of operational information, buses have the disadvantage of unstable time delays compared to other transportation, such as airplanes and trains.

In addition to the active involvement of PTPS prioritization, the latest AI and big data technologies can be used to estimate the delay time to individual destinations for each passenger more accurately with good probability. These are major requirements for the ART information center, as well as the two data handling requirements described below.

Congestion Prediction

Rather than vehicle congestion on roads, the ART information center handles congestion caused by the motion and behavior of pedestrians. The timing and method of information provision is important for people wishing to go to an event. Both congestion prediction before the event and real time feedback of the on-going situation are very important for information users. This information provision should also carefully consider various psychological factors.

Walking Assistant System

People using public transportation have to walk from their origin, as well as to their final destination. Walking assistant systems will be very helpful, especially for vulnerable road users such as wheelchair users, the visually impaired, and elderly people to find the optimum route with smaller barriers. One challenge of this approach includes the creation of a standardized open database. Although many kinds of trials are under way in several places, it will not be easy to gather the data from these trials into one single information platform. This project aims to provide an open template for this information.

① Development of Next-Generation Urban Transportation Systems

Survey about Feasibility of Requirements for Next-Generation Urban Transportation System

Tatsuya Hashimoto (Advanced Smart Mobility Co., Ltd.)

ABSTRACT: To make it easier for bus users, including wheelchair users, to get on and off the bus, a survey was conducted to help develop an automated control technology that stops the bus so that the gap between the bus entrance and the bus stop is minimized. Section 1 reports the results of an investigation about the permissible gap and step between the bus entrance and the bus stop. Sections 2 and 3 describe the performance of recognition technology used for controlling the accurate arrival of the bus at a bus stop. Section 4 describes the performance of the arrival control using the recognition technology described in Section 3.

1 Clarification of Permissible Gap for Accurate Arrival Control of Bus at Bus Stop

1.1. Purpose of investigation

This survey investigated the steps and gaps between a bus stop and bus entrance, and defined the permissible steps and gaps that would allow wheelchair users to get on and off the bus.

1.2. Outline of experiment

As shown in Fig. 1, we made a wooden pedestal frame to simulate a bus stop, and used the terrace at the entrance of a building to simulate the entrance of a bus. We used a manual wheelchair and an electric wheelchair for the experiment. The test subjects were six healthy volunteers (ages: 20s to 60, one female test subject), who participated in the experiment after learning how to handle both the manual and the electric wheelchair adequately. There was no assistant, and the experiment was carried out in the ingress/egress environments listed in Table 1. Accessibility was evaluated using the four levels listed in Table 2.

Fig. 1 Experimental situation

Table 1 Implementation content

Evaluation Object	state
Step (4 pattern)	06mm, 18mm, 30mm, 42mm
Gap (4 pattern)	30mm, 45mm, 60mm, 75mm

Table 2 Evaluation index

Evaluation	Description
○	Easy access
△	Requires some effort
▼	Barely possible
×	Assistance required

1.3. Results of the experiment

Tables 3 and 4 show the results for the different step heights using the manual and electric wheelchair, respectively. Tables 5 and 6 show the results for the different gaps. From the evaluation results shown in Tables 3 to 6, the permissible step height was set to 30 mm and the permissible gap was set to 60 mm.

Table 3 Step difference evaluation using manual wheelchair

Step Value	Subject A	Subject B	Subject C	Subject D	Subject E	Subject F
06mm	○	○	○	○	○	○
18mm	○	○	○	○	○	○
30mm	△	△	○	○	×	△
42mm	×	▼	▼	▼	×	▼

Table 4 Step difference evaluation using electric wheelchair

Step Value	Subject A	Subject B	Subject C	Subject D	Subject E	Subject F
06mm	○	○	○	○	○	○
18mm	○	○	○	△	○	○
30mm	△	○	○	○	○	○
42mm	×	▼	▼	▼	×	▼

Table 5 Gap evaluation using manual wheelchair

Gap Value	Subject A	Subject B	Subject C	Subject D	Subject E	Subject F
30mm	○	○	○	○	○	○
45mm	○	○	○	○	○	○
60mm	○	○	○	○	○	○
75mm	▼	○	○	▼	▼	△

Table 6 Gap evaluation using electric wheelchair

Gap Value	Subject A	Subject B	Subject C	Subject D	Subject E	Subject F
30mm	○	○	○	○	○	○
45mm	○	○	○	○	○	○
60mm	△	○	○	○	○	○
75mm	×	○	○	▼	▼	▼

2 White Line Detection for Accurate Arrival Control of Bus to Bus Stop

A white line is laid along the path of the bus to the bus stop, and accurate arrival control is performed based on the amount of deviation between the white line as detected from the camera image and the bus.

2.1. White line detection algorithm

White line candidate points are extracted using the white line width. The widths of the white lines in the input images are made constant by converting the images to a bird's-eye view. Therefore, pairs of edge points with a fixed width can be extracted as white line candidate points. The white lines are detected by applying Hough transformation to the white line candidate points. Figure 2 shows example images from each processing step. The deviation amount is calculated by converting the image coordinates to the bus body coordinates.

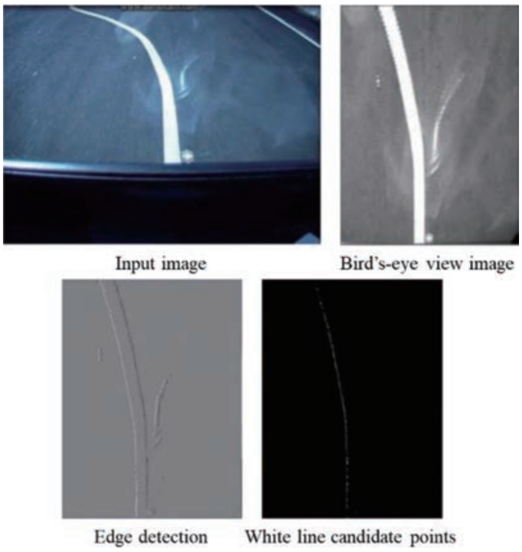

Fig. 2 Image processing example

2.2. Evaluation of white line detection

Figure 3 shows an example result of white line detection, and Figure 4 shows the evaluation results of the deviation amount, which indicates the detection accuracy. The amount of deviation was defined as the lateral distance between the white line and a point 3 meters ahead of the bus. In Figure 4, the vertical axis indicates the detection result, and the horizontal axis indicates the actually measured value. White lines were detectable with an error of ±15 mm up to a deviation amount of 0 to 1350 mm.

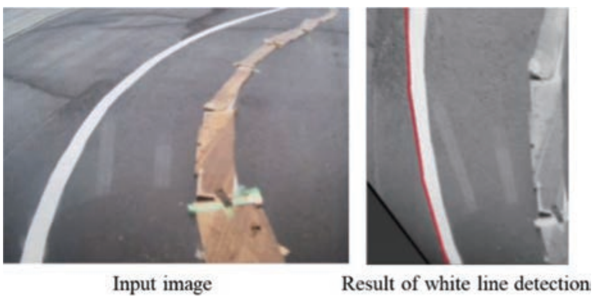

Fig. 3 Example of white line detection result

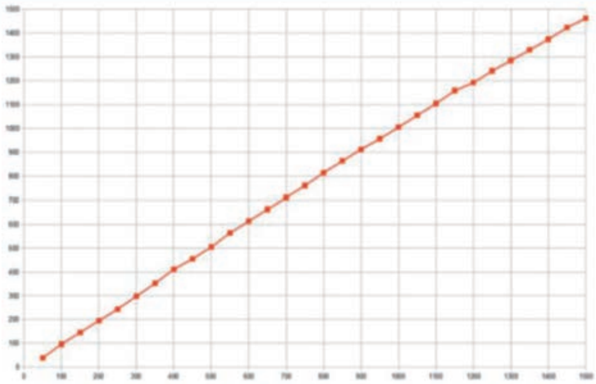
Fig. 4 Evaluation results of deviation detection accuracy

3 Curbstone Detection for Accurate Arrival Control of Bus to Bus Stop

The amount of deviation between the curbstone and bus is detected from a point cloud obtained using LiDAR, and accurate arrival control is performed based on the detected deviation amount.

3.1. Curbstone detection algorithm

The distance deviation d and angular deviation θ between the curbstone and bus as shown in Figure 5 are detected from the point cloud obtained by LiDAR. The normal of

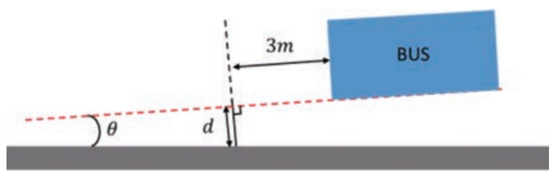

Fig. 5 Relationship diagram of required deviation amount

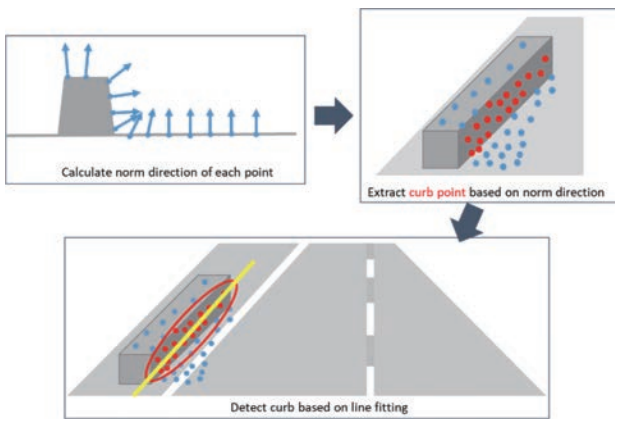

Fig. 6 Flow of curb detection process

each point is calculated, and points on the solid surface as indicated by the red points in Figure 6 are extracted as the curb candidate point cloud. The required amount of deviation is calculated by approximating the curbstone candidate point cloud with a straight line.

3.2. Evaluation of curbstone detection

As shown in Figure 7, LiDAR was attached to the front of the bus, and the accuracy of the detected deviation amount was evaluated using the arranged blocks as a simulated curbstone. Table 7 shows the detection results of the distance deviation amount. The deviation was detected with an error of 0.01 m or less. Table 8 shows the detection results of the angle deviation amount. The angle deviation was detected with an error of 0.7 degrees or less.

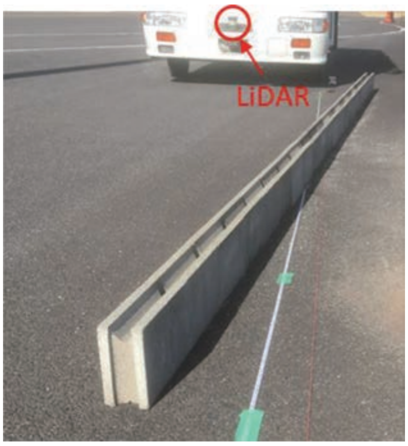

Fig. 7 Evaluation scenario

Table 7 Detection results of distance deviation

Observed value [m]	1.40	1.11	2.30	2.36
Detection value [m]	1.41	1.11	2.30	2.37
Error value [m]	0.01	0.00	0.00	0.01

Table 8 Detection results of angle deviation

Observed value [deg]	1.1	5.6	-5.3	1.5
Detection value [deg]	1.4	5.9	-4.9	2.2
Error value [deg]	0.3	0.3	0.4	0.7

4 Accurate Arrival Control of Bus to Bus Stop Based on Curbstone Detection

The arrival control accuracy of a bus to a bus stop based on curb detection using LiDAR was evaluated. Figure 8 shows the system configuration based on path-following control (1). From the results of the wheelchair ingress/egress experiment in Section 1, the target of the gap between the bus entrance and the curb at the bus stop was set to 4 cm ± 2 cm. As shown by the experimental results in Figure 9, an evaluation was performed 10 times and confirmed that the bus arrival control can be performed with the target accuracy.

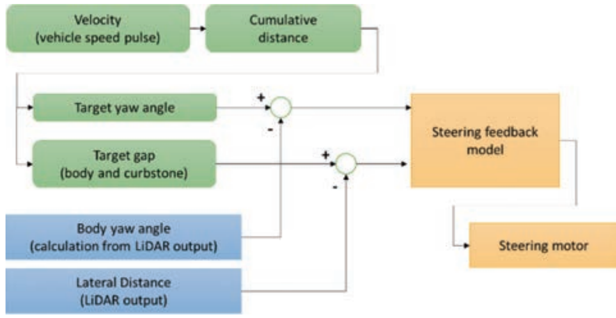

Fig. 8 system configuration

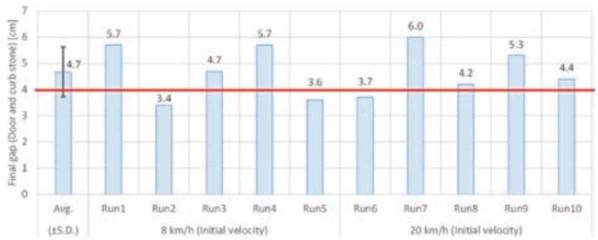

Fig. 9 Results of bus arrival control experiment

Reference

(1) T. Fukao et al.: Preceding Vehicle Following Based on Path Following Control for Platooning, Preprints of IFAC AAC (2013)

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Development of Sensing and Control Technology for Precise Docking of Advanced Rapid Transit system

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ABSTRACT: This research is part of the Strategic Innovation Promotion Program(SIP)/Autonomous driving system project and examines the issues of the so-called Advanced Rapid Transit (ART) automated driving system, which is considered to be a promising next-generation transport system for urban areas. This article describes the docking control project, which aims to clarify basic control issues related to sensing, steering linkage, integrated control with the brakes, and so on. These items are being researched and development to realize docking maneuvering technology with excellent functionality.

1 Overview

A precise docking control system, i.e., an automated precision docking control strategy that aims to minimize the gap between the entrance of a bus and a bus stop, is an important part of realizing a high-quality advanced Rapid Transit (ART) system. Automated precise docking control should contribute to the smooth and safe embarkment and disembarkment of passengers, including the disabled and parents with strollers. This system must be robust in various environments and achieve the best route for docking even in severe conditions. It should also achieve smooth braking and steering control to prevent accidents on the bus and improve passenger comfort. Cooperative docking control with the bus driver should also contribute to enhanced safety.

2 Issues for Precise Docking Control

Steering systems for large vehicles like commercial buses or trucks usually have a complicated structure. The transfer characteristics of the steering system may be asymmetric or non-linear because of long linkages or free play at mechanical connection points. This is one of the difficulties that must be overcome to realize a precise docking control system. Since this issue is difficult to solve through mechanical improvements, the addition of a phase advance control algorithm that compensates for the asymmetric or non-linear steering system characteristics may be an effective countermeasure.

This section described the measurement of steering system characteristics such as phase delay. Factors related to precise docking ability were investigated based on measured steering and vehicle behavior, and a concept for precise docking control was identified.

2.1. Test mule and system structure

2.1.1. Test mule

A large bus was used as a test mule. Figure 1 shows the appearance of the test mule and Table 1 lists its specifications. The axle load was measured with the driver present.

Fig. 1 Appearance of test mule (large bus)

Table 1 Specifications of test mule (large bus)

Wheelbase (mm)	6,000
Track (mm)	Front: 2,065, rear: 1,820
Axle load (kg)	Front: 3,545, rear: 6,590

2.1.2. Precise docking control system

Figure 2 shows the structure of the precise docking control system. Calculation for the docking control is performed using an integrated control ECU (dSPACE GmbH: MicroAutoBox II(*a)). Distance to the lane separation line is supplied by a camera (Mobileye, Inc.: ME560(*b)) and RTK-GPS system (GeneSys Elektronik GmbH: ADMA-G-ECO+(*c)). Vehicle yaw angle, yaw rate, and acceleration values are supplied by a gyro sensor (MEMSIC, Inc.: NAV440(*d)) mounted on the floor of the passenger compartment close to center of vehicle gravity. The vehicle velocity and running distance are calculated from wheel speed pulses.

The steering angle and deceleration commands calculated by the integrated control ECU are sent to the steering actuator ECU and braking control ECU.

(*a) Trademark of dSPACE GmbH
(*b) Trademark of Mobileye, Inc.
(*c) Trademark of GeneSys Elektronik GmbH
(*d) Trademark of MEMSIC, Inc.

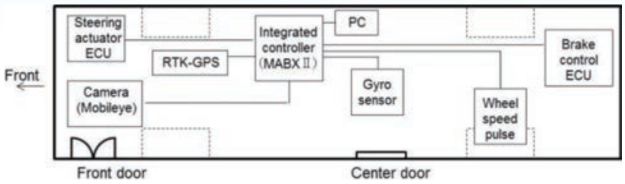


Fig. 2 Control system

Calculation for steering angle commands is based on the path following control method.[1] The basic concept of this method involves following an assumed trajectory (target trajectory).

The target angle δc is calculated by equation (1).

$$\delta_c = \frac{MV}{2K_f}\left[\frac{2(K_f l_f - K_r l_r)}{MV^2}\gamma + \frac{2(K_f + K_r)}{MV}\beta + \omega_r - K_2 e_2 V - K_3 \sin e_3\right] \quad (1)$$

V : velocity, M : vehicle weight, β : slip angle, γ : yaw rate,
lf : distance from gravity center to front axle,
lr : distance from gravity center to rear axle,
J : yaw moment of inertia, Kf : cornering power of front tire
Kr : cornering power of rear tire
e_2 : deviation of x direction,
e_3 : deviation of yaw angle,
ωr : yaw rate of reference vehicle,

Figure 3 shows a block diagram of the control system. The target trajectory is installed as a lookup table to define the lateral distance between the vehicle and the lane separation line against the travel distance. The lateral gap e_2 between the measured and target value is estimated. The heading angle difference e_3 is estimated from the heading angle output of the camera or the RTK-GPS system.

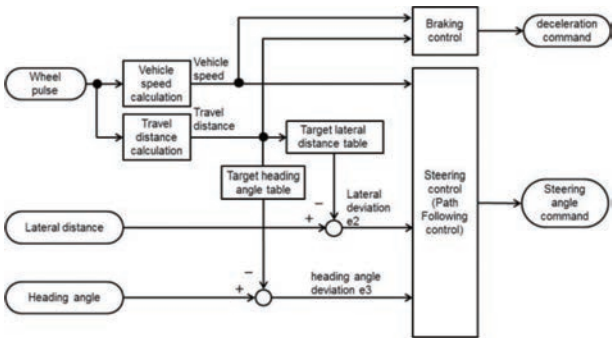


Fig. 3 Control system block diagram

2.1.3. Steering system

The steering system of the test mule consists of hydraulic power steering integrated with a ball screw type gear box. Figure 4 shows an overview of the steering system. The actuator for steering angle control is mounted on the steering column. This actuator receives commands from the integrated controller and controls the steering angle using the PID control algorithm. The lateral displacement of the tie rod is measured as an alternative value to the tire angle.

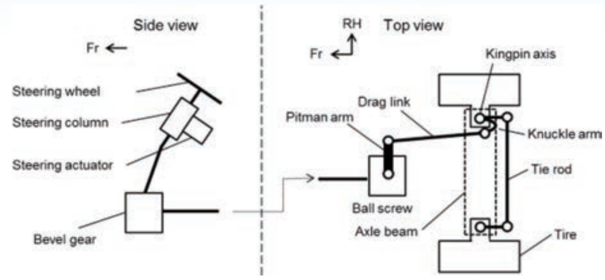


Fig. 4 Overview of steering system

2.1.4. Brake system

An electronically controlled brake system (WABCO Holdings Inc.: EBS[*e]) controls the braking force along with signals from other controllers. Figure 5 shows an overview of the braking control system.

The braking control ECU receives deceleration commands from the integrated controller, calculates the air pressure for each wheel, and sends commands to the braking control unit.

[*e] Trademark of WABCO Holding Inc.

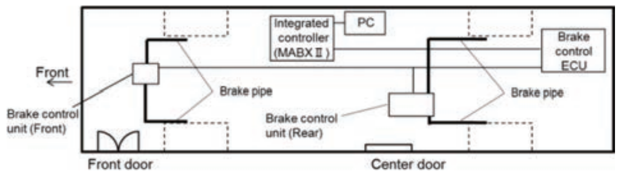


Fig. 5 Overview of braking control system

Table 2 compares the target and actual deceleration value. The characteristics are not linear and the variation is not small.

Table 2 Comparison of average target and actual deceleration (N: 5)

Target value [m/s^2]	Actual value [m/s^2]	Actual/Target
−0.2	−0.198	0.98
−0.5	−0.636	1.27
−1	−1.25	1.25

To avoid the effect of these characteristics, the following control method was introduced to achieve a precise longitudinal stopping position. The target deceleration is calculated from the travel distance S, the assumed stopping position St, and velocity v, using equation (2).

$$a = \frac{v^2}{2(St - S)} \quad (2)$$

a : deceleration, S : travel distance,
St : assumed stopping position, v : velocity

When the difference between the actual and target deceleration, or the deceleration deviation is large, the target deceleration is compensated continuously to adapt to the situation at that time using this calculation. This method also helps to reduce jerk. The target deceleration is also corrected to reduce the adverse effects of the difference between the actual and target deceleration following equation (3).

$$a' = \frac{a}{x} \tag{3}$$

a' : Corrected deceleration, x : Coefficient for correction

The correction coefficient x is estimated considering the deceleration at that timing, based on the results shown in Table 2.

2.2. Improvement of precise docking system algorithm

2.2.1. Optimization of control gain

In the current control method, gain k_2 for compensating the lateral distance is constant in the docking control and other modes. Figure 6 shows an example of lateral distance results using constant control gain k_2 fitted for a straight line trajectory. This result indicates that the error increases during docking control after a distance of 180 meters.

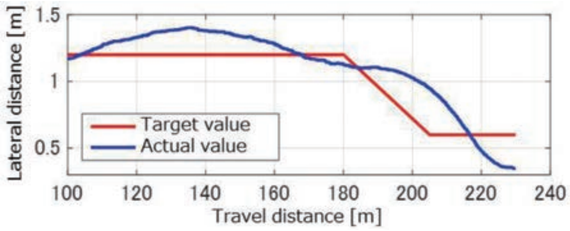


Fig. 6 Vehicle movement under control gain fitted for straight trajectory

A control method was introduced that selects one of two values for gain k_2 based on whether the bus is traveling in a straight line or performing a docking procedure. Figure 7 shows the example of the results using this gain selection method. The difference between the target and actual values is reduced, demonstrating that this is an effective control method for achieving the planned trajectory.

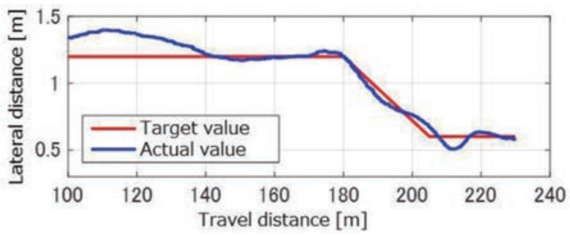


Fig. 7 Vehicle movement under separate control gains fitted for straight or docking trajectories

2.2.2. Compensation for free play of steering linkage

Mechanical free play exists in normal steering systems, and the free play in the steering system of large vehicles, such as this test mule, is larger than in normal passenger cars. This large free play has adverse effects such as delay on the control results. A compensation control method was studied to improve this issue. Figure 8 shows the relationship between the steering and tire angles in a sine wave command. The tire angle response is delayed from the steering angle. The amount of free play is estimated as a steering angle of 11 degrees.

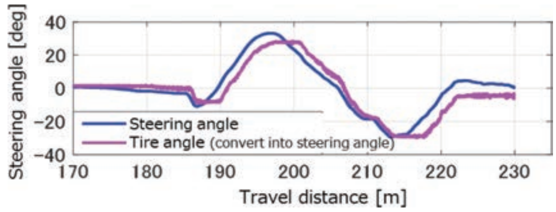
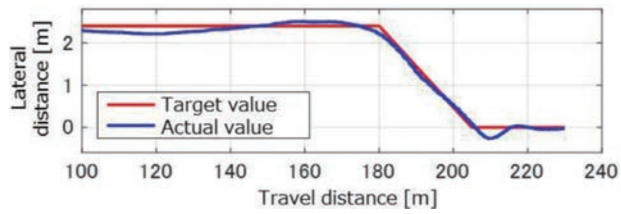
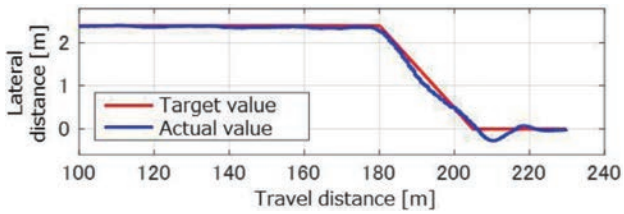


Fig. 8 Relationship between steering and tire angles

The steering angle command is estimated considering these characteristics created by mechanical free play. When the angle command direction is reversed, the free play value is added to the angle command. Figure 9 shows the difference in trajectory with and without free play compensation. Lateral movement is reduced especially on straight trajectories.



(a) Without compensation of steering free play



(b) With compensation of steering free play

Fig. 9 Improvement by compensation of steering free play

2.2.5 Braking control

The brake system is controlled based on equation (2). The deceleration command is $0.5m/s^2$ in the initial braking area

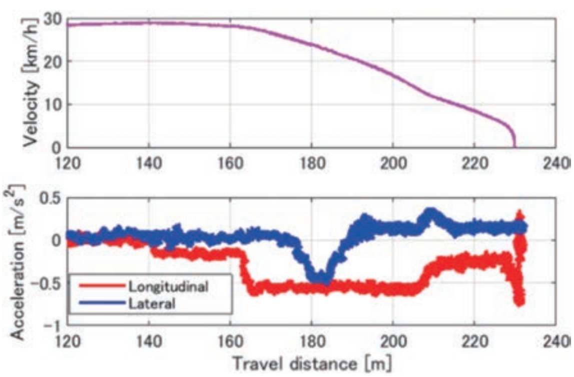


Fig. 10 Vehicle movement under braking control

and 0.2m/s^2 at the stopping position. This method contributes to reducing the braking distance and accidental deceleration deviation at the bus stop. Figure 10 shows an example of vehicle behavior with braking control.

3 Study of Issues Toward Minimization of Infrastructure

A fundamental study into multiple sensing methods and cooperation between sensors is in progress with the aim of realizing more precise docking.

3.1. Characteristics of RTK-GPS and front camera

To build a better sensing device selection method, the characteristics of the RTK-GPS and front camera system were measured. Figure 11 indicates the lateral position difference between the RTK-GPS and front camera. This value relates to the actual distance. The value from the camera is delayed compared to the value from the RTK-GPS (0.3sec).

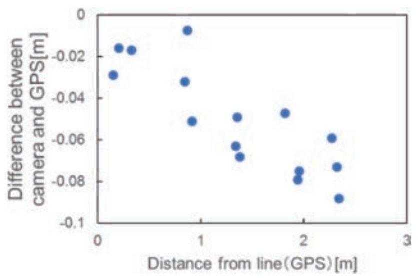


Fig. 11 Distance difference between camera and RTK-GPS

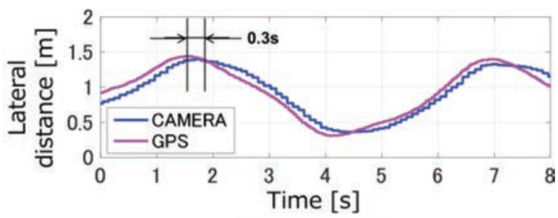


Fig. 12 Time difference between camera and RTK-GPS

The lateral movement is at a similar level as shown in Fig. 13.

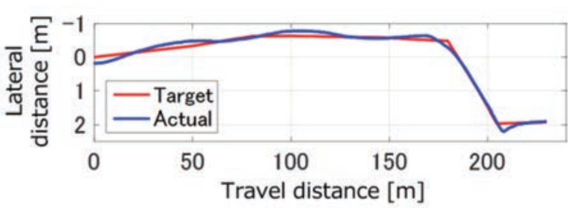


Fig. 13 Vehicle movement using RTK-GPS data

3.2. Future study of sensing for precise docking control

The sensing resolution with RTK-GPS or front camera images is insufficient to realize further accurate control, and additional infrastructure is necessary. For example, specific guidance lines or magnetic markers on the road, side cameras for boundary and position detection of painted lines or curbstones to improve accuracy, and Lidar should be considered.

Multiple sensing methods are preferable to achieve sufficient accuracy under every condition, and a better sensing method should be selected or a cooperative sensing procedure should be adopted.

4 Compatibility of Driver Operation and Automated Control

In the case of a level 1, 2, or 3 automated system, the driver is required to avoid pedestrians and other objects during the docking procedure. Since one of the concerns in this procedure is a delay in the driver's avoidance operation, sharing of responsibility by the driver and automated driving system is preferred. In this case, the driver should always be aware of the driving operation.

This research proposed and evaluated the effect of a prototype system operated based on driver intention (measured using an input force from the driver). This system proposes that the driver should always be touching the steering wheel. Driver steering characteristics using the proposed system were evaluated and analyzed using a driving simulator.

The adoption of a shared control method in the automated docking control system should be studied based on this result.

5 Conclusion

The effect of steering system delay with respect to vehicle behavior was investigated as part of the study into actuators and controls for an ART system.

The prototype system described above was evaluated, and it was found that the proposed system concept of shared control is effective.

However, since the targets for this system are difficult to achieve with current buses, items to be developed to achieve integrated steering and braking control are being investigated.

Current position recognition capabilities are not sufficient to achieve the targets under all environments. Difficult to detect disturbances must also be considered, for example the impossibility of detecting objects in the dead areas of vehicle-mounted sensors.

Further research and studies to solve these issues are required in the future.

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① Development of Next-Generation Urban Transportation Systems

Survey about Precise Docking of Next-Generation Transportation Systems for Strategic Innovation Program (SIP) – Automated Driving System

Ryohta Wakai (The Institute of Behavioral Sciences)

ABSTRACT: Precise docking at bus stops is a key technical requirement for achieving the practical implementation of the next-generation Advanced Rapid Transit (ART) transportation system. Among the control methods for precise docking that are being studied in this research and development project, the road surface guidance lines described in this article are regarded as an effective means of reducing control error. However, some concerns remain, such as their use on roads not used by buses, on which they may cause needless driver confusion. This study investigated guidance lines for precise docking that are readable by cameras mounted on ART vehicles, and conducted several verification experiments to confirm their safety. The effect of this precise docking system on the driving behavior of ordinary vehicles and the recognition rate of these guidance lines were investigated in experiments held at a test course.

1 Introduction

1.1. Purpose of the Survey

This project studied guidance lines for precise docking that are readable by cameras mounted on Advanced Rapid Transit (ART) vehicles, and several verification experiments to confirm their safety were conducted. Through verification in the laboratory and on a test course, we investigated how well the vehicle-mounted cameras recognized the guidance lines, the effect of the guidance lines on the driving behavior of ordinary vehicles, as well as the recognition rate and control error of a precise docking system.

1.2. Study Flow

This study was conducted in the following order:

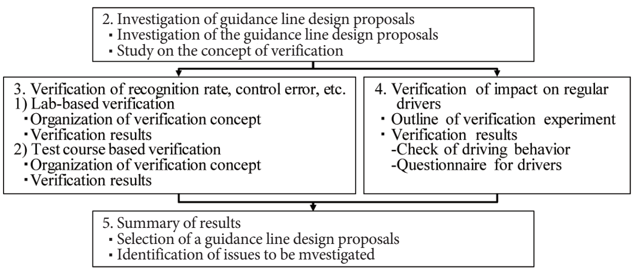

Fig. 1 Study Flow

2 Investigation of Guidance Line Design Proposals

2.1. Guidance Line Design Candidates

When a vehicle passes over guidance lines installed on the road, drivers are inclined to turn the steering wheel toward the roadside or step on the brakes. Therefore, we must consider design proposals for guidance lines that ordinary drivers will not confuse with official traffic lines and that can be recognized by vehicle-mounted cameras. Specifically, we studied guidance line design proposals taking the following into account.

1) Colors used for road markings such as white, yellow, red, and blue should not be used.
2) To allow the camera to recognize the guidance lines, use a guidance line color with a high contrast ratio with the color of the underlying pavement.
3) A proposal that includes putting markings on the road to indicate bus-only use should be considered.
4) We also considered a design that changed the shape of the guidance lines.

* The guidance lines are double-dotted lines that can be recognized by the camera to be used.

Based on the above, the following six proposals were used as the design proposals.

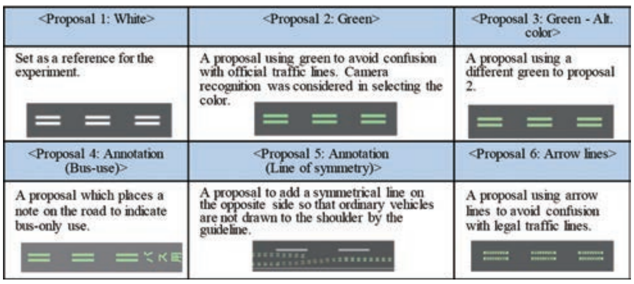

Fig. 2 Guidance Line Design Proposals

2.3. Narrowing Down the Guidance Line Design Proposals

Finally, we selected one proposal from these six proposals based on the results of verification performed in the laboratory and on the test course. The criteria for narrowing down the proposals were as follows, based on the results of preliminary consultations with relevant organizations.

Table 1 Narrowing Down the Guidance Line Design Proposals

Performance index	Overview
1) Likelihood of confusion by ordinary drivers	It is necessary to confirm that there is no negative influence on ordinary drivers, such as noticeable effects on driving behavior.
2) System recognition performance	System recognition performance might be lower due to using green instead of white.
3) Legal compliance	Displays that could be confused with official traffic lines could violate the Road Traffic Act.
4) Construction practicality	In the real-world implementation phase, it is necessary to consider construction and maintenance costs, as well as the construction period.

3 Lab-based Verification

3.1. Overview of Verification

We verified the guidance lines in the laboratory by measuring the image contrast ratio of camera recognition for the different guidance line colors under various lighting conditions, etc. Since the experiment results showed that the recognition performance of the system was satisfactory, the guidance line color and other specifications were selected.

In the laboratory experiment, test pieces consisting of different guidance line colors and underlying pavements were exposed to light simulating daytime sunlight and nighttime street lights, to measure the image contrast ratio of camera recognition. The conditions used in the verification experiment in the laboratory to confirm the system recognition performance were as follows.

Table 2 Conditions of Verification Experiment in the Laboratory

Test Piece		Color	White, green A, green B, green C, orange, pink, purple, blue
		Reflecting material	Glass beads, AWT, Bright Grip
		Base	Asphalt, red iron oxide, heat-insulating pavement
Time	Day	Sunshine	Morning, midday, evening (reproduced with lights)
		Light dir.	Front-lit, backlit, angle
		Wetness	Dry, wet
	Night	Street lamps	With/without street lamps

3.2. Overview of Verification Results

The following results were obtained from the lab verification:

1) Guidance line colors

While both green B and A had an image contrast ratio close to white during the day, green B had a higher measured image contrast than A. Therefore, green B was used as the candidate for green.

2) Reflecting material

The contrast ratio of the glass beads and AWT (a high-performance product) was almost equal, and the "Bright Grip" product had a slightly lower contrast ratio. Since AWT costs 1.5 times as much as (general-purpose) glass beads, a relatively inexpensive general-purpose material can be used.

3) Base material

The contrast ratio of red iron oxide is approximately 0.1 lower than that of asphalt. Even white guidance lines cannot be recognized by the system on top of heat-insulating pavement.

4) At night

Even green B has a contrast ratio which is approximately 0.1–0.2 lower than that of white guidance lines. The required luminosity is 60 lux or more.

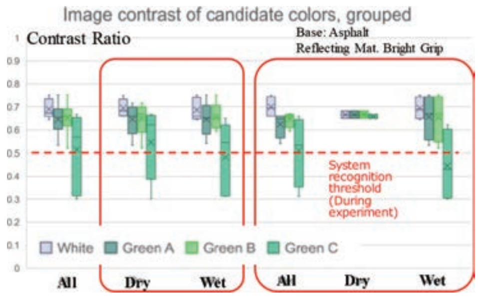

Fig. 4 Basic Performance Evaluation: Morning / Sun / Evening + Dry / Wet

4 Test Course-Based Verification

4.1. Overview of Verification Experiments

4.1.1. Overview of Verification Experiments

The effect of the guidance lines on ordinary drivers was studied on the test course. Test drivers drove on a test course marked with guidance lines while their driving behavior was monitored, and driver awareness during driving was then evaluated by a form-based survey.

The verification experiments were carried out for three days (Sunday, Feb. 11 to Tuesday, Feb. 13, 2018). We used the V2X Urban Proving Ground Course in Tsukuba, which is owned by the Japan Automobile Research Institute (JARI) as the test course. A total of 32 test drivers participated in the experiments, considering the balance between genders and age groups.

Based on the results of prior investigation, we selected proposal 1 (reference) (guidance line 2: white), proposal 2 (guidance line 1: green), proposal 4 (guidance line 3: "For Buses" marking) as the guidance line patterns used in the verification experiments.

A schematic diagram of the test course is shown below:

① Development of Next-Generation Urban Transportation Systems

Survey about Precise Docking of Next-Generation Transportation Systems for Strategic Innovation Program (SIP) – Automated Driving System

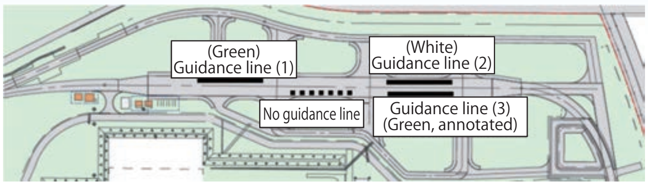

Fig. 5 Test Course for Driving Experiments

4.1.2. Details of Verification Experiments

In the verification experiments, each test driver drove through four sections: three with guidance lines and one without. We measured the traveling speed and position (lateral direction) to check the operating situation of the brakes and steering wheel while driving along the guidance lines, and observed the physical effects. Here, we used GPS data at one-second intervals to measure the traveling speed and recorded the traveling position by taking video images showing the distance to the roadside line using a camera mounted on the vehicle. We also conducted a form-based survey immediately after the test drivers drive over the guidance lines for the first time and after passing over all the guidance lines to ask them how they reacted when they noticed the guidance lines. Because drivers are especially strongly affected when seeing the guidance lines for the first time, the test drivers were grouped into three groups and the driving routes were set so that each group experienced a different type of guidance line first.

4.2. Verification of Effect on Drivers Passing along Guidance Lines

4.2.1. Effect on Braking

The effect on braking when passing through the guidance line section was verified. During the first experience (first sight) of the guidance lines, the average traveling speed of all the test drivers and the standard deviation variance did not differ depending on the type of the guidance lines. Although the behavior of individual test drivers showed no rapid deceleration (defined as 0.3 G as a value indicating a sudden surprise), some test drivers released the accelerator to reduce speed a little.

4.2.2. Effect on Steering

The effect on steering when driving through the guidance line section was examined. Although no major differences were observed depending on the type of the guidance line, there was an overall tendency to drift to the right. No major differences were observed between the areas with and without guidance lines. The behavior of individual test drivers showed a lateral change of approximately 20 cm for each guidance line.

For the guidance lines 2 (white) and 3 (text marking), we checked the driving behavior of three test drivers with large steering wheel operation. One driver drove to the right side within the range of the lane in the case of guidance line 2 (white), while the other two misunderstood that guidance line 3 (text marking) was a bus-only lane, and drove along the guidance line section from right to left.

4.3. Verification on Effect of Guidance Lines on Driver Awareness

The main results obtained from the form-based survey about the guidance lines after the first experience and after passing over all the guidance lines were as follows:

Table 4 Main Answers to Form-based Survey

	Main answers
First experience	・For guidance line 1 (green), one test driver was uneasy because there was no explanation. ・Three test drivers recognized guidance line 2 (white) as an indication to move to the left. Two test drivers moved to the right to avoid driving on the line. ・Six test drivers saw the "For Buses" marking of guidance line 3 (text marking) and recognized the marking as being for a bus lane.
Second experience	・Among the test drivers who first drove on guidance line 3 (text marking), one test driver correctly recognized guidance lines 1 and 2 as "Being related to buses, and not for me." ・One test driver saw the "For Buses" marking for guidance line 3 (text marking) during the second drive, and changed lanes thinking that it was a bus lane.

4.3. Verification Test Results on Test Course

Based on the results of both the lab-based and the test course-based verification, we decided to employ guidance line 1 (green).

Table 5 Results of Guidance Line Selection

No	Guidance line (1)	Guidance line (2)	Guidance line (3)
Characteristics	Green	White	Text marking: For Buses
Legality	Good	Bad	Good
System recognition performance	Good	Best	Good
Construction practicality	Good	Good	Good
Likelihood of confusion	Good	Good	Fair

*We evaluated construction practicality based on the results of interviews with suppliers who mark road surfaces.

5 Conclusion

This study verified the color and other elements used for guidance lines for precise docking from the viewpoints of legal compliance, system recognition, construction practicality, and likelihood of confusion with official traffic lines. As a result, we decided to employ guidance line 1 (green B). However, in the real-world implementation phase, it will be important to let various users on public roads understand that these guidance lines are for buses, together with the benefits realized by precise docking in order to increase safety. It will be necessary to convey the importance of the guidance lines and precise docking among the general public, verify the recognition performance of the guidance lines under conditions other than the test environment (on public roads, at night, etc.), and investigate how to install, maintain and manage the guidance lines in the real-world implementation phase.

Examination of Enhancement of Bus Priority Control in Next-Generation Urban Transport Systems

Toru Mabuchi (UTMS Society of Japan)

ABSTRACT: Next-generation urban transport systems are being developed in order to ensure safe and smooth traffic around the venues of the 2020 Tokyo Olympic and Paralympic Games, and to secure means of transportation for the elderly in Japan's super-aging society. The UTMS Society of Japan developed a system that performs bus priority control using vehicle-to-infrastructure communication via the 700 MHz radio frequency and conducted verification through field operational tests. The equipment specifications and communications standards established in this development will be adopted as standard specifications to promote future the introduction and dissemination of the system.

1 Purpose and History of the Development

1.1. Purpose of PTPS enhancement

The Universal Traffic Management System promoted by the National Police Agency of Japan aims to realize a safe, comfortable, and environmentally friendly traffic environment through the provision of real-time traffic information to drivers using two-way communication with individual vehicles via infrared beacons, and through the active management of traffic flow. As a sub-system of UTMS, Public Transportation Priority Systems (PTPS) have already been put into practical use.

In recent years, driving safety support systems (DSSS) using vehicle-to-infrastructure communication via the 700 MHz radio frequency band have been practically implemented. Because the roadside radio equipment of these systems is installed near intersections and provides a communication range of several hundred meters, this radio equipment also has the potential to be utilized for PTPS. In order to resolve various issues with the existing PTPS, the UTMS Society of Japan is working to enhance these systems using vehicle-to-infrastructure communication via the 700 MHz band.

1.2. Background of the development

In fiscal 2014, studies and research were carried out, including surveys about the current situation of public road transport, as well as current situation surveys and literature surveys and analyses about bus priority control.

In fiscal 2015, requirements for the enhancement of PTPS were identified and a basic design was developed.

In fiscal 2016, a central computer was developed by equipment manufacturers in accordance with the basic design and a model system was set up in Tokyo by the Tokyo Metropolitan Police Department. An on-board unit supporting the system was also developed by an automotive manufacturer. In parallel, design verification was conducted through simulations.

In fiscal 2017, using the above-mentioned model system, effectiveness verification was performed in a real-world environment involving vehicles.

2 Details of PTPS Enhancement

2.1. System design policies

This system was designed to enhance PTPS, which are currently realized by infrared beacons, through the utilization of the 700 MHz radio frequency band. The enhanced system was designed to satisfy the main PTPS upgrade requirements shown in Table 1. These enhancement requirements were compiled and determined based on the results of questionnaire surveys performed at each prefectural traffic control center, as well as the results of interviews bus companies, with consideration also given to the viability of the system.

Table 1 Main requirements for enhanced PTPS

No	Requirements
1	The performance of priority control must be improved by taking advantage of the benefits of wireless communication
2	Equipment costs, construction costs, etc. must be reduced by covering multiple routes with one unit of equipment
3	System construction costs must be low (modification costs for the existing equipment must be low).
	Coverage of PTPS must be expanded.
4	Routes with bus stops
5	Routes where infrared beacons cannot be installed (bridges, elevated roads, etc.)

2.2. Bus priority control function

(1) Purpose

A PTPS that uses infrared beacons estimates a bus arrival time at an intersection using bus passage information collected by infrared beacons installed upstream of the intersection. However, because the arrival time is predicted using a design speed containing a certain margin, one issue is the wasted green traffic signal time resulting from the difference with the actual speed. To resolve this issue, the performance of the priority control was improved.

(2) Functional overview

Figure 1 shows a conceptual diagram of the system and Fig. 2 shows an example of green traffic signal extension ("green extension") control operation. The ITS roadside radio equipment receives real-time vehicle information (described below as "vehicle-to-vehicle communication information") transmitted over the 700 MHz radio band from a bus equipped with an on-board unit supporting the system and traveling toward the control target intersection.

Based on the vehicle location data included in the vehicle-to-vehicle communication information received from the bus, the system determines the passage of the bus through the first bus passage check point (passage determination point), estimates the arrival time of the bus at the intersection using a design speed close to the actual speed, decides whether to provide priority control at the intersection, as well as the operations to be provided (green extension/red truncation), and then performs signal control. The system further determines the passage of the bus through the second passage check point located around 50 m upstream of the stop line, estimates the bus arrival timing at the stop line using a design speed with an adequate margin, and provides a further green extension as needed.

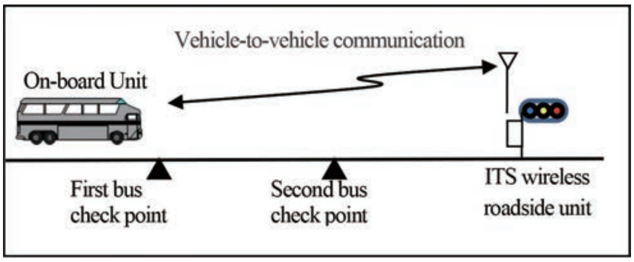

Fig. 1 System image

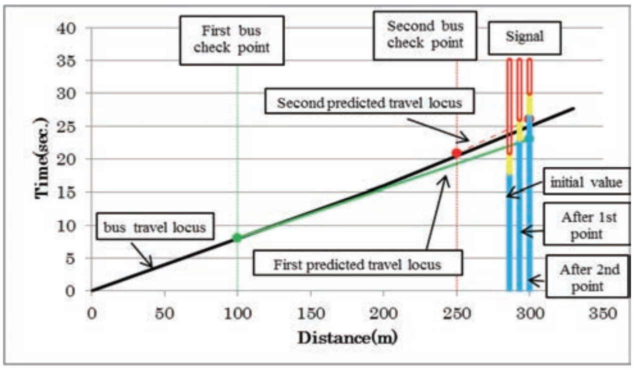

Fig. 2 Example of green extension control

(3) System configuration

Figure 3 shows the system configuration. The bus ID, priority request information indicating the presence of a priority request, and vehicle-to-vehicle communication information are sent from the on-board unit to the ITS wireless roadside unit. Service information, such as the bus passage checkpoint loci, maximum green extension time, maximum red truncation time, and the like are sent from the ITS wireless roadside unit to the on-board unit.

The ITS wireless roadside unit determines the passage of the bus through the bus passage check point and sends the priority request information to the central computer. The central computer sends signal light information to a signal controller based on the timing of the priority request information, by which signal control is performed.

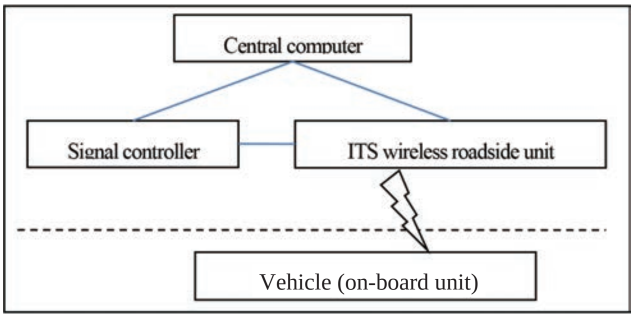

Fig. 3 System configuration

3 Effectiveness Verification

3.1. Effectiveness verification by simulations

(1) Outline of effectiveness verification

The purpose of the effectiveness verification by simulation was to confirm the system's effectiveness in advance and in theory prior to verification with a model system, and also to confirm effectiveness under various conditions that cannot be tested with a model system. To this end, verification was carried out using a microscopic traffic flow simulator on a virtual route of about 3.5 km with ten intersections and on a model route with the target intersection in front of Tokyo Wangan Police Station.

(2) Main verification items and results of verification on virtual route

The verification of basic functions in dedicated bus lanes confirmed that the enhanced PTPS can reduce bus travel times by 4% or more compared to the existing PTPS. Even without dedicated bus lanes, the enhanced PTPS was able to reduce bus travel times by about 3.9% to 5.8% compared to the existing PTPS.

The analysis of maximum green extension times confirmed that bus travel times can be further reduced by about 8% by changing maximum green extension times from 10 to 20 seconds. However, since this increases travel times on minor roads, a decision needs to be made for each intersection on which the system is to be introduced.

Analysis of the negative effects of GNSS positioning errors confirmed that, when positioning errors are within the range of +/- 30 m, the effect on the reduction in travel time is 0.5% or lower.

(3) Main verification items and results of verification on model route

The verification of basic functions confirmed that the enhanced PTPS can reduce bus travel times by about 2% compared to the existing PTPS. This value is almost identical to the expected value calculated in theory. Therefore, the priority control was judged to be operating as designed.

To validate the number of bus passage check points, a simulated comparison was made between cases with two and three points, the results of which confirmed that bus travel times can be very slightly reduced by 0.1% when three points were provided. However, considering that the existing signal controllers cannot be used for realizing such a system and because of the low cost effectiveness of providing three points, a system with two check points was judged optimal.

3.2. Effectiveness verification using model system

(1) Outline of effectiveness verification

The purpose of the effectiveness verification using a model system was to verify system operation under various real environmental conditions, to verify design methods, and to identify the influence of parameters on the effectiveness of the system, thereby obtaining findings capable of maximizing the effects of such parameters with a view to implementing the system in other areas in the future.

The verification was conducted using the model system installed in fiscal 2016 by the Tokyo Metropolitan Police Department at the intersection in front of Tokyo Wangan Police Station and test vehicles (two buses, one light truck and three passenger cars) prepared by automotive manufacturers.

https://maps.gsi.go.jp/

Fig. 4 Test site (Tokyo Odaiba area)

(2) Main verification items and results of verification

Before implementing the bus priority control, the range of ITS wireless communication using the 700 MHz band and the GNSS accuracy were checked. Some routes are covered by radio communication with a range of about 300 m or more, and others with a range of about 200 m. Therefore, confirmation is necessary for each area where the system is introduced. GNSS accuracy errors are a few meters or less in most areas, with relatively large errors observed on route 3, which was assumed to be due to the effects of buildings beside the road.

In the verification of bus priority control operation, three operation cases (with green extension control, without red truncation control, and without control) were confirmed to be operating normally based on the logs in the on-board units and central computer. In particular, it was confirmed that green extension times were extended appropriately at bus passage check point 2 (see “Figure 5 Green extension control results”).

The effectiveness evaluation at the intersection downstream of the bus stop confirmed that effective priority control can be achieved by setting the first bus passage check point further upstream, although it is difficult to predict the bus acceleration status.

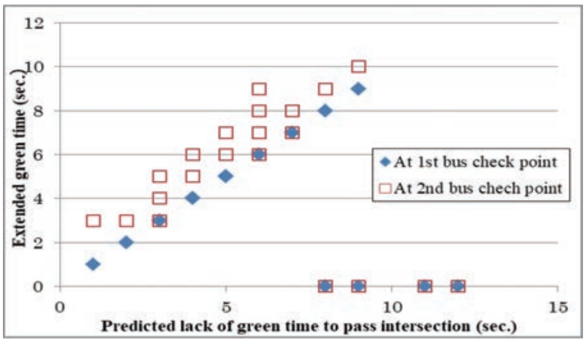

Fig. 5 Result of the green extension control

4 Conclusion and Future Issues

Through the real-world verification using ITS wireless roadside units, on-board units, and a central computer supporting the enhanced PTPS, it was confirmed that bus priority control using the 700 MHz ITS wireless communication is achievable.

The operation verification required time and effort because logs had to be collected from on-board units and the central computer, respectively for analysis. It would be desirable to realize a function that can readily determine the success, failure, and effectiveness of bus priority control. Also, when applying the system to intersections where large GNSS errors are detected, it is recommended that the accuracy of GNSS be confirmed in advance and the occurrence of wasteful green traffic signal time be verified after applying the system.

A Study on the Speediness and Safety of Advanced Rapid Transit

Daisuke Oshima, Akira Mitsuyasu, Takane Imagawa (Pacific Consultants Co., Ltd.)

ABSTRACT: This study on the speediness and safety of the Advanced Rapid Transit (ART) system involved the building of on-board units for a Public Transportation Priority System (PTPS), and the evaluation of the effectiveness of the resulting Advanced PTPS. Specifically, the basic requirements were designed for the advanced PTPS on-board units, which communicate with roadside units that control traffic signal timings (i.e., to extend the green light interval or truncate the red, based on bus locations sent by the on-board units). These units also have a priority arbitration function, which grants priority over other buses when a bus meets the criteria for priority, as well as an HMI function, which notifies the priority status information and supports passage through the intersection. The extent to which Advanced PTPS improves timeliness and speediness, and its effects on general traffic were evaluated. It was clarified that Advanced PTPS and priority arbitration can improve both speediness and timeliness.

1 Overview

A Public Transportation Priority System (PTPS) is a means for improving the timeliness and speediness of buses running among general traffic. PTPS ensures priority for public transportation by means of priority signal control, which controls the timing of traffic signals to allow public transportation vehicles to pass through signalized intersections without stopping, and includes the introduction of priority roads for public transportation. PTPS has been introduced throughout Japan. A vehicle-to-infrastructure communication system using optical beacons, which is conventionally used in PTPS, communicates once before the vehicle enters an intersection. In contrast, the National Police Agency, which oversees traffic managers across Japan, considered that more flexible priority signal control could be realized by utilizing the 760 MHz band that had been allocated to ITS following the digitalization of terrestrial television broadcasting, and the Agency has been examining the development of roadside units (roadside ITS radio sets, hereinafter referred to as "roadside units") for that purpose. Therefore, the following research and development has been conducted in the current project from FY2015 to FY2018:

(1) Examination of the functional requirements for on-board units that communicate with Advanced PTPS roadside units and the building of prototypes

(2) Simulated evaluation of the extent to which Advanced PTPS improves timeliness and speediness and how it affects general traffic

(3) Evaluation of the effectiveness and influence of Advanced PTPS through a field operational test

(4) Research into the introduction requirements, issues, and effectiveness of the nationwide deployment of Advanced PTPS

2 Examination of Functional Requirements for On-Board Units that Communicate with Advanced PTPS Roadside Units and Building of Prototypes

2.1. Functions of Advanced PTPS

A conventional PTPS detects the passage of target vehicles using an optical beacon installed at only one point upstream of an intersection, predicts the timing of arrival of the vehicle at the intersection, and extends the green signal or truncates the red. Meanwhile, by using 760 MHz band radio communication, Advanced PTPS can (1) improve communication performance over obstacles and distance, (2) allow continuous communication, (3) allow interactive communication, and (4) cover buses on all approach routes with one beacon. These measures will help to overcome the restrictions on installation locations for PTPS roadside units, reduce the introduction cost, react to vehicle speed changes in real time, inform the bus driver of the status of priority control on the relevant approach route, and detect the approach of multiple buses and determine which bus is to be prioritized. This research aimed to develop on-board units with the following three functions.

The first is a function for communicating with the roadside units. A roadside unit has two determination points (the first and second virtual beacon positions) upstream of an intersection to detect the passage of a bus, predicts the time of arrival of the bus, which is making a priority request, at the intersection at each point, and controls the signal timing (extends the green light interval and truncates the red) in two stages accordingly. Meanwhile, the on-board unit transmits position information, the validity of the priority request, and other information to the roadside unit so that the unit can detect the passage of the bus. The second function is the HMI, which allows the on-board unit to identify the priority control status by receiving downlink information (e.g., DSSS signal information)

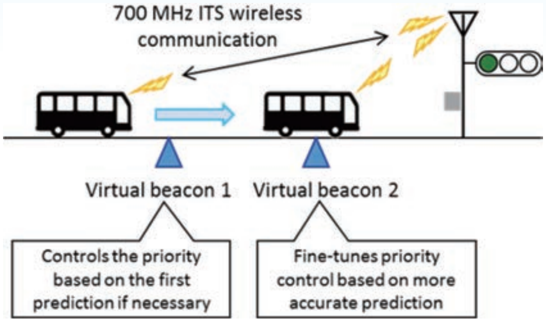

Fig. 1 Image of multistage control in Advanced PTPS

from the roadside unit so that the unit can assist passage through the intersection (acceleration/deceleration support), while providing the driver with priority request information. Figure 2 shows the intersection passage support on the screen of the HMI under development. If the signal turns yellow when a bus enters a signalized intersection and the bus brakes hard, it is dangerous since it may cause passengers in the bus to fall over. Therefore, minimizing the frequency of buses stopping in signalized intersections, while providing drivers with intersection passage support information, contributes to safer bus operation. The third function is priority arbitration. For example, if several buses approach an intersection at the same time, this function transmits "Priority request: Valid" to the roadside unit only for a bus that urgently requires priority due to a significant delay or the like, and "Priority request: Invalid" for other buses of lower priority, so that the bus in urgent need is prioritized. The validity of the priority request is determined by the on-board unit by comparing the vehicle status index with the preset threshold (the criterion for priority). For the priority index, the delay time, congestion degree, combinations thereof, and specific time zone and route designation were examined. In addition, more appropriate priority arbitration may be possible by identifying the bus that urgently needs priority in real-time from the real-time operation status of multiple buses. Therefore, two approaches were tried: the first used a fixed threshold preset in the on-board unit (static threshold), and the second used a threshold that was successively updated based on the operation status of multiple buses (dynamic threshold) in collaboration with the ART Information Center function, which is separately conducting

Fig. 2 Intersection passage support screen

research and the like. Determining the threshold based on the operation status of multiple buses was accomplished by multiplying the highest priority index by a certain coefficient. Among the priority indices, "crowdedness" was defined based on an approximate classification of the number of passengers estimated by the ART Information Center function using in-vehicle cameras.

2.2. Examination of functional requirements for on-board units and building of prototypes

An Advanced PTPS on-board unit was designed to transmit and receive information using a 760 MHz band radio set, identify the vehicle status from the information provided by GPS and CAN, obtain information in collaboration with existing bus location systems and the ART Information Center function, which is separately conducting development, determine the priority request necessity, and provide appropriate information to the driver using HMI such as displays. The main requirements are listed in Table 1. In addition, an on-board unit that meets the requirements was developed. As shown in Fig. 3, the unit consists of an on-board PC connected with a 3G USB dongle for 3G communication, a sensor unit for receiving GPS information and vehicle speed pulses, a monitor with an HMI function, an antenna for 760 MHz communication, and a 760 MHz radio set.

2.3. Functional verification

Functional verification of the developed on-board unit was carried out using passenger cars and the roadside unit installed at the intersection in front of Tokyo Wangan Police Station in FY2017. The results confirmed that the on-board unit worked as designed: that the setting information can be transmitted correctly between the vehicle and infrastructure, and that the HMI of the on-board unit is accurate enough to inform the driver of the priority status. Figure 4 shows the difference in time required for vehicles to pass through the signalized intersection resulting from the extension of the green signal, which was confirmed through the verification. The priority arbitration function was also verified. Specifically, the on-board unit was confirmed to be able to determine the validity of the priority request of the vehicle based on the threshold preset in the unit and to transmit the validity information to the roadside unit. Furthermore, the on-board unit was confirmed to be able to determine the threshold after considering the ART statuses (the delay time and congestion degree) of multiple vehicles in collaboration with the ART Information Center function, and then determine the validity of priority request accordingly.

Table 1 Main requirements for an Advance PTPS on-board unit

Requirement	Description
Communication	· Transmit the vehicle status, including the vehicle position and vehicle speed, as well as PTPS priority request to the roadside unit. · Receive information on the availability of the PTPS service, signal information, and other information from the roadside unit. · Transmit and receive bus operation information and management information to and from the ART Information Center.
Situation identification and determination	· Obtain information on the shape of the intersection, positions of virtual beacons, and signal indications. · Identify the operational status, including the delay time and congestion degree, in collaboration with the bus location system and the ART Information Center. · Identify the signal information and the validity of priority request. · Determine whether the vehicle can pass through the intersection during a green signal and calculate the target deceleration.
Information to driver	· Inform the driver of the validity of the PTPS priority request. · Provide the driver with intersection passage support information.
Priority arbitration	· Compare the priority index of the vehicle with the threshold for priority request in collaboration with the ART Information Center, and transmit the priority request to the roadside unit if the index exceeds the threshold.

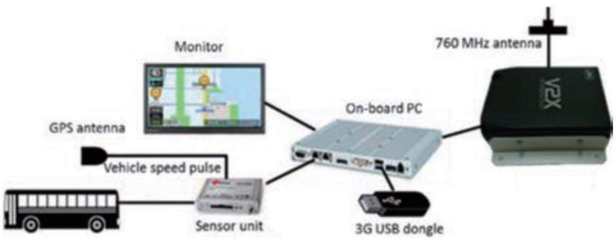

Fig. 3 Configuration of the Advanced PTPS on-board unit

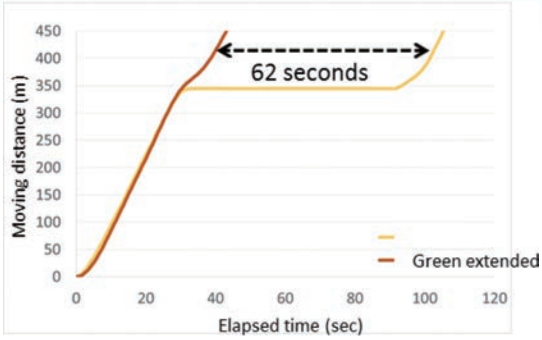

Fig. 4 Difference in transit time due to extension of green signal time

3 Simulation Evaluation of the Extent to which Advanced PTPS Improves Timeliness and Speediness and How it Affects General Traffic

The extent to which Advanced PTPS improves timeliness and speediness, and how it affects general traffic were evaluated through simulation using the micro traffic simulation software "VISSIM."

3.1. Verification on Tokyo Ring Road No. 2

Simulated verifications were carried out in some sections (Kachidoki intersection, Harumi 5-chome intersection, and Toyosu New Market intersection) of Tokyo Ring Road No. 2, as shown in Fig. 5. The results showed that introduction of PTPS reduced the travel time by approx. 30 seconds (about 7%) (Fig. 6). Priority arbitration decreased the maximum delay from the schedule by 69 seconds (about 8%). Priority arbitration also decreased the average delay time by approx. 30 seconds (about 13%). Furthermore, due to variation in delay time, the dynamic threshold is less dispersed than the static threshold after priority arbitration (Fig. 7).

3.2. Simulated verification assuming a virtual local city

Simulated verification assuming a local city other than Tokyo was carried out by constructing a virtual network as shown in Fig. 8. A network was constructed to include a main road running east–west and two narrow east–west streets sandwiching it, intersecting with five main roads running north–south and several narrow streets parallel to them. Then, the road through which the eastbound and westbound buses pass (hereafter referred to as the "center main road," see Fig. 8) was changed to a two-, four-, or six-lane road in order to simulate several cases of road structures and regulations. Advanced PTPS was set up at each of three signalized intersections in the center of the center main road.

② Sophisticated Local Transportation Management

A Study on the Speediness and Safety of Advanced Rapid Transit

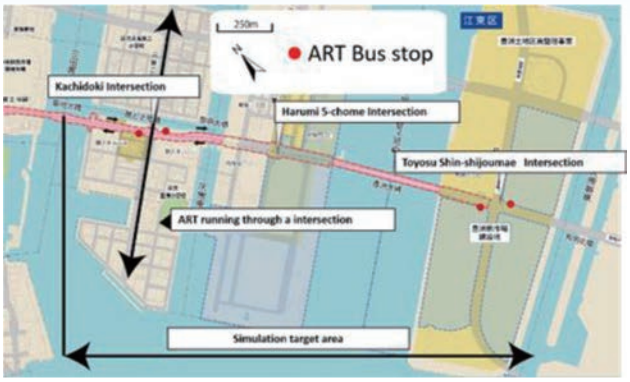

Fig. 5 Simulated verification sections of Tokyo Ring Road No. 2

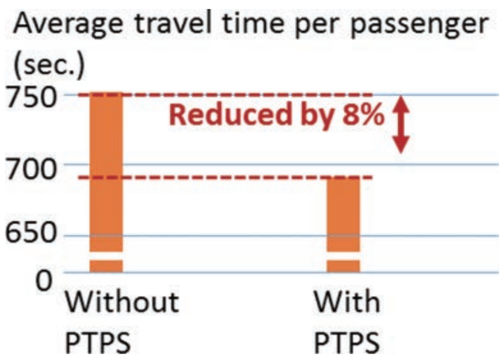

Fig. 6 Results (travel time)

As a typical result, Fig. 9 shows the number of buses delayed by five minutes or more in terms of average travel time per passenger on a six-lane road. On the four- or six-lane road with a dedicated bus lane, the average travel time of buses was found to be significantly reduced, also resulting in less variation in travel time. Moreover, it was shown that additionally introducing Advanced PTPS reduced the average travel time by more (reduced by 16% in the case of a six-lane road), significantly improving the speediness and timeliness of buses.

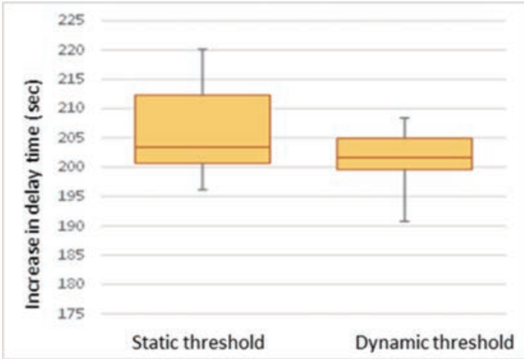

Fig. 7 Results (Variation in delay time)

4 Evaluation of the Effectiveness and Influence of Advanced PTPS through Field Operational Test

To verify the improvement effect on the speediness of buses, a field operational test using the roadside units installed at three points on Tokyo Ring Road No. 2 is scheduled to be conducted from November, 2018. Two route bus-size buses will be used for the test. The test is scheduled to be performed along a section from the Toyosu Market Entrance to the Ariake Station area on Tokyo Ring Road No. 2 where Advanced PTPS roadside

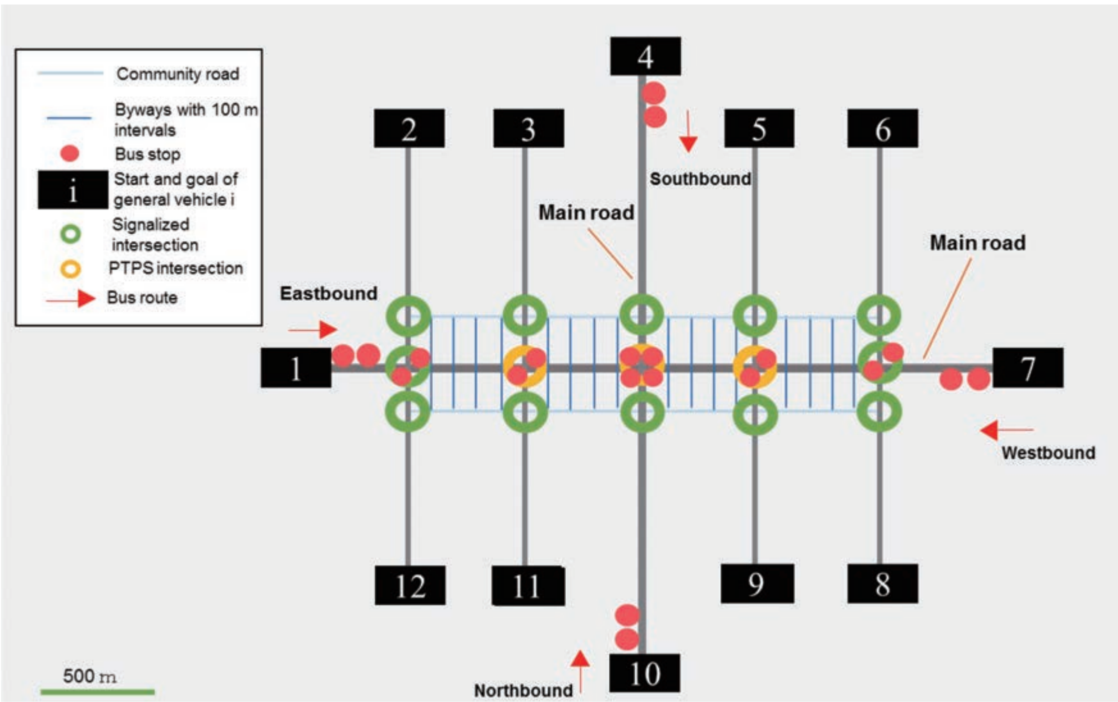

Fig. 8 Simulated virtual network assuming a local city

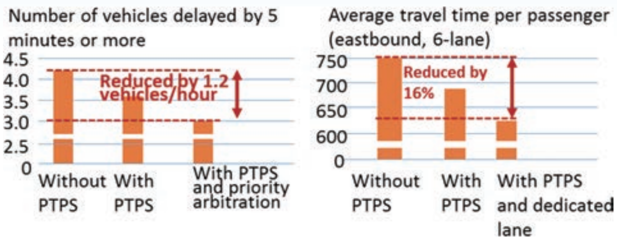

Fig. 9 Results (Average travel time and number of delayed vehicles)

units have already been installed. For details, refer to "Large-scale Field Operational Tests on Advanced Rapid Transit."

5 Research into Introduction Requirements, Issues, and Effectiveness of Nationwide Deployment of Advanced PTPS

5.1. Introduction requirements and issues

To identify the feasibility of introducing Advanced PTPS in cities across Japan, a survey of relevant organizations such as local governments and bus companies was conducted mainly in areas where bus rapid transit (BRT) was recently introduced and areas that are considering introducing BRT. The results showed that the challenge ahead is how to ensure the speediness and timeliness of buses and that many local governments, especially those that are considering introducing BRT, need to introduce PTPS in order to solve the challenge. However, issues of project cost and gaining a consensus on introducing PTPS were also found. In one area where PTPS using optical beacons has already been introduced, there was an opinion that although beacons need to be updated, it is difficult to quickly introduce new types of facilities due to the cost. Meanwhile, Advanced PTPS controls multiple routes and intersections with one roadside unit. Therefore, if the superiority of Advanced PTPS over optical beacons in the initial installation cost can be demonstrated, it may possibly persuade organizations to introduce Advanced PTPS. There was also an opinion that it is difficult to gain a consensus on introducing PTPS. To do so, it is important to present the quantitative effects of PTPS by, for example, estimating the effects on general traffic in addition to the improvement in speediness and timeliness of buses.

5.2. Simulation verification assuming a local city

In the future, we plan to select two cities from the area surveyed, simulate bus operations on actual bus routes in the cities, and verify the effects of introducing Advanced PTPS.

6 Conclusion

This research showed the following:

(1) Regarding the examination of functional requirements for on-board units that communicate with Advanced PTPS roadside units and building of prototypes, the basic requirements for Advanced PTPS were examined, and prototypes were built based on the results. One of the features of the prototype unit is that it supports a priority arbitration function, that is, when several ART vehicles approach an intersection at the same time, the PTPS on-board unit in each ART vehicle determines the priority of the vehicle and determines the validity of the priority request, so that the vehicle to be prioritized is determined appropriately. In addition, by linking with the ART Information Center function, it was possible to dynamically control the priority considering the operation statuses of multiple ART vehicles.

(2) Regarding research into the introduction requirements, issues, and effects of the nationwide deployment of ART and Advanced PTPS, a survey of relevant organizations such as local governments and bus companies was conducted. The results showed that many local governments need to introduce Advanced PTPS but there are issues of project cost and gaining a consensus.

(3) Simulated evaluations of the extent to which Advanced PTPS improves timeliness and speediness, and how it affects general traffic were carried out using a road network in a virtual local city and Tokyo Ring Road No. 2. The results showed that Advanced PTPS and priority arbitration can improve both speediness and timeliness. In the remaining research period, we plan to conduct demonstration experiments on public roads as well as simulations in order to confirm the effectiveness of Advanced PTPS on actual public roads. We also plan to verify its effectiveness through simulation in local cities with a view to nationwide deployment. In the future, it will be necessary to coordinate actual installation with bus companies and local governments in areas where there is a strong need for PTPS, examine the HMI of the PTPS on-board unit and the method of priority arbitration after considering costs and operation, and make proposals according to the local situation, to encourage the actual introduction of Advanced PTPS.

② Sophisticated Local Transportation Management

Development of ART Information Center Function

Chiemi Tsuchiya, Kojin Yano, Miyu Tsukamoto, and Junko Ushiyama (Hitachi, Ltd.)

ABSTRACT: The functions of an Advanced Rapid Transit (ART) information center were investigated to help realize services using ART-related information and to associate various public traffic information. Experimental receiving/publishing data APIs were produced to realize five ART information center functions. A bus information-provision service for bus users was developed to exemplify the function of utilizing the information collected and stored in ART information center platform. We plan to investigate the usefulness of the information and the service provided by ART information center function in a large scale field operational test from October to November 2018.

1 Purpose

An Advanced Rapid Transit (ART) information center is an open platform for the collection and utilization of information related to public transportation. Its purpose is to help resolve transportation-related issues by providing valuable information and services to both the operators and users of public transportation, including ART (Fig. 1). In this report, we describe platforms within the ART information center and a bus information-provision service as an example of the utilization of the information collected and stored in the ART information center platform.

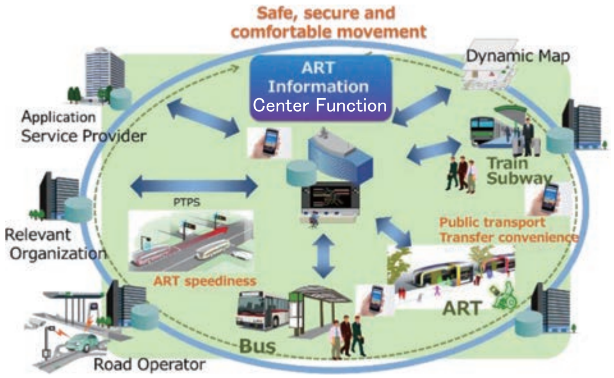

Fig. 1 Overview of ART information center function

2 Functions and Services of ART Information Center

We defined the following two rules for the ART information center. One is to collect and store information related to public transportation, such as bus operation information and various information obtained from on-board devices in the ART system or buses. The other is to modify the information collected and stored into an easy-to-use format and share it with traffic business operations and application developers. The functions of the ART information center and information provision services are shown in Fig. 2. The information collected and stored in the ART information center, such as information from the on-board devices in buses, is shown in the upper part. The information and services provided to business operators of public transportation and passengers are shown in the bottom. The following five functions of the ART information center are shown in the middle.

- PTPS priority mediation function
- Getting on/off announcement support function
- Degree of crowding announcement support function
- Dynamic connection announcement support function
- Forecasting of congestion function

The getting on/off announcement support and forecasting of congestion functions were developed in collaboration with SIP-PJ "Improving the speediness of ART with advanced PTPS" and SIP-PJ "Investigation of methods for forecasting traffic congestion and guiding congestion avoidance", respectively. These functions collect and store traffic information, which is processed in accordance with each user's requirements and shared with them. As a result, the information given by the ART information center will help passengers to utilize public transportation more conveniently.

2.1. ART information center platform

The ART information center is composed of five functions as shown in Fig. 3. In the inbound data platform (1) and data portal platform (2), the common interface and APIs are prepared so that plural business operators can utilize different data structures in various system applications. Six APIs for receiving data were developed (e.g., a bus location data-receiving API and a bus crowding information-receiving API). Six APIs for publishing data were also developed (e.g., a PTPS priority decision-providing API and a target bus estimated time of arrival (ETA)-providing API). The data format, such as longitude and latitude, depends on the business area and data processing systems. Therefore, the ART information center also has a data format transformation function. The data storage and analysis platform (3) collects data using the APIs, modifies/transforms the data in accordance with the users' purposes, and shares the data with them. The support platform for application developers (4) supplies the application developers with the data stored in the ART information center using the development support tool/function. The

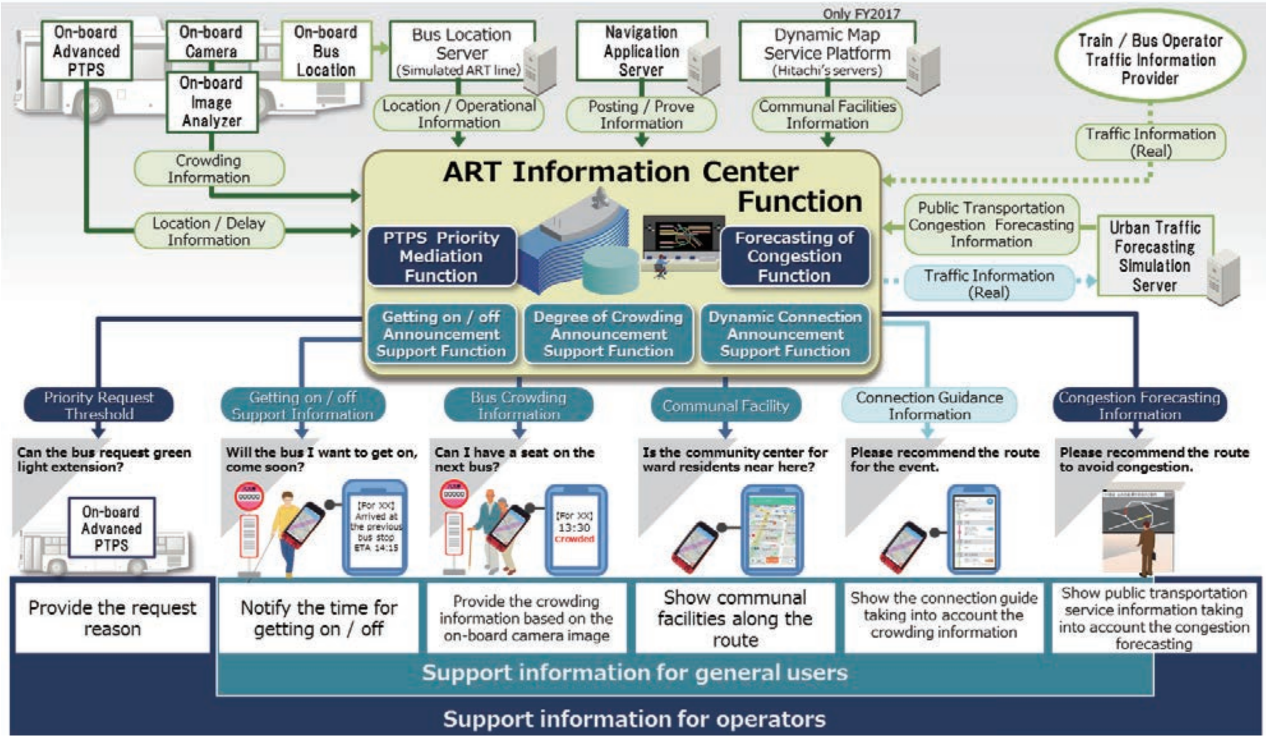

Fig. 2 Functions of the ART information center and information provision services

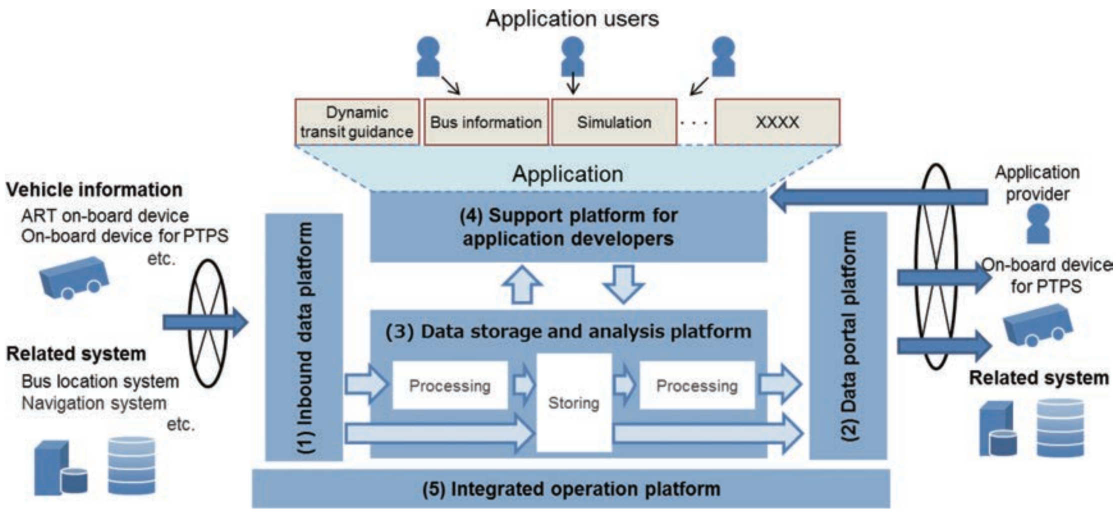

Fig. 3 Block diagram of the ART information center platform

integrated operation platform (5) manages security and resources by controlling the ART information center.

2.2. Bus information provision service

In the SIP-PJ "A research of the pedestrian support system common platform", field verifications were performed with the cooperation of people with limited movement capabilities, such as visually impaired people and wheelchair users. As a result, the necessary information for transfers was studied and evaluated. It was found that these people want to know how close an approaching bus is to them and how close their bus is to the destination bus stop. Information on approaching buses on each route is already provided in some areas. However, it is difficult to specify which bus should be selected when the bus stop serves plural routes. It is important to supply bus passengers with information about the approaching bus that they want to ride and information about how close the bus is to the destination bus stop from their point of view. We developed an application that notifies bus passengers about how close and how crowded approaching buses are to exemplify the function of utilizing the information collected and stored in the ART information center platform. The application is run on two smartphone platforms (Android OS and iOS).

The outline of the information service about how close and how crowded approaching buses (hereinafter called the "bus information-provision service") are shown in Fig. 4. The bus information-provision service can collaborate with the navigation service. The information is created using the information about the travel route obtained by the navigation system and the information stored in the ART information center platform (bus stop, crowding level, timetable, estimated arrival time, etc.), and notified to bus passengers. The information displayed on the screen can be provided audibly using a smartphone, and switched ON or OFF.

The bus information-provision service is started by pushing the button shown on the page of the route found via the navigation service (1). On the smartphone screen, the estimated arrival time and the crowding level are shown for the selected bus (2). In the development, we categorized four levels of bus crowding. In addition, we defined occupied/vacant information for wheelchair spaces. Bus passengers are notified of whether the bus they are planning to ride has reached the nearest bus stop or not and how close the bus is to their bus stop (3)(4). After getting on the bus, they are notified of whether the bus has reached the nearest bus stop and how close the bus is to the scheduled destination bus stop (5)(6). The information is notified by pop-up displays, sounds, or vibrations.

The bus crowding level is categorized using images from on-board cameras. An on-board tool for image analysis was developed in this project. The crowding level information processed by the on-board tool is sent to the ART information center platform at intervals fixed in advance. Some of the information handled by the on-board tool is shown in Table 1. The camera images are not stored in the ART information center platform from the standpoint of personal information regulations.

Last year, we took pictures of the inside of a bus and analyzed them (Fig. 5). Four cameras were used in the bus, with one focusing on the wheelchair space. As a result, it was confirmed that the analysis of the limited area observed by the four cameras was an effective way of identifying the crowding level of the whole bus. Camera images are shown in Fig. 6. It was clarified that the crowding level

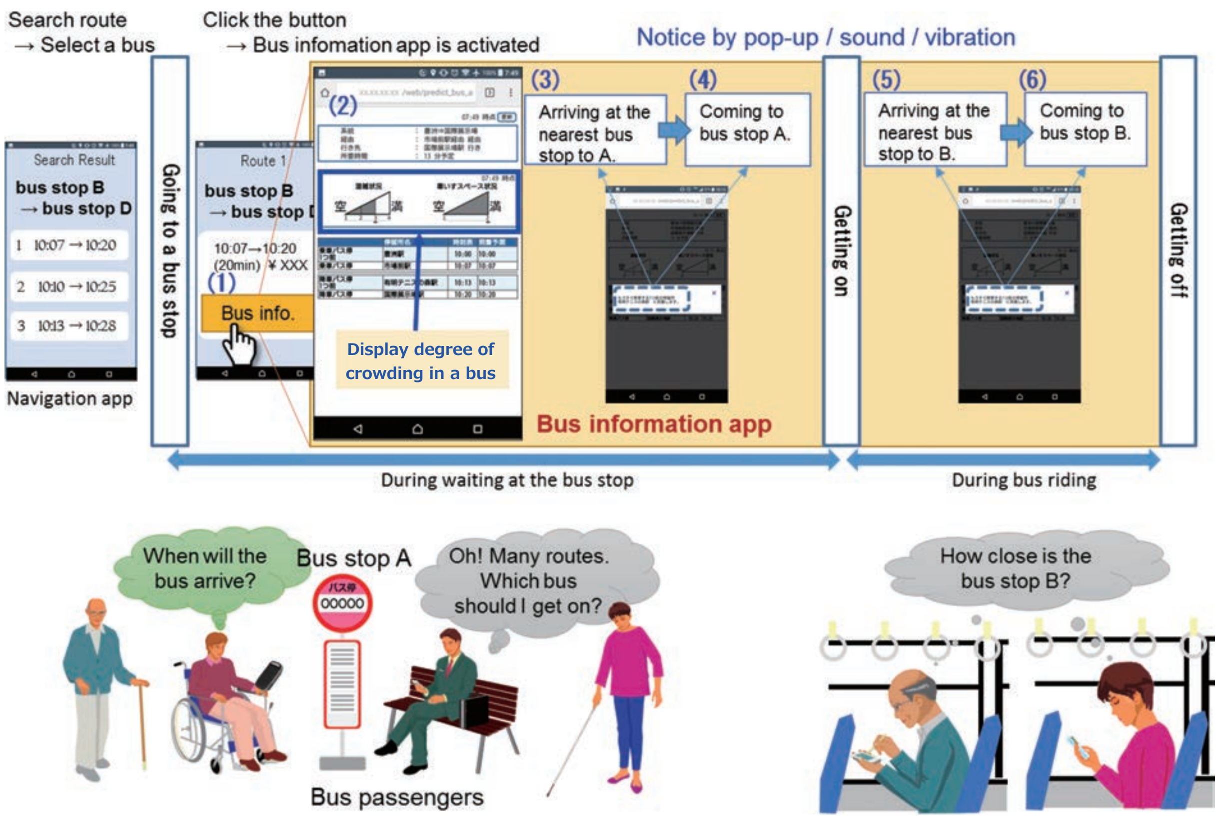

Fig. 4 Outline and use scenarios of bus information-provision service

Table 1 Information handled by the on-board tool (extract)

Item	Value
Crowding level	1~4 (1 : unoccupied seats, 2 : All seats occupied, 3 : Space in Aisle, 4 : Fully crowded)
Crowding Information	Analyzed headcount (countable)
Wheelchair space occupancy	0 : unoccupied, 1 : occupied

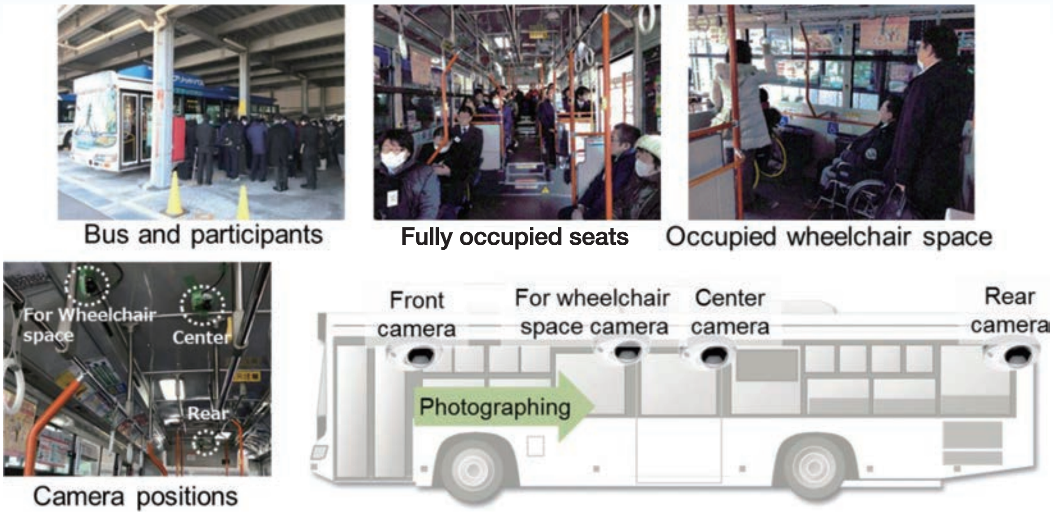

Fig. 5 Field verification of providing bus crowding information

Fig. 6 Images from on-board cameras

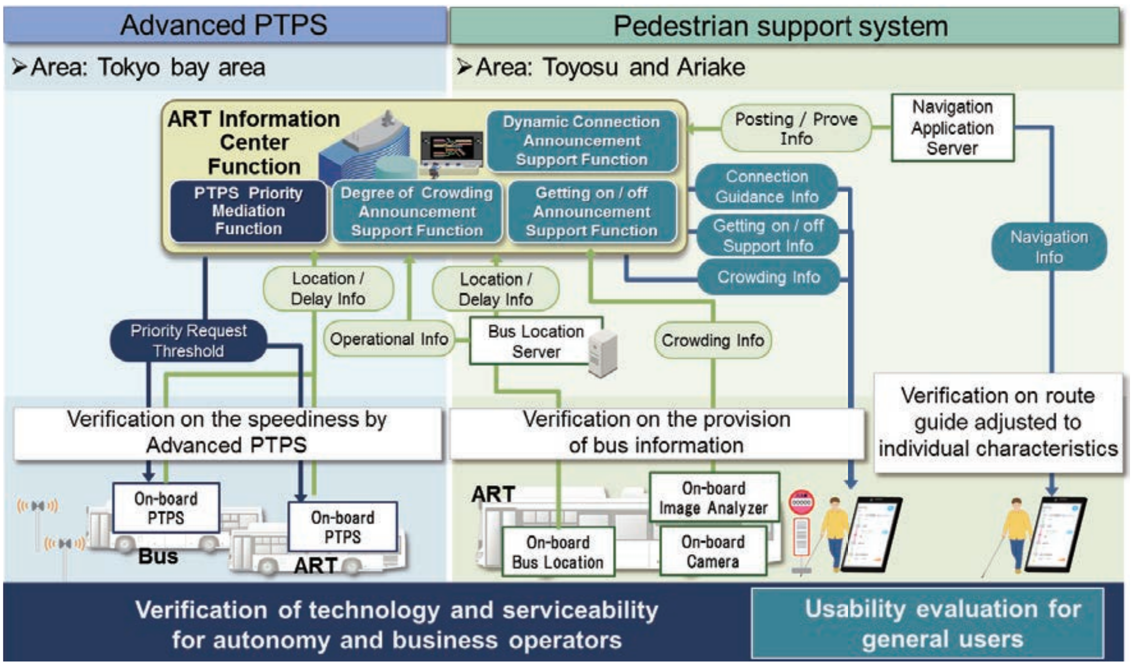

Fig. 7 Operation of the ART information center function in large-scale field operational test

of the whole bus is difficult to identify using images from the rear of the bus due to interference by standing passengers in non-step buses because the floor is higher at the rear. Therefore, to precisely understand the crowding level, we decided to use a combination of three camera images taken at the front, center, and rear.

These results will be verified in the test to be held in October.

3 Verification in Large-scale Field Operational Test

The ART information center function will correlate and share the data in the large scale field operational test to verify the results of the pedestrian support system common platform and improvements in the speediness of ART using advanced PTPS (Fig. 7). The field operational test will be conducted from October to November in 2018.

In the test to verify the improvements in the speediness of ART using advanced PTPS, the ART information center platform obtains bus position and delay data from the onboard Advanced PTPS. The ART information center platform gives it a priority request threshold set by the PTPS priority mediation function.

In the test to verify the results of the pedestrian support system common platform, the ART information center platform provides bus passengers with a bus information sharing service using the crowding degree announcement support function and getting on/off announcement support function via a smartphone application. The test participants will be asked whether these functions supply information and services as well as expected. The usefulness of the information and services will be also evaluated in the field operational test.

4 Conclusion

The ART information center is a traffic information infrastructure that collects various kinds of information on public transportation, modifies it into an easy-to-use format, and shares it to traffic business operation and application developers. Here, we developed five functions and six necessary APIs. It was confirmed that external systems can handle the data obtained by the APIs developed in this experiment. We developed an application to share the information to bus users to demonstrate how well the data processing in the ART information center platform is working. In a field operational test to be held in the near future, we will investigate the usefulness of the information and services provided by the ART information center platform.

Investigation of Methods for Forecasting Traffic Congestion and Guiding Congestion Avoidance

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ABSTRACT: The purpose of this study is to identify behavioral and psychological characteristics by analyzing a large quantity of data about major events held in Tokyo in close cooperation with relevant entities, including the Olympic Organizing Committee, the Tokyo Metropolitan Government, and railway/bus operators. We are conducting social experiments regarding behavior modification and guidance targeted at relatively major events to form and verify hypotheses of models to be used for congestion prediction. Based on these verification results, we intend to suggest a new scheme that can provide congestion predictions and traffic information appropriate for the 2020 Olympic and Paralympic Games to minimize impacts on individuals attending or affected by the games, mainly by targeting people who will visit the Olympic and Paralympic Games and citizens that live or work in Tokyo and use public transportation including Advanced Rapid Transit (ART).

1 Objectives and Goals

This study is conducting experimental surveys to estimate the effects of measures to avoid congestion, considering examples of methods to forecast traffic congestion and congestion-avoidance guidance. Then, based on these results, traffic conditions during a major event are being simulated, and draft plans for a demonstrative experiment are being drawn up. Effective traffic congestion-avoidance measures will be suggested based on the results of this demonstrative experiment.

2 Outline of Overall Information Provision Scheme

2.1. Basic understanding

To consider the prediction and mitigation of congestion during a major event like the Tokyo Olympic and Paralympic Games, a comprehensive framework is required to predict overall transportation demand based on the daily transportation demand. Especially for areas where greater transportation demand than normal is expected, this demand may not be satisfied by individual (existing) transportation facilities. Therefore, it is important for these facilities to work in cooperation with each other. In this case, citizens that usually use these transportation facilities must play an active role in reducing demand, including behavior modification.

To establish an overall scheme, it is also necessary to provide information on transportation services that matches the variety of visitors, including their nationalities, disabilities, ages, and the like, as well as their purpose of travel (including travel to Olympic venues, sightseeing, eating, and so on). At the same time, attention should be paid to provide information responding to unforeseen contingencies or emergencies.

2.2. Proposal of overall information provision scheme

For this scheme, it is necessary to 1) assume what transportation entities/purposes correspond to the following two types of transportation demand: normal daily trans-

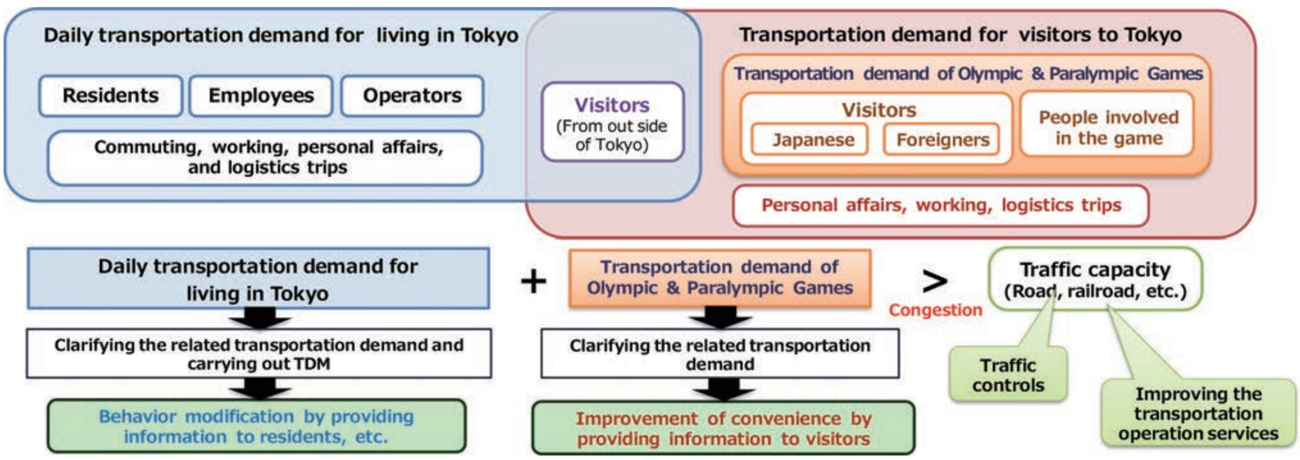

Fig. 1 Overall scheme of providing information for realization

portation in Tokyo and transportation for visitors (including transportation demand for the Olympic games), 2) provide hourly predictions for these two types of demand corresponding to the transportation entities, and 3) implement measures that allow to provide appropriate transportation services corresponding to the traffic volume.

At the same time, it is also important to provide transportation services and information for visitors of different nationalities, level of disability, age, and so on, including responses to unforeseen contingencies or emergencies. For this reason, to establish an overall information provision scheme, the issue with the highest priority is cooperation between the Organizing Committee of Olympic Games, the national and local governments responsible for transportation administration, the police, transportation operators, and other authorities. Based on this cooperation, it will be necessary to study the contents of information, how to provide the information, as well as the timing, feasibility, and impacts to encourage various transportation entities to change behavior.

3 Various Transportation Entities and Purposes to be Considered

It is necessary to focus on various transportation "entities" and "purposes" to predict congestion and to provide information for a major event. Transportation entities can be roughly divided into "individuals living in Tokyo" and "individuals visiting Tokyo." Some individuals living in Tokyo are residents of Tokyo, some are employees commuting to Tokyo, and some are "operators" who run businesses in Tokyo. Furthermore, it is necessary to consider individuals with mobility limitations, including elderly and disabled persons. Furthermore, although some visitors to Tokyo will be attending events, others will be there on business or the like. Also, some individuals living in Tokyo may also intend to attend events. By focusing on the transportation entities and purposes mentioned above, the different transportation characteristics of travelers can be identified (Table 1). For example, transportation for commuting in Tokyo is concentrated in the morning and the evening, mainly by rail. Transportation for commuting is also steady with small fluctuations.

Table 1 Transportation characteristics corresponding to various transportation entities and purposes, and matters to be considered

Transportation entities Purposes/attributes		Characteristics	Main mode	Stationarity	Matters to be considered
Commuting		Concentrated in the morning and the evening	Rail	Steady (small fluctuations)	Cannot be controlled easily by commuters
Working/logistics		Work occurs mainly in the daytime, but logistics occur at night as well	Vehicles (or rail if no luggage)	Rather steady	Some demand cannot be controlled when an event occurs
Personal affairs		Mainly take place in the daytime	Rail	Unsteady	
Individuals with mobility limitations (daily transportation)		Mainly travel in the daytime	Walking/ bicycle	Rather steady	Have limited transportation modes, routes, and times
Travel not for an event		Mainly occurs in the daytime.	Rail/ taxi	Unsteady (large fluctuations)	Some demand cannot be controlled when an event occurs
Event	Individuals with mobility limitations (non-Japanese people, etc.)	Occurs in addition to normal demand, and such individuals have little knowledge about transportation conditions in Tokyo	Rail/ taxi	Unsteady (large fluctuations)	Have limited available transportation modes, routes, and times, and cannot understand publications in Japanese
	Japanese (visits from outside Tokyo)	Occurs in addition to normal demand, and such individuals have little knowledge about transportation conditions in Tokyo	Rail (some by bicycle)		Cannot access publications targeted only for the Tokyo area.
	Visitors from the Tokyo metropolitan area	Occurs in addition to normal demand, and such individuals have little knowledge about transportation conditions in Tokyo	Rail		May make decisions based on daily transportation conditions

4 Outline of Traffic Congestion Forecasting and Congestion-avoidance Guidance (Current Situation)

We are trying to avoid traffic congestion based on a behavioral modification process, by providing the appropriate information depending on individual attributes and situations. We are also trying to forecast traffic situations dynamically in cooperation with the ART Information Center (Figs. 2, 3).

Most recently, we have simulated traffic situations using a traffic simulator (by applying agent-based modelling), integrated with behavioral modification based on the information provided (Fig. 4).

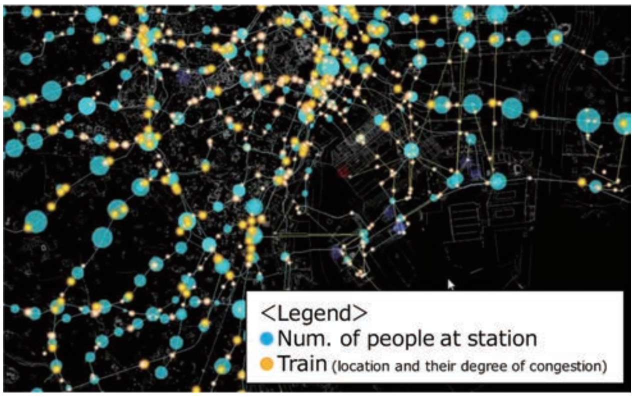

Fig. 2 Simulation output (example)

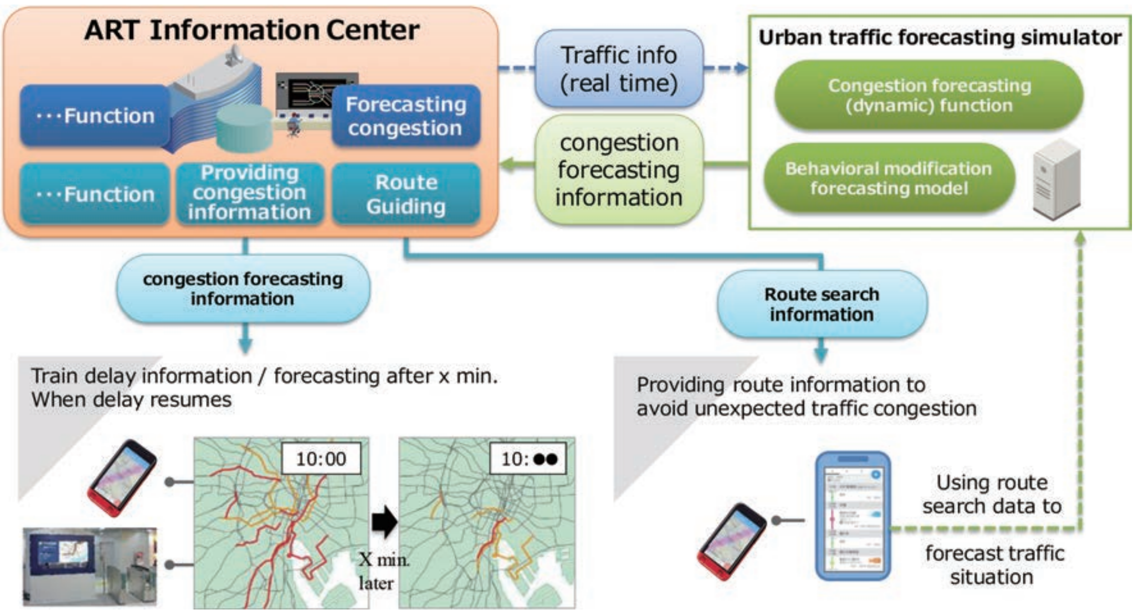

Fig. 3 Outline of traffic congestion forecasting and congestion-avoidance guidance

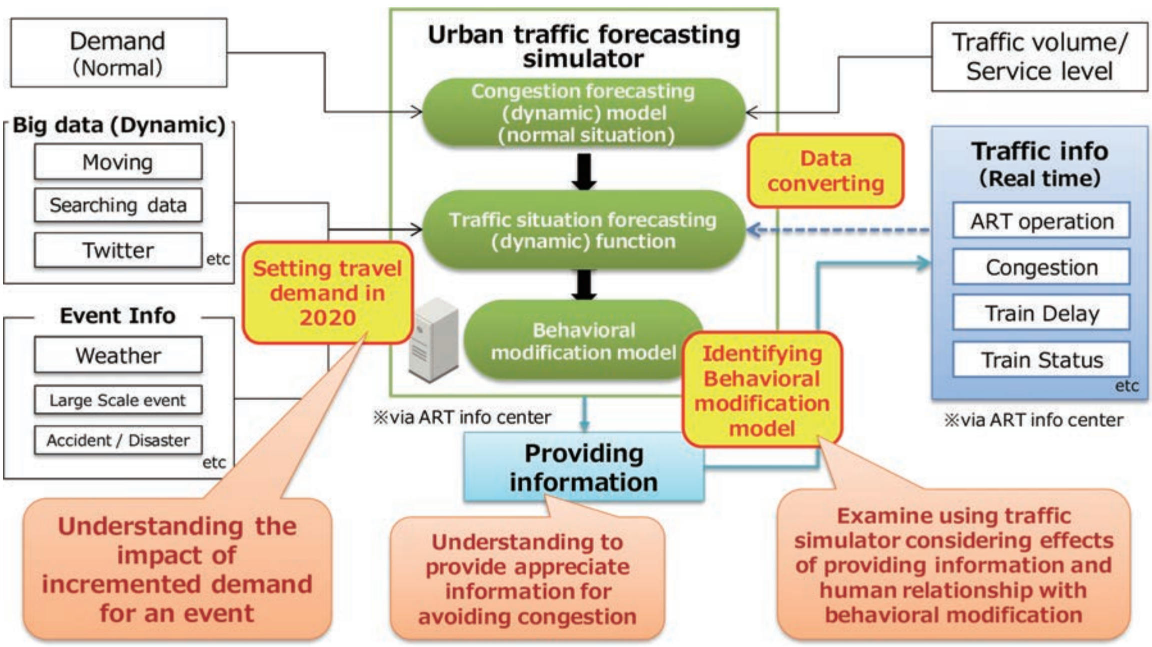

Fig. 4 Outline of urban traffic forecasting and information provision (current situation)

③ Improvement and Popularization of Accessible Transportation (Initiatives for People with Restricted Access to Transportation)

Development of Movement Support System for People with Mobility Constraints

Yukiko Hatazaki (UTMS Society of Japan)

ABSTRACT: As Japan faces a super-aging society, movement support for people with mobility constraints has become an important social issue that needs to be addressed. To cope with this situation, technology development, as well as research and surveys are in progress to help realize safe, secure, and smooth movement support for people with mobility constraints that also satisfies convenience and economic rationality requirements. The UTMS Society of Japan is working on the enhancement of the existing Pedestrian Information Communication Systems (PICS) and proceeding with studies to help realize services that provide intersection crossing support using smartphones.

1 Purpose

During the 2020 Tokyo Olympic and Paralympic Games, heavy traffic is expected due to visitors and spectators of the Games. Therefore, the provision of movement support for people with mobility constraints, including wheelchair users, has become an important element for the success of the Games. Movement support for people with mobility constraints is also a critical social issue in Japan, which needs to be addressed as the country faces a super-aging society. To cope with this situation, technological development, as well as research and surveys are in progress to help realize safe, secure, and smooth movement support for people with mobility constraints that also satisfies convenience and economic rationality requirements.

2 Background of the Development

The overall plan for the development of moving support systems for people with mobility constraints is shown in Fig. 1.

Research, surveys, and basic design activities were conducted from fiscal 2014 through 2015, during which problems in the existing systems were identified and draft measures were proposed. The results found that existing Pedestrian Information Communication Systems (PICS) are not as widely used as desired due to cost and maintenance problems resulting from the systems' high installation costs and availability, which is limited to the users of a dedicated hands-free terminal or long cane. Therefore, draft measures were proposed to provide services using smartphones that have become increasingly common, not only among people without disabilities, but also among people with mobility constraints.

In fiscal 2016 and after, an experimental system was set up and field verification is underway to identify the specifications of the system.

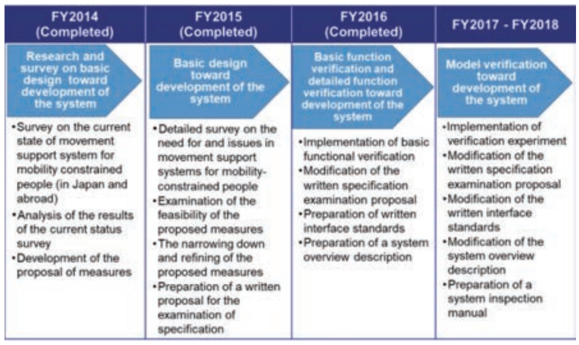

Figure 1 Overall plan

3 Outline of the New System

3.1. Services to be realized

The following two services were decided to be realized.

(1) A "signal information provision service" that provides information on the name of the intersection and the pedestrian signal status.

(2) A "pedestrian green signal time extension service" that extends the green time of the pedestrian signal.

3.2. Communication protocol

Bluetooth connection, which is standard with relatively new smartphone models, was chosen as the protocol for communication between the roadside equipment and smartphones.

3.3. User interface

Using a smartphone while walking on a busy street may result in accidents. This behavior is already recognized as a social issue. Therefore, smartphone applications were examined and a simple screen display was designed so that even people with weak eyesight can recognize the current traffic signal status displayed on the screen based on a voice or vibrotactile user interface.

3.4. Determination of service area

From the aspect of cost, it was decided that the poles on which traffic signal controllers are installed should be used for the Bluetooth transmission/reception units (hereafter referred to as "BLE beacons"). As a result, the communication area is within the radius of the pole on which the signal controller is mounted, which depends of the location of the pole. If the service is realized using one BLE beacon, it is necessary to transmit radio waves to the farthest sidewalk. However, this results in differences in the area on each sidewalk in which communication can be established. As a solution, it was decided that a location should only be defined as part of the service area when it is within a certain range from the center of the intersection, based on information from the smartphone GPS receiver. The relationship between the communication area and service area is shown in Fig. 2.

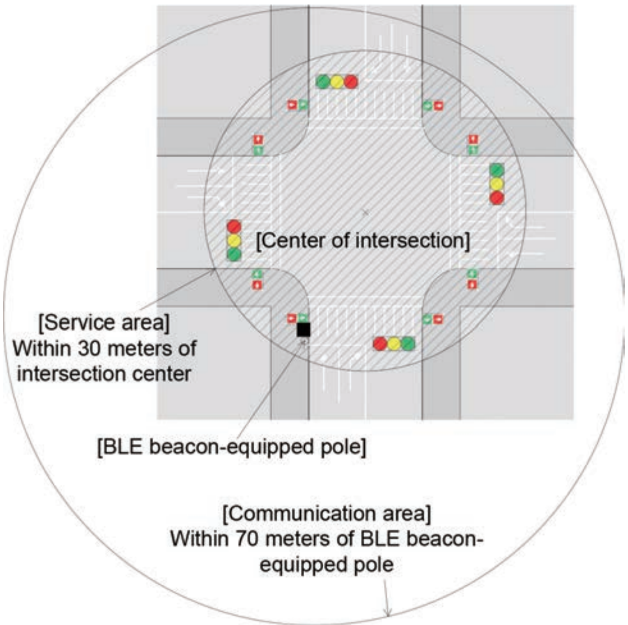

Figure 2 Service area

3.5. Application to large-scale intersections

Because the guaranteed range of radio wave coverage by one BLE transmission/reception unit is defined as a radius of 70 m, radio waves cannot cover the required range in the case of large-scale intersections. As a result, areas where tactile paving is installed for visually impaired individuals to wait to cross streets may not be covered by the service in some cases. People with visual impairment often feel unsafe when crossing intersections with long crossing distances. Therefore, it is important to provide support at large-scale intersections. To cope with this, more than one BLE transmission/reception unit must be installed at large-scale intersections to enable provision of the service.

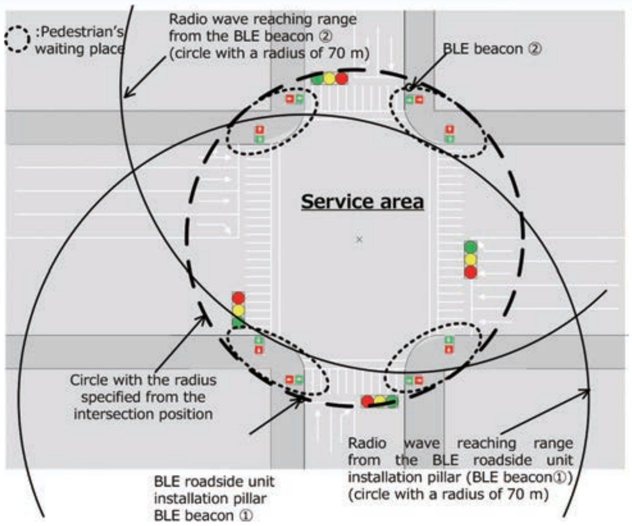

Figure 3 Range of radio wave coverage from two BLE transmission/reception units

3.6. Display of remaining pedestrian green signal time/wait time

Indication of the remaining pedestrian green signal time and the wait time until the pedestrian signal turns green has been implemented using countdown timers as a function of pedestrian signals. In order for visually impaired individuals to decide whether or not to start crossing a street, it was decided to introduce the same function to the developed system through smartphones.

Figure 4 Pedestrian signal lamp (indication of time passed)

4 Model Verification

4.1. Experiment location

A verification experiment was carried out at the Shinmisato Ekimae intersection in Saitama Prefecture in fiscal 2016 and at the Shintoshin (Nishi) intersection in Saitama Prefecture in fiscal 2017. The service was experienced by visually impaired people, and a questionnaire survey was conducted.

4.2. Results of the experiment

Evaluation was carried out using ten devices running "Andorid6.9" or higher, or "iOS" or higher and supporting

Bluetooth 4.0 or higher, with a dedicated application installed. The results found that all devices were able to properly provide the service. The questionnaire survey for visually impaired people who experienced the service showed that about 90 percent of the participants though that the service was necessary, and many comments were received to open-ended questions. The results demonstrated that visually impaired people are highly interested in this movement support service at intersections.

5 Conclusion

(1) Through model verification, it was confirmed that the developed system can be applied to real intersections.

(2) A questionnaire survey of people that experienced the service and discussions with experts confirmed the effectiveness of the movement support service at intersections using smartphones.

(3) Based on the results of the model verification and examinations, draft experimental specifications and draft standards were prepared. The draft specifications and standards prepared are described below:

- System definition document (draft) for a movement support system for people with mobility constraints using smartphones
- Written proposal (draft) for the examination of specifications for BLE roadside equipment
- Standards (draft) for an application that communicates between BLE roadside equipment and smartphones
- Written proposal (draft) for a BLE roadside equipment inspection manual
- Written proposal (draft) for the examination of a comprehensive inspection manual for a moving support system for people with mobility constraints using smartphones

6 Future Issues

In the future, it will be necessary to develop a concrete operational procedure for the whole system, with a view toward differentiation between the new system and other existing pedestrian support systems, as well as cooperation with other applications such as navigation systems.

Research into Common Pedestrian Support System Platform

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ABSTRACT: To improve pedestrian accessibility through route guidance adjusted to the individual characteristics of each pedestrian, the following studies, investigations, and developments were performed. First, the information necessary for transfers and the method of collecting this information were studied and evaluated through field verifications. As a result, data collection applications on smartphones were adopted as a low-cost and continuous method for information collection. Second, demonstration experiments to develop walking networks using the data collection application were implemented. In addition, the serviceability of common platform information was evaluated using a prototype personal navigation application on smartphones, and a field verification of route guidance corresponding to the personal attributes of pedestrians. Furthermore, cooperation between personal navigation systems and advanced PICS was studied. A large-scale demonstration experiment regarding route guidance will be performed in October 2018.

1 Outline and Objectives

Pedestrian support systems aim to realize a safe and secure traffic environment for a wide range of people, including elderly and disabled persons, by reducing traffic accident fatalities and improving the accessibility of public transportation. These systems should be able to provide public transportation information necessary for moving from a departure location to a destination (common platform information), as well as route guidance suited for different types of pedestrians. The objectives of this project are to study easy and efficient methods to collect this common platform information, and to evaluate its serviceability and acceptance through demonstration experiments in which various kinds of people with restricted transportation capabilities participate.

2 Study of Common Platform Information and Collection Methods

2.1. Investigation of common platform information

Figure 1 outlines the demonstration experiments performed between 2015 and 2017. With the cooperation of people with restricted transportation capabilities, demonstration experiments were performed in the Tokyo Bay area each year. We assumed that different information would be required in accordance with the type of person with restricted transportation capabilities (e.g., wheelchair users, visually impaired persons, the elderly, etc.). The importance of the information was investigated by extracting common platform information for each pedestrian attribute through field verifications and surveys, and through route guidance demonstration experiments.

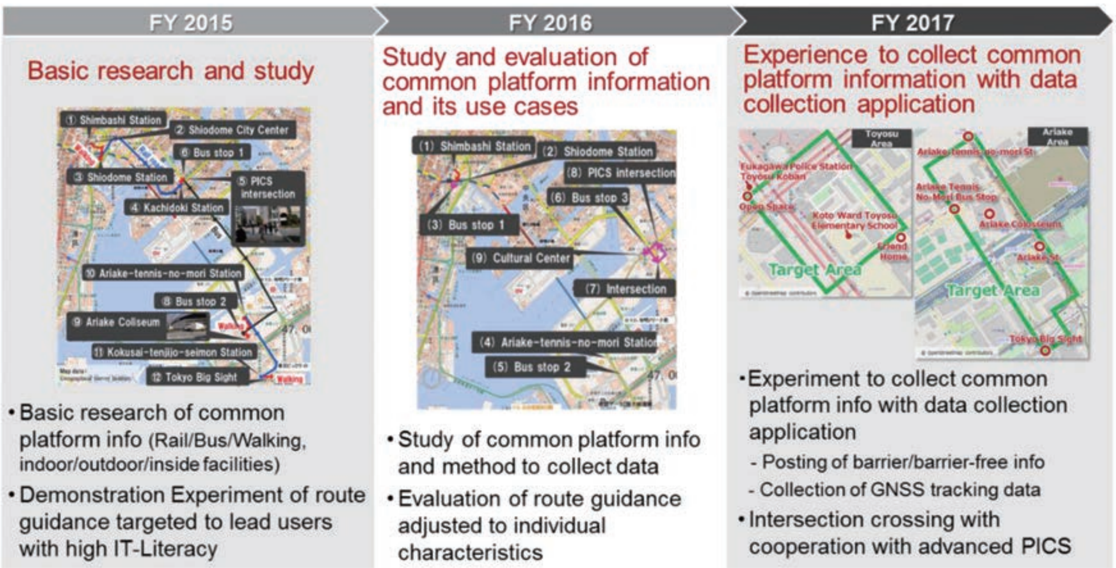

Fig. 1 Outline of demonstration experiments between 2015 and 2017

Table 1 shows the results of the investigation. The common platform information was classified into nine categories. All the people with restricted transportation capabilities responded that they required "vertical transportation" and "detailed information of public transportation". In addition, the results show that information on "crosswalk intersections", and "sidewalk road conditions" is also important. Figure 2 shows photos of the route guidance field verification.

2.2 Collection of common platform information

It is obvious that exact and updated information is the best for users. However, it is not acceptable for the sustainability of the services to expend large amounts of time and money to collect and update this information. This project used a data collection application, through which common platform information can be easily obtained through mobile devices such as smartphones and published on the Internet. The application collects common platform information by users posting information about bumps, road width, gradients, slopes, studded paving blocks, and crosswalks. In addition, we aimed to develop an accessibility map suitable for people with restricted transportation capabilities by collecting global navigation satellite system (GNSS) probe information.

A demonstration experiment to collect common platform information was performed in November 2017 (Fig. 1). Sixty-three people with restricted transportation capabilities such as wheelchair users, visually impaired persons, baby buggy users, and the elderly participated. The participants used smartphones installed with the data collection application, moved around the Toyosu-Ariake area, and posted important information using the application.

Table 2 shows a summary of posted data categorized by the attributes of the people with restricted transportation capabilities. The total number of posts was approximately 1,700 and contained features corresponding to the attributes of the users. Visually impaired persons mainly posted photos and comments, and information regarding key landmarks for transportation. Wheelchair users posted much information regarding pedestrian walkways. The elderly posted both information regarding themselves as well as other information that they thought might be helpful for other people with restricted transportation capabilities.

We investigated transportation routes in the demonstration experiment using questionnaires. GNSS tracking information and responses to the questionnaires were analyzed, and recommended routes were formulated from the analysis results. A demonstration experiment regarding route guidance adjusted to the individual characteristics of each pedestrian will be held in 2018 using a personal navigation application containing walking networks developed based on the common platform information obtained through the previous demonstration experiments and field verifications.

Table 1 Importance of common platform information (results of verification by demonstration experiments)

Attribute \ Common platform information	Vertical transportation	Crosswalk Intersection	Sidewalk Road conditions	Differences in level and slopes	Audio sign	Rest spot	Restroom	Ticket gate Station platform	Detail information of public transportation
Wheelchair	◎	○	◎	◎	—	△	◎	○	◎
Totally blind	◎	◎	◎	○	◎	△	○	◎	◎
Low vision	◎	◎	◎	○	○	△	○	◎	◎
Elderly	◎	◎	○	◎	—	◎	◎	○	◎

High ← ◎ ○ △ — → Low
Degree to be required

Fig. 2 Scenes from the field verification performed in the Shimbashi-Ariake-Toyosu area in 2016

Table 2 Results of posts classified by attributes

Attributes	Number of Posts	Information of Walkway				
		Bump	Road Width	Slope	Slant	Studded Paving Block
Total Blind	467	4	4	5	4	17
Low Vision	503	6	3	9	10	50
Electric Wheelchair	223	67	74	85	80	73
Manual Wheelchair	221	50	52	74	93	63
Baby Buggy	242	62	96	36	47	69
Elderly	45	11	12	9	13	3
Total	1701	200	241	218	247	275

Fig. 3 Sample screen of personal navigation system

3 Route Guidance Corresponding to Attributes of People with Restricted Transportation Capabilities

3.1. Prototyping of personal navigation application

A prototype personal navigation application was created to evaluate the common platform information used for route guidance corresponding to the attributes of each type of person with restricted transportation capabilities. This personal navigation application shows the results of route searches based on the attributes of the user, and navigates the preferred route. Helpful information during transportation such as barriers and barrier-free facilities are shown as pins on the guidance maps (Fig. 3).

3.2. Demonstration experiments of route guidance corresponding to attributes

In the 2018 demonstration experiment, the serviceability of the provided public transportation information will be evaluated, in addition to the serviceability of route guidance (refer to the Development of ART Information Center report). Figure 4 shows the planned scenarios of the demonstration experiment. The preliminary experiments over the last three years have proven that route guidance adjusted to individual characteristics is acceptable, and there are high expectations of providing common platform information.

4 Preliminary Experiment of Cooperation with Advanced PICS

The acceptance of cooperation between a personal navigation application for route guidance and an advanced Pedestrian Information and Communication System (PICS) was researched, and a preliminary experiment was performed to examine the feasibility of support on crossing walkways and facilitate safer transportation of visually impaired persons. In our research in 2017, we designed a PICS terminal application and a personal navigation application as separate programs, and developed a cooperation function between these applications. The demonstration experiment proved the acceptance of a personal navigation system that cooperates with an advanced PICS, especially for visually impaired persons.

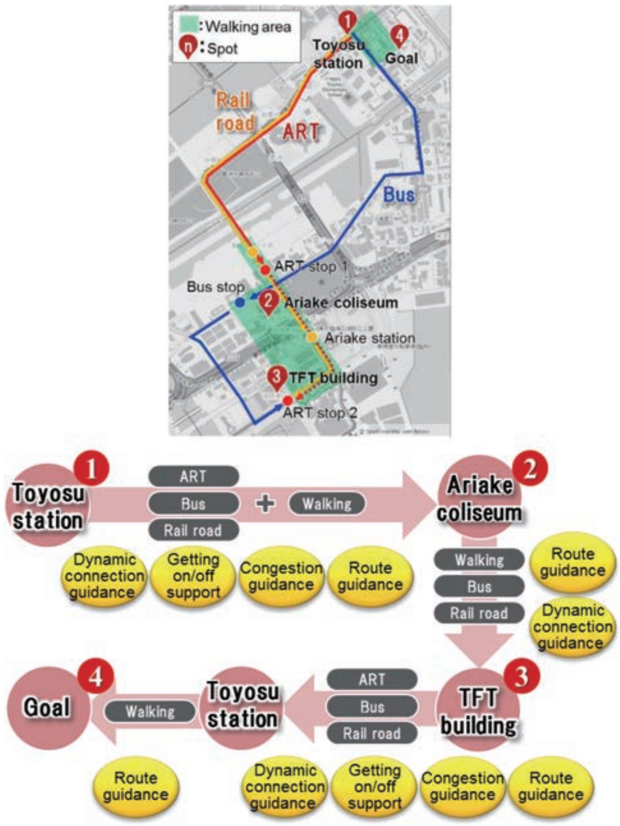

Fig. 4 Planned scenario of demonstration experiments

5 Conclusion

Three years of demonstration experiments showed that route guidance corresponding to the attributes of people with restricted transportation capabilities is highly acceptable. Continuous collection of common platform information and the practical application of route guidance adjusted to individual characteristics are likely to be implemented in the near future.