Development of Core Technology for Reducing Traffic Accident Fatalities and Traffic Congestion, and Creating Social Acceptance of Automated Driving

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1 Introduction

This chapter describes mainly the results of studies related to the reduction of traffic accident fatalities. The numerical target of the Japanese government is to reduce the annual number of traffic accident fatalities to fewer than 2,500 by 2020. The use of automated and connected technologies is considered a prerequisite for achieving this target. This article presents an overview of these studies.

2 Traffic Accident Analysis

The study presented here analyzed Japanese traffic accidents over five years. First, it identified common accident types that cause many fatalities each year. Next, it integrated similar accident types into a pattern. The results of this integration defined more than 200 patterns. These patterns can be considered as representative of traffic accidents in Japan. Analyzing these patterns every year can reveal increasing or decreasing trends for the number of fatalities of each pattern. As a result, it was revealed that accident patterns involving collisions between pedestrians and vehicles are not showing a decrease in fatalities.

3 Vehicle and Pedestrian Communication Systems

Accident analysis found that the main cause of vehicle and pedestrian accidents was recognition error. Therefore, the study presented in this section describes technologies that use communication systems to assist the recognition of pedestrians. The main system is a direct communication system between vehicles and pedestrians. Both pedestrians and vehicles are equipped with a small device that functions as a communication and positioning system. These devices exchange their position, speed, and direction to enable mutual recognition. The key technologies of this vehicle-to-pedestrian (V2P) system relate to pedestrian positioning and estimation of pedestrian states. This study realized these technologies by eliminating GPS multi-path errors and implementing pedestrian dead-reckoning using map technology. The effectiveness of these technologies was verified in field operation tests. Under another approach, a new infrastructure sensor for detecting pedestrians and a system that provides detected information from infrastructure to vehicles were studied. Moreover, another study provided high-definition moving pictures for the front visual field of the vehicle for the development of in-vehicle sensors.

4 Simulations

The presented study describes some simulation technologies. Its efforts focused on the development of a simulation system capable of estimating traffic accidents using automated and connected technologies. This simulation technology uses a multi-agent system capable of showing many independent agents as drivers, pedestrians, and other traffic participants. The agent can implement individual recognition, decisions, and operations based on models derived from experimental data. Here, traffic accidents occur in cyberspace by some error in agent behavior. This simulation system was used to calculate the potential reduction in accidents due to the effects of V2P systems. Moreover, each vehicle in the cyberspace has its own emissions model. The emissions model changes in accordance with the behavior of the vehicle depending on the use of automated and connected technology. The simulation system can observe the amount of CO_2 emissions for the various models. Therefore, it can calculate the potential reduction in CO_2 emissions achieved by these technologies.

5 Impact Assessment

The presented study reviews the impact of automated driving technologies on society and industry by drawing a future vision utilizing several automated driving systems. It also considers specific issues about future society and public reception.

6 Conclusion

The multi-agent simulation system described in this study is capable of calculating the numbers of accidents and observing the negative effects of automated driving systems on trust and so on by creating appropriate agent behavior models. This simulator is regarded as a promising means of estimating the effects of various technologies.

Pedestrian Safety Support Using V2P Communication Technology

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ABSTRACT: Pedestrians and cyclists account for almost half of traffic accident fatalities. To achieve the national goal of reducing traffic fatalities to 2,500 or less by the year 2020, it is critical to establish a vehicle-to-pedestrian (V2P) communication system that can help to prevent collisions by exchanging position data between pedestrians and vehicles. This research establishes the fundamental technologies for a V2P communication system. Furthermore, we have created prototypes of the pedestrian terminal and the in-vehicle terminal for experiments and verified their effectiveness.

1 Overview

In 2017, the number of traffic accident fatalities was 3,694. Pedestrians (36.5%) and cyclists (13%) account for almost half (49.5%) of this number[(1)]. There is an urgent need to take measures to prevent traffic accidents involving pedestrians and cyclists. V2P communication systems are being research and developed with the aim of preventing collisions by exchanging position data between pedestrians and approaching vehicles.

In this research, we developed two types of technologies: direct communication technology using a newly developed pedestrian terminal capable of 760 MHz communication (the ARIB STD-T109) with an in-vehicle system, and technology using mobile phone networks.

Because technology using conventional mobile phone networks has a communication delay of up to 10 seconds, this can be used to notify pedestrians in cases where there is longer than 10 seconds before a predicted collision. In contrast, direct communication technology should be adopted in cases where the response time is less than 10 seconds. The results are presented below.

2 Direct Communication Technology

With direct communication technology, the pedestrian terminal and in-vehicle terminal communicate directly with each other using 760 MHz ARIB STD-T109 communication, by broadcasting their own position data (latitude and longitude), speed, and moving direction. Both terminals estimate the future paths and predict a collision when these paths overlap. When a collision is predicted both terminals issue alerts. Figure 1 shows an overview of direct V2P communication.

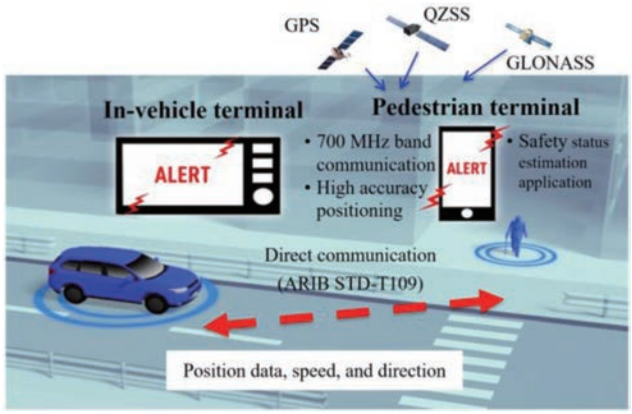

Fig. 1 Overview of V2P communication

2.1. Range of Support

This system only supports people (pedestrians and drivers) by issuing alerts via the V2P communication system. Support for automatic vehicle control systems (e.g., automatic emergency braking (AEB)) is beyond the scope of this research. Although the main beneficiaries of the system are pedestrians, driver support is also discussed. The following sections describe the selected scenarios in which support is required and those in which support is not required.

2.1.1. Scenarios Requiring Support

To focus on high-priority scenarios, we first analyzed historical data of traffic accident fatalities involving pedestrians, and then selected the top ten scenarios with the highest fatality rate by referring to an existing research report[(2)]. By combining patterns occurring at the same location and under similar situations, the five scenarios shown in Fig. 2 were finally selected as the scenarios in which pedestrians require safety support.

① Initiatives to Reduce Pedestrian Accidents

Pedestrian Safety Support Using V2P Communication Technology

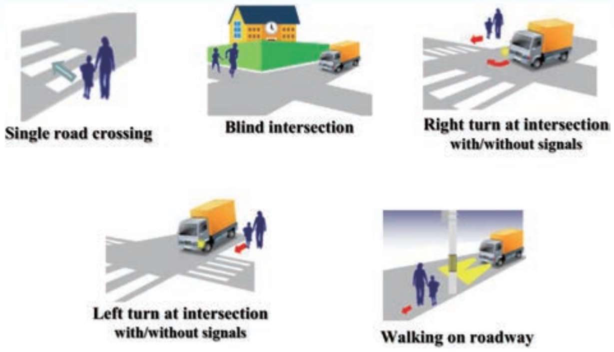

Fig. 2 Scenarios requiring support

Notifications are known to be more effective when issued on multiple levels (e.g., by providing information, warnings, and then alerts) depending on the time to collision (TTC).

The timing to start providing pedestrian support was determined by referring to the results of a monitor evaluation described in the survey report on requirements for vehicle-to-pedestrian communication(3). The timing to start providing driver support was determined by referring to ASV4(4). However, we determined that cases when the TTC is less than two seconds should be handled by automatic vehicle control (e.g., AEB), and our system does not provide support for such cases. The cases in which our system provides support are defined in Table 1, where information provision, warnings, and alerts are adopted as the multiple support levels up to a TTC of two seconds.

Table 1 Support timing

	TTC (time to collision)	
	Pedestrian support	Driver support
Alert	Less than 2.0 seconds	Less than 2.0 seconds
Warning	6.5 – 2.0 seconds before	3.7 – 2.0 seconds before
Information	10 - 6.5 seconds before	6.0 – 3.7 seconds before

2.1.2. Scenarios not Requiring Support

Support is not required when the pedestrian is in a safe location. To define such scenarios, we first considered life patterns showing what people spend most time doing during the day. Referring to a survey report on how Japanese people spend their time(5), we selected two scenarios in which safety support is not required (inside a building and inside a vehicle).

In addition, we selected three other scenarios in which support is not required, considering their relationship to the scenarios defined as requiring support: on a sidewalk, on a pedestrian overpass, and on/under an overpass. In total, we selected five scenarios not requiring support, as shown in Fig. 3.

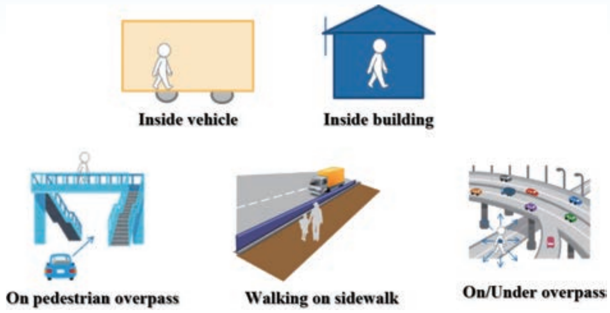

Fig. 3 Scenarios not requiring support

2.2. Performance Target

We set a performance target for our V2P communication system considering the scenarios defined as requiring or not requiring support. Based on the guidelines provided by the system commercialization working group (WG), the target was defined using two values: a correct support operation rate of 80% or higher for scenarios requiring support and a false support operation rate of 20% or less for scenarios not requiring support. We conducted our study based on these target values.

2.3. Research Plan

A viable V2P communication system requires three fundamental technologies: (1) accurate pedestrian positioning, (2) advanced risk prediction technology that can provide appropriate support even if some pedestrian positioning error occurs, and (3) a communication protocol that launches direct communication only when necessary to reduce power consumption. We have developed all these technologies as described in Fig. 4. It is planned to conduct an extensive field test with ordinary users, consisting of five vehicles and twenty pedestrians, during the final year (FY2018) of the project. To confirm the effectiveness of the system, we created and provided prototypes of the in-vehicle and pedestrian terminals with improved communication distance and battery duration performance.

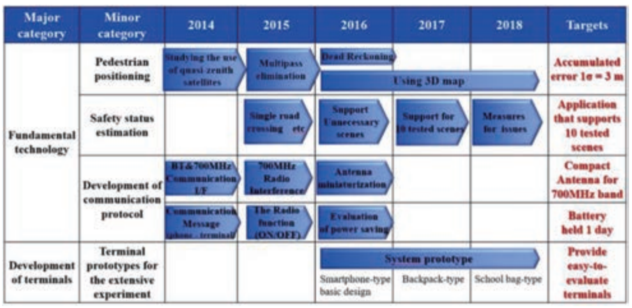

Fig. 4 Research plan

2.4. Pedestrian Positioning

To achieve 80% or higher correct support operation rate, the target pedestrian positioning error was assumed to be around 3 m considering the standard width of a road. In addition, to facilitate stable positioning in business districts, we tested integrated positioning using GNSS and sensors, as well as 3D map positioning using an accurate 3D map.

2.4.1. Integrated Positioning

In addition to satellite positioning with GNSS, we developed the following technologies to improve GNSS: An integrated positioning system also incorporating direction and speed detection using Doppler frequency deviations, and automated navigation for relative positioning using pedestrian dead reckoning (PDR) with motion sensors such as acceleration sensors. The process flow of the integrated positioning is shown in Fig. 5.

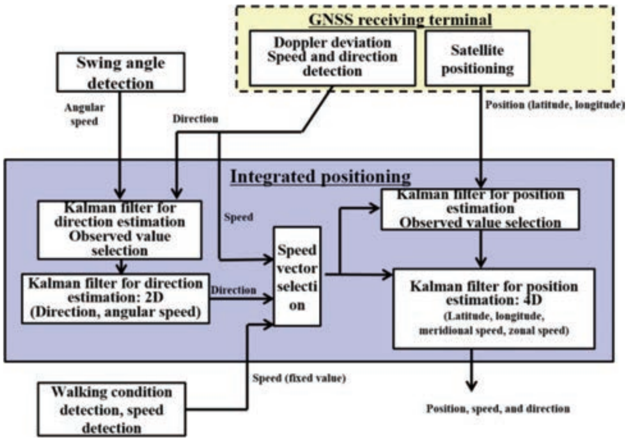

Fig. 5 Integrated positioning

The evaluation result in the Odaiba area, where the planned extensive experiment will also be carried out, is shown in Fig. 6.

In an open area, an accumulated error of 68% corresponds to a horizontal error of 3.3 m, while in an obstructed area, the error becomes 5.9 m. From Fig. 6, one can easily see that the horizontal error is closely related to the field of view. The 3 m level is achieved in an open area in which there are no obvious obstructions. In contrast, the positioning accuracy is worse in the area with obstructions such as railroads, because the field of view is restricted. As

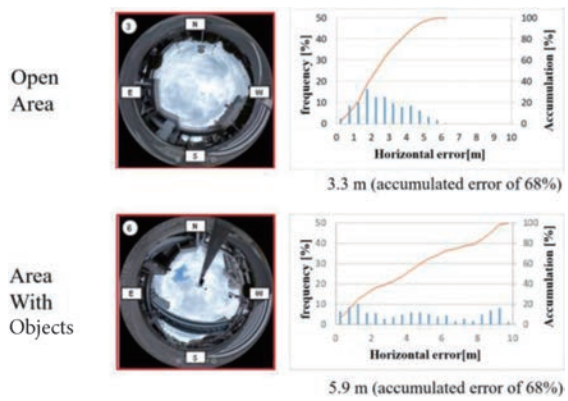

Fig.6. Results of integrated positioning

it was assumed that the field of view would deteriorate further in an area with high-rise buildings, thereby creating even more severe positioning conditions, we investigated an alternate method that is described in the following section.

2.4.2. 3D Map Positioning

We tested a 3D map positioning method with dedicated 3D map data developed by Kamijo Laboratory of the Institute of Industrial Science at the University of Tokyo.

Factors causing positioning errors can be categorized into two groups: satellite related (e.g., orbit data, clock) and transmission path related (e.g., ionospheric delay, tropospheric delay, multipath). Particularly, multipath interference significantly affects positioning accuracy. Errors due to the satellite or delays in the ionosphere or troposphere can be corrected using multiple frequencies and DGPS. However, errors caused by multipath interference are difficult to correct with these measures and a different approach is needed. A technique of improving positioning accuracy by determining whether the received radio wave from a satellite is on a line of sight (LOS) or behind an object (NLOS: non-line of sight) using 3D map data, which includes height data of structures such as buildings, was proposed. LOS/NLOS distinction is achieved with ray tracing. Errors can be distinguished between cases due to interference between the LOS and NLOS signals and cases due to shadowing as the LOS signal is sufficiently small compared to the dominant NLOS signal. We tried to improve positioning accuracy with 3D map positioning for the latter case, in which the effect is greater.

In addition to Odaiba, Shinjuku, Hitotsubashi, and Shinagawa were added for evaluation as areas containing

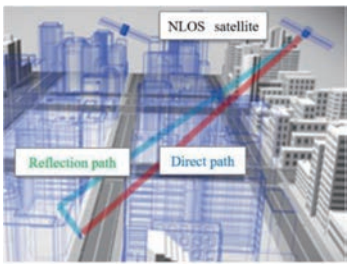

Fig. 7 3D map positioning

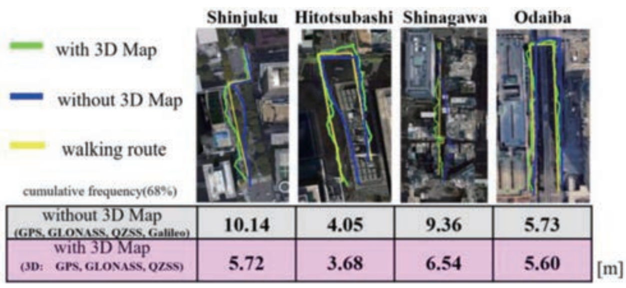

Fig. 8 Results of 3D map positioning
(Map data source: Google Earth)

high-rise buildings where the conditions are severe. The evaluation results are shown in Fig. 8.

The above results show that the use of a 3D map generally improves accuracy, and that the 3 m error level was achieved at Hitotsubashi. The reason for this improvement was the suitable use of reflected waves, which were a major cause of positioning error previously.

In the future, to achieve a horizontal error of around 3 m in the remaining three areas, we will try to improve positioning accuracy by adding the Galileo Satellite and by applying correction using the reference station data (DGPS).

2.5. Risk Prediction

A risk predication algorithm was developed and applied to each of the five selected scenarios requiring and not requiring support. For the former, the correct support operation rate was examined with respect to the target rate of 80% or higher. For the latter, the false support operation rate was examined, with respect to the target rate of 20% or less.

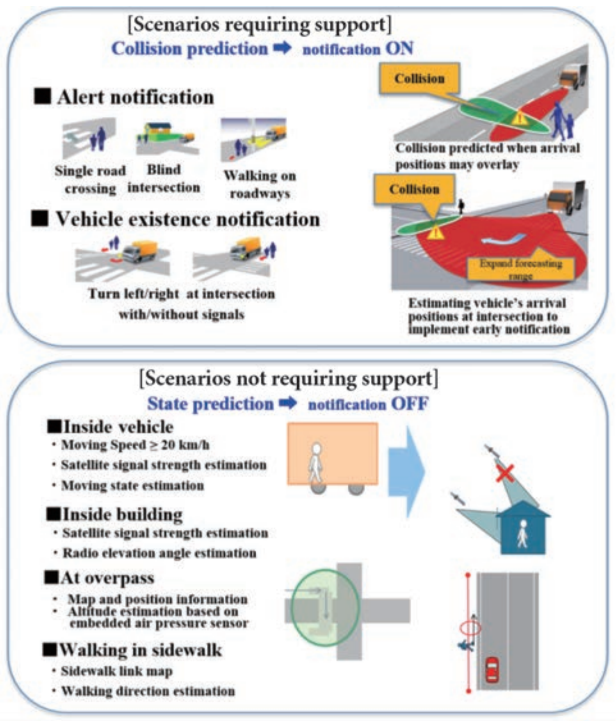

Fig. 9 Risk prediction (support required and not required)

2.5.1. Scenarios Requiring Support

For the scenarios of a single-lane road crossing, blind intersection where a collision may occur, and walking on a roadway, support is provided based on collision prediction. In detail, terminals communicating each other via V2P communication share position, speed, and moving direction data and then predict the possibility of a collision. When a collision is predicted, the terminals alert the pedestrian and the driver respectively. Because errors will occur in the communicated data in a real-world environment, the collision prediction algorithm also takes into account the error when predicting a collision. Collision prediction with errors incorporated is illustrated in Fig. 10.

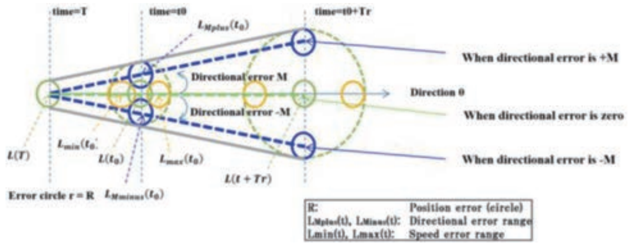

Fig. 10 Collision prediction with errors incorporated

The above collision prediction algorithm is not applicable to the case of a right or left turn at an intersection because it uses linear extrapolation. Large errors in predicted position may delay the provision of correct support.

Hence, a new function to notify the presence of a pedestrian was added for the case of a right/left turn at an intersection. When both the pedestrian and the vehicle are present within an intersection, the prediction range on the vehicle side is expanded to include possible collisions during a right/left turn. Whether a vehicle or a pedestrian is within an intersection is decided based on map data containing the intersection information.

2.5.2. Scenarios not Requiring Support

For the five selected scenarios (inside a vehicle, inside a building, on a pedestrian overpass, on a sidewalk, and on/under an overpass) an algorithm was developed to confirm the safety status and suppress the provision of support information to pedestrians and drivers.

A pedestrian is determined to be inside a vehicle in the case of two patterns. If the moving speed and duration are high and long enough and no step movements are detected, the pedestrian is assumed to be inside a moving vehicle. When the carrier to noise (CN) value of the radio signal from a high elevation angle satellite is poor while no step movements are detected, the pedestrian is assumed to be inside a stopped vehicle. The pedestrian is determined to be inside a building when CN values below a specified threshold continue for a certain duration. The pedestrian is determined to be on or under a pedestrian overpass or overpass based on map data of the sidewalk and roadway networks with the necessary attribute values, and pressure data from pressure sensors.

The pedestrian is determined to be on a sidewalk by first determining whether a sidewalk exists based on map data of the sidewalk and roadway networks. Even if a sidewalk exists, the system also determines whether the pedestrian facing a roadway. No support is provided when a pedestrian is on a sidewalk but is not facing a roadway. Support is necessary if the pedestrian is facing a roadway since the pedestrian may step into the road.

2.6. Communication Protocol for P2V

This section focuses on the technique to reduce mutual coupling with existing systems using adjacent frequency bands, and on the communication protocols for power saving.

2.6.1. Coexistence with existing systems

Radio frequency interference with the 760MHz band cellular system (LTE Band 28) is a problem for the operation of a P2V system using the 760 MHz band. It occurs when antennas for different wireless systems are placed in close proximity (Fig. 11). When these antennas are built into one terminal, it is one of the most severe conditions for operating a P2V system.

Figure 12 shows the proposed mutual coupling reduction structure for ensuring isolation between these radio frequency (RF) front-end circuits. A cellular antenna and P2V communication antenna were built into a unit carried by pedestrians. For cellular multi-input multi-output (MIMO) communication, there are two cellular antennas as the main antenna and aux antenna. Three parasitic elements are installed around these antennas to reduce mutual coupling. Band pass filters for cutting off the signal of the other system are mounted in the RF front-end circuit.

Figure 13 shows the improvement of isolation characteristics between these RF front-end circuits by the proposed method. The red line in the figure is the target value for suppressing interference between these systems[6]. Isolation between these antennas is greatly improved and meets the target value. From the result, it can be seen that the P2V system can coexist with existing systems even under severe conditions, such as being built into one terminal by applying this mutual coupling reduction technique.

2.6.2. Communication Protocol for power saving

In the future, power saving will be necessary to promote the use of the pedestrian terminals. Figure 15 shows the current consumption of the pedestrian terminal. Assuming that the power consumption when sending data (radio function: ON) is 100%, 25% consumption is achieved when the radio function is OFF.

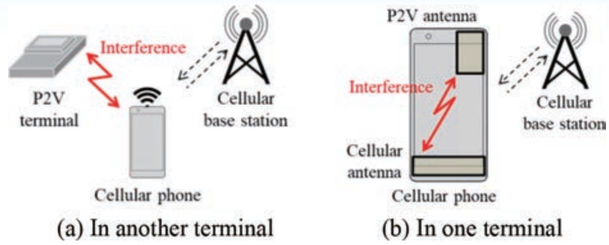

Fig. 11 Condition of radio frequency interference

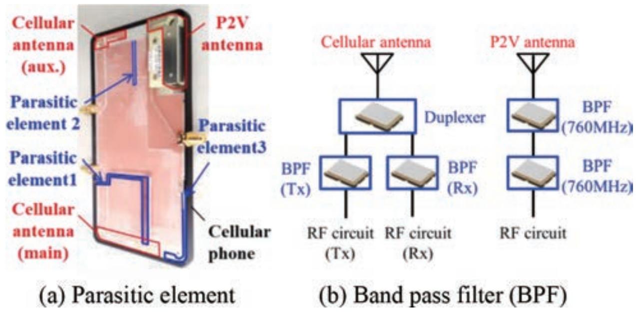

Fig. 12 Mutual coupling reduction technique

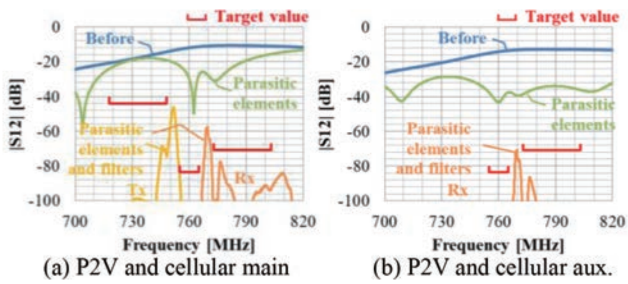

Fig. 13 Isolation between RF front-end circuits (S12)

Next, we examined the life patterns of the target users. According to Traffic Statistics[7], a high proportion of pedestrians involved in traffic accidents are elementary school students. We recorded the behavior of elementary school students, and studied their life patterns based on the National Time Use Survey[5]. It was found that elementary school students spent 8 to 11 hours outside and 1 to 4 hours traveling.

We evaluated the battery specifications by calculating the daily power consumption based on the time that elementary school students spend outside. This time was categorized between scenarios requiring support (i.e., Radio function ON) and scenarios not requiring support (Radio function OFF). Figure 14 compares the current consumption with reference to a smartphone battery.

From the above results, the power consumption of the pedestrian terminal can be suppressed and the terminal can be operated for one day by switching the radio function ON or OFF according to the scenario.

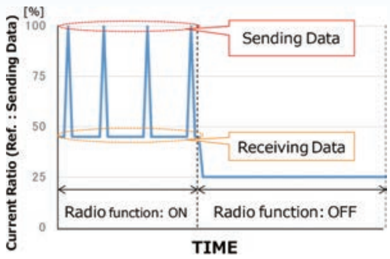

Fig. 14 Comparison of current consumption

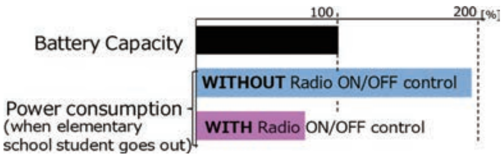

Fig. 15 Comparison of battery capacity and power consumption

2.7. Prototype of Terminals

2.7.1. Overview

To achieve efficient use of the system, the pedestrian terminal and the in-vehicle terminal share the same hardware configuration as illustrated in Fig. 16. They are distinguished by different working modes: pedestrian mode and vehicle mode.

Prototypes were developed considering usability and battery duration performance so that they can be handled easily and tested smoothly.

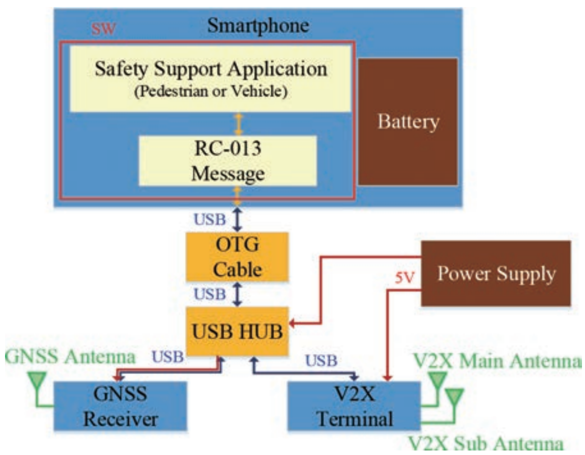

Fig. 16. System configuration of terminal prototypes

Fig.17. Exterior views of terminal prototypes

A backpack capable of holding every piece of equipment was selected as the pedestrian terminal with ease of usability for the tester. Antennas were installed on the backpack. A dedicated antenna for the in-vehicle terminal was selected, and power is supplied to the terminal via a cigarette lighter socket as shown in Fig. 17.

2.7.2. Antenna Design

For the pedestrian terminal, the performance of the antenna should be ensured considering the effect of the body of the pedestrian carrying the backpack.

The antenna selected for the pedestrian terminal requires a ground aluminum plate. Hence, the antenna was installed on a plate, which was placed in the cover pocket of the backpack.

As shown in Fig. 18, the main antenna and the sub antenna for V2X communication were placed at the edge of the ground plate to achieve performance compensation through reception diversity, while maintaining gain in the forward direction when placed in the backpack. A GNSS antenna was placed between the above two V2X antennas. It was also placed on the ground plate and faces the zenith direction.

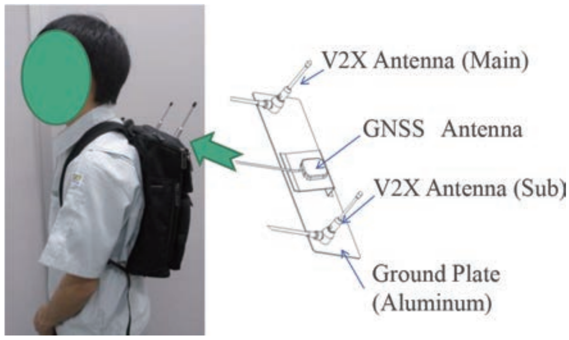

Fig. 18 Antenna configuration of pedestrian terminal

Figure 19 shows the communication distance distribution. It is measured through the antenna gain when the prototype terminal is actually placed on a human body.

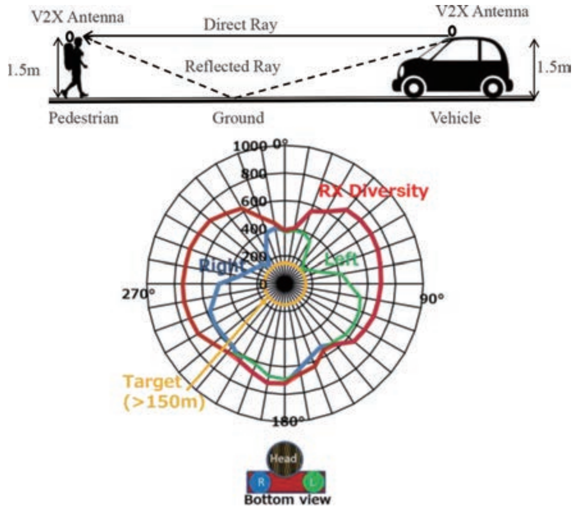

Fig. 19 V2P communication distance

The distance becomes shorter at angles at which the head and the antenna overlap, but it still can reach the target value of 150 m or longer (400 m or longer is achievable with reception diversity).

Figure 20 shows the performance of the GNSS antenna. The antenna gain becomes poor at angles at which the head and the antenna overlap under vertical plane conditions (2), but it is still -6 dBi or greater at angles between -30 and +30 degrees (0 degrees is the zenith position).

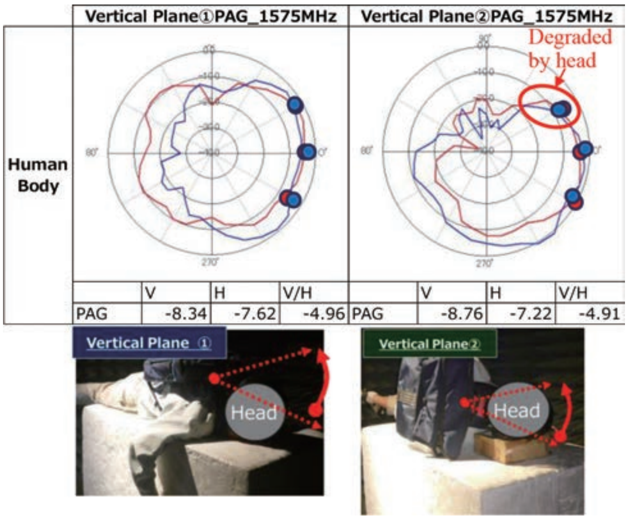

Fig.20. GNSS antenna characteristics

2.7.3. Pre-Test Results

A test was conducted in the Odaiba area before the planned extensive experiment by providing the pedestrian and in-vehicle terminals described in Section 2.7.1. For the scenarios requiring support, alerts below a TTC of two seconds were not counted and were excluded from the research scope. Successful instances of presence notification at the intersection, information provision, and warning/alert provision were counted. The correct support operation rate was calculated based on the ratio of successful instances with respect to the number of tests. In the case of the five scenarios not requiring support, the provision of any support information was counted as a false support operation. The false support operation rate was calculated based on the ratio of false information provision with respect to the number of tests.

Results of the pre-test are shown in Table 2. The main factor that lowered the correct support operation rate was poor adaptation to vehicle speed fluctuations. The main factors that lowered the false support operation rate resulted from the testing method, as well as positioning and moving direction errors. This pre-test verified the effectiveness of the developed technology for improving the V2X communication distance and GNSS accuracy, and no obvious problem occurred.

Fig.21. Pre-test

Table 2 Pre-test results

Scenarios requiring support (Succes Rate≥80%)			Scenarios not requiring support (Failure Rate≤20%)		
No.	Scene	Result	No.	Scene	Result
1	Single road crossing	95%	1	Walking on sidewalk	0%
2	Blind intersection	100%	2	Inside vehicle	0%
3	Right Turn at intersection	100%	3	Inside building	0%
4	Left Turn at intersection	100%	4	On pedestrian overpass	0%
5	Walking on roadway	100%	5	On/Under overpass	0%

3 Mobile Phone Network Utilization Type Technology

Risk prediction was the target for the technology using mobile phone networks. Pedestrian positioning detection in intersections and data collection/broadcasting technology using Web technology for risk prediction are reported below.

3.1. Pedestrian Detection within Intersection

3.1.1. Overview

Safety support measures for pedestrians are desirable. Experiments were carried out using an application to detect pedestrian positioning information and the like within an intersection to help reduce traffic accidents.

3.1.2. Purpose of Experiment

The experiment assumed that highly directional BLE beacons were installed in the vicinity of the traffic lights at a simulated intersection. This experiment aimed to verify and clarify the pedestrian detection areas in the intersection area shown in Fig. 22

① Initiatives to Reduce Pedestrian Accidents

Pedestrian Safety Support Using V2P Communication Technology

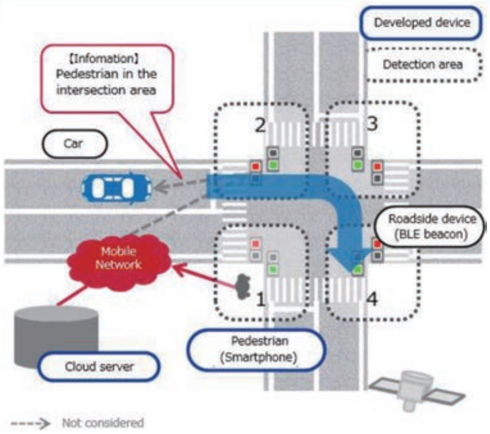

Fig. 22 Illustration of pedestrian detection in intersection area

3.1.3. System Overview

To help reduce traffic accidents, pedestrians in the intersection area are detected by signals received by pedestrians (smart phones) transmitted by the BLE beacons.

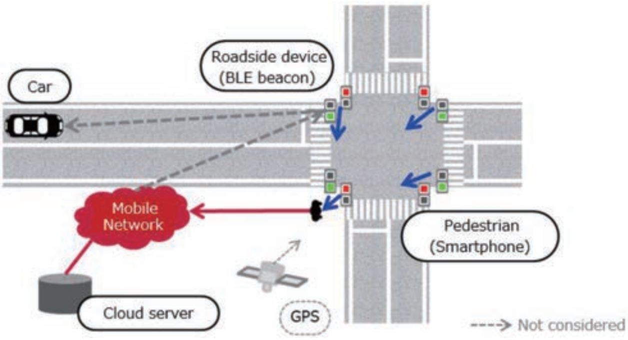

Fig. 23 System overview

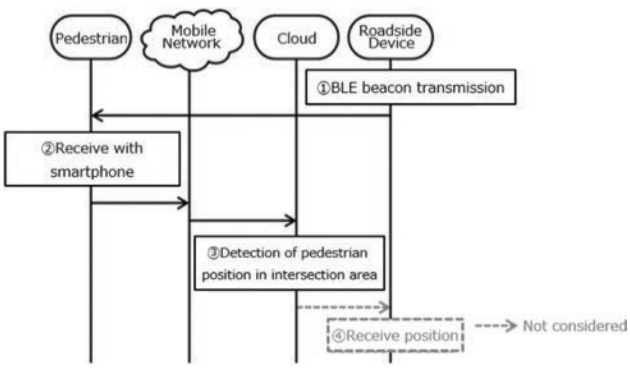

Fig. 24 Sequence Diagram

3.1.4. Consideration

Based on the experimental results, it is possible to identify only the neighboring BLE beacon as shown in Fig. 22 by setting a threshold value. As a result, as shown in Fig. 23, it is possible to detect a pedestrian in the intersection.

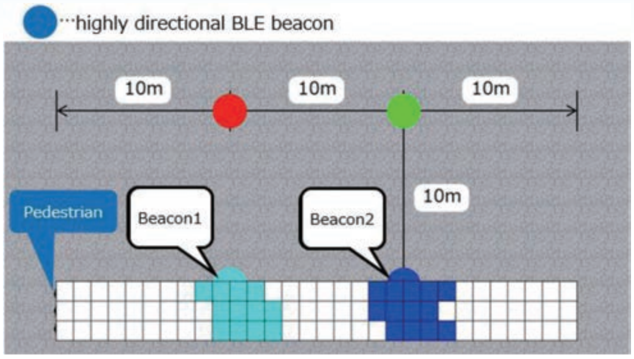

Fig. 25 Pedestrian detection result (threshold: -62 dBm)

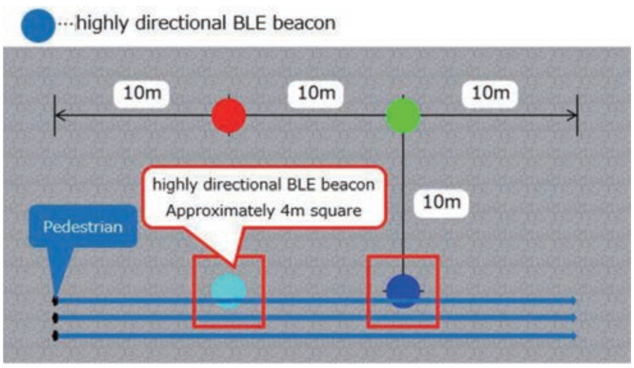

Fig. 26 Detection of pedestrian pool

3.2. Development of Information Collection and Distribution Subsystem using Web Technology over Mobile Networks

3.2.1. Basic Concepts of R&D Subsystems

This approach is a basic way to both collect information from moving vehicles and deliver information to moving vehicles and pedestrians over a mobile cellular network from the standpoint of service coverage. The types of pedestrian-related information for predicting risk and warnings can be summarized as shown in Fig. 27. For example, if you know a crowded crosswalk is ahead, then you can minimize collision risk by turning left a block earlier.

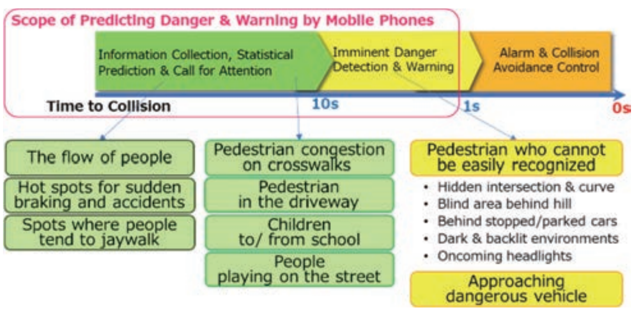

Fig. 27 Pedestrian-related information

The identification of such data, including other vehicle data (e.g. vehicle speed and hard braking) from cars that have already passed through an area on all roads using the

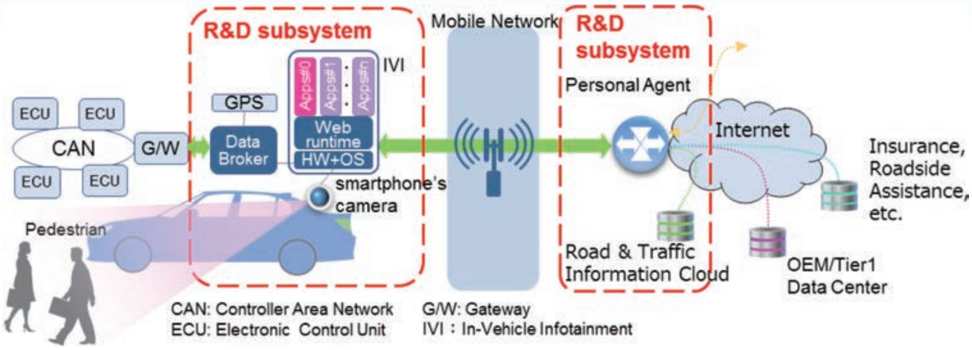

Fig. 28 Overall configuration of mobile network-based web platform for next generation ITS

mobile cellular network has already been proved effective in earlier research.

In contrast, mobile phones and installed OS commonly have built-in WRT (browsers), enabling the universe of compatible devices to be maximized, and minimizing the impact of heterogeneous OS and apps. Rapid and global deployment can be expected by using the Vehicle Web APIs and generic sensor API currently being standardized by W3C. Based on such concepts, we developed a mobile network-based web platform as a part of the next generation ITS as shown in Fig. 28.

3.2.2. Development of Web Runtime

We developed and implemented a W3C Vehicle API to web runtime in two ways: as a native WRT and as a polyfill, enabling us to replicate real-world browser heterogeneity. The native version has been fine-tuned for memory optimization.

3.2.3. Providing Situational Awareness of Pedestrians to Drivers

We developed a subsystem to upload short videos from smartphones to the cloud when the car is stopped or if hard braking occurs (as shown in Fig. 29), as well as a pedestrian-related information API for quantifying pedestrians and detecting sudden hard braking.

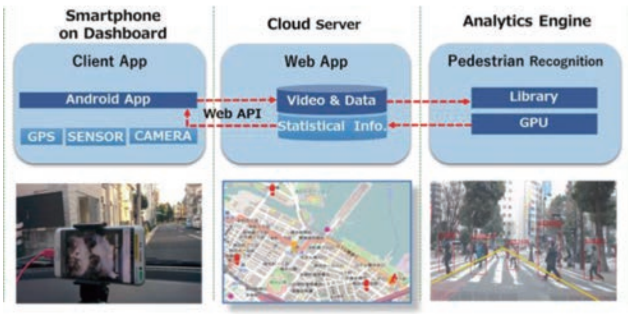

Fig. 29 Pedestrian-related information subsystem

3.2.4. Privacy Protection Measures

Privacy protection strategies will be required in circumstances where the driver can be easily identifiable by some key data or by statistical analysis of the driving context.

An individual may drive a car driven by others. An individual may drive multiple cars and use various apps. To whom does this data belong? Are there exceptions, such as emergencies? Privacy settings will be adjusted each time a different driver drives the car.

To cope with such issues, we have developed what we call a Personal Agent, which is composed of a proxy server for privacy protection and which controls data transfer by managing privacy settings per the preferences of the individual and the situation.

4 Conclusion

As fundamental technologies to achieve a V2P communication system, we developed an accurate positioning technology for pedestrians and an advanced risk prediction technology to predict possible collisions even with some positioning errors. We also developed a communication protocol that launches direct communication only when support is required, thus reducing power consumption. The effectiveness of these technologies was confirmed in a pre-test.

To enable installation of the system in a smart phone, a compact 760 MHz band communication antenna was developed and correlation with cellular antennas was lowered to enable coexistence. We also analyzed the usage scenarios of the pedestrian terminals and confirmed that 760 MHz band communication terminal could run for 24 hours using a smart phone battery.

Pedestrians are detected using BLE beacons at intersections. By detecting pedestrians on the intersection sidewalks, positioning data of the pedestrians can be provided to vehicles.

A mobile network-based web platform has been developed in line with the current W3C activities, enabling the collection of pedestrian-related information including other vehicle data (e.g. vehicle speed and hard braking) from cars that have already passed through an area on all roads, and the provision of alerts.

In addition, a new privacy protection mechanism has been implemented in the above subsystem.

Our aim is to contribute to reducing pedestrian traffic fatalities to zero by popularizing pedestrian terminals. Future work includes examining the feasibility of installing the system on smart phones, studying the commercialization of the system, and improving the terminals.

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Research and Surveys for Enhancing Driving Safety Support Systems (DSSS) Utilizing Radio Waves, and Research and Surveys for Establishing Technology to Provide Vehicle/Pedestrian Detection Information Toward the Realization of Automated Driving

Masafumi Kobayashi (UTMS Society of Japan)

ABSTRACT: To promote the realization of safe driving support and automated driving, it is essential to observe the conditions surrounding the vehicle, including beyond the vehicle's line of sight, and to provide vehicles with traffic information in real time that contributes to the prevention of traffic accidents using roadside sensors. Therefore, research and surveys were conducted into a system that provides vehicles with constantly changing traffic information using radio communication. In fiscal 2014 and 2015, research and surveys were conducted into the enhancement of driving safety support systems (DSSS) promoted by police, and the specifications of low cost versions of the systems, with the aim of implementing the systems across the country. In the following fiscal year of 2016, examinations were carried out with an eye toward the realization of automated driving. These involved the classification of traffic accident types and vehicle behavior at intersections, identification of the types of moving objects (vehicles, pedestrians, bicycles, and the like) that need to be detected, together with the required range of detection to ensure vehicle safety in each accident scenario, followed by an examination of the configuration of roadside sensors required for detection.

1 Purpose of the Research and Surveys

Safe driving support and automated driving systems are expected to have the following effects: (1) reducing traffic accidents, (2) mitigating traffic congestion, (3) reducing environmental burden, (4) providing mobility support for the elderly, and (5) increasing the comfort of driving. In particular, at a time when Japan is becoming a super-aging society, and as a country aiming to achieve the world's safest road traffic environment, realizing the practical use of safe driving support and automated driving systems, and making them widely available at an early stage is of extreme importance. Also, to enable safe driving support and automated driving, it is important to observe the conditions surrounding the vehicle, including beyond the vehicle's line of sight, and to provide vehicles with traffic information in real time that contributes to the prevention of traffic accidents using roadside sensors. Therefore, these research efforts and surveys were designed to enhance driving support systems through the development and verification of a system that provides vehicles with constantly changing traffic information utilizing radio communication with 700 MHz band. This report presents the results of the research and surveys conducted over a period of three years from fiscal 2014 through 2016.

2 Procedure of the Research and Surveys

2.1 Research system

Through the examination, research, and development of intelligent transport systems (ITS), the UTMS Society of Japan promotes ITS for surface roads and pursues standardization activities for domestic and international ITS. From the end of the 1990s, UTMS Japan has promoted research and standardization activities for driving safety support systems (DSSS) with the aim of reducing traffic accidents by supporting driver recognition, judgment, and operation using ITS technologies, to create conditions for comfortable driving. Before launching these research efforts and surveys, a new examination body (the DSSS Enhancement Examination Sub-working Group) was established within the Vehicle-Infrastructure Cooperation Systems Working Group, which has promoted the research and standardization of DSSS.

3 Research Results for Fiscal 2014

Services regarded as having the potential to produce the desired effects on DSSS were developed as shown in Table 1 from the perspective of the types of traffic accidents that occur at intersections or curves with poor visibility due to driver inattention, and from the perspective of the violation of traffic regulations such as traffic signals and road signs.

② Development of Basic Technologies to Reduce Traffic Accident Fatalities

Research and Surveys for Enhancing Driving Safety Support Systems (DSSS) Utilizing Radio Waves, and Research and Surveys for Establishing Technology to Provide Vehicle/Pedestrian Detection Information Toward the Realization of Automated Driving

Table 1 List of safe driving support services

Classification	Name of service
Based on accident types	Crossing collision prevention service
	Right-turn collision prevention service
	Left-turn collision prevention service
	Crossing pedestrian collision prevention service
	Rear-end collision prevention service
Based on the perspective of traffic violations	Signal violation prevention service
	Traffic regulation violation prevention service

For each of the developed services, the functions and operational flow required for each of the components of the infrastructure system, that is, the traffic control center, signal controllers, vehicle-to-infrastructure radio communication devices, as well as roadside equipment including roadside sensors and on-board systems, were compiled in a system definition document. The research also examined communication protocols to establish secure communication between vehicles and roadside infrastructure even in an environment where vehicle-to-vehicle and vehicle-to-infrastructure communications coexist, specifications for the message sets provided to on-board units via vehicle-to-infrastructure communication, and the identification of performance requirements for roadside sensors when using a 79GHz band high-resolution radar. Furthermore, to reduce installation costs for DSSS and promote nationwide implementation and broader coverage, surveys and research were conducted into low-cost versions of DSSS that would be both inexpensive and satisfy the required functions. The following proposed revisions were developed.

(1) Simplification of roadside systems aimed at reducing equipment and construction costs
- Elimination of the need for infrared beacons that notify the location of points of origin upstream of intersections (Location reference by GPS)
- Integration of roadside equipment (integration of information relaying and determination devices with ITS radio equipment)

(2) Standardization of management functions of traffic control centers
- Reduction of the number of central computers supporting DSSS and streamlining through standardized processing
- Reduction of data preparation costs through revisions to road shape information requirements

(3) Revisions to detection areas to reduce the number of roadside sensors.

Figure 1 shows the proposed architecture reflecting these proposed revisions.

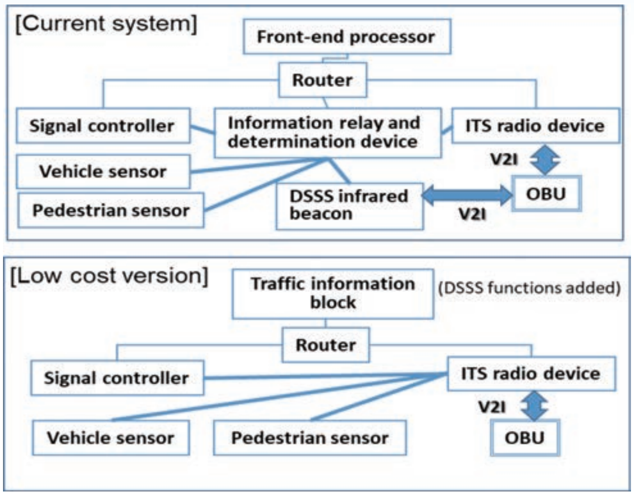


Fig. 1 Proposed revisions to system architecture

5 Research Results for Fiscal 2015

To verify the revisions developed based on the surveys and research into the low cost versions of DSSS conducted in fiscal 2014 (i.e., the revisions to road shape information requirements, revisions to the detection areas of DSSS pedestrian sensors, and revisions to the detection areas of DSSS vehicle sensors), a verification experiment was carried out using roadside systems installed on a test course in fiscal 2014 by the National Police Agency for a research project called “Creation of an internationally open research and development environment” (NPA 6). System acceptance was assessed through a questionnaire survey. Based on the results of the experiment, constraints under which the revisions to the detection areas for pedestrians and vehicle sensors can be applied, such as the range of sight of oncoming traffic from a right-turning vehicle, were defined. Also, with respect to infrastructure maintenance in cases where road shape information was changed due to road improvements or other reasons, which had been an issue for system operation, guidelines relating to the operation and maintenance of road shape information were developed.

6 Research Results for Fiscal 2016

In fiscal 2016, research and surveys for establishing technology to provide vehicle/pedestrian detection information towards the realization of automated driving was conducted. The configuration of the roadside sensors required for detection were examined after classifying traffic accident types and vehicle behavior at intersections and identifying the types of moving objects (vehicles, pedestrians, bicycles, and the like) that need to be detected, together with the required range of detection to ensure vehicle safety in each accident scenario. These efforts also examined a new DSSS for left-turn support using radio communication based on an existing right-turning support system. Functional specifications for a pedestrian recognition (at left turns) enhancement system were examined and a model system was developed for verification. Furthermore, to ensure the operation and management of DSSS, research examined the functions of traffic control centers, and the operation and management of roadside equipment, including security management during the lifecycle of the roadside equipment. This includes the installation of new roadside equipment and the relocation and disposal of existing equipment.

7 Conclusion

This research project, which was carried out over a period of three years from fiscal 2014 through 2016, defined requirements for the enhancement, installation, and widespread deployment of DSSS that provide vehicles with constantly changing traffic information using radio communication. In the future, further research and surveys must be pursued on the basis that this DSSS will evolve into an infrastructure system designed for automated driving.

Development of Practical Roadside Sensor Utilizing Millimeter-Wave Radar Technology

Yoichi Nakagawa (Panasonic Corporation)

ABSTRACT: This article reports the results of a research initiative to apply high-resolution millimeter-wave radar to roadside sensors for the purpose of reducing pedestrian accidents using cooperative driving support. Millimeter-wave radar technology installed at intersections and the like can realize sensing functions, such as the detection of pedestrians and bicycles with high accuracy, regardless of the weather and time. To facilitate the practical adoption of this technology, detection processing software compatible with high-resolution radar has been developed and verified under severe weather conditions such as hard rain and snowstorms. A prototype 79 GHz band millimeter-wave radar system was installed at actual intersections to evaluate the detection performance of crossing pedestrians and so on. This report mainly describes the development of the radar technology and the progress of the public road experiment.

1 High-Resolution Radar Technology

1.1. Summary

We are carrying out a research initiative to apply the latest radar technology to infrastructure systems in consideration of the evolution of millimeter-wave devices and sensor software. Specifically, we are promoting technological development and demonstration experiments with the aim of applying high-resolution millimeter-wave radar to roadside sensors at intersections, assuming the adoption of this system by Intelligent Transport System (ITS) applications such as cooperative driving support(1)(2). In order to provide so-called look-ahead information as driving support, an appropriate wireless communication technology that shares sensor data in real time will be used in addition to sensor technology that accurately measures the speed of approaching vehicles and the position of crossing pedestrians (Fig. 1).

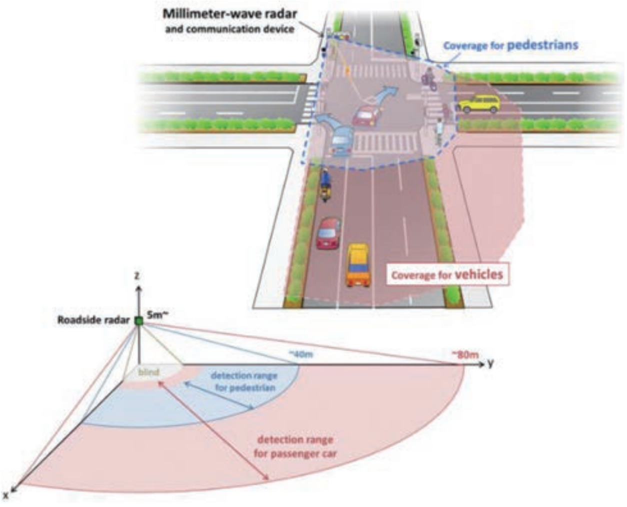


Fig. 1 Coverage of the roadside radar installed at intersection

There are growing expectations for spatial imaging using millimeter-wave radar, and short-range wide-angle scanning is becoming a standard function of high-resolution 79 GHz band radar. The maximum effective detection distance of this radar is about 30 to 40 m for pedestrians and about 70 to 100 m for automobiles, depending on the radar cross section (RCS) of the target. A typical planar antenna configuration is capable of detecting the location of a target up to a field of view (FOV) of about 90°. However, this configuration can measure range up to a FOV of 150°. Further, since the usable frequency bandwidth exceeds 1 GHz, the theoretical range resolution is 15 cm or less. Therefore, scattering points existing in the same range bin are reduced, and the angular resolution is effectively improved.

In addition, since a Doppler frequency shift occurs in the echo of a moving target, the velocity of the target can be estimated from the Doppler frequency. When the carrier wave is 79 GHz, the wavelength is about 4 mm. For example, a velocity resolution of 0.1 m/s can be obtained with an observation time of 20 ms. Because of its high range resolution, radar has excellent separation performance for multiple targets that are close to each other and have slight velocity differences. For pedestrian detection, it is possible to analyze the Doppler frequency spread due to the vibration of limbs as a feature value superimposed on the Doppler shift. Indeed, understanding the echo characteristics inherent in such targets has led to the extension of radar detection functions(3).

1.2. Radar detection software

Algorithms for realizing millimeter-wave radar detection are generally implemented as software to increase the options of the device. This detection software often includes a filtering block for extracting candidate cells and measured values (range, angle, Doppler frequency, and power) from scan data of mesh-like cells outputted by the radar device, a clustering block for grouping multiple candidate cells for each target, and a tracking block for making time-series data frames correspond with each other. The detection result output depends on the application using the radar system, but includes information such as position, speed, movement trajectory, number of targets, and target type.

In order to improve the effective detection accuracy of a radar system, it is essential to optimize clustering and tracking based on the echo characteristics of targets (Fig. 2). For example, the echoes of vehicles observed with high-resolution radar are separated into a large number of scattering points. Therefore, it is necessary to treat spatially spread candidate cells as part of the same group using the Doppler frequency or the like. Pedestrian detection has low distance dependence when resolving scattered points, but the echo intensity drops discontinuously over time. Therefore, it is necessary to interpolate the measurement position using the preceding and succeeding data frames considering that a pedestrian is an object moving at low speed.

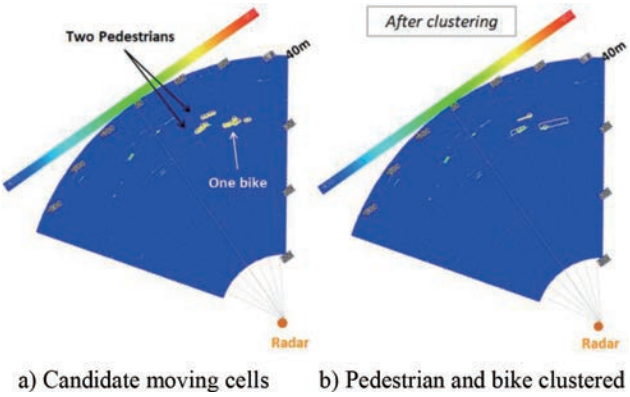


Fig. 2 Radar data processing to detect targets

The roadside sensor equipment consisted of a millimeter-wave radar device as the sensor unit and an industrial personal computer (PC) as the control unit realizing the applications. When a camera is used as a roadside sensor, the control unit performs both a process to extract the target from the image data, and a process to estimate the distance and the velocity. However, with a radar system, since the distance and the velocity of the target are included in the data generated by the sensor unit, it is possible to suppress the processing and cost requirements of the control unit compared to a camera-based system.

2 Roadside Sensor System

2.1. Basic design

A millimeter-wave radar with the performance and functions described above was installed at the roadside of intersections and used to detect passing pedestrians and vehicles. The radar was installed at intersections to detect pedestrians and measure the traffic flow. This configuration is considered to be applicable to both safety support and signal control systems. Although cameras are generally used to recognize objects, radar can obtain stable accuracy regardless of the weather or time to detect pedestrians and count the number of vehicles.

When this type of roadside sensor is installed, it is necessary to prevent blocking by vehicles in front of the detection target. The height of the traffic signal on which the system is installed is a guide of sensor range. For example, when the installation height is 5 m above the ground and the vertical plane beam width of the millimeter-wave radar is 10 degrees, the effective range coverage for passenger cars is calculated to be about 15 to 75 m. This is because the radio link is designed considering the regulations of 79 GHz band high-resolution radar[4], in which the sensitivity characteristics within the data frame over a period of 100 ms or less is used as an indicator.

Furthermore, since pedestrian echoes have large fluctuations in power and random variations, it is necessary to statistically analyze measurement data and identify its characteristics. Specifically, based on an experiment using standard dummies that can simulate walking, the difference in the RCS of an adult and child is about -4 dB (Fig. 3). When these fluctuation characteristics are represented by 95 % values of cumulative probability, the difference between a passenger car and pedestrian instantaneously becomes as much as -20 dB. Therefore, it was calculated that the detection distance range of pedestrians is about 20 to 40 m, although the actual range depends on the installation conditions of the radar.

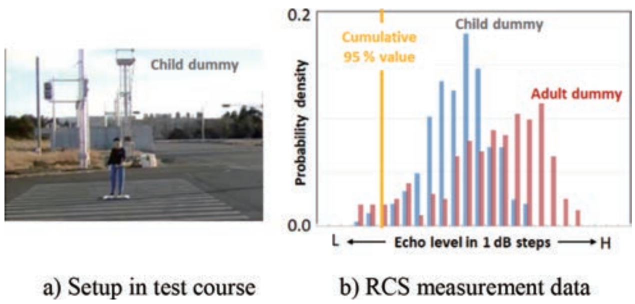


Fig. 3 Measurement of pedestrian dummies for link design

2.2. Multiple-radar integration

This section briefly describes the features and functions of a system for installing the radar sensors at the diagonal corners of an intersection to achieve coverage of the entire intersection. This multiple sensor system is an effective way of preventing blockage by large vehicles and complementing the blind areas generated below the sensors. As these multiple sensors must be integrated to detect the positions of targets precisely, the raw data outputted by the radar devices are transmitted and aggregated in real time while ensuring time synchronization.

Cases of crossing pedestrians or bicycles passing through the blind spots of drivers are a cause of accidents at intersections on public roads. A system that simultaneously operates radars installed at the diagonal corners of an intersection can also improve detection accuracy by increasing the scan data samples (Fig. 4). When a vehicle is inside the common area within the intersection, echoes scattered from the front of the vehicle are observed by one radar and scattering from the sides and back are dominant at the others. That is, integration processing is needed to identify data indicating different positions for a target vehicle.

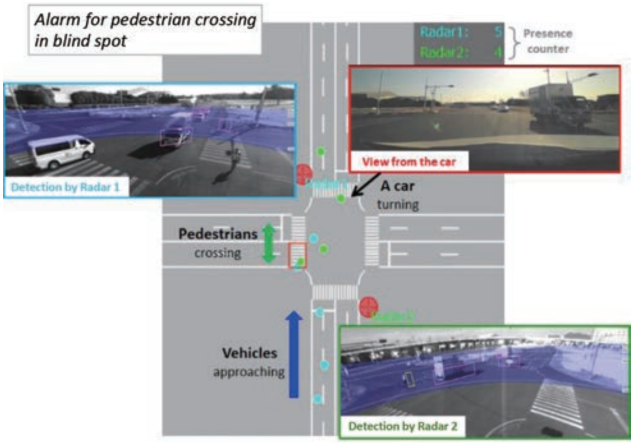


Fig. 4 Verification of simultaneous operation of multiple radars

We have also considered applying this intersection-based radar system for merging support on highways(5). Often, the merging point of a highway is a place in which it is difficult for a vehicle moving up the lamp and a vehicle traveling on the main lane to detect the presence of each other using onboard sensors. Therefore, it may be possible to realize smooth automated driving by identifying the situation of vehicles on the main lane and that of merging vehicles in real time and transmitting this information to nearby vehicles.

3 Technical Verification under Severe Weather Conditions

3.1. Objective

For radars where stable operation is expected even in bad weather, heavy rainfall is the most severe condition. Even short-range millimeter-wave radar is unable to ignore the influence of attenuating radiating radio waves due to scattering from raindrops during heavy rainfall. In contrast, the attenuation is low during heavy snowfall despite the worsening in visibility. This is because radio waves are absorbed by water and the actual precipitation during snowfall is low, and because snow manifests as ice grains. In other words, the practical adoption of millimeter-wave radar requires technical verification assuming hard rain caused by typhoons or the like.

3.2. Design for heavy rainfall

The attenuation characteristics with respect to the amount of rainfall based on the results of experimental analysis were modeled and reflected in the radio link design of the 79 GHz radar system. Specifically, experimental rainfall data was used to obtain a relational expression concerning rain intensity and attenuation per unit distance. For example, when the line margin for detecting a pedestrian 40 m ahead is designed as +10 dB, it is possible to estimate with a margin of +5 dB at a rainfall intensity of 50 mm/h and 0 dB at 100 mm/h. Alternatively, it is also possible to estimate the effective coverage at a distance of 32 m when a link margin of +10 dB can be secured at a rainfall intensity of 50 mm/h, and 27 m at 100 mm/h in the same way (Fig. 5).

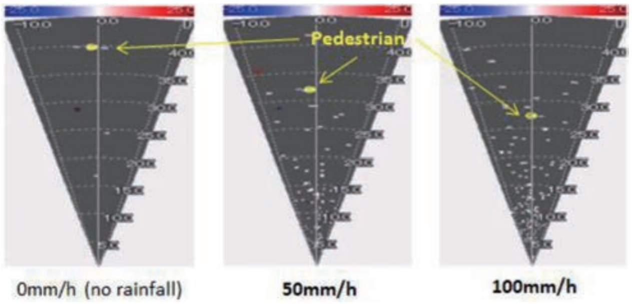


Fig. 5 Pedestrian detection performance in heavy rainfall

To reduce the sensitivity of millimeter-wave radar to echoes scattered by raindrops, it is necessary to optimize the detection threshold in order to determine the existence of the desired targets. In this optimum design, the physical characteristics of randomly generated raindrop echoes are extracted. Here, the characteristic that the received power of the raindrop echoes is inversely proportional to the square of the range is utilized. This characteristic is confirmed by analyzing measured data under heavy rainfall.

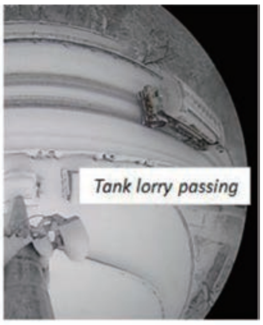
Furthermore, to reliably suppress false alarms due to raindrop scattering, the threshold of radar detection, which is a distance function, is adjusted in correspondence with the assumed rain intensity. That is, an adjustment method for uniformly shifting the threshold set in inverse proportion to the square of the range is used. It was confirmed that raindrop sensitivity can be suppressed to 0.1% or less using the rain intensity data at 50 mm/h acquired in the attenuation experiment. However, since this raindrop sensitivity and the desired target detectability have a trade-off relationship, the threshold must be set appropriately according to the system requirements.

3.3. Experiment during snowfall

In cold climates where the amount of snowfall is large, snowstorms sometimes cause poor visibility. Therefore, radar is regarded as potentially particularly effective compared to visible cameras and laser imaging detection and ranging (LiDAR). As described above, robustness during snowfall can be secured relatively easily if radar technology compatible with severe rainfall conditions can be established. This section describes experiment results for a 79 GHz band millimeter-wave radar conducted in a region with heavy snowfall.

In this experiment, a pillar was temporarily installed at the side of a single-lane road and installed with a prototype radar. To detect vehicles traveling behind large-sized vehicles, the installation angle was adjusted so that the vehicles are irradiated from the rear (Fig. 6). Moreover, the measurement accuracy was verified by counting the number of vehicles passing through to the radar detection software.

a) Appearance of prototype



b) View from radar position

Fig. 6 Prototype 79 GHz radar experiment

Several consecutive 24 hours of data, including severe weather conditions such as snowstorms, were selected to verify the radar measurement accuracy. Table 1 shows the accuracy verification results (vehicle counting data) for each day with heavy snowfall, including sleet and snowstorms. Although some over-counting and non-counting occurred, a detection accuracy of 99% or more was obtained in both conditions. Furthermore, a functional verification was carried out by extracting all the time periods in which a vehicle was not present for more than two minutes, but no false alarm occurred in either condition.

When analyzed in more detail, cases occurred in which the number of large vehicles was over-counted or two vehicles driving close to each other were counted as one. However, the occurrence of these events is not attributable to weather conditions such as rainfall or snowfall. Suppressing the over-detection of large vehicles has a trade-off relationship with the separation performance of vehicles in proximity with each other. In other words, if parameters are adjusted to suppress excessive detection of trucks or the like, non-detection of multiple vehicles close to other tends to increase. In practice, algorithms and parameters will be optimized to meet the performance requirements required by roadside sensor applications.

Table 1 Verification of vehicle count accuracy in snow

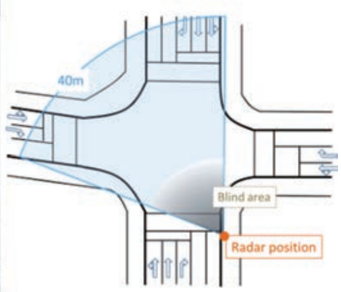
Weather condition	Number of vehicles	Over-counted	Non-counted	False alarms
Heavy snow (20 cm/day)	4,598	1	1	None
Wet snow & snowstorm	2,930	4	0	None

4 Detection Accuracy Verification on Public roads

An experimental 79 GHz radar system has been installed at an actual public road intersection, and the detection performance of pedestrians on the crosswalks and the measurement of traffic volumes on the roads leading to the intersection were verified. The verification field is the intersection between a single-lane road and a two-lane main road, which is common on Japanese public roads. The traffic volume of this intersection is high despite the narrow road width. Also, because it is located near a subway station, pedestrian and bicycle traffic is high in the morning and evening, when the roads are also crowded.

The experimental system was installed in an existing signal pillar, and consists of a radar unit attached 5 m above the ground and a control PC inside a cabinet. In this verification experiment, the radar device was adjusted to face diagonally across the intersection. Figure 7 shows the relationship between the detection range for pedestrians and each lane, and the radar has a field of view (FOV) on the horizontal plane of 70°. Since the vertical plane beam width of the radar antenna is about 10°, a blind area is present at ground level about 15 m from the radar installation point.

a) Installation of the radar



b) Bird's eye view of the

Fig. 7 System configuration for public road experiment

The present system is set to output the scan data at a frame period of 50 ms, the maximum detection distance for a pedestrian is about 40 m, and a passenger car can be detected up to about 80 m. When the detection target is a pedestrian, the power of the echoes fluctuate randomly, so interpolation processing using multiple data frames is required. In general conditions with a walking speed of 1 ms, a moving distance of 20 cm occurs in the processing period of 200 ms. That is, even if the processing is performed in a period corresponding to multiple frames, the influence on positioning accuracy is slight. In addition, in order to avoid a collision, the moving direction of the pedestrian may be also required. In this case, the tracking process for estimating the velocity and trajectory of the target is executed using a time series of coordinate position data sets.

Samples of the evaluation results are shown in Table 2 for a case in which one of the crosswalks shown in Fig. 7 is set as the detection area. When performing interpolation processing using four frames, a detection rate of 95% or more was achieved, and a false alarm rate of about 1% was obtained. The main reason for the occurrence of false alarms is multipath scattering caused by vehicles passing in front of the desired target parallel to the crosswalk. Possible countermeasures include setting an upper velocity limit for pedestrian detection.

Table 2 Detection accuracy for crossing pedestrians

Presence	Time (frame)	Detection	False alarms
Yes	165 s (3300)	95.5%	n/a
No	402 s (8040)	n/a	1.1%

It is necessary to detect pedestrians on crosswalks in drivers' blind spots as a driving support application at intersections. From another viewpoint, for example, in traffic control applications, it is required to measure direction-specific traffic flows at intersections. In Japan, traffic flow on public roads is measured with ultrasonic sensors installed above each lane. Therefore, the total cost of deployment as an infrastructure system could be suppressed if roadside millimeter-wave radar systems installed for driving support can also measure the number of vehicles passing through multiple lanes.

5 Conclusion

As described above, we have carried out research and development for applying the latest millimeter-wave radar technology to the roadside sensors at intersections. Specifically, we implemented clustering technology for scattered echoes obtained by high-resolution radar and verified a roadside sensor system diagonally covering an entire intersection. Moreover, we demonstrated the radar detection function in rainfall exceeding 50 mm/h and during snowstorms. A 79 GHz radar prototype is currently operational at an actual intersection, and we are working to develop technology to improve detection accuracy through long-term data acquisition. In particular, it is expected that a detection rate of 95% or more and a false alarm rate of 1% or less can be achieved with respect to the detection of pedestrians and bicycles.

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Study of Japanese Traffic Accident Patterns for Estimating Effectiveness of ADAS Based on ITARDA Macro Database

Toru Kiuchi, Satoko Ito (Institute for Traffic Accident Research and Data Analysis)

ABSTRACT: In Japan, the authors analyzed accident data using automated driving systems under the auspices of the Cross-ministerial Strategic Innovation Promotion Program (SIP) of the Cabinet Office of the Government of Japan. Based on ITARDA macro data from 2013, 255 SIP accident patterns with three or more fatalities were established and studied for four years. This article describes the background, accident patterning methodology, a pattern sheet sample, analysis of sheets, and some study results using the 255 SIP accident patterns. It also introduces the future plans for these SIP accident patterns in a national accident database.

1 Background

The number of Japanese traffic accident fatalities in 2017 was 3,694, a decrease of 210 from the previous year and the lowest number since 1948 when the National Police Agency started keeping traffic accident statistics.

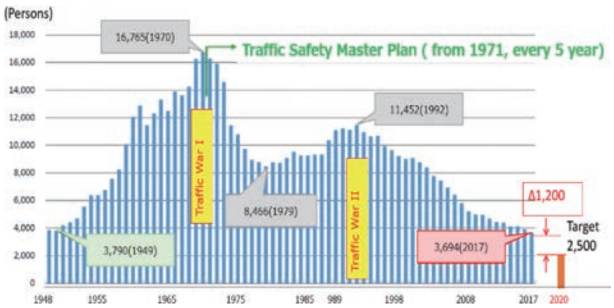

Fig. 1 Trend of traffic accident fatalities in Japan

The Institute of Traffic Accident Research and Data Analysis (ITARDA) was established in 1992 as a public benefit corporation approved by the National Police Agency and the Ministry of Transportation and Construction. It conducts comprehensive and scientific research into traffic accidents from the three standpoints (people, roads, and vehicles), and provides the results of its research to the public and private traffic safety organizations to help them realize safer road traffic. The 10th Traffic Safety Master Plan (in March, 2016) states that "by 2020, the number of traffic accident fatalities should be reduced to 2,500 or less to realize the world's safest road traffic environment." To achieve this goal, it is necessary to reduce the number of traffic accident fatalities by about 1,200 in the remaining three years.

Started with Prime Minister Abe's remarks aiming for world-leading's technologies at the 107th Council for Science, Technology and Innovation (March, 2013), the Cross-ministerial Strategic Innovation Promotion Program (SIP) is being strongly supported by the Japanese government. SIP is promoted beyond the boundaries of the ministries and sectors, and is allocated its own budget, from basic research to completion (practical application/commercialization).

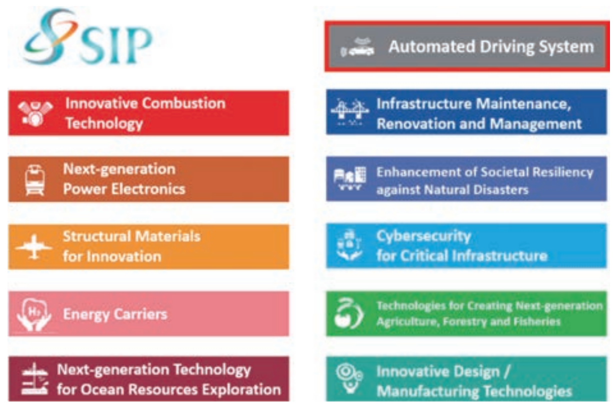

Fig. 2 Eleven projects of SIP

The 11 SIP themes launched in 2014 include one called "Automated Driving System." This theme targets the achievement of national goals such as reducing traffic accidents, the realization and dissemination of automatic driving systems, cooperative development with the Tokyo Metropolitan Government with the 2020 Tokyo Olympics and Paralympic Games as a milestone, the development and demonstration of systems including large-scale demonstration experiments, as well as the development of basic technologies to reduce the number of traffic fatalities and traffic congestion.

ITARDA has been conducting research to help estimate the effect of basic technologies on automated driving systems aiming to reduce the number of traffic accident fatalities. The title of this research is "Analysis of traffic accident patterns using the latest ITARDA macro database," and is part of a survey and study for achieving the national goal of reducing traffic accident fatalities.

③ Estimating the Effectiveness of Measures to Reduce Traffic Accident Fatalities

Study of Japanese Traffic Accident Patterns for Estimating Effectiveness of ADAS Based on ITARDA Macro Database

This article describes the background, accident patterning methodology, a pattern sheet sample, analysis of sheets, and some study results using the 255 SIP accident patterns.

2 Patterning of ITARDA Macro Data

2.1. Methodology for patterning

In the first year of this SIP research, the ITARDA macro accident database for 2013 was studied and classified using the accident classification items shown in Table 1.

Table1 Items and classifications for patterning

Item	Classification
Type of collision	Head-on, rear-end, crossing, single, vehicle-to-pedestrian, vehicle-to-bicycle, etc.
Primary party	Car, motorcycle, bicycle, pedestrian
Secondary party	Car, motorcycle, bicycle, pedestrian
Type of road	Public road, Expressway
Location	Intersection, near intersection, curve, straight, bridge, tunnel, other
Traffic control	Signal, stop sign, no control
Traveling maneuver	Going straight, turning left, turning right, etc.
Relative position of secondary party	Same direction, opposite direction, right side, left side, other

Table 2 at the bottom of this page shows the numbers of fatalities and patterns classified by combinations of accident types and primary or secondary parties. Changing the threshold of the number of fatalities to five or more, four or more, or three or more increases the number of both fatalities and patterns, as well as the coverage ratio. Consequently, we chose three or more fatalities as the threshold to cover over 80% of the total traffic accident fatalities in 2015. This resulted in 255 SIP patterns.

2.2. Pattern sheet example

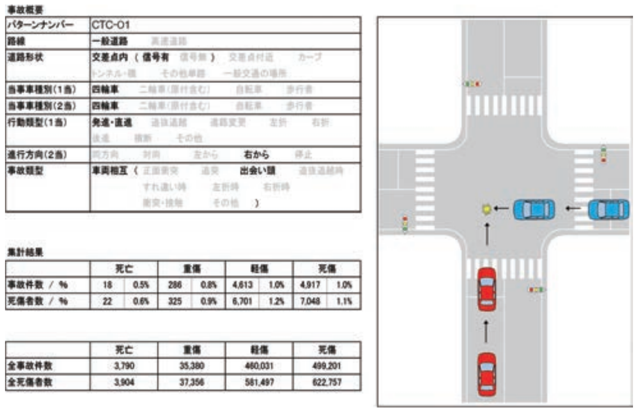

Fig. 3 Example of SIP accident pattern sheet (Japanese only)

Figure 3 shows an example sheet of the 255 SIP patterns. This pattern sheet shows car-to-car crossing accidents at signalized intersections on public road excluding expressway. The secondary party (blue car) is coming from the right side of the primary party (red car). The accident summary table at the top left shows the keywords from the classification items for patterning shown in Table 1. An accident diagram is shown on the right. The middle table shows the number of accidents involving fatal, serious, and minor injuries included in this pattern, and the number of fatalities, seriously injured, and slightly injured occupants.

In addition, the bottom table shows the total number of accidents and casualties for the year as a reference.

Table 2 Numbers of fatalities and patterns, and ratio covered (note: numbers are not revised)

Road type	Accident type	Primary party	Secondary party	Code	Fatlities involved	Fatlities categorized			Numbers of patterns		Ratio covered	
						Fatalities ≥5	Fatalities ≥4	Fatalities ≥3	Fatalities ≥4	Fatalities ≥3	Fatalities ≥4	Fatalities ≥3
Public road	Vehicle to vehicle	Car	Car	CTC	636	546	574	583	25	28	90.3%	91.7%
		Car	Motor cycle	CTM	283	172	196	211	17	22	69.3%	74.6%
		Car	Bicycle	CTB	359	272	276	300	20	28	76.9%	83.6%
		Motor cycle	Car	MTC	204	133	137	140	12	13	67.2%	68.6%
		Motor cycle	Motor cycle	MTM	13	0	0	3	0	1	0.0%	23.1%
		Motor cycle	Bicycle	MTB	8	0	0	3	0	1	0.0%	37.5%
		Bicycle	Car	BTC	132	80	80	89	4	7	60.6%	67.4%
		Bicycle	Motor cycle	BTM	5	0	0	0	0	0	0.0%	0.0%
	Single vehicle	Car	–	SCA	650	501	525	552	38	47	80.8%	84.9%
		Motor cycle	–	SMA	214	120	148	163	18	23	69.2%	76.2%
	Vehicle to pedestrian	Car	Pedestrian	CTP	1297	1143	1143	1173	40	50	88.1%	90.4%
		Motor cycle	Pedestrian	MTP	37	23	23	26	3	4	62.2%	70.3%
		Pedestrian	Car	PTC	126	100	100	106	8	10	79.4%	84.1%
		Pedestrian	Motor cycle	PTM	6	0	0	0	0	0	0.0%	0.0%
Expressway	Vehicle to vehicle	Car	Car	HCTC	95	66	66	72	6	8	69.5%	75.8%
		Car	Motor cycle	HCTM	7	0	0	3	0	1	0.0%	42.9%
		Motor cycle	Car	HNTC	7	0	0	0	0	0	0.0%	0.0%
		Motor cycle	Motor cycle	HMTM	0	0	0	0	0	0	—	—
	Single vehicle	Car	–	HSCA	82	51	63	69	8	10	76.8%	84.1%
		Motor cycle	–	HSMA	18	0	4	4	1	1	22.2%	22.2%
	Vehicle to pedestrian	Car	Pedestrian	HCTP	14	0	0	3	0	1	0.0%	21.4%
		Motor cycle	Pedestrian	HMTP	0	0	0	0	0	0	—	—
Total					4193	3207	3335	3500	200	255	76.3%	80.0%

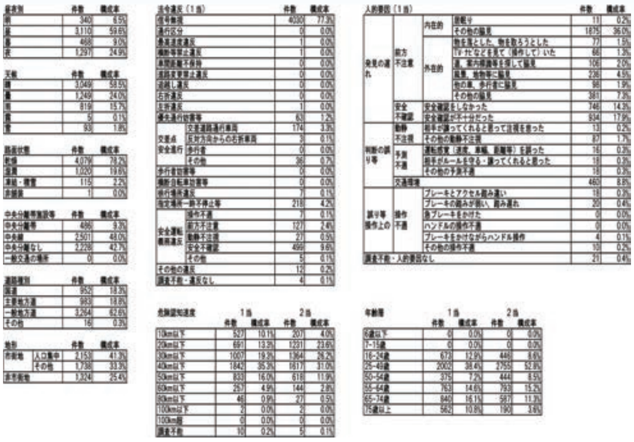

Fig. 4 Example of detailed SIP analysis sheet (Japanese only)

Detailed analysis was carried out for each pattern and analysis results. Information such as whether the accident occurred during the day or at night, in fine or rainy weather, or on urban or rural roads, whether the primary party violated any regulation, as well as the travel speed, human factors, and age group in the accident pattern were clarified. The results of this detailed analysis were prepared for all accident patterns.

3 Application of 255 SIP Patterns

Over four years of studies, the 255 SIP patterns were applied to various topics, including the following.

1) Estimation of the effectiveness of ADAS provided with pedestrian detection technologies for reducing fatal car-to-pedestrian accidents
2) Estimation of the effectiveness of ADAS provided with lane keeping technologies for reducing accidents in which single cars run off the road
3) Identification of patterns with 20 or more fatalities and a fatality rate of 5% or more among fatal car-to-bicycle accidents
4) Identification of trends in the number of accidents and fatalities of each pattern over nine years, and to investigate the reasons for these trends

Details of the results of these topics are introduced in annual reports published by ITARDA (see the references).

4 Issues to be Solved and Future Plans

From the standpoint of fixed point observation, the 255 SIP patterns have been maintained for the past four years. However, the coverage rate has been decreasing year by year because of the decreasing total number of road fatalities in Japan. In the first year, 255 SIP patterns were established using 2013 accident data, and the fatalities categorized in these patterns accounted for 80.0% of the total traffic accident fatalities. However, in 2015, after only two years, the coverage rate fell to 76.8% and to 75.5% in 2016.

Currently, in the final year of the research project, we plan to review the existing patterns and identify potential new patterns to improve the coverage rate. For example, in single-vehicle accidents involving a car or motorcycle, these patterns are extremely fragmented according to the classification of the traffic accident statistical codes. In the case of single-vehicle accidents, cars or motorcycles that depart from their lane for some reason might collide with fixed objects, or collide with nothing and drive off the road. In such cases, the collision object is decided by the road environment. Therefore, to improve the coverage rate, we are investigating the possibility of reducing the number of accident patterns by combining collision objects. From the standpoint of active safety, there is an idea that all colliding objects may be integrated. In contrast, from the standpoint of passive safety, it is necessary to separate collision objects with high fatality rates such as utility poles and sign posts.

In addition, we are also studying patterns in which the number of traffic accident fatalities has increased in recent years, and new patterns such as single-bicycle accidents, which were not covered four years ago.

After these studies, it should be possible to finalize new SIP patterns in a national traffic accident database for Japan.

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Development and Substantiation of Simulation Technology for Estimation of Detailed Traffic Accident Reduction Effects

Sou Kitajima (Japan Automobile Research Institute)

ABSTRACT: The aim of this project is to develop novel multi-agent traffic simulation software capable of predicting the impact of automated driving systems on traffic safety. The software is designed to incorporate variables for human perception and recognition, decision-making, and errors, dependent on age and gender. In this study, the software was applied to a 6 x 3 km^2 area in Tsukuba city. Over a simulated period of time that included more than 500 agents (vehicles, drivers, and pedestrians), the software simulated and identified at least five types of accidents. Different automated driving technology penetration scenarios were applied to conduct preliminary estimations of the potential impact of these technologies on safety.

1 Introduction

Automated vehicles are regarded as a promising means of helping to achieve safer roads[1]. Comprehensive estimations of the potential impact of such vehicles on traffic safety at a national level require the application of simulation methodologies. Within the Japan SIP-adus strategic research program, the aim of this project is to develop and verify a multi-agent traffic simulation methodology capable of estimating the safety improvement potential of automated vehicle technologies.

2 Methodology

2.1. Simulation Concept

Automated driving systems have the potential to help achieve the Japanese government's target of realizing the world's safest traffic environment. Although studying methods of assessing the impact automated driving functions is an important part of this approach, there are several challenges, such as the development of pragmatic behavior models of various traffic participants. From the standpoint of research ethics, we cannot assess impacts on fatality reduction by field operational tests (FOTs) in the real world. Therefore, research is under way into the development of macro traffic simulation software that consists of multi-agent traffic participants. This simulation aims to generate both normal traffic flows and critical traffic situations.

2.2. Simulation components

2.2.1. Overall structure

Figure 1 shows the composition of the multi-agent traffic simulation. The simulation is composed of scenario files, road data, and a simulation module. The simulation module includes three management modules and two traffic participant models. If an accident occurs during a simulation, log data such as collision velocity, collision angle, and the driver's age are recorded to calculate the probability of serious injury.

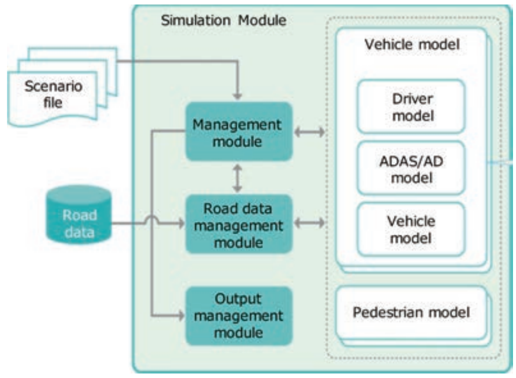


Fig. 1 Composition of multi-agent traffic simulation

2.2.2. Behavior model of traffic participants

(1) Driver behavior model

The driver behavior model is composed of three main processes including perception/recognition, decision making, and actions. This simulation incorporates two types of driver visual fields to simulate various safety confirmation actions (Fig. 2). Various typical driver errors, such as inattentive driving, aimless driving, misjudgment, and inade-

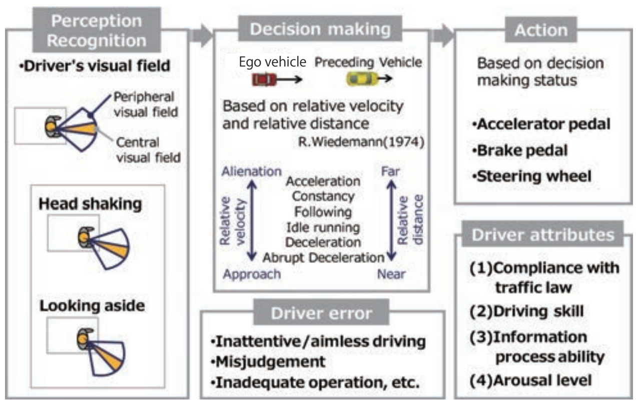


Fig. 2 Outline of driver agent model

quate operation are reproduced by utilizing the driver behavior model. Furthermore, since drivers have diverse characteristics due to age, gender, character, and driving style, the simulation also includes four different driver personality attributes.

(2) Pedestrian behavior model

Figure 3 indicates the pedestrian behavior model used to reproduce road crossing behavior. In Japan, about 25% of fatal accidents are collisions with a crossing pedestrian at a non-intersection area. It is important to develop a pragmatic model based on pedestrian safety confirmation actions. There are six parameters for reproducing road crossing behavior, such as walking velocity. The distribution of parameters was reflected in the behavior model based on fixed-point observation and examination[(2)].

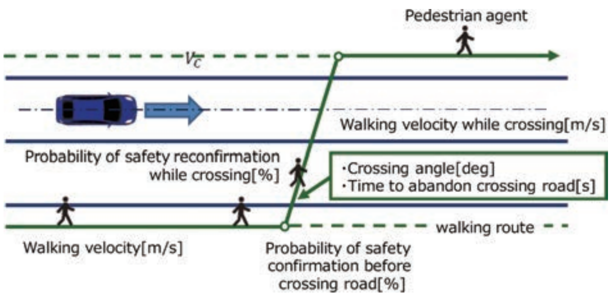


Fig. 3 Outline of pedestrian agent model

2.2.3. Advanced driver assistant system (ADAS)/automated driving

Advanced driver assistant system (ADAS) and automated driving specifications can be defined by the number of sensors, detection range, and angle. Figure 4 shows an example of an automated driving system. In this article, the estimation of accident reduction effects is computed through this system.

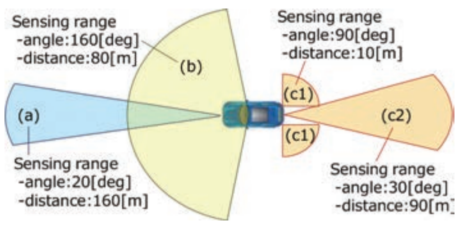


Fig. 4 Specifications of sensors for automated driving system

2.3. Functional testing of multi-agent traffic simulation

2.3.1. Road network

Figure 5 shows a simulated area that was created for the detailed modeling of a part of Tsukuba City. The road network is composed of various routes, such as an expressway, major roads, and narrow streets.

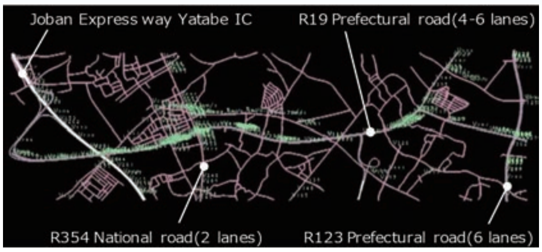


Fig. 5 Road network for functional testing

2.3.2. Simulation conditions

Typical automated driving penetration rates were applied to compute and compare the results of diverse technology penetration scenarios. The simulation contains multiple driving modes, including manual driving, autonomous emergency braking (AEB), lane departure warning (LDW), and automated driving (Table 1). It is important to set up mixed scenarios consisting of various driving modes to estimate safety impacts more practically.

Table 1 Technology penetration scenarios

Simulation Scenarios	*1*	*2*	*3*	*4*	*5*
Manual Driving (MD)	100	50	25	25	-
Autonomous Emergency Braking (AEB)	-	50	25	-	-
AEB + Lane Departure Warning (LDW)	-	-	50	50	25
Automated Driving (AD)	-	-	-	25	75

3 Simulation Results

3.1. Reproduction of realistic traffic flows

To obtain pragmatic estimations of accident reduction effects, it is essential to reproduce realistic traffic flows via simulation. The current simulation can reproduce approximately 500 agents with individual behavior (Fig. 6). Traffic densities and travel velocities are set beforehand based on road traffic census data.

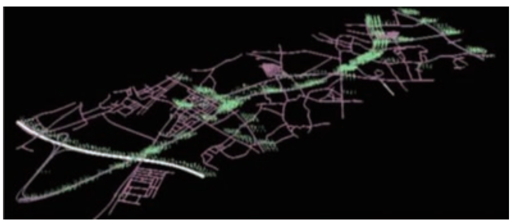


Fig. 6 Multi-agent traffic simulation including 500 agents

3.2. Reproduction of accidents

Typical accidents such as head-on collisions occur occasionally due to driver agent error. Figure 7 shows an example of an accident. The driver agent started to depart from the driving lane because of driver error (i). Lane departure continued even though the vehicle reached the opposite lane (ii). Although the driver agent perceived the lane departure and began an emergency operation (iii), it was not effective at avoiding a collision (iv).

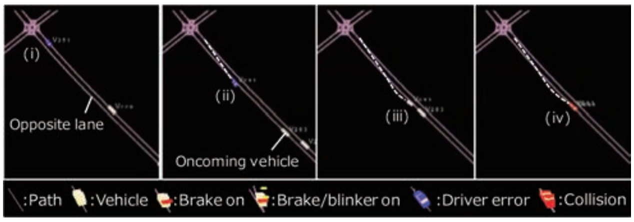


Fig. 7 An example of a head-on collision at a basic road section

3.3. Comparison between simulated results and accident statistics

Figure 8 compares simulated results for 100% manual driving with traffic accident statistics. These accidents occurred in proportions and locations similar to those of real-world accidents.

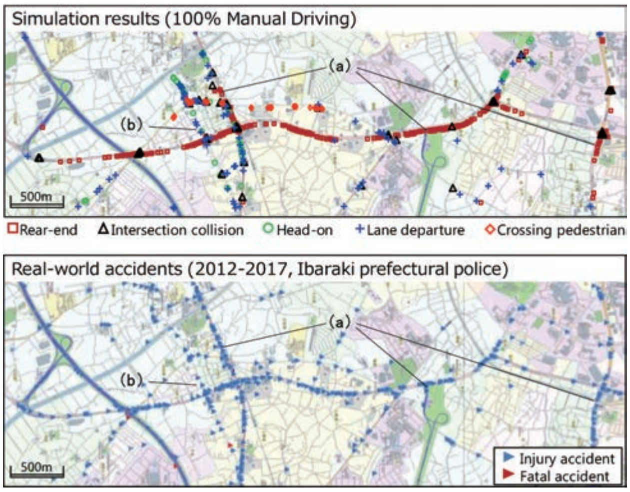
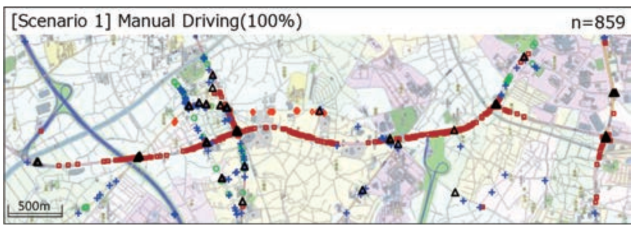


Fig. 8 Comparison of accident occurrence locations between simulation results and real world accidents

3.4. Frequency and occurrence locations under different simulation conditions

Figure 9 shows the simulation results under different simulation conditions to estimate the accident reduction effect of different systems. Each result shows different characteristics in terms of frequency and occurrence locations. This simulation is an effective way of quantitatively estimating the safety impacts of different levels of penetration of advanced driving assistant systems or automated driving.



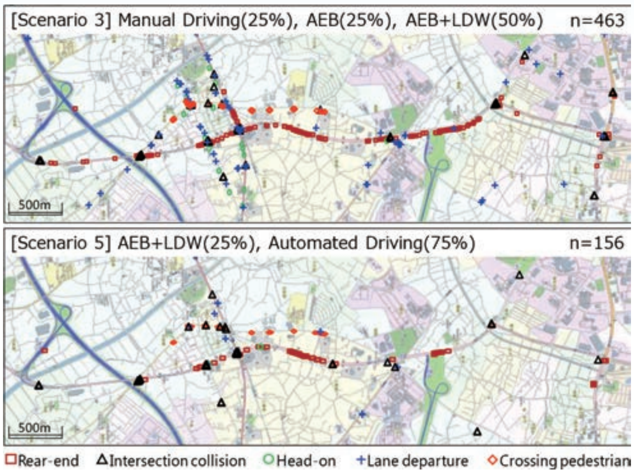


Fig. 9 Comparison of accident occurrence locations (scenarios 1, 3, 5)

The simulation can adopt different automated driving technology penetration scenarios to estimate the potential impact of different technologies on safety.

3.5. Comparison of number of accidents and accident rate

Under 100% manual driving, the system simulated a total of 859 accidents of five types. The number of predicted accidents decreased as the level of automation increased, falling to 156 accidents at the highest simulated automation level (25% of vehicles with AEB + LDW and 75% with level 4 automated driving) (Table 2). Figure 10 shows that all the considered technologies contributed to an absolute decrease in accidents. This decrease was dominated by reductions in rear-end and lane departure-related crashes.

Table 2 Synoptic table of simulation results

No.	Total			MD	AEB	AEB LDW	AD
	NoA [Freq.]	*AR* [Freq. /km]	*RAR* [%]	*RAR* [%]	*RAR* [%]	*RAR* [%]	*RAR* [%]
1	859	0.011	100	100			
2	622	0.008	70	101	41		
3	463	0.006	56	113	46	36	
4	430	0.005	46	116		30	14
5	156	0.002	16			29	12

NoA: Number of Accidents, AR: Accident Rate, RAR: Relative Accident Rate

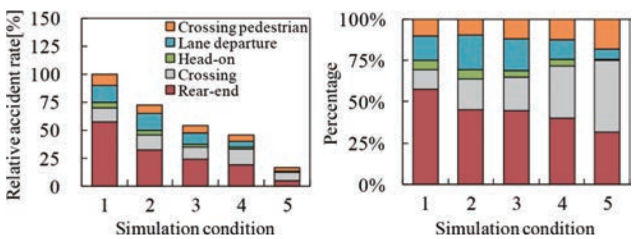


Fig. 10 Comparison of relative accident rates and compositions

4 Concluding Remarks

Novel multi-agent traffic simulation software was developed and applied to an 18km^2 area in Tsukuba City, Japan. Over a simulated period of time with more than 500 agents, the software simulated and identified five types of accidents. Different automated driving technology penetration scenarios were applied to estimate the potential impact of different technologies on safety. Future work will also address the validation of behavior models and the expansion of the current methodology to wider regions.

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Development and Evaluation of Technologies for Constructing Driving Video Database

Kazunori Nomoto, Hiroshi Tanigawa, Akito Adachi (Japan Automobile Research Institute)

ABSTRACT: The safety of automated driving systems, which are regarded as a promising means of helping to reduce traffic accidents, is greatly dependent on functions for recognizing pedestrians and objects, and on making early and accurate judgments of potential collision risks. The collection of large volumes of driving data and the development of technologies and tools for using this data efficiently are recognized as common issues for strengthening competitiveness in the development of such recognition and judgment functions. This article describes efforts undertaken to research and evaluate the utility of a driving video database and simulation evaluation technology needed for developing camera image recognition technology.

1 Development Aim

Human error is the cause of over 90% of traffic accidents, and nearly all fatal accidents occur on ordinary roads. Implementing automated driving on ordinary roads is being promoted as a national project in Japan with the aim of reducing fatal traffic accidents.

There is intensifying competition to research and develop techniques capable of accurately judging at an early timing the presence and potential risk of a collision with pedestrians and two-wheeled vehicle riders, who account for a large percentage of traffic accident fatalities. In addition to automated driving systems for ordinary roads, application of these techniques is also being targeted at advanced driver assistance systems (ADASs) that have already been implemented in production vehicles, and efforts are being made to further improve them and expand their application.

Original equipment manufacturers (OEMs) and suppliers are proceeding with R&D activities using data collected in driving tests conducted using vehicles equipped with proprietary systems developed by each company. However, an enormous amount of time and expense is required to obtain the large volumes of driving video data needed for training image recognition engines and for conducting simulations to evaluate the recognition performance of these systems. Meanwhile, the camera image data collected by these proprietary systems is highly dependent on the hardware used, such as the specifications and mounting positions of the cameras. Moreover, companies cannot easily share their data with others since images may contain confidential information about products under development. Consequently, there is a need to construct a large-scale driving video database that is premised on shared use by every company involved.

The aim of this project is to improve R&D efficiency and competitiveness by providing large volumes of teaching data to OEMs and suppliers for use in developing automated driving technologies, as well as to universities, research institutes, IT business ventures, and the like, which are looked to for research on cutting-edge technologies such as artificial intelligence (AI). Such data is needed for developing recognition engines for pedestrians and two-wheeled vehicle riders along with artificial intelligence for predicting the risk of a collision using driving environment recognition systems based on camera images.

2 Overview of Research and Development Work

In this driving video database project, large volumes of driving video data (approximately 1,500 hours, 4.2 petabytes (10^{15}) and 100,000 scenes) were collected for use in developing and evaluating the performance of pedestrian recognition systems. The associated key technologies for constructing an easy-to-use database were also developed, including functions for tagging data and conducting data searches.

Over a three-year period from fiscal 2014, activities were undertaken to develop and verify an automated driving system for universal services, as well as technologies for constructing a driving video database in the Cross-Ministerial Strategic Innovation Promotion Program (SIP). From fiscal 2017, this project commissioned by the Ministry of Economy, Trade and Industry was launched to research, develop and verify an advanced automated driving system for social implementation. This project undertook research and development work necessary for achieving an advanced automated driving system.

2.1. Research and development objectives

2.1.1. Construction of driving video database

The image data collected in this database is limited to scenes involving pedestrians, two-wheeled vehicles, including bicycles, and motor vehicles, based on the opinions of people concerned with the development of automated driving technology. In addition, the camera system used was configured to take wide-angle forward images and 360-degree images of the surroundings in order to record the presence and movement of pedestrians, two-wheeled vehicles, and other objects around the vehicle. This is because one of the issues raised in the Euro NCAP (European New Car Assessment Programme) 2020 Roadmap is the prevention of accidents at intersections.

The vehicle-mounted cameras used in automated driving systems have different specifications depending on the manufacturer, and their performance is being improved every year as result of further technological progress. This driving video database is intended to provide teaching data for use in simulations to evaluate the performance of such camera systems. The image quality must be as good as or better than that of the vehicle-mounted cameras to be evaluated. Taking into account the specifications of cameras currently used in ADASs and projected performance improvements over the next five years, it was concluded that the cameras should have approximately twice the number of imaging elements as current cameras and a wider horizontal angle of view, among other specifications. Accordingly, a Hi-Vision (high-resolution two-megapixel imaging element) camera system was adopted to provide the desired performance.

Existing image recognition databases are capable of recognizing faces and handwritten characters, and the volume of data needed at the level of practical performance is said to be in the order of several million items. The pedestrian databases currently provided by research institutes in other countries contain still images, but video image data is needed to analyze pedestrian behavior at intersections and other places.

Based on these considerations, it was decided to record four million frames of different pedestrian types, including men, women, and children of all ages, in different postures and carrying different objects, and 107,497 video images of walking scenes, including walking along the side of roads, at intersections, crossing roads, and other situations.

2.1.2. Construction of simulation evaluation environment

Data collected by driving test vehicles on public roads provides useful information for use in technological development because it includes various types of real-world traffic environments, such as different road structures, natural environments and the presence of pedestrians, nearby vehicles, and other objects. However, it would be impossible to record every driving situation that might occur in the real world. One conceivable way of complementing actual equipment evaluations and simulations using recorded driving data would be to build a virtual environment and to conduct simulations under a variety of given conditions. Based on actual recorded images, computer graphics (CG) technology, like that widely used in the video game industry and elsewhere in recent years, was applied to create a virtual space on a computer. In this way, an evaluation environment was constructed for conducting simulations under virtual conditions and its utility was verified. Various adverse circumstances were created for use in the simulations by freely combining natural conditions, such as daytime, nighttime, and rain, as well as the positions and movements of pedestrians and nearby vehicles.

2.1.3. Promotion of database use by the private sector

The existence of the driving video data recorded in this project was publicized widely among OEMs and suppliers that are developing automated driving systems, as well as among research institutes, universities, IT venture businesses, and other entities involved in cutting-edge core technologies such as AI. Sample data was made public in order to collect a wide range of information about various aspects, such as needs concerning insufficient data, as well as technologies or tools for practical use of the database.

3 Construction of Driving Video Database

3.1. Data collection

Various types of sensors are available for detecting a vehicle's direction of travel and surrounding circumstances, including cameras, millimeter radar, LiDAR devices and ultrasonic sensors, among others. A monocular camera system was selected for recording forward wide-angle and all-around image data because the data volume is smaller than a stereo camera system and high-resolution wide-angle images can be obtained. Because the distance accuracy of a monocular camera system to potential object is inferior, long-range scanning LiDAR sensors were used in parallel. A system was adopted for synchronized collection of both image data and LiDAR data.

The camera system consisted of five 2.3-million pixel monocular Hi-Vision cameras. One was a forward remote monitoring camera with an angle of view of approximately 90° and the other four had an angle of view of approximately 180° and were positioned at the front and rear and on both sides of the vehicle. Corresponding to the cameras were five LiDAR sensors and large-capacity data recording devices with a maximum recording time of six hours. The vehicle was equipped with two types of GPS devices for measuring its position. The appearance of the vehicle that was developed for collecting driving video data is shown in

Fig. 1.

Fig. 1 Vehicle developed for collecting driving video data

3.2. Data processing

In order to use large volumes of data efficiently and effectively according to a particular purpose, it is necessary to be able to comprehensively search all the related data by specifying certain priority conditions These might include driving scenarios such as straight-ahead travel or turning right or left at an intersection, conditions such as daytime, nighttime, or rain, and the presence, positional relationships, and other aspects of pedestrians or nearby vehicles. For that purpose, it is essential to classify scenes so that objects of interest can be found in specific time frames in individual driving scene files that contain, for example, scenes of pedestrians or bicycles crossing the road. Therefore, all the images in this driving video database have been classified into 27 types of scenes.

Figure 2 shows a breakdown of the overall 258,364 driving scenarios. The database contains 107,497 pedestrian scenes obtained from city streets, shopping/entertainment streets, sightseeing areas, and cold regions, and 6.45 million frames of pedestrian image data. As a result of analyzing, classifying and organizing all the data, the development targets of 4 million frames of pedestrian image data and 107,497 scenes of pedestrians walking were ultimately obtained.

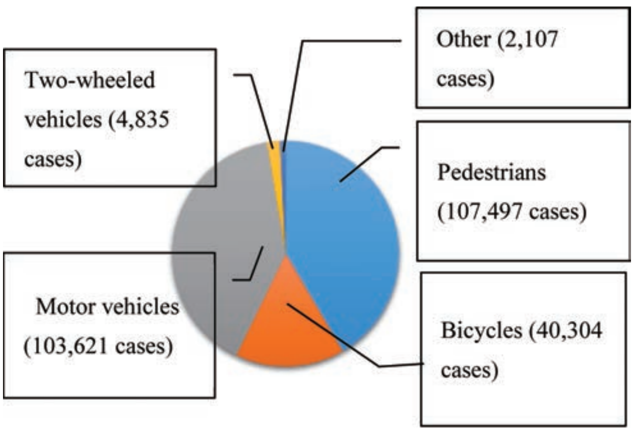

Fig. 2 Breakdown of the numbers of targeted objects in driving scenarios

3.3. Database evaluation

A portion of the driving video database was provided to the representatives of eight organizations, including OEMs, suppliers, and research institutes in order to perform a multifaceted evaluation of the data with respect to quality, ease of use, utility, and other aspects. Although the results confirmed the utility of the database, room for further improvement was also found.

In addition, four briefing sessions were held from January to March 2018, which were attended by 112 participants from 81 organizations. Figure 3 shows one of the nine sample driving scenarios shown to the attendees. The aim was to encourage use of the database by organizations engaged in R&D work on cutting-edge core technologies, including the development of recognition engines for pedestrians, two-wheeled vehicles, and the like, as well as the development of AI for predicting the risk of a collision. People from research institutes and other organizations accounted for approximately 35% of the total attendees, which shows that the aim of broadening the range of R&D activities was accomplished. JARI has also independently taken the initiative to supply 288 sample datasets to interested parties, and has launched activities to encourage use of the driving video database by private sector organizations.

Fig. 3 Driving video data showing a pedestrian crossing the road against sunlight

4 Construction of a Simulation Evaluation Environment

It would be difficult to record every situation that might occur in the real world, including various weather conditions, near misses and so on, by driving test vehicles on public roads to collect driving video data. Constructing a virtual environment and conducting simulations under a wide variety of given conditions is regarded as a more effective method. For that reason, a simple prototype simulation environment was constructed and its utility was verified.

Specifically, some of the recorded driving data was used to extract playbook-like scenarios of vehicle behavior of the vehicles, pedestrians and other traffic participants appearing in those scenarios. In addition, from among the models of structures, people, vehicles and the like developed by the private sector, ones closely resembling actual objects were selected and various simulation conditions were determined, including the weather. Computer graphics technology was then used to recreate virtual driving scenarios on a computer. It should be noted that the models of structures, people, and vehicles used were prepared in advance on the basis of actual photographic materials so that they would be equally recognizable by image recognition engines and AI in the same way as actual objects. Consequently, they could be used in the evaluation of image recognition performance and eliminated any concerns concerning personal information.

Evaluations performed in a prototype virtual simulation environment were compared with evaluations of driving scenarios obtained using test vehicles. This was accomplished by positioning people and vehicles on a test course in the same manner as in the virtual driving scenarios and then recording images of the test driving scenarios. Differences between the two driving scenario datasets were evaluated using the same recognition engine, and the utility of the virtual simulation environment was verified by the fact that nearly identical results were obtained.

In order to verify the safety and utility of an automated driving system, driving tests must be conducted using test vehicles equipped with the system to be evaluated. A prototype environment was constructed that can use virtual simulation evaluations to verify object recognition and vehicle control algorithms at the design and development stage before conducting actual driving tests. The utility of this environment was also verified in this project.

The simulation evaluation environment was constructed with a high level of reality by combining digital map data (accurate road structures, lane configurations, and the like) and object assets (nearby structures, guardrails, trees, and the like) using MATLAB/Simulink and Prescan, as an example of a general-purpose evaluation environment. This was carried out to realize a usable simulation environment for conducting comprehensive safety evaluations of the recognition and judgment functions of automated driving systems.

5 Conclusion

Efforts were undertaken in this project to research and evaluate the utility of a driving video database and simulation evaluation technology needed for developing camera image recognition technology. As a result, approximately 1,500 hours of driving image data amounting to 4.2 petabytes and 107,497 scenes of pedestrian image data were collected in the database. The utility of a simulation evaluation environment using computer graphics technology was also verified.

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(2) Report on Development and Verification of Autonomous Driving System and Technologies for Constructing a Driving Video Database in the Cross-Ministerial Strategic Innovation Promotion Program (SIP) in Fiscal 2015 (in Japanese).
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Development of Tool for Assessing Impact of Automated Driving Systems on Traffic Flow and CO_2 Emissions

Daisuke Oshima and Takashi Kurisu (Pacific Consultants Co., Ltd.)

ABSTRACT: We have developed a tool for visualizing the CO_2 emissions of vehicular traffic, which can quantitatively evaluate how the introduction of automated driving systems might affect traffic flow and, consequently, changes in the amount of CO_2 emissions from vehicular traffic. To develop this evaluation tool, we combined traffic simulation with CO_2 emissions models and performed necessary verifications in accordance with an international joint report issued as part of NEDO's "Development of Energy-saving ITS Technologies" project. In addition, we used the tool to evaluate certain automated driving systems in specific scenarios, where the tool proved applicable to the evaluation of those systems.

1 Purpose

Automated driving systems are expected to reduce traffic fatalities and alleviate traffic congestion, possibly resulting in lower CO_2 emissions. This project aims to develop an evaluation tool for visualizing the CO_2 emissions of vehicular traffic, which can quantitatively evaluate how the introduction of automated driving systems might affect traffic flow and CO_2 emissions from vehicular traffic, as a tool for assessing the social impact of such systems. The evaluation tool is intended to help set priorities for the technological development of various automated driving systems, help determine how best to implement such systems in society, and help raise public awareness through visualization of the amount of CO_2 emissions, thus promoting the practical and widespread use of such systems.

2 Development Plan

2.1. Basic configuration of evaluation tool for visualizing CO_2 emissions of vehicular traffic

As a technique for estimating CO_2 emissions based on changes in vehicular traffic flow, a method that combines traffic simulation with CO_2 emissions models was established in the "Development of Energy-saving ITS Technologies" project (Energy ITS project) conducted from FY2008 to 2012. This method involves simulating the movements of all vehicles traveling in a study area, calculating CO_2 emissions based on the reproduced vehicle movements using CO_2 emissions models, and summing the results for all vehicles to estimate the CO_2 emissions from all the vehicular traffic (Fig. 1).

An international joint report titled "Guidelines for assessing the effects of ITS on CO_2 emissions" issued as part of the project specifies the requirements to be met in the calculation process. The results of calculations that comply with these requirements are deemed internationally reliable. To develop the evaluation tool, we combined the traffic simulation with CO_2 emissions models in accordance with the international joint report.

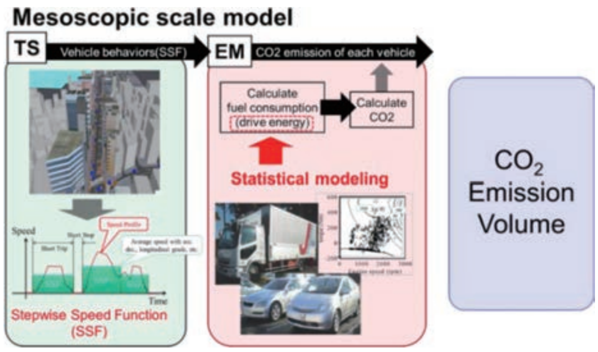

Fig. 1 Method for estimating CO_2 emissions from vehicular traffic flow[1)]

2.2. Scope of evaluation

The following five automated driving systems were selected for evaluation by the tool:

- Green wave driving utilizing traffic signal control information, etc.
- Advanced Rapid Transit (ART) (smooth acceleration and deceleration of buses)
- Truck platooning
- Automated driving on expressways and general roads
- Local traffic control systems (automated last-mile transport and automated valet parking)

The introduction of automated driving systems might have the following three main effects leading to lower CO_2 emissions: (1) changes in travel demand caused by improvements in the convenience of automobiles, (2) changes in vehicle behavior caused by system control, and (3) fewer traffic jams caused by traffic accidents (Fig. 2). The area enclosed by the dotted lines in Fig. 2 was selected as the scope of application of the evaluation tool, and the effects shown outside the dotted box were regarded as given conditions. That is, the technology does not estimate how introducing automated driving systems will change travel demand or reduce traffic accidents.

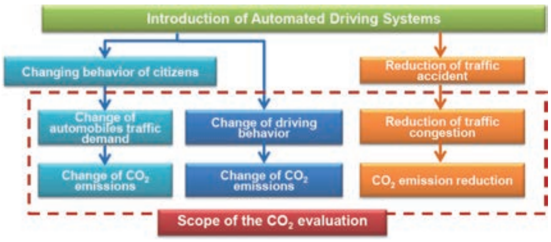

Fig. 2 Effects of automated driving systems on CO_2 emissions from vehicular traffic

3 Development of Local Traffic CO_2 Emissions Visualization Technology

3.1. Modeling of changes in traffic flow caused by introduction of automated driving systems through traffic simulation

3.1.1. Identification of CO_2 emissions reduction mechanisms and determination of requirements for the assessment tool

The international joint report states that the mechanisms of how the measures under evaluation might affect driver and vehicle behavior and help reduce CO_2 emissions should be represented by diagrams called “reference models”. Additionally, the report recommends using the reference models to verify that the assessment tool appropriately considers these mechanisms and that, in actual evaluations of automated driving systems, their effects are quantified based on the models.

Therefore, in preparation for simulation-based modeling, we defined a mechanism for reducing CO_2 emissions for each automated driving system being evaluated. As an example, Fig. 3 shows a reference model of truck platooning.

Next, based on the mechanisms of how the automated driving systems might help to reduce CO_2 emissions (represented by the created reference models), we identified the requirements for the simulations to be performed to evaluate each system.

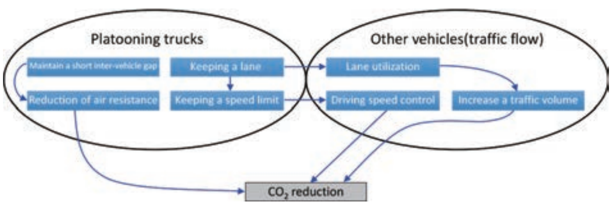

Fig. 3 Reference model of truck platooning

3.1.2. Modeling of automated driving systems and implementation of models in traffic simulations

In accordance with the requirements identified in 3.1.1, we modeled the automated driving systems and implemented these models in traffic simulations. For example, we modeled platooning trucks that maintained a consistent following distance (modeling of truck platooning) and automatic overtaking and merging maneuvers (modeling of automated driving on expressways) and implemented the models. Then we tested the operation and confirmed that the automated driving systems were represented by the traffic simulation as intended.

3.2. Development of technology for estimating emissions from changes in driving behavior caused by automated driving

3.2.1. Expansion of CO_2 emissions models

We used existing CO_2 emissions models as base models (some of which were created in the Energy ITS project). However, because CO_2 emissions models of diesel passenger cars and hybrid minivans (which are becoming more popular in recent years) and buses (evaluated in this project) were not available, we bench-tested these types of vehicles to obtain data on their driving behavior and CO_2 emissions, and created CO_2 emissions models for them based on the data.

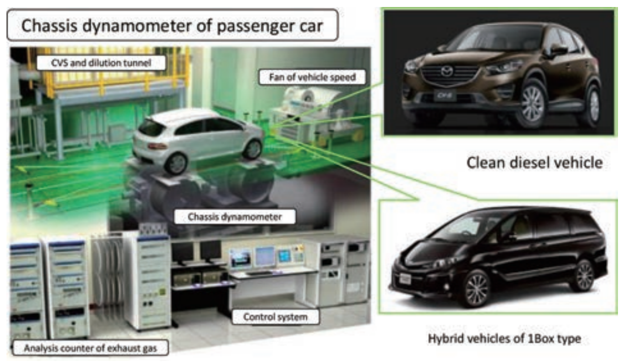

Fig. 4 Bench-testing to create CO_2 emissions models

3.2.2. Creation of CO_2 emissions models assuming automated driving systems have been introduced

We created CO_2 emissions models assuming that automated driving systems have been introduced and have affected the driving behavior of vehicles. For truck platooning, for example, we created a CO_2 emissions model that reflects the reduced air resistance of following trucks due to the shorter following distance; for automated driving on expressways and general roads, we created a CO_2 emissions model that reflects optimal starting (acceleration), cruising, and stopping (deceleration) maneuvers.

3.3. Development of technique for estimating CO_2 emissions reductions due to reduced traffic accidents

In order to estimate CO_2 emissions reductions due to fewer traffic jams caused by traffic accidents (Fig. 2), it is necessary to perform calculations while randomly changing the locations of accidents prevented by the automated driving systems. Therefore, we adopted a method of estimating CO_2 emissions reductions by using a simplified evaluation simulation and macro CO_2 emissions models. (The simplified evaluation simulation technique assesses the impact of a reduction in the traffic capacity while taking into account the space-time propagation of congestion. This technique is based on the simplified kinematic wave theory using data obtained from a dynamic traffic flow simulation that assumes normal traffic conditions not affected by accidents or other incidents.)

To determine the impact of accidents on traffic flow (to be used as an input value in simplified evaluation simulation), we analyzed traffic congestion caused by accidents using probe data and data on accidents on general roads in the 23 wards of Tokyo.

4 Evaluation in Model Cities

We evaluated automated driving systems using the developed evaluation tool. Before conducting evaluations, we compared observed data (such as traffic volume and travel speed) with the results from the traffic simulation to verify that the current traffic conditions in the study area were accurately reproduced by the simulation, as recommended in the international joint report. Here, evaluation results for truck platooning are described as an example.

4.1. Simulation conditions

We performed calculations for the Tomei–Shin-Tomei network (Yokohama-Aoba IC – Toyota JCT – Tomei-Miyoshi IC) (shown in Fig. 5) assuming 24 hours of travel between 4:00 a.m. on a weekday and 4:00 a.m. on the next weekday in September 2016. We also assumed that:

- 50% of heavy vehicle trips between Tokyo and Nagoya were made by platoons of four vehicles maintaining a following distance of 4 m (approximately 3,000 trips made by platooning vehicles, which account for 1.7% of the total number of heavy vehicle trips (approximately 182,000 trips) on the Tomei–Shin-Tomei network).
- 1,000 of the 3,000 vehicles departed at night (between 9:00 p.m. and 1:00 a.m. the next day).
- The platooning vehicles traveled on the Shin-Tomei route (shown in red in Fig. 5) at a target speed of 80 km/h (the target speed of conventional heavy vehicles is 75–95 km/h).

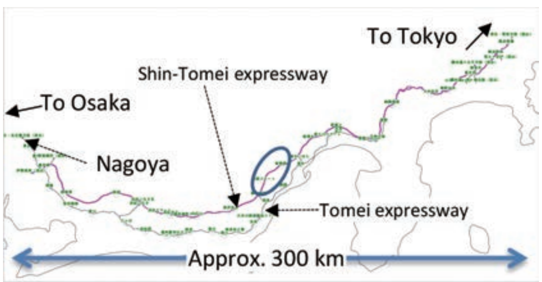

Fig. 5 Network used for platooning simulation

4.2. CO_2 emissions estimation results

The reduction in CO_2 emissions from the base case level was estimated at 0.3% for the 1,000 platooning vehicles (midnight), and 0.8% for the 3,000 platooning vehicles (24 hours). The main possible causes of these reductions are the reduction in the air resistance of following vehicles due to platooning and a reduction in the average speed of the surrounding traffic due to the vehicle platoons traveling at an average speed of about 80 km/h. In this project, the evaluation focused on weekdays, when congestion is low. We believe that platoons of vehicles traveling on weekends or holidays might yield a more significant reduction because platooning helps to reallocate road space.

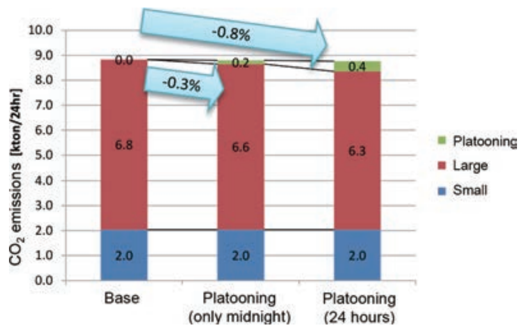

Fig. 6 Evaluation results of truck platooning

5 Conclusion

We have developed an evaluation tool that can quantitatively evaluate how the introduction of automated driving systems might affect traffic flow and CO_2 emissions from vehicular traffic. Although automated driving systems are expected to help alleviate traffic congestion and reduce CO_2 emissions, they may fail to deliver the expected benefits, especially during the transition period in which such vehicles and conventional vehicles share the road. The evaluation tool can be used to find the desired parameters, such as the performance or penetration rate of automated driving systems, and to predict and evaluate what effects the systems might have under various conditions. We hope that this tool will be used in various studies to enhance the potential benefits to society of introducing automated driving systems.

Reference

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Analysis of Social and Industrial Aspects of Developing and Popularizing more Advanced Automated Driving Systems

Yoshihiro Suda, Takashi Oguchi, and Koichi Sakai (The University of Tokyo)

ABSTRACT: The following are regarded as preconditions for encouraging the development and widespread use of more advanced automated driving systems (ADS): Clarification of the impacts on society and industry inside and outside Japan, as well as the risks that will result from such changes, the implementation of measures to mitigate these impacts and risks, the formulation of scenarios from a long-term perspective, and greater understanding of ADS on the part of the general public. This study clarified the evolution of ADS, proposes a future vision for these systems and scenarios for issue resolution, and defined specific actions to prepare for the implementation of ADS through a study team composed of academic specialists from various fields.

1 Aims of This Study

The following are regarded as preconditions for encouraging the development and widespread use of more advanced automated driving systems (ADS): Clarification of the impacts on society and industry inside and outside Japan, as well as the risks that will result from such changes, the implementation of measures to mitigate these impacts and risks, the formulation of scenarios from a long-term perspective, and greater understanding of ADS on the part of the general public. A study team was established to clarify the evolution of ADS, propose a future vision for these systems and scenarios for issue resolution, and define specific actions to prepare for the implementation of ADS.

2 Establishment of Study Team

The team that was established to conduct this study is primarily made up of key figures from universities in wide-ranging areas such as traffic engineering, mechanical/robotics engineering, informatics, urban planning, cybersecurity, and other engineering fields, as well as public economics, civil procedures, technology management, and other socioeconomic fields, in addition to the fields of education, cultural anthropology, and so on.

3 Evolution of Automated Driving Systems

Level 2 and 4 systems are regarded as most likely to respond to societal needs (Fig. 1).

Level 3 ADS are affected by issues such as whether users will be able to resume driving tasks in response to system requests while engaged in secondary activities such as napping, and whether users will respond positively to such systems. It is possible that level 3 systems will be developed as a part of the technological progress toward level 4 systems.

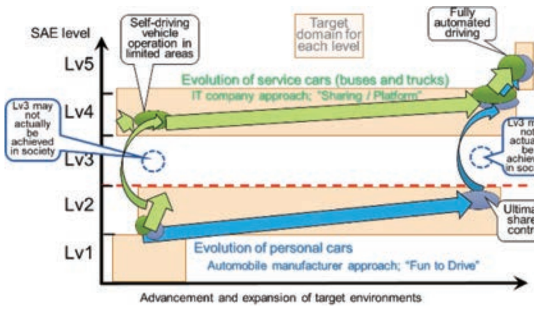

Fig. 1 Evolution of automated driving systems

Although level 3 systems may be popular with professional drivers and other people with advanced driving skills, such systems are not expected to be favored by the average driver. Therefore, it is possible that they may not actually be adopted in society.

4 Future Vision for Automated Driving Systems and Scenarios for Issue Resolution

4.1. Preconditions for study

Based on the two-level evolution discussed in Section 3 above, analysis was conducted for two different time frames: the near future (by around 2025) and the medium- to long-term (by the late 2030s). Figures 2 and 3 show the anticipated technological development and dissemination status for each of these time frames.

4.2. Future vision from the standpoint of societal needs

Societal needs can be categorized from the standpoint of road traffic issues, public transport systems, and logistics systems. This section will consider in greater detail ways to ensure mobility for vulnerable transport users (both those who drive and those who do not have a driver's license) within the category of public transport systems, as well as the future of logistics systems (ways to resolve the driver shortage and reduce logistics costs).

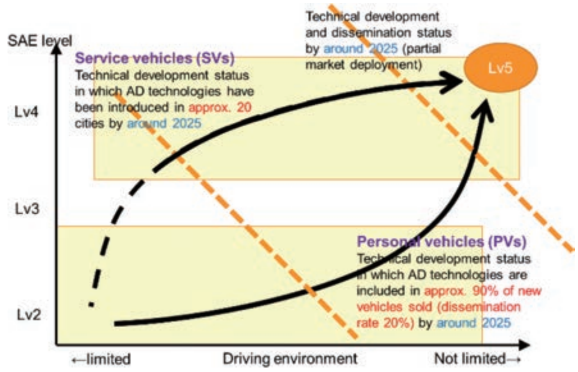

Fig. 2 Technological development and dissemination status by around 2025

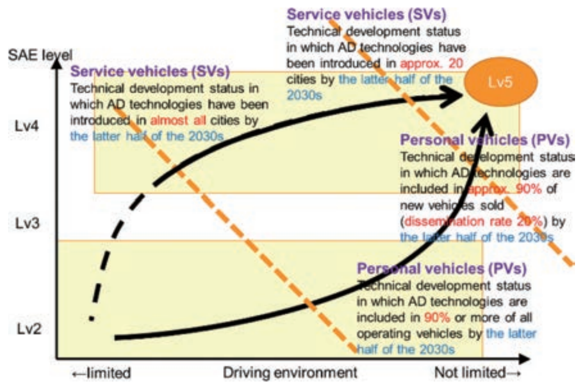

Fig. 3 Technological development and dissemination status by the late 2030s

4.2.1. Ensuring mobility for vulnerable transport users (when users drive themselves)

By around 2025, level 2 private vehicles with advanced driving safety support systems are expected to appear. Restriction-relaxed licenses will enable these vehicles to be operated by everyone, from young people to senior citizens. Legal systems will evolve along with technological progress, such as through the establishment of new restriction-relaxed licensing classifications that enable people to drive only vehicles equipped with advanced driving safety support systems.

By the late 2030s, although such systems will handle almost all driving tasks, fully-featured shared control systems (level 2) will exist that make it seem as though the driver is operating the vehicle by himself or herself.

4.2.2. Ensuring mobility for vulnerable transport users (users without driver's licenses)

By around 2025, low-speed, small-ridership transport services using level 4 ADS will appear, although these will be limited to certain areas such as sparsely populated regions, planned housing developments, and dedicated roads.

By the late 2030s, level 4-5 ADS dedicated vehicles (ADS-DV) will be employed for regular route buses and ridesharing services. In addition, new modes of transport will appear. Level 4-5 ADS-DV for car sharing services that provide a private transport environment will be available for individual use, and on-demand and shuttle type level 4-5 ADS-DV small-ridership type ridesharing services will also be available.

4.2.3. Resolution of the driver shortage and reduction of logistics costs

By around 2025, there will be widespread use of level 2 vehicles as lead vehicles and electronically coupled trucks (level 4 vehicles) as following vehicles on certain expressway sectors. On ordinary roads, level 2 restriction-relaxed licenses for truck drivers will make it unnecessary to have advanced driving skills to operate trucks. There will also be mixed passenger and cargo transport on regular route buses and in ridesharing services (also with level 2 restriction-relaxed licenses), in accordance with demand.

By the late 2030s, it will be possible to operate level 4-5 ADS-DV in all sectors of both expressways and ordinary roads. There will also be mixed passenger and cargo transport and ridesharing services using level 4-5 ADS-DV regular route buses, in accordance with demand.

4.3. Social impacts and issues of automated driving systems from the standpoint of societal needs

Tables 1 through 3 show specific issues as viewed from the perspective of societal needs, scenarios for progress in technological development, social impacts, negative impacts and issues, and scenarios for issue resolution.

5 Actions in Preparation for Implementation of Automated Driving systems

The key specific issues that must be resolved through cooperation among industry, government, and academia to implement driving automation systems in society are as follows:

- Human factors
- Cooperation on infrastructure, urban planning, and mobility support (collaboration with society)
- Technologies for self-driving cargo transport (contribution to economic activities)
- Legal systems and insurance systems

⑥ Analysis of Social and Industrial Aspects of Automated Driving

Analysis of Social and Industrial Aspects of Developing and Popularizing more Advanced Automated Driving Systems

Table 1 Social impacts and scenarios for issue resolution related to ensuring mobility for vulnerable transport users (when users drive themselves)

Category	Item
Societal needs	Ensuring mobility for vulnerable transport users (senior citizens, physically disabled, young people)
Scenarios for progress in technical development	Level 2 private vehicles with advanced driving safety support, provided by means of restriction-relaxed licenses that enable users from young people to senior citizens to drive
Social impacts	Ensuring mobility (increased opportunities and expanded environment for driving oneself), health improvement by driving oneself
Negative impacts and issues	•Need to establish requirements for restriction-relaxed licenses (driving capacity assessment) •Need for policies to disseminate level 2 vehicles, etc.
Scenarios for issue resolution	•Establishment of requirements for restriction-relaxed licenses (driving capacity assessment) and establishment of new systems for licensing and training *[G]* •Obligation of people who do not meet restriction-relaxed license requirements to surrender license *[G]* •Study of measures to disseminate level 2 vehicles *[I&G]*, etc.

* *I*: industry, *G*: government, *A*: academia

Table 2 Social impacts and scenarios for issue resolution related to ensuring mobility for vulnerable transport users (users without driver's licenses)

Category	Item		
Societal needs	Ensuring mobility for vulnerable transport users (senior citizens, physically disabled, young people), Measures to alleviate the shortage of public transport drivers and reduce operating costs, and ways to improve profitability of public transport operators		
Scenarios for progress in technical development	*[by around 2025]* •Regular route buses through level 2 restriction-relaxed licenses and ridesharing services •Low-speed, small group transport services (limited routes, and/or dedicated area level 4 system)	➔	*[by the late 2030s]* •Level 4-5 ADS-DV regular route buses and ridesharing services •Level 4-5 ADS-DV individual use of car sharing type self-driving vehicles, use of on-demand type and patrol type level 4-5 ADS-DV services for small group ridesharing
Social impacts	Ensuring mobility (maintenance of public transport etc.), regional stimulus, emergence of level 4 car sharing service operators, emergence of mobility providers and other platform providers, alleviation of driver shortage and crew specialized in conductor tasks		
Negative impacts and issues	*[by around 2025]* •Need to ensure societal acceptance for level 4 vehicles •Need to construct the infrastructure required for level 4 vehicles, clarify maintenance standards and devise measures for early deterioration •Need to establish social systems relating to level 4 vehicles, such as legal and insurance systems •Need to organize requirements for establishment of business models, etc.	➔	*[by the late 2030s]* Return to compact cities, concern for increased costs throughout society as a whole, etc.
Scenarios for issue resolution	*[by around 2025]* •Promotion of public understanding and societal acceptance of Lv4 vehicles *[I, G, society &A]* •Study of infrastructure requirements for level 4 vehicles *[I, G&A]* •Study of legal systems and insurance systems for level 4 vehicles *[I, G&A]* •Fee structure for business establishment and assessment of corporate structure from the standpoint of social welfare and social efficiency *[I&A]*, etc.	➔	*[by the late 2030s]* •Reassessment of urban transport strategies to add ADS technologies, including road charges and tax systems *[G]*, etc.

* *I*: industry, *G*: government, *A*: academia

Table 3 Social impact and scenarios for issue resolution the driver shortage and reduce logistics costs

Category	Item		
Societal needs	Measures to resolve the driver shortage and reduce logistics costs		
Scenarios for progress in technical development	*[by around 2025]* Level 2 restriction-relaxed licenses, and/or level 4 in limited environments (electronically coupled vehicles operating in limited areas or on dedicated routes including expressways)	➔	*[by the late 2030s]* Level 4-5 ADS-DV operation
Social impacts	Improvement of driver shortage, reduction of logistics costs, high-efficiency logistics, reorganization of business scheme		
Negative impacts and issues	*[by around 2025]* •Need for establishment of environment (requirements for restriction-relaxed licenses, legal status of electronically coupled vehicles, securing of location for forming electronic coupling, status in terms of labor management, optimization of location planning for logistics centers, establishment of system for mixed cargo and passenger transport etc.) •Need to carefully assess conditions for establishment of business models •Need to increase acceptance on the part of drivers of surrounding vehicles, etc.	➔	*[by the late 2030s]* •Need to carefully assess new costs (maintenance, operation, tax and fee systems) •Need for advanced management of people and goods (including study of redeployment of logistics facilities) •Need to deal with the creation of monopolies and oligopolies due to increased size of operators as a result of reduced costs including personnel costs, etc.
Scenarios for issue resolution	*[by around 2025]* •Environment establishment above mentioned *[I, G&A]* •Study of establishment of business models *[I, G&A]* •Study of human-machine interface with surrounding vehicles (including need for standardization) *[I&A]*, etc.	➔	*[by the late 2030s]* •Study of costs and tax and fee systems *[I&A]* •Study of advanced management for people and goods *[I&A]* •Measures for creation of monopolies and oligopolies *[I, G&A]*, etc.

* *I*: industry, *G*: government, *A*: academia

6 Conclusion

The following items were conducted in this study.

- Establishment of study team
- Clarification of ADS evolution
- Proposal of future vision for ADS and scenarios for issue resolution
- Proposal of specific actions in preparation for the implementation of ADS

Future Needs of Automated Driving Systems, and Analysis and Research of Issues Arising out of such Needs

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ABSTRACT: To create social acceptance of automated driving systems, public events called "citizens' dialogues" have been held since FY2016. These events provide information about automated driving to the public to facilitate understanding of these systems. In addition, we have been sorting and analyzing new awarenesses and visions of these systems based on opinions and responses, including the concerns and expectations of the public, to provide input for guiding future research and development activities, as well as to foster social acceptance. At the dialogue sessions held over the past two years, opinions were exchanged among a variety of stakeholders, accurate information on automated driving was provided, and expectations and concerns about automated driving were extracted. The positive outcomes of the initial events and acceptance of the activities are illustrated by dissemination of the activities to provincial areas during FY 2018.

1 Background and Objectives of the Research

It is essential to create social acceptance of the Strategic Innovation Promotion Program (SIP) - Automated Driving for Universal Service (adus) in order to direct research and development outcomes toward practical application, commercialization, and deployment within society. In doing so, it is important to further social acceptance of automated driving systems through public events to facilitate understanding of driver support systems whose trials are already in progress, as well as the technologies and benefits of automated driving now being studied and developed. It is also important to assess and validate the opinions and responses presented at such events.

Toward this objective, events called "citizens' dialogues" started in FY2016 as a forum for interactive communication in which participants discussed and exchanged opinions about the social needs of automated driving systems and the various associated constraints. Thus, to realize the goals of automated driving at the societal level, efforts are being made to heighten social acceptance by providing information to the public and by addressing community concerns and public needs.

2 Activities and Outcomes of Research

2.1. Activities in FY2016

In FY2016, three public "citizens' dialogue" events were held. The first dialogue recruited university students, who will forge the next-generation of car users, and opinions were exchanged on the theme "Social change: the realization of automated driving." In this of age of fewer and fewer young people holding a driver's license or owning a car, views were shared on what university students expect from automated driving and what kind of society they believe they have to build from various perspectives, including the perspective of drivers and inhabitants. When asked about the characteristics of a future that accepts automated driving vehicles, participants responded that it will allow effective utilization of time, increase convenience in regions without public transportation, and create a new use of roads. The first citizens' dialogue ended with a summarizing conclusion that "a network is being formed to discuss social innovation and ethics through public-private cooperation. This kind of movement will become important from now onward."

The second citizens' dialogue invited professional drivers and transport industry workers. Under the theme "Connections between automated driving and society," views were exchanged regarding how society and future automated driving are mutually connected from the viewpoints of people working at transportation sites and elsewhere. The topics of discussions included how a society that has realized automated driving would differ from the present society, how the relationship between vehicles and society would change, and whether lifestyles and other aspects of life would change in terms of fears, expectations, and even education. Labor shortages and the aging of the population were highlighted as problems of those holding vehicle-related jobs. At the same time, high expectations for automated driving were presented. Concerns about automated driving were the usage of automated driving itself as well as the problematic aspects of trying to foresee the extent to which such systems would be built. Concern was also expressed about who should take responsibility in the case of an accident and whether the division of the roles of the system and humans at level 3 would work properly. Regarding education targeting correct understanding of automated driving, it was suggested that it would be important to effectively use automated driving through the involvement of and education by people from different walks of life such as education by manufacturers, education by those experienced in automated driving, and dissemination of information by motor journalists.

The third citizens' dialogue invited legal and insurance professionals and university law students to participate in a discussion session themed "The rights and responsibilities of drivers," which had been touched upon in the first and second dialogues. Should the law protect drivers or manufacturers? In the context of issues at each stage of the evolution of automated driving, legal professionals, law students, and business professionals representing the automobile industry, who also participated in the second dialogue, exchanged opinions on the future relationship between humans and artificial intelligence (AI) from a legal perspective. As for the problems of fully automated driving, various views were presented from the positions of business and legal professionals. Concern was expressed that it would take a long time for society to understand automated driving, because the safety of automated driving vehicles remains unconfirmed. Some participants emphasized that it was difficult to discuss who should bear responsibility in general, because the situation would differ from case to case, such as the matter of maintaining accountability for functional limitations. Participants also said that the scope of product liability should be extended to programs and data rather than limited to tangible goods, that a scheme similar to the compulsory automobile liability insurance has to be established, and that because the first priority is to identify the cause of accidents, the persons in question should cooperate in the cause-identification process rather than being held liable for negligence. Therefore, criminal punishment should be avoided."

2.2. Outcomes achieved in FY2016

The citizens' dialogues in FY2016 achieved the following outcomes:

Creation of social acceptance of automated driving was discussed in the three SIP-adus citizens' dialogues. Various parties including university students and business and legal experts actively shared their views from a variety of angles. Their conversations deepened understanding of the technology, benefits, and issues related to the automated and cooperative driver support systems that are already realized. They also suggested directions automated driving should take in the future. In particular, it is a significant achievement of the citizens' dialogues that ideas generated by university students and other young people who, as mentioned earlier, will forge the future of automated driving, contributed innovative suggestions to existing norms. Furthermore, a survey of participants conducted after the citizens' dialogues showed that over 80% of participants were satisfied, that their understanding of automated driving had deepened, and that their expectations for the realization of automated driving had increased. These results demonstrate that this activity heightens social acceptance.

2.3. Activities in FY2017

In FY2017, SIP organized two citizens' dialogues as a forum for interactive communication to extract and analyze future needs, to discuss new awarenesses and visions, and to gain new insights through exchanges with the public. SIP conveyed accurate information through panelists, the general audience, and others who participated in the citizens' dialogues, and the outcomes, published on the SIP-adus website, received broad media coverage. While built on the achievements of the previous fiscal year, the FY2017 citizens' dialogues featured the following five elements:

(1) Collaboration with the Tokyo Motor Show: this popular event allows information to be spread widely among the public

(2) The first dialogue was designed to focus on the distribution of information and the second on dialogue among the public

(3) Active utilization of the ideas and perspectives of youth, who are the next- generation leaders

(4) Theme setting based on the perception of automated driving as an ecosystem, such as a city or MaaS rather than as an independent system

(5) The introduction of new approaches including online posting tools and graphic-enhanced recordings to collect the opinions of a large segment of the population and, as a result, activate dialogues

The first citizens' dialogue held in collaboration with Tokyo Motor Show was made possible through the joint cooperation of the event's organizer, the Japan Automobile Manufacturers Association. Through the positive effects of teaming with a large-scale external event, the SIP-adus citizens' dialogue attracted 399 applications and 311 visitors. The theme "Mobility and urban design" was decided with the intention of allowing the general public to find a personal relevance in automated driving in terms of travel and daily life by considering both transportation and cities as a combined living space, and to extract needs from future-oriented and public viewpoints by considering future urban design.

The session was divided into three parts: (1) imagining an ideal life and travel based on the issues and needs of current mobility and cities, (2) presentation of opinions on automated driving technologies necessary for an ideal life and travel, and on the ideal form of cities that adopt automated driving, and (3) sharing of opinions on the elements required to realize these ideals and future mobility and cities.

The audience was given an opportunity to post opinions online. In a post-event survey, 372 questions were posted online and 216 questionnaires were returned, providing many useful insights. The results of analysis of online responses are summarized below.

(1) The need to accurately convey information on automated driving

Many respondents perceived that the activities of SIP-adus were not correctly understood, expressed concerns about automated driving in terms of mixed traffic, and placed importance on safety and security. This made clear the need to correctly convey what is possible and what is not in order avoid overestimations or distrust of automated driving, and it made clear the existence of issues of how to convey what is possible and what is not. In addition, there was the opinion that sharing the vision for the future is an effective way of helping people to understand the yet-to-be realized technologies associated with automated driving.

(2) Responding to diverse needs

Although citizens' dialogues have been ongoing in Tokyo since the first year, a large part of the audience suggested the need for diversity, such as the participation of people from non-urban areas and the elderly. Also, some felt that the development of flexibility and agility would be necessary to respond to diverse needs.

(3) Attention also needs to be paid to factors other than the automobile industry

It is necessary to think about automated driving not as a singular thing but within a whole design that encompasses various elements, such as urban planning, changes in ways of working, regions, and attributes. Additionally, some respondents felt that logistics and parking-lot management may be improved by automated driving.

The second dialogue in FY2017 set the theme as "Future society and MaaS." Based on mega-trends including aging of the population, urbanization, and globalization, ideas were discussed on what kinds of needs would be created in life and travel in the year 2030, what kinds of services would meet those needs, what would be required to realize those services, and what roles automated driving would play in that context. The second citizens' dialogue led to awareness of the following:

(1) Future needs for MaaS

In addition to just moving to a destination, travel itself or other aspects can be the purpose of travel. The purposes of travel will become increasingly more diversified.

Travel can also become an opportunity for socialization and communication with others.

(2) Ideas for addressing needs

Data linkage will be important in service deployment. One issue is how to share data already owned by individual firms. In addition, increased added value by packaging, for example, will possibly spread and expand services.

(3) Toward realization of services

Another issue is how to best show people automated driving services that have not yet been realized.

Moreover, the concept of data collection and utilization in the minds of the public will change. The introduction of Internet of Things (IoT) technology may create opportunities for decentralized automated transportation that suits each region. Another issue is the necessity of a platform to consolidate travel-related data. Published data will be combined and used in transportation. It will be further processed by the private sector to provide customized services.

Collaboration will also become important. Existing transit guidance is effective in everyday life, but it cannot comprehensively address unexpected situations. Guidance for the best modes of travel requires data linkage.

2.4. Outcomes achieved in FY2017

The outcomes of the citizens' dialogues in FY2017 are summarized below. These indicate the directions of future research and development.

(1) Consideration of a decentralized automated model in line with regional characteristics

In the dialogues, the needs and issues concerning mobility were approached by members of the general public on the panel. A wheelchair user said, "I can drive by myself now, but as I get older I'm worried whether I'll be able to move about as freely as I can now." An exchange student from France commented that travel in Japan in the middle of the night was inconvenient. Also, while there were unique perspectives such as "ultimately I'd love for my house to move," it was also pointed out that in a disaster-hit area movement that is important to one person might be considered unreasonable to another. From the individual environments and backgrounds of the public panelists it became clear once again mobility is perceived as having diverse needs and issues.

Also, in metropolitan areas, particularly in the center of cities, public transportation networks are well developed and, although there are issues such as with commuting, it is non-urban areas that tend to have the most deep-rooted concerns in terms of regular transport. This was reflected in the opinions of the public panelists, and also in many of the people who responded to the questionnaire survey and online posting tool.

Many people also voiced expectations that automated driving systems could respond to more diverse needs. As shown in the survey analysis of the first dialogue and the awareness brought about from the second dialogue, opinions were that decentralized automated services would be an effective way of addressing needs that vary regionally. A nationally unified infrastructure environment should probably be somehow secured, also from a public notion. However, instead of simply expanding a standardized service, a decentralized automated model that matches different traits and regions, while securing a fixed platform for the whole of society, will probably be accepted by each regional area as something sustainable.

(2) The necessity of perceiving automated driving not as a singular thing but within the common social foundation

In the first dialogue about cities, and the second one about MaaS, it was understood that better services should be created by considering these services within the common social foundation, in which a variety of players are involved as an ecosystem. One of the speakers in the second dialogue explained that "there is a need for a platform that can smoothly and seamlessly match the needs of users who want to move with the suppliers of mobility, including trains and buses." People affected by the heavy snowfall in January raised the problems of fragmentary information on public transport operation and that information fails to respond to true mobility needs. For this reason, there should be a platform where data is linked and utilized across different businesses. However, multiple issues need to be resolved before such a platform can be built and operated. Also, in order to realize automated driving services, governments and private enterprises must work together on a common social foundation, fulfilling their respective roles as part of an ecosystem, thereby preserving sustainable socioeconomics.

(3) Offering a platform to convey information

Since the citizens' dialogues have a mission to bring about social acceptance, conveying information is an important function of these events.

While more information related to automated driving systems has become available in recent years, accurate information will not be conveyed to the public unless it is actively obtained out of interest. This is reflected in the first session's survey results that found around half of the participants were unaware of SIP-adus activities. There is a need to convey correct information on automated driving systems to those whose response to these systems is passive, and to avoid overestimations and information that is untruthful.

The citizens' dialogues were planned as a forum to bring together SIP-adus members, intellectuals, and the general public for mutually meaningful communication. Properly offering accurate information to the public at these occasions is highly significant in bringing about social acceptance.

There was also the opinion that actualizing services will also deepen understanding of these systems, further identify system needs, and cause these systems to be seen as something attractive.

(4) Future possibilities for citizens' dialogues

The first dialogue attracted a wide general audience by teaming the event with the Tokyo Motor Show. The fact that the dialogue was able to convey information to a large number of the general public can be considered a significant outcome in this research, whose objective is to foster social acceptance.

Conversely, we held the second dialogue with interested parties only. In terms of the dialogue with the public and the needs that were pointed out, the benefit of a smaller scale event is that it allows deeper conversations.

A total of 18 panelists from the general public participated this year. The event was held in the dialogue form to focus on interactive discussions, which resulted in a limited number of panelists per dialogue. Additionally, because the event was held in Tokyo, it was not possible to source issues and needs related to non-urban areas.

Another opinion expressed in the two dialogue sessions was that transport should match the separate issues of individual regions. This issue is best understood by the people living in these regions. It was concluded that, by holding citizens' dialogues in regions where interests are diverse, inviting participants from different walks of life, including the elderly and people engaged in child rearing, perhaps the needs and issues of mobility not understood in Tokyo will start to come forth.

2.5. Activities in FY2018

Over the past two years, the citizens' dialogues have revealed that in metropolitan areas public transportation networks are well developed, and that, although there are issues related to commuting, it is non-urban areas that tend to have the most deep-rooted issues. In these non-urban areas, while the aging of the population and depopulation accelerate the scrapping of public transportation networks, new means of travel are required to meet the needs of growing tourism. In addition, a sense of insecurity about mixed traffic still exists. Therefore, automated driving has to be accurately understood so that it is not overestimated or distrusted as it spreads socially.

Taking the above matters into account, FY 2018 activities will pay attention to regions interested in introducing automated vehicles as a public transportation system. In regions without public transportation and when the administrators of these regions express willingness to introduce roadside stations and automated driving systems across hilly and mountainous terrain, a dialogue-form meeting will be held on a per region basis to discuss the adoption of automated driving. Furthermore, at the Tokyo Motor Festival to be held in early October, a symposium on the safety and security of automated driving will be held with the aim of eliminating concerns and correcting/facilitating understanding about automated driving. In this way, efforts to create and increase social acceptance will be made to help realize automated driving.

3 Conclusion

Having started in FY2016, this project is now in its third year. The project has provided information on automated driving to various stakeholders and audiences, and has provided a platform for exchanging, summarizing, and analyzing the opinions expressed. The project has also provided a platform for extracting the needs, expectations, and concerns about automated driving. Guided by the project results, efforts have been made to further social acceptance of these systems. This activity has facilitated understanding of these systems through dialogues with the general public. It has demonstrated that it is a useful means of creating social acceptance for the incorporation of automated driving into the societal structures of Japan.