4 A Society with Automated Driving

(1) Automated Driving Mobility Services in Regional Communities

Automated Driving Transportation Services in Semi-Mountainous Regions (Overview)

Koichi Sakai (Ministry of Land, Infrastructure Transport and Tourism)

Japan is facing the social issues of a decreasing population and super-aging society. Aging is particularly pronounced in semi-mountainous regions, where securing the flow of people and goods has become an urgent problem. Since 2017, we have conducted field operational tests (FOTs) for automated driving transportation services using michi-no-eki roadside stations as hubs in 18 locations around the country to secure that flow in such regions where the population is aging. This paper prevents an overview of the outcomes of those tests, as well as of the issues faced by social implementation and planned further initiatives.

1 Social Issues in Regions and Significance of Automated Driving Transportation Services

In Japan, the elderly people account for a high proportion of traffic accidents as the population ages. At the same time, securing means of transportation and solving the shortage of drivers has become a pressing issue in local regions and other depopulated areas. The length of regular bus routes discontinued between 2007 and 2017 exceeds 15,000 kilometers. At the same time, approximately 40% of truck drivers are over 50 years old, and the number of people aged 65 or over who voluntarily returned their driver's license rose to 400,000 in 2018, a twentyfold increase over the 20,000 returns made in 2007, illustrating the rapid aging of the population. This tendency is especially prominent in semi-mountainous regions, where the elderly account for 35% of the population (as of 2015). This ratio is not only significantly higher than the national average of 26%, but also represents the nationwide aging awaiting Japan in ten years.

Automated driving transportation services are expected to prove highly effective at solving the above issues, including the driver shortage.

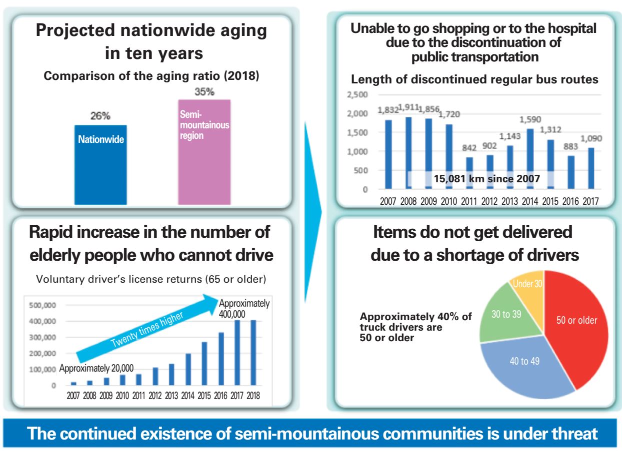


Fig. 1: Issues and Situation in Semi-Mountainous Regions

2 Outcomes Achieved in the Local Region FOTs

(1) Overview of FOTs in the Regions

In an effort to address the issue of aging in both semi-mountainous areas and all of Japan, we introduced services relying on automated driving technology, and started the Field Operational Tests of Automated Driving Services in Semi-Mountainous Regions Using Michi no Eki Roadside Stations as Hubs in September 2017 for the purpose of securing the flow of people and goods in such regions. As of June 2021, we had automated vehicles actually driving at 18 locations around Japan as part of FOTs. At the Kamikoani Michi-no-Eki (Akita), the results for the technical and business model aspects of the tests led to the formal adoption of the services in November 2019, which has now been managed without risk for over a year, with the vehicle driving safely over more than 6,000 km.

In addition, City Council in Okueigenji Keiryunosato (Shiga) has approved formal adoption of the services starting in April 2021(Figs 2, 3 and 4).

(2) Initiatives in the regions

The FOTs were divided in stages. Short-term tests were used to study business models as well as technical aspects such as road structures and other impacts on traffic, the local environment (weather, communication conditions), cost, social acceptance, and impact on the community. Long-term tests focused on aspects that directly affect adoption, such as vehicle technical issues, the road environment required to allow driving by automated vehicles, and the sustainability of the services. Regions that have laid the required groundwork are gradually proceeding with the social implementation of the services.

In regions that have proceeded to social implementation, we are studying solutions to business model issues, the maintenance of road infrastructure, and other factors that will contribute to nationwide deployment (Fig. 5).

Automated Driving Transportation Services in Semi-Mountainous Regions (Overview)

Fig. 2: Automated driving in Kamikoani

Fig. 3: Automated driving in Okueigenji Keiryunosato

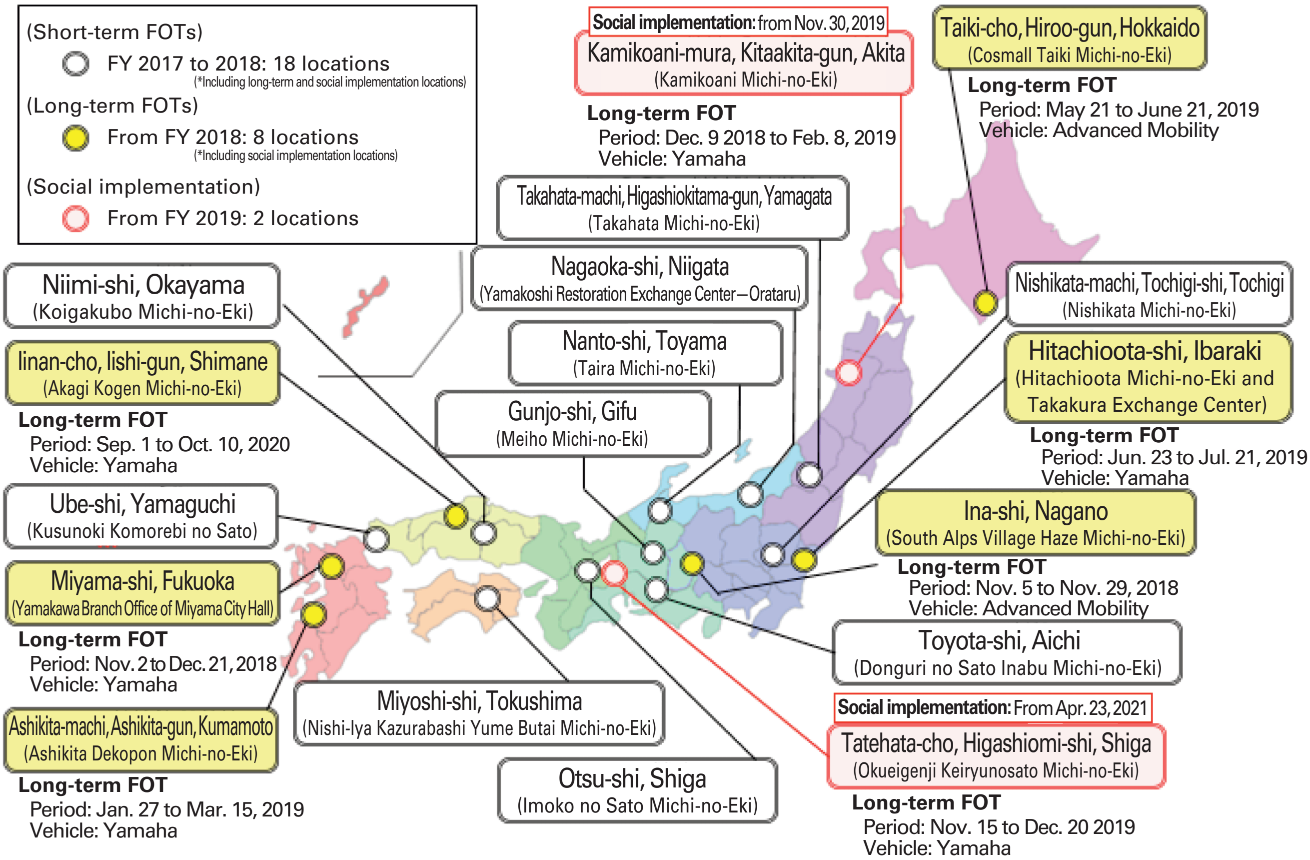


Fig. 4: Locations of the FOTs of Automated Driving Services in Semi-Mountainous Regions Using Michi-no-Eki as Hubs

(3) Automated Vehicle Technical Issues and Solutions

During the FOTs conducted at 18 locations, the need to avoid pedestrians or other traffic objects, the unavailablity of GPS in mountains or tunnels, or reduced lidar functionality in poor weather conditions such as snowfalls or fog created situations requiring manual intervention and preventing the continued use of automated driving. After identifying and scrutinizing such technical issues, we examined the possibility of supporting road infrastructure for automated driving to enable automated vehicles to determine their position and drive safely and smoothly. The Kamikoani Michi-no-Eki vehicle that rely on electromagnetic induction lines demonstrated their validity in achieving stable driving even in rain, snow, or other poor weather conditions. Based on the above, the Road Act was amended in November 2020 to define supporting infrastructure for automated driving as road accessories, allowing businesses, road administration offices or local public bodies to install them on their own (Fig. 6)

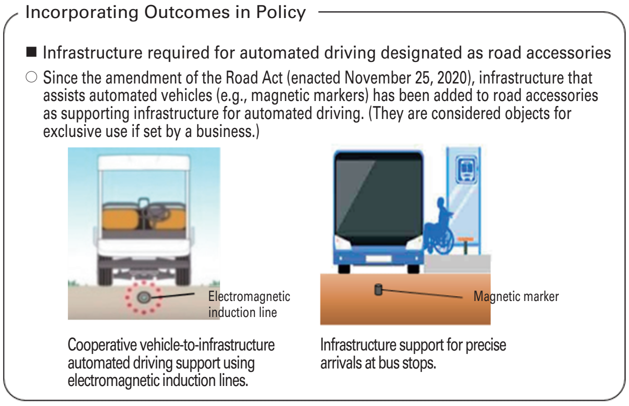


Fig. 6: Overview of the Amendment to the Road Act

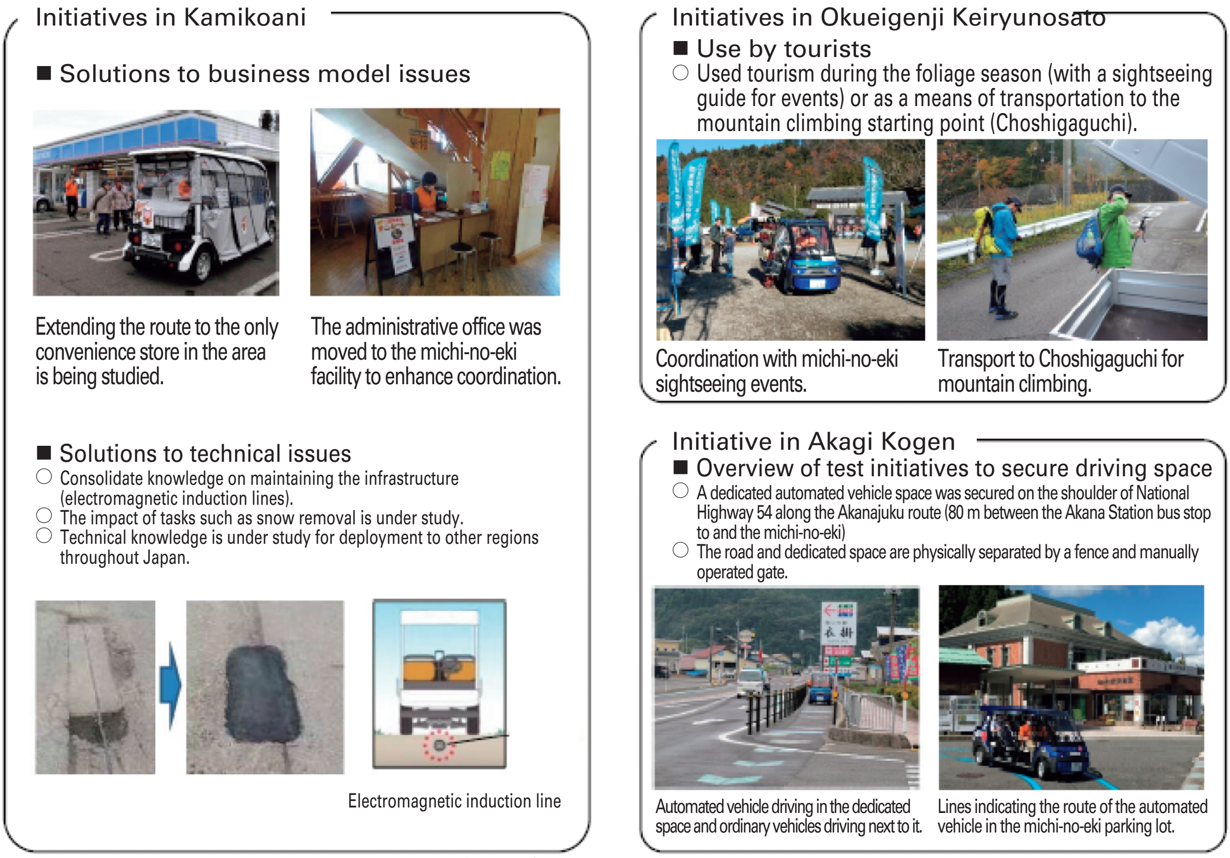


Fig. 5: Initiatives in the Regions

3 Technical and Business Issues Concerning the Social Implementation of Automated Driving Services in Local Regions, and Future Initiatives

The social implementation of automated driving services targeting local regions with a low volume of traffic requires finding solutions to business issues.

One issue in conducting business is the securing of road space. At the Kamikoani Michi-no-Eki, traffic control people were employed to stop traffic, securing a dedicated space for the automated vehicle and achieving level 4 driving without a driver on board. However, due to the cost involved, securing a dedicated space for the automated vehicle using road markings and eliminating the need to employ traffic control people will be assessed (Fig. 7).

Another issue is profitability. It will be necessary to both reduce expenses by collaborating with the michi-no-eki to, for example, have its staff handle booking tasks performed by an outsourcing provider, and to increase revenue through partnerships with other business and the introduction of new services. In cooperation with local government bodies and other stakeholders we will carry out the investigative research required to build business models allowing sustained operation for automated driving and related services. We are also going to work on strengthening coordination between regions and other initiatives needed for social implementation while keeping the financial capacity of the local authorities introducing automated driving services in their region in mind (Fig. 8).

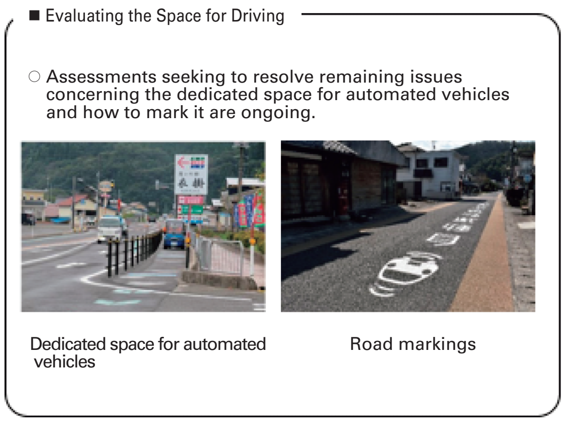


Fig. 7: Measures to Secure Road Space

Fig. 8: Strengthening Cooperation between Regions

4 In Closing

Field operational tests (FOTs) were conducted at 18 locations nationwide, with eight locations conducting long-term tests and two locations establishing social implementations. In November 2020, the Road Act was amended to define supporting infrastructure for automated driving as road accessories.

Starting in 2020, we applied the know-how acquired through these tests to provide support for the adoption of automated driving services in collaboration with the future technology social implementation business of the Cabinet Office, as well as assisted municipalities considering adopting such services in formulating plans and making preparations for their implementation.

In the Public-Private ITS Initiatives/Roadmaps 2020 approved by the IT Strategic Headquarters on July 15, 2020, the government has followed up on its target of achieving driverless automated driving services in designated regions with the goal of expanding such services to the entire country by 2025, indicating its support for the further spread of automated driving.

Establishing the Environment for the Commercialization of Transportation Services Relying on Automated Driving

Nobuyuki Kato (Highway Industry Development Organization)

In preparation for the commercialization of transportation and logistics services relying on automated driving, local regions with a low volume of other traffic were first considered as locations to introduce automated driving transportation services and find solutions to social implementation issues such as securing driving space on roads and operations management. Guidelines for the adoption of automated driving transportation services in local regions were formulated, and standards for securing road space for automated vehicles were established in anticipation of nationwide deployment. Therefore, examinations focused on building business models allowing sustained operation for automated driving and related services, and the validation of those examinations, are being carried out in cooperation with local governments and other stakeholders. Based on acceptance by the adopting local governments, the field operational tests (FOTs) in local regions are narrowed down to only the areas necessary for social implementation. Consequently, we are working on strengthening coordination between regions and other initiatives needed for social implementation while keeping the financial capacity of the local governments introducing automated driving services in their region in mind.

1 Introduction

The automated driving services initiated in designated regions are intended to achieve social implementation in multiple regions throughout Japan to eventually offer such services on a permanent basis. The initial phase of social implementation will focus on solving local social issues while also serving an opportunity to study measures that address issues shared across the various FOTs, such as disseminating ways of securing driving space and making the services commercially viable. In addition, this initial phase will also lead to suitably updating the existing manuals on automated driving services and contribute to the ultimate goal of expanding commercialized instances of automated driving services.

In preparation for the commercialization of transportation and logistics services relying on automated driving, local regions with a low volume of other traffic were first considered as locations to introduce automated driving transportation services and find solutions to social implementation issues such as securing driving space on roads and operations management. Guidelines for the adoption of automated driving transportation services in local regions were formulated, and standards for securing road space for automated vehicles were established in anticipation of nationwide deployment. Therefore, this project is carrying out examinations focused on building business models allowing sustained operation for automated driving and related services, and the validation of those examinations, in cooperation with local governments and other stakeholders.

2 Locations and Vehicles Studied for Commercialization

2.1. Target Locations

Building on the outcomes of the 2019 to 2020 projects, this initiative is evaluating and validating social implementations in several locations to further accumulate knowledge that will contribute to the dissemination of social implementation use cases, as well as to identify and solve issues that arise when that knowledge is applied to a different location.

Table 1: Scheduled FOT Locations

	Location	Schedule	Remarks
1	Region A	In operation since 2019	
2	Region B	Scheduled to start social implementation in 2021	
3	Region C	Scheduled to start social implementation in 2021	
4	Region D	Scheduled to start social implementation in 2021	
5	Region E	Scheduled to start social implementation in 2021	
6	Region F	The technical validation and the validation of the business model for social implementation is scheduled to take place over one month during the 2021 fiscal year.	Long-term test

2.2. Vehicles Used

The vehicle used in this initiative consists of the cart that follows a specified route (equivalent to level 2) by detecting the magnetic force from the electromagnetic induction lines buried in the road, which were adopted in projects from 2018 to 2019. Long-term FOTs to validate the technology in a separate vehicle making use of cooperative vehicle-to-infrastructure (currently under active development by the manufacturer) will also be conducted.

Fig. 1: Vehicle Used in This Initiative

Some of the projects from this initiative are presented below. (Note that the details of some projects are still being worked out with the stakeholders, and not all projects of evaluations are covered.)

3 Progress of Initiatives by Region

3.1. Social Implementation of Automated Driving Transportation Services in Region A (Ongoing)

(1)Overview of Initiatives from the Previous Years

In Region A, a short term FOT (one week) was conducted in

2017 to evaluate aspects such as drivability and safety on snowy hills and the convenience of transporting vegetables to the michi-no-eki. In 2018, this was followed by a long-term FOT designed to validate the setting of a dedicated automated driving section, booking by local volunteers, and future operational structures. The results led the region to initiate a social implementation in November 2019, and the service has been operated by a local NPO without accidents for over one year (as of March 2021).

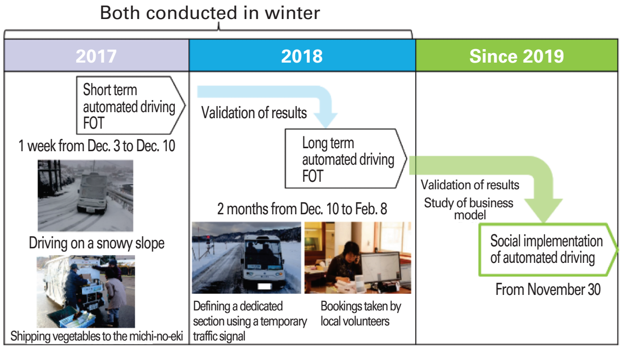


Fig. 2: Overview of Initiatives in Region A

(2)Study of the business model in the region

We consolidated the existing local paid transportation conditions as shown in Table 1 to analyze regional usage characteristics and build a locally sustainable operational framework for social implementation in Region A. The results were used to assess revenue from the established fares, as well as the route and timetable.

Table 2: Paid Transportation Conditions in the Region

Type	Operator	Vehicle & conditions	Frequency & fare
(a) Paid transport (lack of transportation)	Social Welfare Council	• Passenger car, 7 occupants • Reservation by phone	• Morning, afternoon, evening • Adults 1,000 yen, children 500 yen (one-way)
(b) Paid transport (transport for welfare purposes)	Social Welfare Council	• Passenger vehicle • Limited to driving people with a certification of long-term care need or a physical disability certificate to the hospital or events.	200 yen within the region 600 to 2,000 yen outside the region
(c) Paid transport in depopulated areas		• Passenger vehicle • Local people of high school age or older making regular hospital visits, people with a physical disability, pregnant women, and so on.	A joining fee of 200 yen, an annual membership fee of 800 yen, and a fare based on the destination are paid by users.
(d) On-demand share taxi	Individual taxi companies	• Passenger vehicle • Reservation in advance, board at home	Adults 2,000 yen Children 1,000 yen
(e) Clinic bus	Local government	• Micro bus, capacity of 20	Only one trip on weekdays

However, due to the difficult of achieving a stable budget using only fare revenue, day-to-day operation is entrusted to volunteers, and it will eventually be necessary to create a framework that can continue to be operated locally by establishing the service as an additional business within an existing organization such as the michi-no-eki or Social Welfare Council.

In terms of profitability, labor constitutes a large proportion of expenses. In addition to considering a switch to operating every two days rather than daily to reduce operational costs, measures to attract more users and increase revenue from sources other than fares will be necessary.

► Measures to attract more users: open new routes, draw in tourists or other non-local customers, and more.

► Measures to obtain revenue other than fares: collecting subsidies from the michi-no-eki, obtaining private-sector cooperation, organizing inspection or study tours, and more.

Dealing with vehicle or electromagnetic induction line breakdowns or replacements, vehicle insurance fees, and other large one-time payments will have to be made sooner or later. Financial assistance from the local governments, or other new or improved forms of public assistance that also encompasses labor expenses will undoubtedly be necessary. However, there is not financial support system that completely matches current regional public transportation policies. Regions can be self-supporting to an extent, depopulated and aging regions are limited in that respect.

Revenue increasing measures considered in such cases include working with destination marketing organizations (DMOs) to prepare sightseeing plans, as well as assessing plans to obtain corporate financial support or advertising revenue by offering routes for testing purposes. At the same time, the maintenance framework for the vehicles and infrastructure is being evaluated from the perspective of reducing costs.

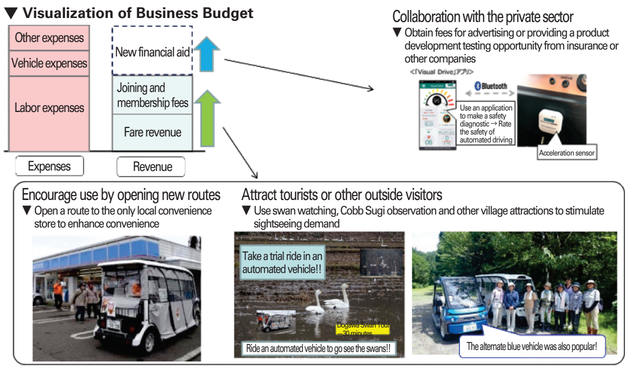


Fig. 3: Study of Measures to Strengthen the Budget

(3)Study of Future Approaches to Operation

The one-and-a-half year of social implementation in Region A confirmed the strong need for vehicles offering features such relaxed transportation between villages, safe driving, or ease of boarding and deboarding as a means of transportation for the elderly people. However, measures enhance convenience by encouraging short-range use (events, for example) or commuter ticket use (making them free for residents, for example).

Closing the service on low-demand weekdays (Tuesdays and Thursdays, for example), and planning sightseeing tours for people from outside the region on holidays is also under consideration. In addition, residents who have appreciated the benefit of automated driving (about 20 people) have become repeat users, and demand from referral by those people will have to be complemented with regular PR activities such as offering trial rides in nearby communities.

(4)Study of Infrastructure Maintenance for Automated Driving Services

Region A has a very limited budget for asphalt repair and other road maintenance, and snow removal damages the asphalt, making it necessary to find solutions to the worsening of ride comfort and apply maintenance to address the exposure of the electromagnetic induction lines. Yet another remaining issue is the need for additional snow removal in winter due to snow falling from roofs or snow piles blocking the driving space (electromagnetic induction lines) and forcing the vehicle to drive around that snow.

Last year, the road act last was amended to designate the electromagnetic induction lines, RF tags, and other equipment needed for automated driving services as road accessories. This is likely to make public aid for asphalt and other road maintenance a necessity. Conversely, the maintenance of automated driving sensors (RFID tags) and electromagnetic induction lines has to be performed by a specialized operator, and it will be necessary to provide education and training to enable local operators to perform that maintenance.

(5)Summary of the Progress of Initiatives in Region A

Region A is the most depopulated region in Japan and also subject to heavy snowfalls. The first social implementation of automated driving in Japan was initiated here. Until now, local volunteers have set up local stops and otherwise established themselves as the local support for getting around. They secure means of transportation for the elderly in the region, and provide assistance with shopping, going out for tea, participating in social events, and other activities outside the home, as well as support for health and fitness and other aspects of day-to-day life.

Many elderly people live in the region, and assistance to facilitate boarding and deboarding will also become necessary.

We intend to eventually secure repeat users, support the lifestyle of the elderly, and extend their health expectancy by expanding on-demand operation in response to user demand for shuttle service to popular convenience stores, the JA cooperative, the learning center, or nearby villages. At the same time, proactive efforts to capitalize on the appeal of automated driving and revitalize tourism in the village as well as inspection or study tours will have to be pursued to attract customers from other areas.

3.2. Study for the Social Implementation of Automated Driving Services in Region B

(1)Overview of Initiatives from the Previous Years

The short term test (5 days) conducted in 2017 in this region primarily focused on the technical validation of the automated vehicle. The test used a bus that drove on the national and prefectural roads connecting the michi-no-eki and the village.

This was followed up with the 36-day long-term test in November and December 2019 that centered on establishing automated driving services in the region and used a compact golf cart that drove from the michi-no-eki to nearby villages.

Based on that initiative, a social implementation that takes advantage of the paid passenger transportation system in private cars in cooperation with transportation operators enacted in December 2020 is being planned. The operation of the service will be entrusted local volunteers, with management support provided by local transportation operators, in the context of the municipal private car paid passenger transportation business framework mainly run by the local governments.

(2)Social implementation policy to resolve regional issues

In 2020, the implementation policy, operational format, routes, schedules and other factors were assessed to initiate implementation in 2021, and the resulting report was approved by the local FOT council. Some of the details are presented below.

The intended course of action for social implementation is to both ensure a means of transportation for elderly people who lack such means due to returning their license through "shared" local transportation, and to reduce the travel burden for the elderly by relying on automated driving for the short trip to the michi-no-eki, and switching to a community bus for the longer trip from the michi-no-eki to the local branch office.

The community bus is currently used to travel within the region. The eventual goal is to have people use a locally operated automated vehicle to go from the village to the michi-no-eki, and then board the community bus to travel to the city center, thereby offering a transportation environment that makes it easier to go to the michi-no-eki at any time.

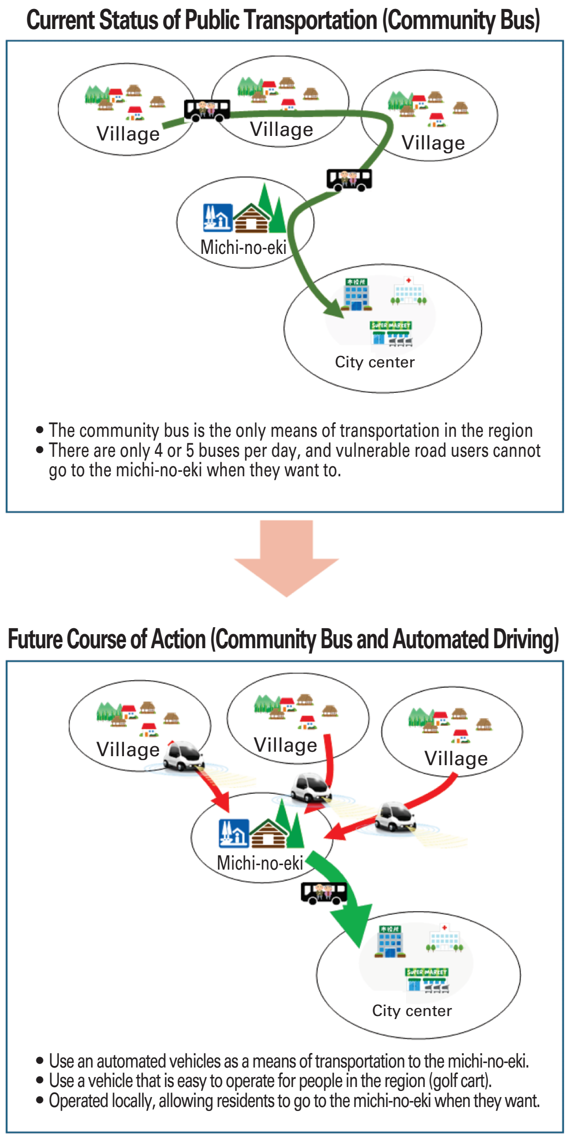


Fig. 4: Course of Action for the Social Implementation of Automated Driving Services

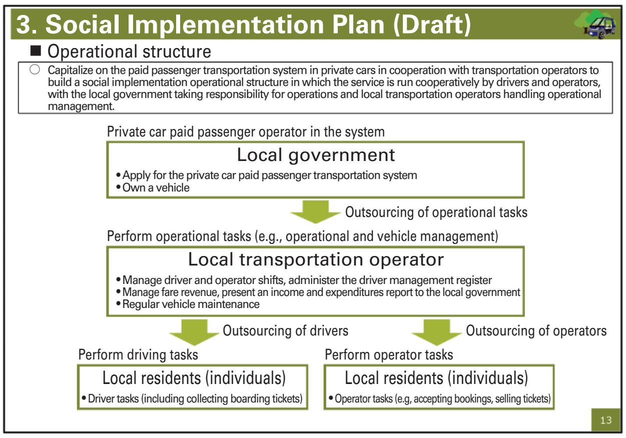


Fig. 5: Operational Structure of the Social Implementation of Automated Driving Services

(3)Study of Envisioned Use Scenarios

We aim to offer the four services below in Region B.

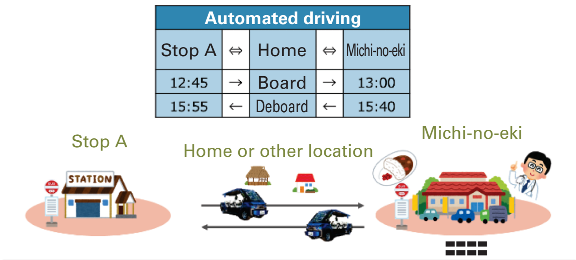
- Provide transportation support for the day-to-day life of the elderly by offering a shuttle service that takes them to and from the michi-no-eki regional hub.
- Provide transportation support for tourists visiting the region for its foliage, mountain climbing, camping, and other sightseeing attractions.
- Use mixed passenger and goods transportation to deliver agricultural products to, or ship products from, the michi-no-eki.
- Use transfers to the community bus to provide support for residents to travel to the city center.

The implementation of the above services aims to secure stable fare revenue and combines it with other measures to raise profits and build a business model that minimizes reliance of subsidies from the local government and can be managed by the region itself on an ongoing basis.

At the same time, we prepared scenarios with a recommended timetable for each use case to encourage people to use the automated driving services.

(a) Transportation between the home and the michi-no-eki

This case is based on using the automated vehicle as a means of transportation to the regional hub (michi-no-eki), which carries out town office functions and contains a branch clinic in addition to allowing shopping. It targets local residents who want to shop at the michi-no-eki or use town office services, as well as people using it as a base for selling or shipping goods.



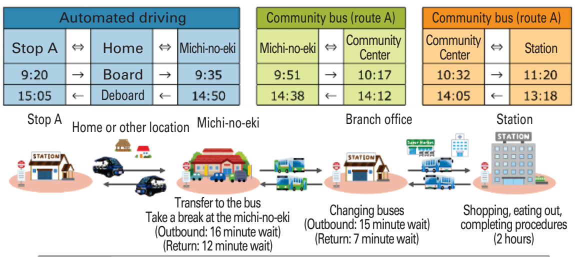
Automated driving				
Stop A	⇔	Home	⇔	Michi-no-eki
12:45	→	Board	→	13:00
15:55	←	Deboard	←	15:40

Remarks	• Facilities in the michi-no-eki *Closed Tuesdays Cafeteria (10:00 to 17:30*) • Direct sales shop (9:30 to 17:30*) *Until 16:30 in December Branch clinic (14:00 to 16:00 *Only on the 1st and 3rd Wednesdays of the month) and more • A mixed passenger and goods service to transport items sold at the michi-no-eki will be considered

Fig. 6: Visualization of Use as a Means of Transportation between the Home and the Michi-no-Eki

(b) Transferring between the automated driving service and the community bus

This case targets residents who want to go to the community center or the Higashiomi city center, and envisions an eventual division of roles with the existing trunk transportation (community bus) to support transfers (changing vehicles at the michi-no-eki).



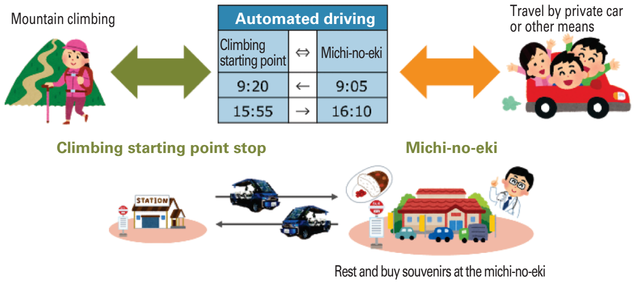
Automated driving					Community bus (route A)			Community bus (route A)		
Stop A	⇔	Home	⇔	Michi-no-eki	Michi-no-eki	⇔	Community Center	Community Center	⇔	Station
9:20	→	Board	→	9:35	9:51	→	10:17	10:32	→	11:20
15:05	←	Deboard	←	14:50	14:38	←	14:12	14:05	←	13:18

Remarks	• Branch office ↔ Yokaichi Station (supermarket, hospital, City Hall, and more) • Branch office and surrounding area (community center, clinic, supermarket, and more) • Facilities in the michi-no-eki (cafeteria, direct sales shop, branch clinic, and more)

Fig. 7: Visualization of Transferring between the Automated Driving Service and the Community Bus

(c) Use by tourists (mountain climbers)

This case is based on using the automated vehicle to transport mountain climbers from the michi-no-eki to the starting point for mountain climbing, and targets mountain climbers (wanting access to the starting point) who traveled to the michi-no-eki using public transportation or their own car.



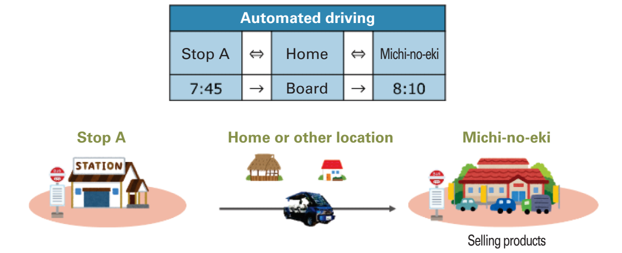
Automated driving		
Climbing starting point	⇔	Michi-no-eki
9:20	←	9:05
15:55	→	16:10

Remarks	• Study schemes that also bring profit to the michi-no-eki, such as selling automated vehicle tickets at its shop.

Fig. 8: Visualization of Use by Mountain Climbers (Access to the Starting Point)

(d) Use for Shipping Goods to the Michi-no-Eki

This case envisions using the service to ship goods to the morning market held at the michi-no-eki every Sunday, and targets people who want to sell or ship goods there (only shipping goods/transport for the sellers themselves), in response to the need expressed during the long-term test. (Operated when shipping has been confirmed beforehand.)



Automated driving				
Stop A	⇔	Home	⇔	Michi-no-eki
7:45	→	Board	→	8:10

Remarks	• Yamasato Market: Held outdoors in front of the michi-no-eki shop starting at 9:00 every Sunday. If offers locally produced fruits, vegetables, crafts, and other goods.

Fig. 9: Visualization of Use for Shipping Goods to the Michi-no-Eki

(4)Fare collection and ensuring profitability

Although the fee collected during the long-term test was only enough to cover fuel costs, the social implementation includes plans to set a per-boarding fare to secure a stable revenue. The fare set will be based on the results of the questionnaire conducted during the long-term test.

Diverse ticket options, including commutation tickets, commuter passes, and one-day tickets will also be offered to make the service easy to use for local residents. Fees will also be collected on a per-shipment basis for the transportation of goods. However, if the shipper also boards the vehicle, only the boarding fare will be charged.

Table 3: Tickets That Will Be Offered

	Type of ticket	Target user
	One-time use	• Tourists coming for mountain climbing, camping, or the foliage
Various types of tickets	Commutation tickets (6)	• Residents who use the automated vehicle occasionally
Various types of tickets	Commuter pass (one month)	• Residents who use the automated vehicle regularly to travel to the michi-no-eki or other destinations
Various types of tickets	One-day ticket	• Residents coming to the michi-no-eki to check out the Yamasato Market and then going back home
	Transportation of goods (one time)	• Residents selling agricultural products or other goods at the Yamasato Market

* Only the passenger fare is paid if the seller also boards the vehicle with the goods.

Fare revenue alone will not ensure profitability. Therefore, measures to increase profits, such as posting advertising in the automated vehicle, will be studied to achieve a regionally autonomous operation with minimal reliance on local government subsidies.

• Revenue from advertising space

Visualization of advertising on the side of the bus (source: Omi Railway Corporation website)

• Collaborating with sightseeing tours to create package deals

Sightseeing events during the long term FOT

• Holding events to encourage use by local residents

Salon for residents during the long term FOT

Fig. 10: Visualization of Measures to Enhance Profitability

3.3. Study for the Social Implementation of Automated Driving Services in Region C

A long term FOT was conducted at this location in from September to October 2020. Preparations for a social planned social implementation are underway. The operation of the service will be entrusted local volunteers, with management support provided by local transportation operators, in the context of the municipal private car paid passenger transportation business framework mainly run by the local governments.

An assessment of the policy, operational format, and other aspects of the above implementation conducted in 2020 identified issues concerning winter (snow) operation and the cooperation framework to address for year-round operation.

Table 4: Overview of Driving Validation in Winter (Snow)

Item	Details
Date	Friday, January 29, 2021 *Once in the morning and once in the afternoon
Overview	• The route was divided in short sections, and the vehicle drove several times in each of them. • Issues were identified by having the vehicle drive in the parking lot and on public roads (continuous flat stretches, steep slope at the orchard) • An exchange of opinions meeting was held at the michi-no-eki after the test • User opinions were obtained by rotating participants inside and outside the vehicle
Vehicle equipment	• Chains attached to studless tires (attached in the morning, removed in the afternoon) • Heated cushion set on the seats • Vinyl curtain kept down at all times while driving as a measure against the cold from the snow.
Participants	• Town, tourist association, local transportation operators, local government leader, Ministry of Land, Infrastructure, Transport and Tourism, consulting companies (total of 14 people)

Fig. 11: Meeting to Exchange Opinions Held After the Trial Drive

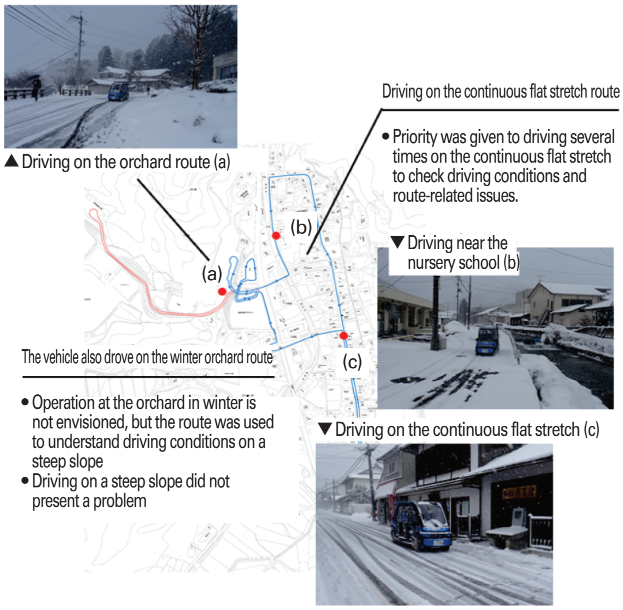


Fig. 12: Validation Drive in Winter (Snowfall)

(5)Evaluation of Driving on Snow Roads

In the winter trial drive, although the snow interfered with white line and electromagnetic induction line detection, no major problem occurred while driving on snowy roads. Studless tires proved sufficient to allow driving if there was little snow, and the emergency braking applied to simulate emergency manual intervention on a steep slope operated without problem.

Conversely, in continuous flat stretches with a lot of snow, there is a risk that piles of snow on the shoulder will prevent driving. This means that defining rules for local snow removal in continuous flat stretches by the operator, appropriate switching to manual driving, and criteria for suspending operation will have to be assessed in preparation for actual operation.

(6)Evaluation of the vehicle environment

The use of the vehicle in winter led to comments such as the vinyl curtain alone allowing wind to blow through gaps near the floor, and snow getting on the floor inside the vehicle and freezing due to the cold, making the flow slippery. These issues will require solutions such as sealing the vinyl curtain, lending lap blankets and installing electric heated cushions, and setting non-slip mats on the steps and floor.

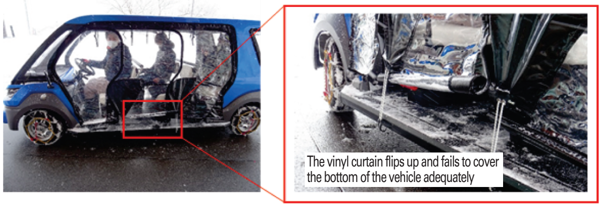


Fig. 13: VInstallation of the Vinyl Curtain Provided with the Vehicle

It was also noted that lowering the vinyl curtain created poor side mirror visibility. This issue was addressed at the operational level by asking operators to instruct drivers not to rely on the side mirrors and look around visually to ensure safety when driving with the curtain lowered.

At the same time, due to the higher amount of luggage carried by users in winter, measures to ensure smooth boarding will include taking steps to provide a space umbrellas, thick coats, canes, and other items prior to actual operation.

(7)Evaluation of vehicle performance

After the trial drive, participants that while the shape of vehicle itself is stable, evaluating its balance while driving when the position of the passengers, for example, create an unbalanced load will also be necessary. Concern over swaying under windy conditions, and the need to evaluate how much the vehicle shakes was also expressed. Since the vehicle is not currently year-round, there is not enough data to determine whether this is a seasonal effect or an issue with the performance of the automated vehicle or infrastructure components such as the tags. A further exchange of information with other regions will clearly be necessary.

4 Summary

Since 2018, we have been working to build systems that can achieve the social implementation of automated driving services in local regions. We have also been using the outcomes of the regional field tests and validation of issues to advance the development of automated driving systems that can be deployed nationwide. The outcomes (knowledge) obtained from the field operational tests are intended to go beyond the end of the project and serve as a springboard to work on building sustainable businesses.

The outcomes and issues to date have been categorized in terms of "vehicles", "operation and service", and "preparing the environment (infrastructure)".

For the vehicles, it will be necessary to validate issues such as maintenance that contributes to long-term operation and responding to irregular circumstances, follow-up after their adoption, and enhanced efficiency through collaboration with related businesses. At the same time, remodeling vehicles to provide passengers a greater sense of security, and uses that address regional needs will have to be evaluated.

Operation and service will require obtaining the cooperation of local volunteers and building a sustainable service and operational structure (advancing collaboration with the michi-no-eki or other groups for integration as an additional business). It will also be necessary to diversify both the user base and sources of revenue through partnerships with other businesses, as well as to increase social acceptance in the regions.

Preparing the environment calls for establishing methods of maintaining and upgrading infrastructure cooperative systems that are responsive to emergencies, seasonal changes, or regional variations, as well as for confirming the driving performance of golf carts relying on magnetic markers. Similarly, the maintenance and management of stable operation road spaces in the region, road markings and other aspects of stable operation in cooperation with the region will require ongoing validation.

【 References 】

(1)Local FOT Council for Automated Driving Services Using the Okueigenji Keiryunosato Michi-no-Eki as a Hub: Social Implementation Plan (Draft), (2021)

4 A Society with Automated Driving

(1) Automated Driving Mobility Services in Regional Communities

Development of Support System for Wider Deployment of Automated Driving Services

Kosuke Watabe and Eiji Teramoto (Nippon Koei Co., Ltd.), Ryohei Sanda (Pacific Consultants Co., Ltd.)
Yoshiyuki Kato (Highway Industry Development Organization)

As part of efforts to bring automated driving services to local regions, a service support system has been developed to help overcome the particular issues of each region and factor in different service launch aims, thereby enabling these services to be introduced, implemented, and run more smoothly. First, an architecture model was arranged and functional layers were established based on short-term requirements, versatility, and so on. The location management, safety management, reservation, as well as boarding management functions were identified. Next, the requirements to realize the identified functions were studied and developed. Actual services were then run and evaluated in two regions, which helped to identify a wide range of issues. Based on these issues, a system package that can be easily deployed by automated driving service managers in local regions was developed. The functions were consolidated and integrated on a cloud server to facilitate both maintenance and service deployment to new regions. At the same time, on-board units were integrated to help minimize costs during introduction and operation. The developed system package was applied to automated driving services in three regions to confirm its effectiveness. In the future, it is planned to deploy the system package to automated driving and mobility services across the whole country.

1 Objective

This research is part of a project to bring automated driving services to local regions, which is now at a phase aiming to realize social implementation of such services. In this project, the objective of this research is to identify the basic and service requirements necessary for support systems, and to provide tools and support so that these services can be introduced, implemented, and run more smoothly by overcoming the particular issues of each region and different service launch aims.

Based on the fact that local regions are facing common issues such as aging communities and depopulation, it was assumed that services applicable to every region (service management, location provision, reservation systems, and the like) could be adopted to help address these local issues. Consequently, requirements for an effective application programming interface (API) and applications were studied and a simple operational system was developed. This system was then introduced and evaluated in local regions promoting the social implementation of automated driving services.

Based on the results and issues that were identified through this process, a system package that can be deployed by automated driving service managers in local regions was studied, designed, and developed. Rather than developing a package for experimental adoption, a cloud-based service platform was established so that the package can be implemented as actual services under real-world conditions. Finally, the system package was adopted in regions carrying out trial projects of automated driving services, and its effectiveness was verified.

2 Research and Development Details

This research started in August 2019 and was concluded at the end of May 2021. During this period, requirements for services and applications were studied and developed. These services and applications were then adopted and evaluated in field operational tests (FOTs), leading to the development of a system package for introduction into local regions, the application of this package to the social implementation of automated driving services, and the definition of technical requirements. These details are described in the following sections.

2.1. Mapping to Layers of Reference Architecture Model and Identification of Target Study Data

Despite a wide range of local needs, this research assumed the existence of a service support system (including service management, location provision, reservation systems, and the like) that can be applied in all applicable regions based on commonalities in regional conditions. Therefore, the research identified the study targets and information required to map functions, data, and assets to a reference architecture model. Figure 1 shows the relationship between the identified functional, data, and asset layers. Two types of local region automated driving services were envisioned: private-use transportation for pay that takes individual customers from a departure location to a destination without set routes or timetables, and community bus type transportation that moves multiple customers along a preset route following a preset timetable. The functions and data of the service support system needed to be applicable for both of these services.

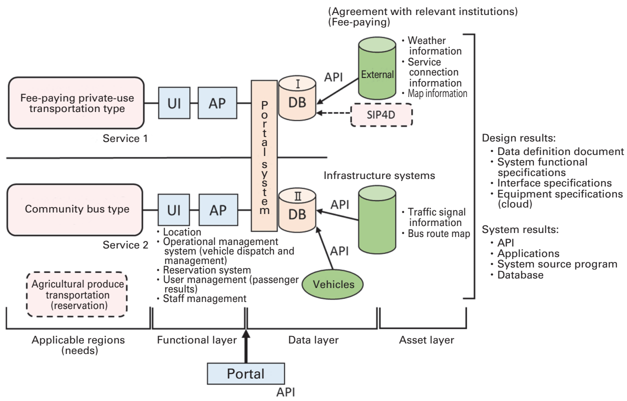


Fig. 1: Relationship between Functional, Data, and Asset Layers

2.2. Identification of Items to Realize Functions

To identify the functions required for automated driving services in local regions, a three-stage configuration was adopted based on the short-term requirements of local regions, versatility, and so on. Figure 2 shows the items that were identified as necessary to realize the functions. Stage 1 includes the items that are most necessary in the short-term, including location management, safety management using images from inside and outside the vehicle, the reservation function, and the vehicle boarding management function. Requirements were studied and developed prioritizing these functions.

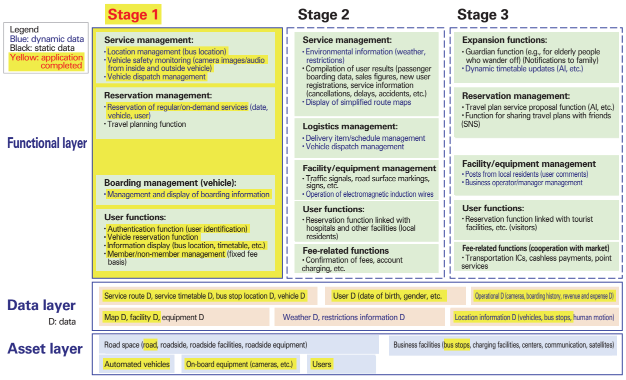


Fig. 2: Identification of Items to Realize Functions

2.3. Study and Development of Requirements for Service Support System

To realize the functions identified in stage 1, the requirements for a support system were studied. Subsequently, a system was developed for evaluation in regions carrying out FOTs of automated driving services.

Figure 3 show the system configuration. The system is consists of three parts depending on the installation location: inside of the automated vehicle, at the office of the service manager, and on terminals such as smart phones of ordinary users. The following items are installed inside the automated vehicle: a terminal that collects location information, cameras that monitor and obtain images from in front of and inside the automated vehicle, and a barcode reader that records when users enter and exit the vehicle. A PC in the office of the service manager is used to monitor the status of the service and to help ensure safety through real-time displays of the location of the automated vehicle and the camera images.

People can use the automated driving services by registering at the office in advance and receiving a service pass. When reserving a seat, users log into the service via a smart phone using the security code number printed on the pass, and follow the menus to enter the departure and destination points, and the like. Measures were adopted so that even elderly people can make reservations easily, such as minimizing the number of menu options and providing large buttons. The passes are read by the barcode reader when users enter and exit the vehicle, creating records of the bus stops utilized by users.

In addition to the location of the automated vehicle and camera images, the office PC also displays user information, such as reservation information, boarding histories, ticket purchase status, and so on. A telephone-based proxy reservation system was also provided for elderly people unaccustomed to using a smart phone.

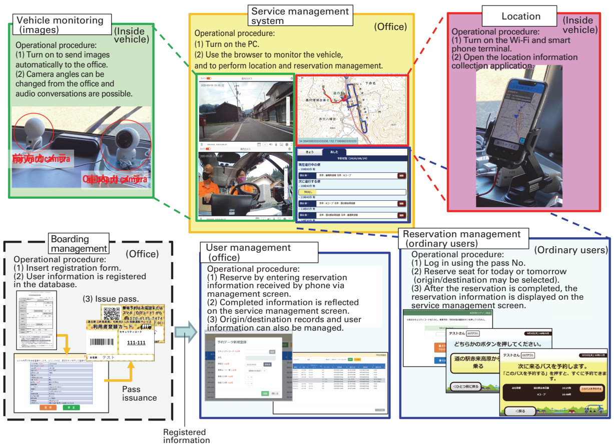


Fig. 3: Configuration of Service Support System

This service support system uses GTFS-JP (a standard bus information format) to define the data used by the reservation function, such as service routes, timetables, and the like[1]. Adopting a common standardized format for the data enables automated driving services in multiple different regions to be used by the same application. In addition, since GTFS files consist of open data, route searches focused on automated driving service bus stops and reservations involving connections with other public transportation systems are possible from route selection services around the world, which should help to greatly enhance usability for local residents.

2.4. Real-World Operation and Evaluation by Social Implementation and FOTs

From March to August 2020, the developed service support system was operated in a social implementation project at the Michinoeki-Kamikoani roadside service station (Kamikoani, Akita Prefecture). Questionnaires and interviews were carried out with the service managers, vehicle crews, and users. Although the coronavirus pandemic prevented evaluations during some of this period, a large number of comments and issues to be improved were collected after long-term use of the service. The first system update to resolve these issues was launched in August 2020. The updated service was then used as the basis for the development of a service support system for the Michinoeki-Akagikogen roadside service station (Iinan, Shimane Prefecture). The developed service was then run and evaluated in a long-term FOT between September and October 2020. Through these real-world applications in two separate regions, various issues regarding the practical implementation of the service support system were identified.

Table 1 shows the identified issues and countermeasures arranged in accordance with each functional layer. The issues can be broadly categorized as follows: those related to the particular environment of the local region (weather or communication environment), and those related to the people involved in the automated driving services (the users and the service managers). For the first category, the service was affected by malfunctions in the on-board cameras and communication system over the long period of use, particularly in the FOT at Michinoeki-Kamikoani. This was caused by the low winter temperatures and vibration from the poor road conditions due to heavy snowfall. These issues underlined the importance of the installation method of on-board equipment and the selection of more robust devices. In contrast, for the second category, the tests found that far fewer elderly users than expected could use a smart phone. Most users made reservations by calling the office, and the number of smart phone reservations remained flat. Additionally, since both the users and office staff were mainly older local residents, virtually no one had experience using computers, which caused many difficulties when introducing the service. Although these issues were anticipated to some extent, the real-world evaluations underlined the need for further countermeasures.

Table 1: Issues and Countermeasures Identified in Real-World Application

Category	Issues	Countermeasures
Service management (images/location)	• Data volume remains high, resulting in high communication costs. • As this is a commercial service, security is a concern. • Low winter temperatures prevent display of camera images.	• Further reduce data volume. • Maintain own image server. • Adopt low-cost cameras capable of operating in low temperatures.
Boarding management (vehicle)	• Large numbers of on-board equipment create a confused layout around the driver's seat. • Boarding management processing is sometimes time consuming.	• Integrate the terminal functions (location + boarding management) • Simplify operation and display.
Reservation management (office)	• Most reservations are direct by telephone or in person. → Insufficient liaison with user reservations when entering information on behalf of the user. • Office staff unaccustomed to using IT equipment. • Insufficient consideration given to tourists and visitors.	• Improve liaison with user reservations when entering information on behalf of the user. • Improve displays and user-friendliness of office software. • Add function to reserve seats for multiple people and revise operation manuals.
User functions (smart phone reservations)	• Little uptake for smart phone reservations (few elderly people use smart phones and due to insufficient PR). • Unable to respond to full range of user requests. • Slow operation, reservation function failures, etc.	• Improve user friendliness and displays, and carry out active PR. • Add input/output functions to meet user needs. • Update software and improve performance.

2.5. Development of System Package to Support Introduction to Local Regions

Based on the results obtained from Michinoeki-Kamikoani and Michinoeki-Akagikogen, a system package that can be easily deployed by automated driving service managers in local regions was developed. This package was developed not just for an experimental system but for an applicable system for actual services with the objective of realizing simple introduction and continued use under real-world conditions. The characteristics of this system are as follows.

(1) Cloud server and functional integration of on-board units

Until this stage, each function had been developed individually. Consolidating and implementing these functions on a single cloud server enables the office, on-board units, and user terminal functions to be operated using a browser. Since new or updated systems can be adopted via the cloud rather than having to go to the actual location of the service, this approach facilitates service maintenance as well as its deployment to new regions.

At the same time, the location information, monitoring cameras, boarding management functions were integrated into a single on-board unit (tablet). Reducing the number of component parts improves reliability and mountability, and helps to minimize costs during introduction and operation. Figure 4 shows the configuration of the system package.

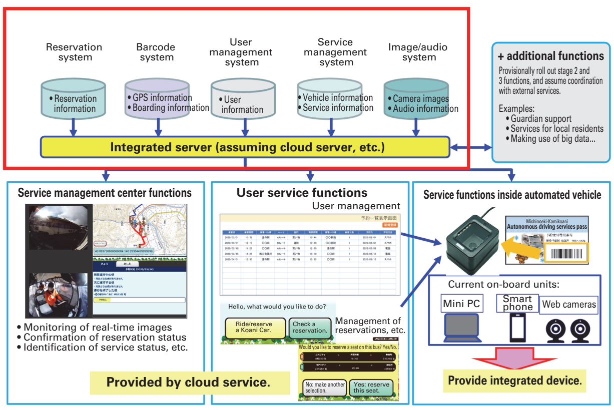


Fig. 4: Configuration of System Package

(2) Improvement of manager and user screen design

The design of smart phone and PC screens was made more user-friendly for service users and managers in local regions that are unaccustomed to using IT equipment. The user and reservation management functions on the manager PCs were provided with larger font on the menu buttons, and the icons and colors were changed to facilitate intuitive selections. In addition, since the font used on vertical smart phone screens is too small, the user screens were redesigned by increasing the size of text to make the screens easier for elderly people to read. Figure 5 shows an example of an improved screen design.

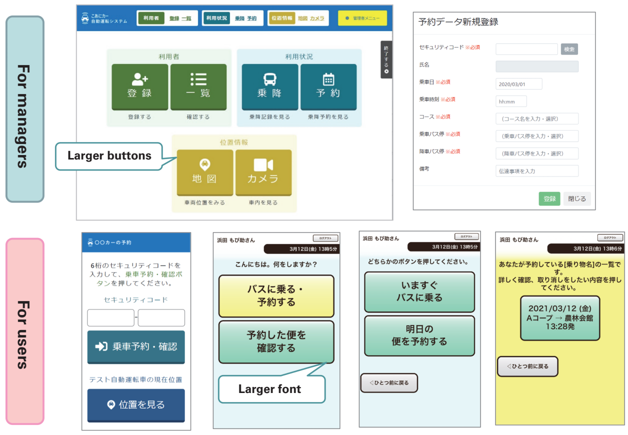


Fig. 5: Improved Screen Design

(3) Improvement of user reservation, service management, and boarding management functions

The original user reservation function was designed with a simple and easy-to-use menu configuration for elderly people. However, based on the requests of users who are accustomed to using IT equipment, the following functions were added to meet the detailed needs of users: reservations up to one week in advance, reservations for multiple people (up to four), return journey reservations, individual cancellations of multiple reservations.

From the standpoint of service and boarding management, new functions to support service managers and drivers were added to the existing location information and boarding management functions. These included displays of the next bus stop and delay times (achieved by comparing the current location information and service timetable), displays of scheduled boarding numbers based on reservation information, and so on. These functions also provide easier compatibility with the GTFS real-time (GTFS-RT) protocol. Figure 6 shows the improvements to the service and boarding management functions.

Fig. 6: Improvements to Service and Boarding Management Functions

3 Wider Deployment for Social Implementation of Automated Driving Services

To enable the deployment of the developed system package to automated driving services in different regions, this research project coordinated with the SIP-adus consortium promoting the long-term social implementation of automated driving services at roadside service stations (michinoeki) throughout the country. Systems for each region were implemented while exchanging information with the consortium members in charge of regional applications.

In addition to Michinoeki-Kamikoani, at which evaluations have already been carried out, as of June 2021, the system had been implemented in a total of three locations: Michinoeki-Okueigenji Keiryunosato (Higashiomi, Shiga Prefecture, abbreviated to Okueigenji below) and the Yamakawa branch office of Miyama City Hall (Miyama, Fukuoka Prefecture). The following section describes the adoption of the system at Okueigenji, which started automated driving services in April 2021.

3.1. Implementation of System at Okueigenji

The full system package was introduced at Okueigenji accompanying the start of automated driving service social implementation in April 2021. Figure 7 shows the route of the automated driving services at Okueigenji. The return route is approximately 4.4 km long and extends from the roadside service station, through hamlets between the mountains to the start of the mountain trail at Suzukajuza (Choshigaguchi). There is a regular service of six buses on the route (seven on Sundays).

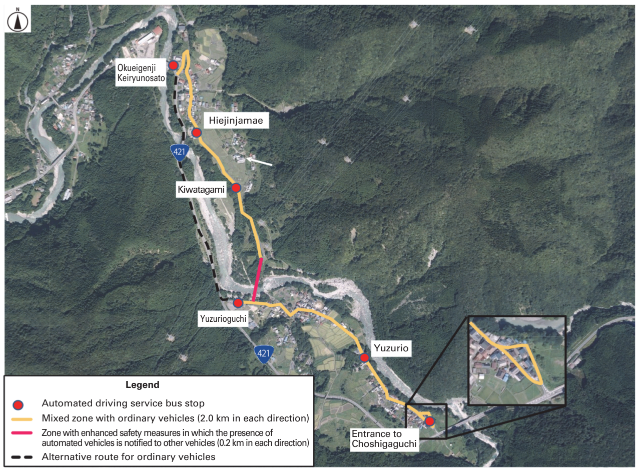


Fig. 7: Route Map for Automated Driving Service Social Implementation at Okueigenji

Figure 8 shows an example of the user reservation screen of the system adopted at Okueigenji. At Okueigenji, the services only run on Wednesdays, Fridays, Saturdays, and Sundays when the roadside service station is open for business. Since services do not run on Mondays, Tuesdays, and Thursdays, these days are greyed out in the reservation menu for greater user-friendliness.

Figure 9 shows images of the on-board units used by the services at Okueigenji. Figure 10 shows an image of the service management system in the manager's office. The system continued to operate smoothly from its introduction in April until the date of this report (June).

Fig. 8: User Reservation Screen at Okueigenji

Fig. 9: On-Board Units Used by Services at Okueigenji (Cameras and Tablet)

Fig. 10: Service Management System at Okueigenji (Office)

The remaining issues are related to communication. Because the radio wave connection is poor in a part of the route, the location information and camera images are interrupted. So we are considering changing the communication carrier or equipment. Since automated driving services in semi-mountainous regions are likely to be introduced in locations other than Okueigenji, the system needs flexibility to respond to the communication situation in each region.

4 Conclusion

As part of efforts to bring automated driving services to local regions, a service support system has been developed to help overcome the particular issues of each region and factor in different service launch aims, thereby enabling these services to be introduced, implemented, and run more smoothly. A system package that can be easily deployed by automated driving service managers in local regions was developed and adopted for automated driving services at three roadside service stations. It is planned to continue wider application of this package to automated driving services throughout the country.

The developed service support system was given the nickname "Mobisuke" by the research and development team members, which works as an abbreviation for “mobility scheduling” and incorporates the Japanese word “tasukeru” (to help), expressing the desire of the team to help mobility in local regions. In the future, it is planned to apply Mobisuke to other automated driving and mobility services, and to build a system to enable continued deployment and operation.

【 References 】

(1)Public Transportation Policy Section of the Policy Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT): Static Bus Information Format (GTFS-JP) Specifications (Version 2) (in Japanese), https://www.mlit.go.jp/common/001283244.pdf (accessed June 27, 2021)

4 A Society with Automated Driving

(2) Public Acceptance of Automated Driving

Initiatives for Fostering Public Acceptance (Overview)

Yuichi Araki and Yasuyuki Koga (Cabinet Office)

In addition to technical development and the establishment of systems, the fostering of public acceptance is an important part of encouraging the popularization of logistics and mobility services using automated vehicles and automated driving technology. While focusing on communicating the correct information about automated driving and quantifying its effects, initiatives being carried out by SIP-adus to foster public acceptance also include more broadly targeted activities connected to the field operational tests (FOTs) to achieve this objective more effectively in the long term.

1 Background and Overall Strategy

A multifaceted approach is necessary to encourage wide ranging public acceptance of the innovative concept of automated driving and to enable the public to use automated driving services with confidence and peace of mind. This includes encouraging the correct understanding of automated driving, quantifying, communicating, and raising awareness of its effects, and establishing insurance and other relevant systems. While focusing mainly on communicating the correct information and quantifying the effects of automated driving, SIP-adus is also carrying out more broadly targeted activities based on a long-term plan.

With regard to information communication, SIP-adus is working closely with the field operational tests (FOTs) being carried out in the Tokyo waterfront area and the FOTs of automated driving mobility services being carried out in local regions. While identifying clear targets for the relevant information, SIP-adus is reinforcing communication through two-way exchanges of information.

In addition, SIP-adus is also holding test drives events and other events accompanying the FOTs in the Tokyo waterfront area, as well as online events and the like connected with the regional mobility service FOTs. It is also actively promoting cooperation with events held by the relevant government ministries.

Then, with regard to the quantification of the effects of automated driving, SIP-adus is developing methodologies to estimate the social and economic impacts of the spread of automated driving, as well as methodologies to gauge the effect of the initiatives to foster public acceptance themselves.

2 Information Communication via the Internet, Social Networks, and the Like

From the standpoint of fostering public acceptance, SIP-adus opened a Japanese language website called “SIP-café” (sip-cafe.media) on October 2019 based on the concept of creating a community for considering a society based on automated driving. This website went online as the FOTs in the Tokyo waterfront area started and aims to communicate information to the general public and foster understanding of automated driving. Under the editorship of the international journalist Kazuo Shimizu, this website provides active and continuous coverage related to automated driving through videos related to SIP-adus and automated driving, accessible articles describing information about automated driving for general readers, editorial columns for the general public written by automated driving experts, as well as other contents. Since the website opened, it has kept up a constant pace of at least ten new posts per month describing the activities of SIP-adus as well as the relevant government ministries and the like related to automated driving. It is also continuing to post features from columnists and other people with a detailed knowledge of automated driving, as well as articles about automated driving initiatives being pursued by private businesses and other bodies.

Similar information communication initiatives connected with SIP-adus include the creation of videos about how the society of the future will look after the realization of automated driving and videos about the activities of participants in the FOTs in the Tokyo waterfront area, and the introduction of the FOTs in the Tokyo waterfront area and the local regions, a portal site (MD communetTM) describing the architecture of geographical data, an app contest (called the KYOTO Raku Mobi Contest), and the Driving Intelligence Validation Platform (DIVP) that demonstrates safety assurance in a virtual space. SIP-adus is also encouraging two-way communication through social media sites such as Twitter, Facebook, and the like.

Fig. 1: Top Page of SIP-Café Website

3 Events for the Media and General Public

3.1. Events for the Media and General Public

In November 2020, to promote collaboration between the different projects of SIP-adus, a status report meeting was held at the Tokyo International Forum for project participants. Held as part of the SIP-adus Workshop 2020, this meeting was broadcast online internationally with the assistance of English materials and simultaneous interpreting. The meeting was attended by more than 1,000 people from inside and outside Japan.

Other events included an attorney-hosted web seminar called Legislation related to Automated Driving in October 2020 and the Legal Revisions for Automated Driving Level 3 and Technical Standards Web Seminar held by experts from the Road Bureau of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and automakers in March 2021.

In concert with the 2020 Tokyo Olympic and Paralympic Games, it was planned to use the FOTs in the Tokyo waterfront area as a forum for a test-ride event aimed at the general public, which was to be held in cooperation with the Japan Automobile Manufacturers Association (JAMA), as well as exhibitions of results and other information from the FOTs. Unfortunately, these events had to be delayed due to the spread of the novel coronavirus COVID-19.

In contrast, although also affected by the novel coronavirus COVID-19, a hybrid real/virtual experience was held in March 2021 that combined an interim status report meeting with a symposium style event. Called the Automated Driving Showcase to Change the Future, this event was held in collaboration with the Ministry of Economy, Trade and Industry (METI) and MLIT.

The interim status report meeting was mainly aimed at business operators and engineers involved in automated driving services. However, to make the meeting as accessible as possible, the intermediate results of the SIP-adus projects were openly disclosed to the public. The meeting presented the results of technical development related to the construction and communication of road traffic environment data, such as traffic signal information, merging lane assistance information, and probe vehicle data. It also provided a forum for actual and video-based exhibitions related to the vehicles used in the FOTs in the Tokyo waterfront area and the semi-mountainous regions, as well as related to the construction and the like of virtual safety evaluation environments and distribution portals for geographical data. This experience was an attempt to provide a novel approach to such events reflecting the so-called new normal, by combining virtual guided tours and virtual 3D walk-through exhibitions.

Finally, in April 2021, a media test-ride event was held in the Tokyo Waterfront City area using around twenty vehicles provided by nine companies participating in the FOTs in the Tokyo waterfront area. With multiple automated vehicles available to test ride at the same time, this event helped to broaden the understanding of the media with respect to the technology and concepts involved.

3.2. Dialog with Citizens

Symposiums and town hall events have been held to create two-way dialogs with citizens, local government bodies, related business operators, and so on.

Particularly in the second phase of SIP- Automated Driving for Universal Services, in addition to events held in Tokyo primarily addressing regional social issues, events have also been held in local regions to discuss how social issues can be resolved by automated driving technologies.

Themes for these events included A Future Vision of Japan in Shodoshima - Regionally Created Mobility Services -, which was held in the town of Shodoshima in the Shozu district of Kagawa Prefecture in December 2018, The Role of Automated Driving in Supporting the Future of People, Towns, and Lifestyles - Toward the Realization of Sustainably Desirable Towns -, which was held in the city of Ina, Nagano Prefecture in August 2019, and The Ideal Town and Automated Driving, which was held in the Maebashi, the capital city of Gunma Prefecture in January 2021.

Additionally, a regional automated driving summit was held in March 2021 in which leaders of Iinan, Shimane Prefecture, Eiheiji, Fukui Prefecture, Kamikoani, Akita Prefecture, Chatan, Okinawa Prefecture, and Higashiomi, Shiga Prefecture discussed the initiatives of their local authorities as well as their approaches to automated driving. This was followed by a panel discussion that included representatives from stakeholders engaged in regional automated driving initiatives, public transportation operators, automated driving venture businesses, and the like. This discussion covered two topics: the resolution of regional issues, and next-generation public transportation systems and business initiatives. This summit linked various regional stakeholders over the Internet in format typically suited for online events.

4 Quantification of the Effects of Automated Driving

Based on trends encompassing the level of automated driving technology and the extent of its propagation, SIP-adus is working to analyze and quantify the impact of automated driving with the objective of providing materials to encourage open discussions about its advantages and latent risks.

More specifically, this entails quantitative evaluations of the social and economic impacts of automated driving, such as reductions in traffic accidents, congestion, and the like carried out by economic researchers, as well as studies and research into enhancing the accuracy of simulations to measure the effect of decreases in traffic accidents developed in SIP phase 1. At this point, a certain amount of conclusions have been reached. In addition, investigations and research involving cooperation between the fields of medicine and engineering have evaluated the effectiveness of driving support technologies for visually impaired people. The results of this research underlined the effectiveness of advanced driving support systems and the importance of the visual field in driving.

SIP-adus has also started developing a methodology to measure the effect of these public acceptance initiatives. To this end, roughly 10,000 people from all round the country took part in questionnaire-based surveys in January 2020 and 2021 (carried out with the cooperation of METI and MLIT). Carrying out questionnaire surveys of the same scale in consecutive years allows the year-on-year progress of the public acceptance initiatives to be gauged. The contents of the responses can also be used for analysis, such as by quantifying the current state of various public acceptance factors (such as lifestyle changes, learning, cost, intrinsic and technical limits, measures if an accident occurs, and so on). Key performance indicators (KPI) and key goal indicators (KGI) have also been created based on these questionnaire responses. SIP-adus intends to continue analyzing the year-on-year progress of public acceptance based on these questionnaire responses to evaluate the status of the initiatives to foster public acceptance and provide feedback.

Surveys and Evaluations for Fostering Public Acceptance

Yukiko Miyaki (Dai-Ichi Life Research Institute Inc.)

In addition to technical development and the establishment of systems, fostering public acceptance will play an indispensable role in enabling the social implementation of automated driving technologies. Proper understanding and flexible actions by consumers will help to accelerate the early and efficient adoption of these technologies, while also helping to ensure the safety of new road transportation systems. In collaboration with the relevant government ministries, this project has received and carried out commissions for consumer awareness surveys about automated driving over several years. While tracking the changes in these survey results, this project aims to identify what types of information in which areas are necessary to help effectively foster public acceptance of automated driving. Based on some of the results of past questionnaire surveys and the results of qualitative information collected from regions around the country, this article describes an action evaluation checklist to help fostering public acceptance, and underlines the importance of creative systems of collaboration through discussion of the following points: (1) stagnating consumer awareness about automated driving, (2) low user appreciation of the benefits of driving support systems, (3) insufficient understanding of the functions of driving support systems by users, (4) disconnection between the strong need for mobility focused on elderly people and expectations for the technology, and (5) low acceptance of the cost as well as the uniqueness and the technical limits of automated driving.

1 Project Flow and Details of Surveys

1.1. Background and Objectives of Surveys

The social implementation of automated driving technologies rests on three pillars: technical development, the establishment of legal framework, and fostering public acceptance, each of which must be pursued at the same time. For the first two of these pillars, field operational tests (FOTs) of automated driving have been carried out in various regions around the country to verify the technology and identify consumer needs, and legal framework are currently being established through the revision and enactment of relevant laws to facilitate practical adoption. In contrast, the state of public acceptance including consumer awareness and understanding is far from satisfactory.

Since 2016, Dai-Ichi Life Research Institute Inc. has participated on the expert committee of a project charged with carrying out research, development, and verification to enable the social implementation of advanced automated driving systems, focusing on studies into the civil liability and public acceptance of automated driving ("Research, Development, and Demonstration Project for Social Implementation of Advanced Automated Vehicle Systems: Research on Civil Responsibilities and Social Acceptance of Automated Vehicle"), which has been conducted under the auspices of the Ministry of Economy, Trade and Industry (METI) and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) since 2016. In the same year, Dai-Ichi Life Research Institute Inc. also inaugurated in-house questionnaire surveys related to automated driving with the objective of understanding the stance of consumers. Subsequently, the contents of this questionnaire were fixed and incorporated by the METI/MLIT project in January 2019 (the 2018 fiscal year). Since then, the questionnaire has been used to collect an ongoing data history related to changes in consumer behavior and awareness. The 2020 survey (the 2019 fiscal year) was carried out as a joint investigation with items added by SIP-adus.

In addition, as a part of the METI/MLIT project, qualitative data has also been collected through World Cafe-style regional workshops and by listening to comments from local consumers at presentations held around the country to foster public acceptance of automated driving.

This article provides a broad overview of the current situation, mainly focusing on the results of the automotive/automated driving questionnaire survey held in 2021. It also describes the creation and proposal of key performance indicators (KPI) and key goal indicators (KGI) for actions aiming to foster public acceptance, and discusses the proposal process for formulating a strategy.

1.2. Overview of Questionnaire Survey

An overview of the questionnaire survey is as follows.

- Target of survey: men and women from all regions of Japan, aged 18 to 79
  24,583 people (METI/MLIT questions)
  (Of which, 12,392 people responded to the SIP-adus questions.)
- Survey timing: January 2021
  METI/MLIT survey: January 6 to 11
  SIP-adus survey: January 16 to 24
- Survey format: Internet survey

The survey period was split into two halves: the first was carried out using the questions determined for the METI/MLIT survey and was answered by 24,583 people. The second survey was then carried out using the questions submitted by SIP-adus, and responses were received from 12,392 people. The results of the two were then combined. Analysis of the results focused mainly on the 18 to 69 age group, and was extended to the results from people in the 70s when necessary.

This article describes the results of the overall survey, not just the SIP-adus questions.

1.3. Survey Items

In addition to SIP-adus, METI, and MLIT, the survey items were also determined with the cooperation of the National Police Agency (NPA) and the Consumer Affairs Agency. The main contents of the survey are as follows.

Questions from METI/MLIT:

- Overall acceptance score for each category of automated driving
- Degree of Understanding of automated driving
- Whether the respondent has a driving license, vehicle usage status, types of vehicle used
- Number of vehicles owned
- Accident and near-miss experiences
- Changes in transportation usage due to COVID-19
- Frequent destinations and means of transportation
- Changes in frequency of leaving home due to COVID-19
- Surrendering of driving licenses by the elderly
- Usage of Safety Support Cars (cars equipped with certain driving support safety technologies functions) and Safety Support Car financial incentives
- The mobility environment
- Awareness of MaaS
- Awareness and situation related to automated driving
- Degree of Usage and understanding of driving support technologies
- Expectations for automated driving service vehicles

Questions from SIP-adus:

- Awareness of area of residence
- Degree of Acceptance of items related to automated driving
- Understanding, cooperation, and awareness regarding the popularization of automated driving
- Specific hopes for the realization of automated driving services
- What users must do to encourage popularization
- Restrictions on mobility and changes in lifestyle caused byCOVID-19
- Degree of satisfaction about status of mobility in lifestyle
- Actions to help prevent the spread of COVID-19
- Actions to help prevent the spread of COVID-19 and the potential of vehicles
- Hopes for changes to working styles (for working people)
- Values and behaviors

* The underlined items were used to obtain an ongoing response history.

2 Issues for Fostering Public Acceptance Identified from Survey Results

2.1. Issues

The survey results identified the following points as potential issues for fostering public acceptance of the social implementation of automated driving technologies.

(a) The last few years have seen virtually no change in the distribution of expectations and concerns regarding social changes caused by the development and popularization of automated driving. The proportion of disinterested respondents with neither expectations nor concerns also remains stalled.

(b) Currently, people using Driver-Assistance Systems have low awareness that these functions are installed on their vehicles, do not use these functions to a great extent, and have little appreciation of their benefits. In other words, a knock-on-effect from innovators, early adopters, and other pioneering users cannot be relied upon.

(c) Currently, people using vehicles equipped Driver-Assistance Systems have low understanding of these functions. Society in general is currently trending toward the adoption of vehicle sharing and subscription services, as well as the selection of vehicles based on application. This low understanding is a concern from the standpoints of both the under-utilization of these functions, as well as safety when the functions are used.

(d) The feasibility of elderly people continuing to live in their current areas of residence is an issue from the standpoint of mobility and the result shows a strong point of concern. From the standpoint of ensuring mobility in old age, it is difficult for elderly people to surrender their driving licenses in many regions and the lack of drivers in workforce also remains an issue. There are low expectations that technology can resolve these issues.

(e) When questioned about the burdens involved in the social implementation of automated driving, respondents demonstrated a certain acceptance of lifestyle changes and the need for learning. However, there was low acceptance of the cost as well as the uniqueness and technical limits of automated driving.

The following sections describe the status and data of these points in more detail.

2.2. From the Results of the Questionnaire Surveys

(1) Expectations and concerns

Responses regarding expectations and concerns about changes to society caused by the development and popularization of automated driving were cross tabulated and compared with the results from the surveys starting in 2018. Although the figures showed some upward and downward fluctuation, the distributions have remained virtually unchanged.

Even comparing to 2018, the state of automated driving in Japan has changed greatly. Japan has worked to gain a technical advantage and has come to be a world leader regarding the establishment of legal framework. However, this situation is hardly recognized in society and some respondents believe that Japan is actually lagging behind.

It is important to note that reducing the number of "concerned" people is not particularly crucial. In fact, the existence of two extremes (people with high expectations and people with concerns) may be regarded as healthy. An effective way of encouraging the permeation of new technology through society is to proceed carefully while maintaining a certain level of concern. The problem is the consistent voice of people who have neither expectations nor anxieties, because they don't have any interest in automated driving at all. We would better take them into our argument on how we would deploy automated driving technology into our society because mobility is the matter to all of us and we are sharing public roads. In this case, the focus of information should not be on dispelling concerns about automated driving, but in raising awareness of why automated driving is a necessary solution and what exactly automated driving entails.

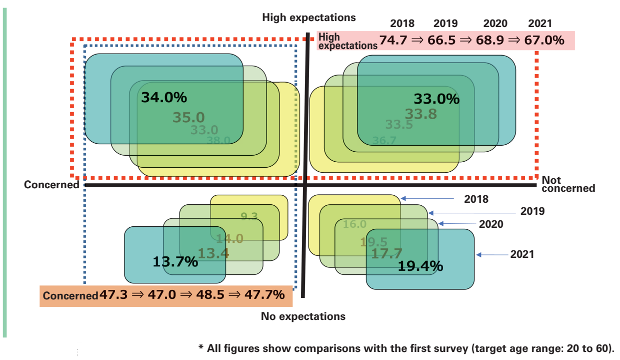


Fig. 1: Expectations and Concerns Regarding Social Changes Caused by Development and Popularization of Automated Driving

(2) Awareness and usage of Driver-Assistance Systems

Consumers were asked for their opinions about driving support functions, which are technical predecessors of automated driving technology.

Although the proportion of respondents' awareness of collision mitigation braking systems, pedal misapplication acceleration suppression systems, constant speed and vehicle-to-vehicle distance control systems, lane departure prevention warning systems, and parking assistance systems trended higher in 2020 and 2021 compared to 2019, there was not a significant increase.

In addition, although the usage rate of vehicles equipped with these functions is gradually increasing, major changes have not occurred. 24.8% of driving license holders were unaware whether their vehicle was equipped with these functions. This lack of awareness is a particular point of concern.

Respondents driving vehicles equipped with a collision mitigation braking system or pedal misapplication acceleration suppression system were asked whether they were normally aware that the vehicle was equipped with these functions, and respondents driving vehicles equipped with a constant speed and vehicle-to-vehicle distance control system, lane departure prevention warning system, or parking assistance system were asked whether they normally used these functions. The overall proportion of affirmative responses has remained in a range between 40 and 60%, indicating that the usage rate and awareness of these functions are not particularly high.

The fact that, currently, people using Driver-Assistance Systems have low awareness that these functions are even installed on their vehicles and do not use these functions to a great extent indicates that people have little appreciation of the benefits of these functions. It also indicates that a ripple effect from innovators, early adopters, and other pioneering users on wider society cannot be relied upon.

	Number of people aware of function			Number of people driving vehicle equipped with function			Number of people who normally use the function*	
Survey year	2019	2020	2021	2019	2020	2021	2020	2021
Collision mitigation braking system	68.8	73.8	69.9	17.8	18.5	20.7	56.1	56.8
Pedal misapplication acceleration suppression system	49.8	61.1	54.6	7.9	7.5	8.5	56.7	56.0
Constant speed and vehicle-to-vehicle distance control system	48.9	54.1	51.1	10.5	10.7	12.1	55.2	51.5
Lane departure prevention warning system	44.5	50.6	47.5	7.8	9.1	10.4	52.3	51.8
Parking assistance system	48.2	52.0	49.3	3.9	4.8	5.5	42.5	44.4
No Driver-Assistance Systems	24.2	20.4	23.4	-	51.7	48.4		
Not sure whether vehicle is equipped with Driver-Assistance Systems	-			-	23.7	24.8		

Note: for collision mitigation braking systems and pedal misapplication acceleration suppression systems, the question was changed to whether the consumer was normally aware that the vehicle is equipped with these functions.

Fig. 2: Awareness and Usage of Driver-Assistance Systems

(3) User understanding of Driver-Assistance Systems

The questionnaires also asked respondents about their understanding of each of these Driver-Assistance Systems. The results show that less than 30% received and understood a detailed explanation of any of the functions, and that between 30 and 40% either received an explanation but did not understand the explanation well or at all, or did not receive any explanation.

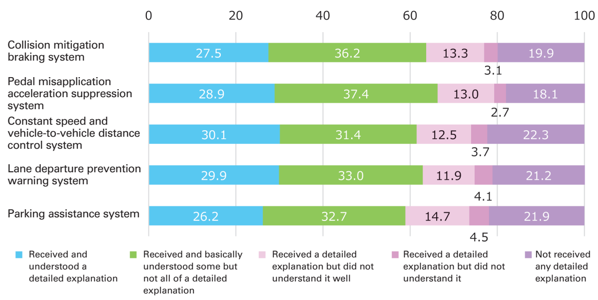


Fig. 3: User Understanding of Driver-Assistance Systems

In a Society that is currently trending toward the adoption of vehicle sharing and subscription services, as well as the selection of vehicles based on application, this low understanding even in drivers actually using vehicles equipped with these Driver-Assistance Systems must be regarded as a concern from the standpoints of both the under-utilization of these functions, as well as safety when the functions are used.

(4) Awareness of mobility issues in old age

Respondents were generally very aware of mobility issues of the elderly. A high proportion of respondents agreed that freedom of mobility in old age would raise the quality of life (74.1%) and that enabling freedom of mobility in old age would help to extend "healthy life expectancies"(A period of time when you can stay healthy and independent.) (69.2%). The survey also confirmed that the number of people wanting to live in their current area of residence in their old age (58.2%) increased significantly with the age of the respondent.

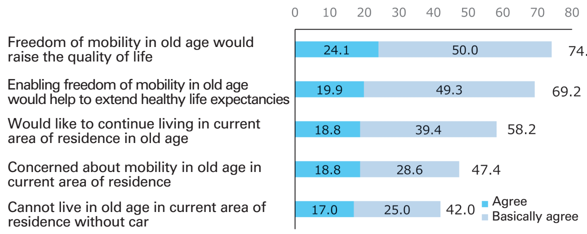


Fig. 4: Awareness of mobility issues in old age

Of the safety-related issues faced by elderly drivers, society is currently focused on the question of surrendering driving licenses. 27.4% of respondents stated that they knew someone around them that should probably surrender their driving license. The largest proportion (31.8%) of these respondents stated that this person was their own father. The questionnaire also asked for comments about how these people were likely to act in the future. Around 30% of respondents in total stated that "the person in question would probably not stop driving in any circumstances", or "the person would probably not stop driving until they realized the risk after experiencing an accident or dangerous situation", or that "the only way to stop the person from driving would be to hide their keys or driving license, or to force them to stop". In contrast, approximately 20% of respondents stated that the person in question would probably surrender their license if alternative means of transportation could be secured.

In conclusion, these results indicate the importance of increasing the diversity of mobility by simultaneously enhancing safety through the adoption of more sophisticated automated functions in privately owned vehicles to extend the driving lifetime of individual drivers, and ensuring alternative means of transportation to private vehicles through the popularization of automated driving vehicles as transportation service.

(5) Four elements of acceptance of automated driving

When considering the public acceptance of automated driving, the following four points are regarded as specific elements that consumers are required to accept.

(a) Lifestyle change: acceptance of various changes to lifestyles by the popularization of automated driving

(b) Learning: acceptance of the need for learning to enable the popularization of automated driving

(c) Cost: acceptance of various cost burdens related to the popularization of automated driving

(d) Uniqueness/ Technical limits: acceptance of the particular characteristics as well as the limits and risks of automated driving

The following diagrams discuss these elements in more detail. Different results were achieved depending on the attributes and situation of the respondent, including gender, age, and the scale of the urban area in which the respondent lived. Proposals for actions are also presented based on an overview of the results.

	Acceptable	Basically acceptable	Basically unacceptable	Unacceptable
Establishing new rules, such as restricting roadside parking and cutting in, for safe drive with automated vehicles	33.5	53.9	9.8	2.9
stricter traffic rules for pedestrians, bicycles, and other vehicles for safe drive with automated vehicles	33.7	53.0	10.1	3.2
helping each other when using, getting in, and getting out of automated buses (public transportation)	24.2	58.5	13.2	4.1
active involvement in studies of routes and rules related to automated buses (public transportation) by local residents of each region	20.4	59.0	16.4	4.3
going to bus stops to ride automated buses (public transportation) rather than private cars	19.7	47.1	24.0	9.1
giving up private vehicles and using automated buses (public transportation)	17.8	36.9	29.7	15.7

Fig. 5: Acceptance of Lifestyle Changes

		Acceptable	Basically acceptable	Basically unacceptable	Unacceptable
Users must understand how to use automated vehicles.		34.4	53.3	9.6	2.7
Regarding the characteristics and limits of automated vehicles	Users must understand the characteristics and limits of automated vehicles.	34.2	53.8	9.5	2.5
	Non-users must also understand the characteristics and limits of automated vehicles.	26.8	54.9	14.6	3.7
Regarding the legal liabilities of accidents involving automated vehicles	Users must understand the legal liabilities of automated vehicles.	33.0	53.4	10.7	2.9
	Non-users must also understand the legal liabilities of automated vehicles.	27.0	53.9	15.1	4.0

Fig. 6: Acceptance of Necessity for Learning

	Acceptable	Basically acceptable	Basically unacceptable	Unacceptable
Taxes must be used to prepare roads and the like for automated buses (public transportation).	16.9	56.4	19.7	7.0
Taxes must be used to prepare roads and the like for private automated vehicles.	15.9	54.9	21.8	7.4
Private automated vehicles will be more expensive than conventional private vehicles.	12.1	41.0	32.1	14.7
The number of automated buses (public transportation) running on a route will increase but bus services will be more expensive.	11.0	41.7	35.1	12.2
The cost of owning a private automated vehicle will be more expensive than a conventional private vehicle.	12.1	38.4	33.6	15.9

Fig. 7: Acceptance of Cost Burden

	Acceptable	Basically acceptable	Basically unacceptable	Unacceptable
Decisions made by automated vehicles may not always be the same as the decisions that a human driver would take.	16.0	53.4	23.8	6.8
Automated vehicle technology must be 100% safe before automated vehicles are practically adopted.	18.9	47.8	24.1	9.2
To ensure safety by following traffic rules and driving at or below the legal speed limit, the operation of automated vehicles might not be in harmony with surrounding traffic flows.	14.4	51.8	26.7	7.1
To ensure safe operation, automated buses (public transportation) might use sensors to stop frequently and confirm safety, resulting in longer journey times than manually driven buses.	13.2	51.6	27.5	7.7
Although accidents caused by driver inattention may drop significantly, accidents may be caused by automated vehicle malfunctions.	12.0	39.6	32.7	15.8

Fig. 8: Acceptance of Uniqueness and Technical Limits

The results of specific items in these four acceptance items were totaled and the historical trends compared. Although the acceptance of lifestyle changes and the need for learning has risen over the last two years, there have been no changes in the acceptance of the cost as well as the Uniqueness /Technical limits of automated driving. Based on these historical survey results, even though respondents have expressed a certain acceptance of social changes and learning, there are many negative opinions about the possibility of higher cost burdens and the occurrence of accidents due to the characteristics of automated vehicles. Working how to raise understanding about these items is likely to be the key to fostering public acceptance of automated driving.

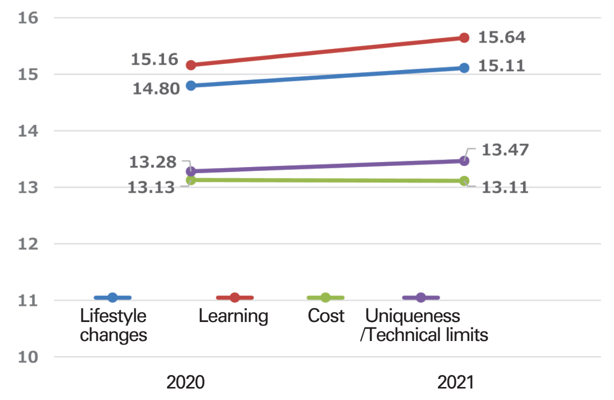


Fig. 9: Historical Changes in Aspects of Social Acceptance

3 Interpretation of KPI and KGI Related to Fostering Public Acceptance

3.1. Limits of Using KPI and KGI as Quantitative Targets

Based on the situation and results described above, Dai-Ichi Life Research Institute Inc. was contracted by SIP-adus to create KPI and KGI for evaluating efforts to foster public acceptance.

The first thing that must be realized to foster public acceptance of automated driving is to raise awareness with providing information. However, there is not a straight correlation between raising awareness with providing information and fostering acceptance. For example, there are some people do not change their negative stance even after obtaining information, while the same information may also cause people that have accepted automated driving without fully understanding it to change their minds.

Therefore, as shown in the bottom part of Fig. 10, in phase 1, it will be necessary to first increase the amount of information available to consumers and raise their awareness while, at the same time, identifying what specific elements are acceptable and unacceptable to people who understand automated driving but have a negative stance toward it. Subsequently, it will be necessary to study the individual issues behind these unacceptable elements and identify suitable countermeasures. Then, as shown in phase 2, it will be necessary to identify the motivations of the consumers who understand automated driving but have a negative stance toward it, and identify ways of finding a consensus by actively helping to resolve their concerns.

Based on the flows shown in the figure, it is important to be cautious when establishing numeral targets for KPI and KGI. It was decided that managing the quality of actions would be more effective as a qualitative target, an approach that was accepted by SIP-adus.

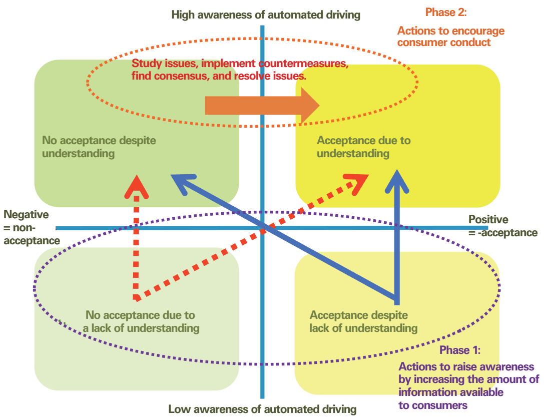


Fig. 10: Awareness and Acceptance

3.2. Evaluating Actions for Fostering Public Acceptance

Actions for fostering public acceptance include specific events and information communication. These activities must be clearly targeted, the information must be selected and prepared specifically for the target audience, and the media to be used must be chosen carefully. As the basis for these actions, it is important to understand the target audience of each activity. Table 1 shows the process incorporating all of these standpoints. The organization that carries out the activity should study each action based on this flow, review the issues raised in actions that have been implemented following this flow, and create opportunities to share that information with other such organizations. While project leaders have been forced to change their policies and study new approaches, due to the large number of restrictions due to COVID-19 in the 2020 fiscal year, active efforts have been made to identify issues by sharing this information and to share ideas among SIP-adus projects. As project leaders have the tendency to operate in isolation, exchanging information in this way has helped to construct creative systems of collaboration particularly in these times that continue to be affected by the coronavirus pandemic.

	Activity items (fixed items)		Check points (update every year)
1	Creation of overall framework and strategy within each project, and coordination between projects Framework and strategy	1	Has an annual activity plan been formulated based on a mid- to long-term comprehensive strategy based on existing information, current states, and the results from the last fiscal year?
		2	Have processes been formulated for each project focusing on clear goals?
		3	Is there coordination to ensure that there is no waste or overlap between projects (comprehensiveness of projects, selection of appropriate targets, etc.)?
2	Target audience, acquisition of background information, and understanding Identification of targets	1	Has sufficient information been obtained and understanding achieved in advance about the target audience for fostering public acceptance (society as a whole, regions, people, etc.)?
3	Selection, editing, and processing of information to be communicated Adaptation	1	Have studies been carried out into selecting the appropriate information for the target audience before the information is communicated?
		2	Has the information been edited and processed in line with the target audience before the information is communicated?
4	Method, media, and location of information communication Means	1	Were the appropriate methods, media, and locations used to communicate the information to the target audience?
		2	Was information communicated consciously from the standpoint of the Society 5.0 concept (merging of the physical and virtual)?
5	Creation of opportunities for hands-on and user experiences (UX) Experience	1	Were opportunities created for the target audience to personalize the issues through realistic customer experiences?
6	Feedback and mutual interaction Communication	1	Was the impact of the communicated information verified from the reactions of the people receiving the information or interactions with the target audience?
		2	Were improvements related to the content of the communicated information and the communication means identified and linked to new ideas from the reactions of the people receiving the information or interactions with the target audience?
7	Information spread and social interest Expansion	1	Did the activity contents or communicated information lead to the spread of related information via the mass media, SNS, etc.?
		2	Were secondary effects such as information transmission by word of mouth achieved?
		3	Was the interest of innovators and early adopters stimulated by raising the satisfaction of existing users?
8	Consumer understanding Understanding	1	Did the understanding of consumers related to automated driving and advanced driver assistance systems (ADAS) increase?
		2	Did the activity encourage spontaneous actions by consumers to understand automated driving and ADAS functions?
9	Consumer and user behavior Use	1	Did the activity help consumers to understand social issues or their own situation, and did it lead to the purchase of related products, services, and functions?
		2	Did the activity prompt the use of products, services, and functions already owned by the user?
10	Consumer acceptance Acceptance	1	Did consumers start to show acceptance of the following items caused by the introduction of automated driving: (1) lifestyle changes, (2) learning, (3) cost, and (4) uniqueness and technical limits?

Fig. 10: Awareness and Acceptance

3.3. Ideas about Fostering Acceptance Obtained from Specific Activity Cases

This project also considered the ideal approach to fostering public acceptance in the future through the actions described above.

A number of interesting ideas were obtained from activities conducted by the local authorities in the town of Sakai in Ibaraki Prefecture. This community has actively accepted automated driving services and is directly addressing mobility issues caused by depopulation and the aging of society. The community has adopted automated vehicles with a brightly colored and stylish appearance. This has helped to create a mobility system that provides extra value and builds connections between people in the community, particularly children. In addition to realizing the primary benefit of providing mobility, these vehicles have also become icons of the community. This has helped to close the distance between automated driving and local residents and psychologically mitigate technical hurdles such as the slowness of the vehicles, and fostered acceptance by both passengers and other traffic users. Local residents have proactively looked for ways to utilize this new mobility technology by, for example, providing sites for bus stops free of charge, looking after passengers getting in and out of the vehicles, and restricting roadside parking. This positive attitude toward learning about this new technology has compensated for the technical limits and intrinsic characteristics of automated driving.

The same reaction were observed at a test ride of an automated shuttle in Armidale, Australia in 2020. Regions like this that are faced with issues such as the aging of the population have recognized the potential of automated driving as a means of daily transportation. At the test ride, the vehicle waited a few minutes on the road to enter a roundabout. However, drivers of other vehicles waited behind the shuttles patiently without pressing their horns. This was probably because the need for automated vehicles in that region, and the characteristics and limits of these vehicles had been recognized to some extent in advance.

In any case, obtaining the understanding of local residents about why automated driving technology should be introduced, why automated driving is a potential solution for social issues, and what automated driving can accomplish or not accomplish is a prerequisite for encouraging spontaneous understanding of how automated driving should be introduced. Acceptance can only be achieved through this process. Following the process described above should help to provide a path to realize breakthroughs in fostering public acceptance as suggested in some of the questionnaire survey results.

3.4. Ideas Obtained from Research

The cost as well as the Uniqueness /Technical limits of automated driving have been identified as particularly difficult issues for fostering public acceptance of a society based on automated driving technology. Ideas to achieve acceptance for these items are summarized below.

(1) Acceptance of cost

Raising acceptance of the cost of automated driving will not be simple, particularly because it requires understanding of new types of cost burdens for elderly people. Private vehicles provide benefits besides the times that they are actually driven. For example, even when parked, these vehicles provide the psychological peace of mind of instant availability, while also satisfying people's possessive instinct. These are major benefits for consumers. Therefore, the rationality that the reduction in cost burden realized by giving up a private vehicle will be transferred to a cost burden related to public transportation may be impossible for people to accept easily.

For this reason, a monetized model in which the costs of a new mobility system are recovered by fares alone, may be difficult to realize. Of course, the enhancement of mobility itself has large intrinsic value. For example, in addition to the economic benefits of enhanced community accessibility, maintaining the mobility of the elderly can help to prevent frailty and extend healthy life expectancies. If these benefits can be viewed comprehensively while factoring in the subsequent reduction in social security costs and other benefits, it may provide the basis to use public funds to establish automated mobility systems. Furthermore, if the non-financial benefits of automated driving, such as improving the wellbeing of consumers by enhancing the mobility environment, are also factored in, some people may also come to understand the substantial social value of automated driving. In the future, when providing context for public acceptance, it will be necessary to incorporate such wide-ranging and long-term standpoints while visualizing their effect through provisional calculations or the like.

(2) Acceptance of Uniqueness /Technical limits

System error is just as inevitable as human error. No technologies can ever be 100% infallible. However, in the same way that technologies have the potential to compensate for human limits, people also have the potential to compensate for the limits of technologies, by providing that these limits are understood. If consumers can understand the necessity for the technology (why automated driving technology is needed) and its intrinsic characteristics and limits (what automated driving technology is), then consumers may identify their own ways to overcome these limits (how automated driving technology can be adopted.). This approach of consumers overcoming technical limits has everyday precedents involving conventional vehicles. Common examples include safety controls, seatbelt usage, and following speed limits.

The Society 5.0 concept refers to a society that works to resolve issues by combining the cyber and physical worlds. The approach of using human attributes to compensate for the limits and defects of new technology has the potential to resolve social issues much faster than relying on technology alone. The fostering of public acceptance as part of the social implementation of automated driving is one way that the Society 5.0 concept can be materialized.

The format of future initiatives to foster public acceptance should include the consumer and the residents alongside the normal representatives of industry, government, and academia. While incorporating the viewpoints described above, this format must also ensure coordination between ministries, liaison between the center and local regions, and cooperation between different companies. With this format in mind, the first step should be to present a grand design for an automated driving-based society that expresses the benefits for the people living in it. After doing so, it will be important to continue dialogs toward the creation of tangible solutions from the standpoint of the wellbeing of everyone in society.

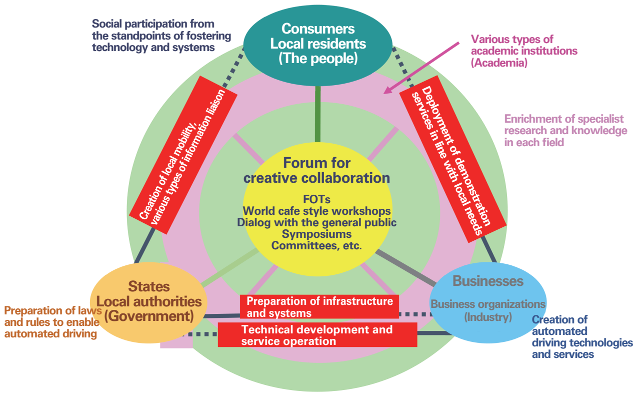


Fig. 12: Creative Systems of Collaboration between Industry, Government, Academia, and the People

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Advanced Driving Support for Drivers with Visual Field Loss (Overview)

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This project aimed to establish a methodology for the use of driving support systems to help ensure the safety of drivers with visual field loss, and to raise public awareness about this methodology. First, driving simulators (DS) were used at medical institutions to construct a database and identify the particular causes of accidents involving visual field loss. The project then studied conditions for driving support systems to counter these accident risks, focusing on automatic braking and audio guidance. Using these results, information about the utility and effectiveness of driving support systems was communicated widely throughout society as a whole and to the relevant institutions using visual field loss as an example, thereby helping to popularize advanced driving support systems and raise awareness about safety.

In this project, self-organizing map (SOM) analysis of the results obtained from the simple DS was able to identify patterns of visual field loss and situations in which accidents are more likely to occur. It was also found that, using both simple and high-precision DS, accidents involving drivers with visual field loss could be reduced using highly sensitive sensors and automatic braking, as well as by providing specific audio directions rather than simple guidance about the vehicle status. In contrast, the results also showed that automatic braking systems that are unable to completely prevent accidents may actually cause accidents to increase. Additionally, communication of these ideas to society as a whole was started by opening the first safe driving outpatient care programs at two eye clinics using the simple DS results.

As described above, this project underlined the pressing issue of drivers with visual field loss and proposed ways to resolve this issue. It will be necessary to raise the awareness of both drivers with visual field loss and eye doctors, and comprehensive measures to communicate this issue to society as a whole, industry, and government ministries will also be important. It is hoped that this project will help to resolve technical issues, while leading to changes in vehicle markings, rules, and other non-technical aspects.

1 Background

There are two types of vision impairment, loss of visual acuity, and visual field loss. Driving license systems around the world have different conditions for visual acuity. For example, most systems in Europe and the U.S. allow people with a corrected visual acuity (CVA) of 0.5 or higher to obtain a license, whereas in California, this value is only 0.1 or higher. Additionally, many systems also have visual field standards (34 states in the U.S.[1] and 23 countries in Europe[2]). In contrast, the system in Japan is more stringent and requires a CVA of 0.7 or higher using both eyes. However, a visual field test is not required for people with a CVA of 0.7 or higher using both eyes or a CVA of 0.3 or higher using one eye. Therefore, people with glaucoma or retinal pigment degeneration (RPD) can easily obtain a driving license under the current system since central visual acuity may not deteriorate until much later in life, even if that person has conspicuous visual field loss.

In Japan, a large number of people suffer from glaucoma (up to one in twenty people aged 40 or older according to the Tajimi Study Review and other sources)[3-5]. Although various types of visual field loss can occur if this condition becomes serious, visual field constriction (VFC) may proceed slowly over several decades, and many patients remain unaware that their visual field has narrowed. Kunimatsu et al. studied the risk related to drivers with visual field loss by recording the occurrence of accidents and brake reaction times in fifteen dangerous situations using a simple driving simulator (DS) capable of being operated in a hospital. This study compared the results of 36 patients with late-stage glaucoma and VFC with 36 healthy people of the same age and driving times. The accident rate of the patients with late-stage glaucoma was significantly higher[6].

In addition, since RPD[7] can lead to the gradual narrowing of the visual field while leaving the center part of the field intact, doctors instruct 80% of RPD patients to stop driving. However, a survey found that 13% of people with this condition drove a car and 6% rode a motorcycle, of which 55% had suffered an accident while driving[8].

Despite these results, many drivers with visual field loss have not been involved in any form of traffic accident. It is thought that these drivers are compensating for a narrower visual field by shifting their gaze while driving. These people have a legal right to drive and summarily banning people whose livelihoods depend on having a driving license from driving is not a reasonable option. Explaining the risks and persuading these people to stop driving is an extremely difficult issue. There is also no official concept of accidents caused by VFC, and the police attribute all such accidents to lack of proper attention to the road ahead. This shows that lack of awareness of drivers with visual field loss is an issue that must be resolved.

In January 2017, the Expert Advisory Council Meeting on Measures to Prevent Traffic Accidents by Elderly Drivers was inaugurated to make wide-reaching studies for formulating the necessary policies to prevent traffic accidents particularly involving elderly people. As a result, the following two measures to address visual field loss and the like, conditions that affect a large number of elderly people, were proposed: (1) study and research the relationship between the visual field and safe driving, and (2) promote PR and awareness-raising initiatives related to the risk of driving with visual field loss. As a result, studies and research are ongoing into the development of new visual field testers to be used in classes attended by elderly people.

The driving process is said to consist of the three steps of recognition, judgment, and operation. However, a perception phase occurs before the recognition step, and it is possible to consider vision impairment by separating these perception and recognition processes. Drivers suffering from dementia have been recognized as a pressing social issue. The fact that some of these drivers also have impaired perception due to the large numbers of glaucoma patients in Japan makes it difficult to create a clear division between perception and recognition. If Japan can take the global lead in recognizing and resolving the problem of drivers with visual field loss who are only affected by issues of perception as demonstrating the need for automated driving, this might contribute to the practical introduction of automated driving technologies,

2 Objectives

Through cooperation between the medical and engineering fields, the objective of this project is to identify the effects of visual field loss on driving and the benefits of providing advanced driving support functions, with the aims of realizing safe mobility for people with visual field loss and reducing traffic accidents.

This project developed a simple DS for eye clinics called the S-Navi to efficiently collect driving behavior data from healthy people and people with visual field loss, thereby helping to identify the particular causes of accidents involving drivers with visual field loss in accordance with the location and extent of that visual field loss.

The project also aimed to use these results to clarify which driving support functions are truly effective for drivers with visual field loss, incorporate these into a high-performance DS, and verify the effectiveness of these functions in reducing accidents.

Finally, this project aimed to study methods for ensuring the safety of drivers with visual field loss using driving support systems, and to raise public awareness of this issue and its countermeasures.

3 Initiatives by SIP-adus

3.1. Construction of Database of Healthy Drivers and Drivers with Visual Field Loss

(1) S-Navi driving simulator

The frequency of accidents particularly involving drivers with visual field loss was verified using the Honda Safety Navi GE (abbreviated as "S-Navi" in this article) DS manufactured by Honda Motor Co., Ltd. and used by eye clinics in outpatient care programs (Fig. 1). The S-Navi is equipped with an accelerator pedal that controls the speed, but the direction of the simulation cannot be changed by turning the steering wheel. As a result, only driving straight on and braking operations can be studied. The steering wheel is provided to enhance the realism of the simulation. The monitor displays fifteen situations in which accidents are likely to occur, including the background environment, various objects, and red traffic signals (Table 1), allowing the identification of accidents that tend to be caused by visual field loss.

After ethical review processes at three medical institutions (the Kobe City Eye Hospital, Niigata University, and Tohoku University), data started to be collected from test subjects in February 2019. In addition, after the transfer of a member of the research team, data collection also started at the Inouye Eye Hospital in July.

During the study period, 108 data cases were obtained from the Kobe City Eye Hospital, 44 from Tohoku University, 113 from Niigata University, and 55 from the Inouye Eye Hospital. Combined with the re-use of 116 cases of research data obtained by the National Police Agency, a database comprising a total of 436 cases was constructed.

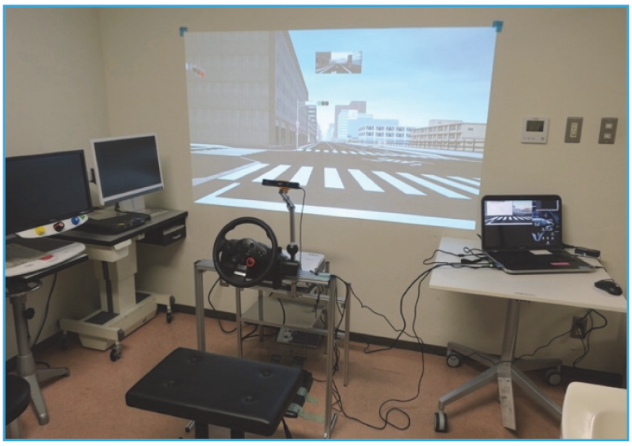

Fig. 1: Simple DS (S-Navi) Installed in Hospitals

Table 1: Driving Hazards

No.	Vehicle speed	Hazard
H1	50 km/h	Red traffic signal
H2		Vehicle crossing from off-road location on left
H3		Oncoming vehicle turning right at signalized intersection
H4		Vehicle merging into driving lane from off-road location on right
H5		Red traffic signal
H6		Vehicle crossing from off-road location on left
H7		Oncoming vehicle turning right at signalized intersection
H8	40 km/h	Vehicle approaching from left at unsignalized intersection and turning right
H9		Red traffic signal
H10	30 km/h	Mobility scooter crossing from off-road location on right
H11		Stop sign
H12		Vehicle approaching from left at unsignalized intersection and going straight on
H13		Mobility scooter crossing from left at unsignalized intersection
H14		Stop sign
H15		Vehicle approaching from right at unsignalized intersection and going straight on

(2) Identification of Particular Causes of Accidents Involving Drivers with Visual Field Loss

A new analysis method for these results using artificial intelligence (AI) was developed with the cooperation of the Deloitte Tohmatsu Group. The feature quantities of the test subjects consisted of almost 100 separate dimensions, including general physical feature quantities (such as age and gender), feature quantities obtained from eye tests (such as visual acuity and the sensitivity of each visual field region), and feature quantities based on driving behavior (such as whether an accident occurred in certain situations). The self-organizing map (SOM) machine learning technique was applied to carry out mapping to simple feature quantity spaces (here, two-dimensional planes) based on constraining conditions to ensure that mutually similar test subjects are located close together. Then, by clustering the test subjects after mapping, it was possible to create large clusters of test subjects with similar characteristics around each pattern of visual field loss. This helped to simplify understanding of the differences in characteristics between test subjects, thereby facilitating studies of the accidents in each situation and patterns of visual field loss (Fig. 2). After clustering these clinical findings related to visual field loss, SOM analysis was carried out again, this time by superimposing the results of accident avoidance in each DS scenario, thereby visualizing the relationship between the type of visual field loss and risk avoidance.

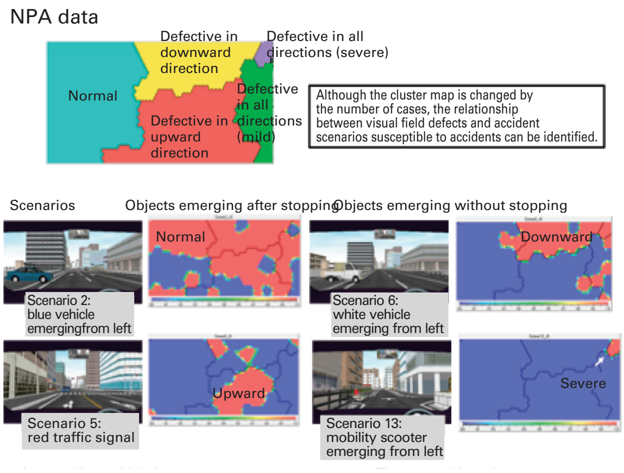

Fig. 2: SOM Analysis

For example, an examination of the relationship between the patterns of visual field loss and scenarios susceptible to accidents shows that even test subjects with a normal visual field were likely to have an accident in scenario 2 (in which a vehicle stops at the left and then suddenly drives out). In comparison, when the vehicle emerged without stopping, test subjects with visual field loss in the downward direction (Fig. 2) were more susceptible to accidents. In addition, subjects with visual field loss in the upward direction were more likely to cause an accidents by disregarding a red traffic signal, and only test subjects with severe visual field loss had accidents in scenario 13, which was almost the final scenario. In this way, likely accidents were linked with visual field loss and it was confirmed that accidents did not occur in many scenarios unless the visual field loss of the driver was severe.

3.2. Identification of Driving Support Conditions to Reduce Accidents

(1) Studies using simple DS

After confirming that visual field loss creates particular risks, the project then studied the effectiveness of various driving support conditions in avoiding and reducing these accidents. First, the S-Navi DS used at the eye clinics was provided with a 65-inch display to create a horizontal visual field of 70 degrees. To obtain information about driver gaze, the Pro-Nano eye tracker manufactured by Tobii AB was used to identify the gaze of the experiment participants at a frequency of 60 Hz. An audio guidance system was realized using a speaker located at the front left of the participants.

The total of sixty healthy adults participated in the experiment. These participants satisfied the following three conditions: (1) holders of an ordinary motor vehicle license and drive on a daily basis, (2) have no pre-existing eye conditions, and (3) have an uncorrected visual acuity (UCVA) or CVA of 0.7 or higher. The participants were divided into six groups of ten as defined below.

To simulate visual field loss in healthy people, a simulated visual field defect system was used.

A mask was displayed on the driving screen in real time based on the gaze information obtained by the eye tracker.

(1) Healthy drivers, without driving support
(2) Drivers with simulated visual field loss, without driving support
(3) Drivers with simulated visual field loss, audio guidance (status)
(4) Drivers with simulated visual field loss, audio guidance (driving behavior instructions)
(5) Drivers with simulated visual field loss, braking support that prevents collisions
(6) Drivers with simulated visual field loss, braking support that may result in a collision

Table 2: Accident-Reduction Effects of Different Driving Support Conditions

Hazard	Without support		Visual field loss + audio guidance support		Visual field loss + braking support	
	(1) None	(2) Mask	(3) Status	(4) Behavior	(5) Early	(6) Late
Total	4/149	6/150	4/150	1/150	0/150	16/149

The results showed that audio guidance was effective in reducing accidents, especially when it provided direct driving instructions rather than commentary on the vehicle status. This is consistent with the results of issue A in phase 1 of the SIP-adus program. In contrast, insufficient braking support is actually likely to increase the number of accidents, indicating that measures to prevent overconfidence in braking support systems will be important.

In addition, to verify the timing of the driving support, an experiment was conducted using a total of 54 participants (26 men and 28 women) aged from 22 to 77 (average age: 49.8, standard deviation: 17.9) who satisfied the same conditions as the experiment described above. These participants were divided into the following four groups.

(1) Without driving support: 13
(2) Warnings provided by audio guidance: 14
(Expressions designed as driving behavior instructions, but at a later timing than group (3))
(3) Warnings provided by audio guidance: 13
(Expressions designed as driving behavior instructions)
(4) Accident avoidance support by automatic braking: 14
(Late braking timing that might result in a collision in some cases)

The results of this experiment found that many drivers in group (3) confirmed the presence of an object after hearing the audio guidance. This group caused fewer collisions than the drivers without support in group (1). It was found that early audio guidance made it easier for drivers to take the appropriate action. The timing of the audio guidance used by group (2) was set to result in a potential collision if the driver took the time to confirm the object after hearing the guidance. Therefore, the drivers learned to listen to the audio guidance and depress the brake to avoid the collision before then confirming the object. In addition, although described as automatic braking, the timing of the system used by group (4) was set to result in a potential collision in some cases. The experiment results found that this system also potentially increased the number of accidents. These results demonstrated that the provision of driving support should be combined with reminders about driver behavior.

(2) Studies using high-precision DS and simulations

The multi-agent traffic environment reproduction simulation technology developed by the Japan Automobile Research Institute (JARI) in the SIP phase 1 project to develop and verify simulation technology to estimate detailed traffic environment reduction effects was used in these studies. Repeated driving simulations were carried out in a virtual traffic environment with three visual field angles (normal vision: 140°, moderate visual field loss: 40°, and severe visual field loss: 20°) and two automatic braking sensor angles (for ordinary vehicles: 40° and for luxury vehicles: 140°) (Fig. 3). The results found that automatic braking reduced accidents, particularly those involving drivers with visual field loss, and that it could reduce fatal accidents to the same level as the simulations with normal vision and no automatic braking (Fig. 4).

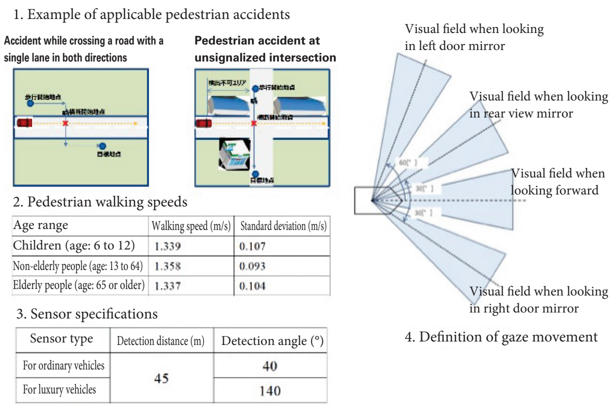

Fig. 3: Simulation Conditions

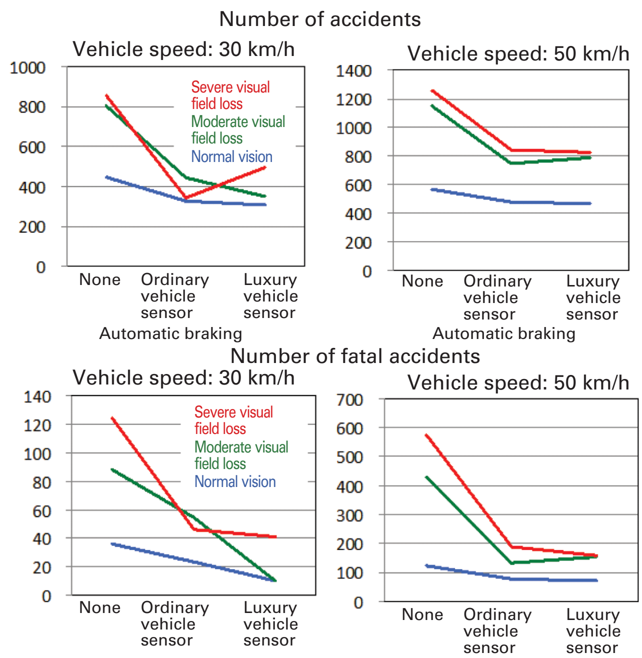

Fig. 4: Results of Preliminary Simulations to Verify Accident Reduction Effect

Next, the simulations were carried out again using the JARI multi-agent traffic environment reproduction technology after incorporating the driver behavior models obtained using the high-precision DS (Fig, 5). A traffic environment was created including roads with single lanes in each direction and intersections (signalized and unsignalized). Pedestrians and vehicles were programmed to appear at random. In the same way as the high-precision DS simulations, three visual field angles (normal vision: 140°, moderate visual field loss: 40°, and severe visual field loss: 20°) were set. However, in these simulations, four types of driving support systems were adopted (warnings only, warnings + automatic braking using ordinary (40°) and luxury (140°) vehicle sensors). Driving was repeated a sufficient number of times under each condition (at least 200,000 times), and the number of accidents that occurred was analyzed. The results confirmed that the combination of automatic braking and the luxury vehicle sensor reduced the number of accidents involving drivers with visual field loss to the same level or lower than the simulations with normal vision and no automatic braking (Fig. 6).

Fig. 5: High-Precision DS Installed at the National Innovation Complex (NIC)

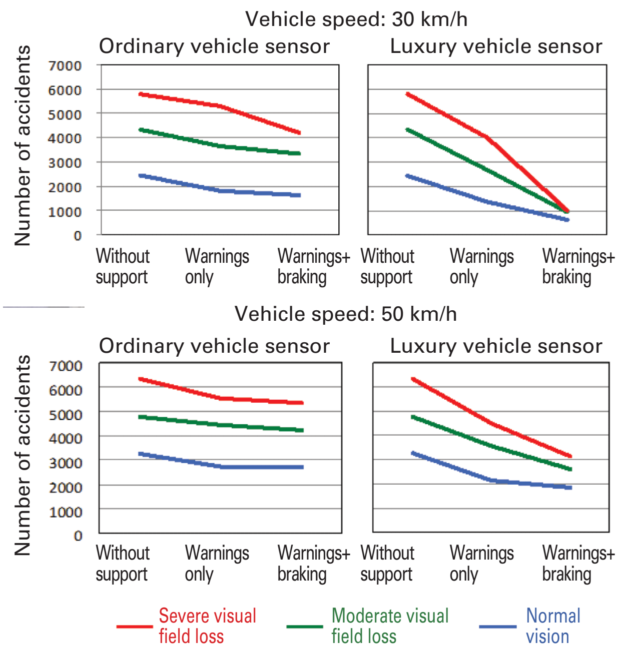

Fig. 6: Analysis Results of Simulations Incorporating Driver Behavior Models

3.3. Awareness Raising

(1) Raising awareness of people with visual field loss: safe driving outpatient care

Based on these results, two cooperating medical institutions, the Inouye Eye Hospital and the Kobe City Eye Hospital started the world's first safe driving outpatient care programs in July and December 2019, respectively (Fig. 7).

In these programs, safe driving outpatient care is provided by medical staff after obtaining data using a DS and a gaze and visual field meter developed by RIKEN, Japan. This outpatient care involves reviewing the risks that occurred while watching replays on the DS based on the results of visual field testing and other tests carried out at the eye clinic. Family members are allowed to attend the care programs, which also provide advice and guidance for any patient concerns or worries. Many patients with visual field loss are not aware of the extent of this loss. Therefore, after operating the DS, the medical staff show the patient the visual field test results while watching the replays on a screen. Explanations accompanied by confirmations such as these help patients to understand the dangerous aspects of their own driving for the first time. In collision scenarios, patients are asked to look in the forward direction. The medical staff then move the video forward frame-by-frame to the point that the emerging vehicle appears and disappears, allowing the patient to recognize the existence of blind spots in their visual field. The medical staff often advise patients to actively move their gaze to eliminate these blind spots and help prevent accidents. In this way, it is important for patients to realize that traffic signals, vehicles, and people may disappear in the visual field of one or both eyes.

In the future, it is possible that medical staff may provide advice about preventing accidents through the use of particular advanced driving support systems in accordance with the location of the patient's visual field loss.

There have also been recent cases of companies inquiring about measures for employees with visual field loss. This suggests that there is a growing need for advice and information targeted at companies about the risks and countermeasures of driving with visual field loss.

These novel safe driving outpatient care programs have also attracted the attention of the media. Television shows featured the programs soon after they started and various types of media have continued to raise awareness of these programs.

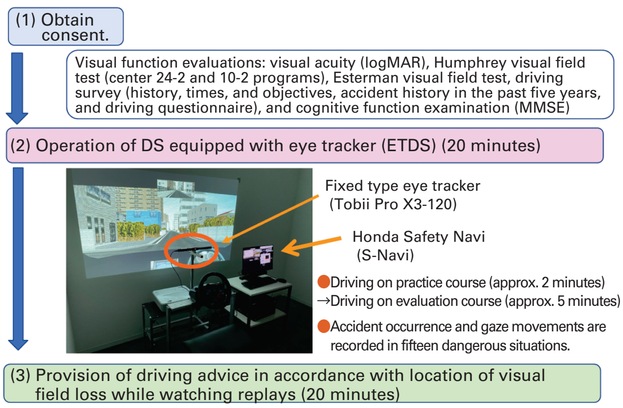

Fig. 7: Example of Safe Driving Outpatient Care Program

(2) Raising awareness of healthy people and families of patients: head-mounted display

Studies of methods to raise understanding of danger of visual field loss in families of patients:

To communicate with patients suffering from visual field loss and to deepen mutual understanding, it is important that the family and people close to the patient have a good understanding of visual field loss and its effects.

Therefore, a simple system that creates a realistic experience of visual field loss in people with normal vision was developed. Systems that apply a visual field loss mask interlocked with an eye tracker to a driving simulator screen are capable of simulating visual field loss focused on the point of gaze. However, since such systems require time-consuming calibration, it is difficult to encourage the families of outpatients at clinics and other medical institutions to try them out.

In response, a head-mounted display system was developed that uses acceleration sensors to apply a visual field loss mask interlocked with head motion rather than eye motion. The background images presented by the head-mounted display are the same as the S-Navi driving images and images are only visible in an approximate 10-degree radius at the center of the screen and the area around this range is blacked out (although regions of visual field loss do not actually seem black, this is a deliberate measure to express a sensation of blindness to people with normal vision).

This system is highly portable and only needs a single PC as hardware. This system was demonstrated at the SIP status report meeting held on March 25 and 26, 2021, and was broadly well accepted by the attendees that tried the system out.

4 Conclusion

This project underlined the pressing issue of drivers with visual field loss and proposed ways to resolve this issue. It is necessary to continue addressing the pressing issue of raising understanding about people with vision impairment within eye clinics. Furthermore, comprehensive measures to communicate this issue to society as a whole, industry, and government ministries will also be important.

It is possible that some people who should not continue driving due to the risks involved may include those capable of driving safely with the assistance of advanced safety technologies such as safe driving support vehicles (Safety Support Car S). As the development of automated driving technologies advances, there is no need to go back to the era of simply banning these people from driving. Instead, an era of greater possibilities is approaching in which impairments can be overcome. Rather than waiting for automated driving to become widely available before opening its use to people with impairments, visualizing the benefits of cutting edge technologies by actually giving priority to people with the greatest need should be the direction of a technological advanced society, and may provide a shortcut to the implementation of automated driving. In discussions of vision impairment, often only those people who have suffered severe loss of vision are considered, with level 4 or higher automated driving systems regarded as necessary for people who are completely unable to see. However, it is important to recognize that there are different grades of impairment running from severe to moderate to slight to normally sighted people, and that some people with slight to moderate impairments are fully capable of continuing to drive with the assistance of advanced driving support systems. While automated driving systems are currently being constructed, these seem to be aimed principally at physically unimpaired people and exclude people with visual impairments. While people with visual field loss need to drive to maintain their lifestyles while placing themselves and others in danger, there is, at the very least, an urgent requirement for subsidized safe driving support vehicles to help realize a safer driving environment.

It is also necessary to work to ensure safety through non-technical measures such as indicating that a vehicle is being driven by a visually impaired person in the same way as a white cane symbolizes visual impairment. It is also important to build structures and systems, such as public subsidies for advanced driving support systems and the like, and to raise awareness so that the visually impaired can enjoy the benefits of automated driving technologies as the people most in need. This approach may provide a short-cut for the practical adoption of automated driving, the significance of which is universally recognized particularly in regions without public transportation systems.

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Development of Assessment Methodology for Socio-economic Impacts of Automated Driving Including Traffic Accident Reduction

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Assessments of the socioeconomic impacts of automated driving have an extremely important role to play in fostering public acceptance, corporate management, and defining government policies. This article introduces the analysis and methods of the various simulations conducted in the research concerning the impacts of automated driving including traffic accident reduction carried out from 2018 to 2021 based on that understanding. First, we present two models (the dynamic and static models) for the simulations of automated vehicle diffusion that forms the basis of socioeconomic impact assessment. That presentation is then followed by an overview of the impact analyses covering road traffic, the transportation services field, and the industry & society field conducted using the results of the simulations.

1 Purpose and Details of the Research

The research and development plan for the SIP-Automated Driving for Universal Services (2018, Cabinet Office) aims to address various social issues such as reducing traffic accidents and congestion, facilitating mobility for vulnerable road users, and improving the situation of insufficient driver numbers and high costs in the logistics and mobility service industries through the commercialization and diffusion of automated driving. Doing so has the potential to help realize a society with a higher quality of life.

This research projects seeks to contribute to that goal by working on evaluating the socioeconomic of automated driving to achieve the two following objectives. The first objective is to foster public acceptance of automated driving. The understanding of automated driving in communities exhibited by the population forms the basic premise for the eventual commercialization and spread of services and vehicles making use of automated driving technology. Obtaining that popular understanding requires taking quantitative measures of both the utility and latent risks automated driving brings to people's everyday lives and to the Japanese economy. The second objective is to contribute to defining government policies and corporate strategies. Assessing the differences on the speed of automated vehicle diffusion and the resulting socioeconomic impacts depending on the scope of economic incentives offered for automated driving and the approach to bringing automated vehicles to the market, for example, is a critical factor in government and corporate decision-making.

With those objectives in mind, this research project proceeded as shown in Fig. 1. We began by establishing the relationship of automated driving to the 17 sustainable development goals (SDGs) and attendant 169 targets by the United Nations to consolidate basic information and look into the significance of automated driving with respect to building a sustainable society. Next, we conducted simulations of automated vehicle diffusion and used the results as basic values in analyzing socioeconomic impacts. These socioeconomic impacts were then quantitatively analyzed from the three viewpoints of impact on road traffic, impact on the transportation services field, and impact on the industry & society field. The impact on road traffic was analyzed from the two perspectives of estimating effectiveness at reducing traffic accidents and estimating effectiveness at reducing traffic congestion and CO_2 emissions. The analyses of impact on the transportation services field focused on the themes of securing mobility for vulnerable road users, as well as in depopulated areas or other regions with poor transportation, mitigating the driver shortage for logistics services, and changing consumer choices for transportation, including vehicle ownership and use. Finally, the analysis of the industry & society field examined how changes in vehicle ownership patterns will affect the automotive industry and industrial sector as a whole, and how automated driving contributes to increased productivity.

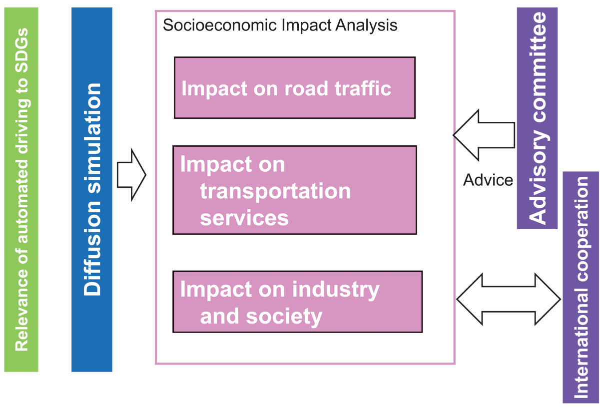


Fig. 1: Overall Picture of the Research Project

These models have the five following features and allows a logical and consistent analysis of a broad range of socioeconomic impacts.

1) The model is built through an integration of social science and engineering that fuses the knowledge of traffic and automotive engineering with that of economics.
2) Share socioeconomic environment data (e.g., population, GDP) was entered as uniform preconditions for the simulation.
3) The automated vehicle diffusion simulation models are based on microeconomic theory, and also account for consumer willingness to pay (WTP) and the production experience curve effect.

4) The rate of automated vehicle diffusion can be estimated for various measures to promote its spread.
5) The estimated rate of diffusion is used as shared data for socioeconomic impact assessments.

In the course of this research project, we set up an advisory committee involving experts from a variety of fields rather than just the engineering field, and advanced our research based on the discussions in the committee meetings. The simulations of automated vehicle diffusion and the changing consumer choices for transportation, including vehicle ownership and use themes from this project are being researched in cooperation with German research institutes in the context of the Japan–Germany joint research project. Following the Joint Declaration of Intent on Japanese – German Cooperation of the Minister of State for Science and Technology Policy of Japan and the Federal Minister of Education and Research of the Federal Republic of Germany on the Promotion of Research and Development on Automated Driving Technologies (January 12, 2017), the Japan–Germany joint research project on socioeconomic impact assessment was established at the Steering Committee meeting held by the Cabinet Office and the German Federal Ministry of Education and Research in January 2019.

The sections below present the outcomes of the project with a focus on the functions and concepts of the simulation models developed in the course of the research.

2 Diffusion Simulation

The S-curve model is commonly used to simulate the growth of goods and services. When the model is applied to goods or services that have not been launched on the market, approaches such as using similar goods or services as reference are used to set the parameters. Several other research projects have also used the S-curve model to make predictions on the diffusion of automated vehicles(1)(2). However, when conditions involving the coexistence of multiple automated driving levels are envisioned, as in our own project, simply applying parameters obtained through such approaches is not appropriate. Moreover, since the S-curve model is extremely simple, it cannot be used for simulations dealing with the effect of government measures or OEM market launch policies on the diffusion rate of automated vehicles. Consequently, an original diffusion simulation model for passenger vehicles was built for this research.

In terms of assessing the spread of automated vehicles, the timing for the introduction of SAE levels 1 to 4 is already being discussed. However, the restrictionless automated driving for level 5 vehicles makes their feasibility and the attendant timing impossible to predict. The diffusion simulation used in this research was therefore divided into two models: one that estimates the spread of automated vehicles up to SAE level 4, whose introduction in the market can be estimated to some extent, and another that estimates the spread of automated vehicles that do not need a human driver (levels 4/5). The first is a dynamic model that captures the process of automated vehicle diffusion and expresses it in slices of five years , while the second is a static model that provides a stationary state estimate of the diffusion rate after automated vehicles that do not require a human driver have been achieved.

For this research, we classified automated vehicles into the eight types shown in Table 1 to build the simulation models. The categories consist of a combination of the SAE levels and the roads on which automated driving is possible for each level. The dynamic model applies from category C0, including vehicles without driver assistance equipment to category C5, SAE level 4 automated driving on major general roads. In contrast, the static model applies to category L2, automated driving that achieves SAE level 2 human driver-led automated driving on all roads, and to category C6, automated driving that does not require a human driver.

(1)Dynamic model

Table 1: Categories of Automated Vehicles

Category	Highways	Generalroads	Compatible technologies	Dynamic model	Static model
C0	SAE Lv. 1 or less	SAE Lv. 1 or less	Level under C1.	✓	
C1	SAE Lv. 1 Driver assistance	SAE Lv. 1	Equipped with all the following four devices: ・Collision-damage-reducing brakes, ・Acceleration limiters for accidental accelerations (due to driver error), ・Lane-departure warning system, and ・Car distance warning system.	✓	
C2	SAE Lv. 2 Partial automation	SAE Lv. 1	In addition to C1: ・On highways, lane keeping systems (LKAS) + adaptive cruise control (ACC), and ・Automatic lane changing on highways	✓	
L2	SAE Lv. 2 Partial automation	SAE Lv. 2	In addition to C2: ・Lv. 2 on general roads		✓
C3	SAE Lv. 3 Conditional automation	SAE Lv. 2	In addition to C2: ・Lv.3 on highways, and ・Lv.2 on general roads	✓	
C4	SAE Lv. 4 High automation	SAE Lv. 3 on major arteries and thoroughfares	In addition to C3: ・Lv.4 on highways, ・Lv.3 on major general roads, and ・On general roads, take - over requests (TORs) for driving operations will be issued in response to system demand	✓	
C5	SAE Lv. 4 High automation	SAE Lv. 4 on major arteries and thoroughfares	In addition to C4: ・Lv.4 on major general roads, and ・Take - over requests (TORs) will not be issued	✓	
C6	SAE Lv. 5 Full automation				✓

The dynamic model covers logistics services (trucks) and transportation services (buses) in addition to passenger vehicles, and estimates the C0 to C5 (Table 1) number of automated vehicles diffused in society and how much they drive for every five years for 2015 to 2050. The estimation method varies for each type of vehicle, and the method used for passenger vehicles is presented below.

The simulation for passenger vehicles first takes the required number of owned vehicle for each year and subtracts the number of remaining vehicles from the previous year to obtain the number of new vehicles for that year. The relationship between supply and demand illustrated in Fig. 2 is then used to determine the distribution of new vehicles for each automated driving category.

The purple lines in the left part of Fig. 2 represent the acceptance rate curve (the proportion of the total number consumers willing to make a purchase at that price) for each automated vehicle category (Table 1). For this research, we conducted a web questionnaire using the double bounded dichotomous choice format to inquire about WTP for the functionality in each automated vehicle category. The acceptance rate curve was obtained by applying logistic regression analysis to the results of the questionnaire, and represents the relationship between the option price (price of automated driving functions) and acceptance rate or each category. Similarly, on the supply side, the model incorporates the mechanism whereby the production experience curve effect acts to determine the option price for each year. The experience curve effect refers to the improvement in production technology and reduction of product cost resulting from increased cumulative production, and has been observed for various products. Our model assumes the same relationship holds for automated driving technology.

The intersection of the consumer acceptance rate and the option price for each year represents the acceptance rate for the automated driving categories, and therefore determines the proportion of customers who intend to buy. However, the simultaneous market availability of several categories must not be forgotten. Consequently, in this model, an acceptance rate based on the acceptance rate curve and the option price is calculated in order from the higher level automated C5, C4, C3, and C2 categories. The difference between the acceptance rates of the applicable automated driving category and the higher level category was then surmised to represent the proportion of new vehicles in the relevant category. New vehicles ranking at C1 or lower were assigned to the C0 and C1 categories based on an exogenously set proportion.

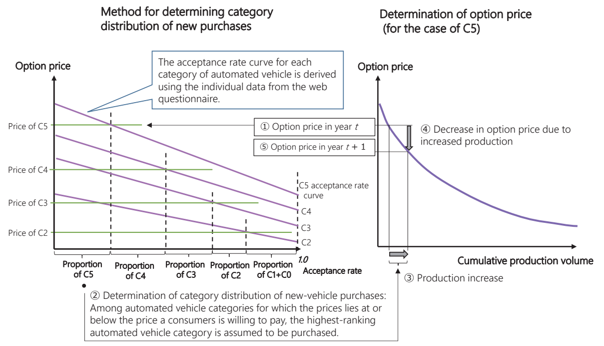


Fig. 2: Dynamic Model Concept

(2)Static model

Unlike the dynamic model, the static model only covers passenger vehicles and presents a stationary state estimate of vehicle ownership and use when automated vehicles that do not require a driver (levels 4/5) has been achieved.

The model envisions not just taxis that use automated vehicles, but also share automated taxis offering lower fares through ride sharing, and is capable of estimating the impact various factors such as fares and waiting time will have on each transportation mode.

This model was built using the answers to a web questionnaire on consumer choice of transportation mode conducted in the context of the changing consumer choices for transportation, including vehicle ownership and use theme from the analysis of impact on transportation services. As shown in Fig. 3, the questionnaire defined six modes of transportation and looked at how the duration and cost of travel, as well as the waiting time for automated taxis, include share taxis, affected the user's choice of transportation mode separately for the categories of weekdays or holidays, purpose of travel, and distance traveled. The core of the static model consists of a choice of transportation mode model built from the results of the questionnaire.

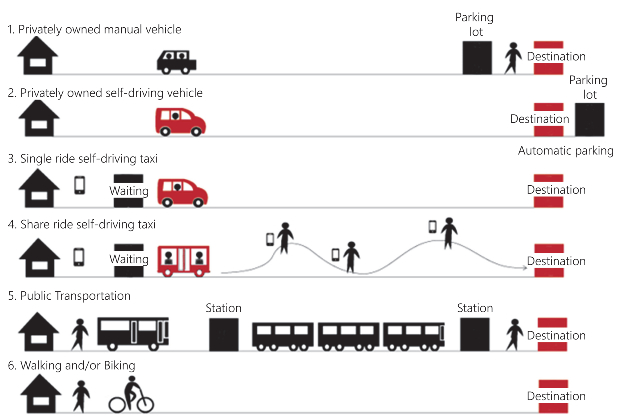


Fig. 3: Transportation Modes in the Static Model

3 Analysis of Socioeconomic Impacts

3.1. Analysis of Impact on Road Traffic

This assessment estimates effectiveness at reducing traffic accidents and effectiveness at reducing traffic congestion and CO_2 emissions.

(1)Effectiveness at Reducing Traffic Accidents

We obtained the results of estimates of the effect of the automated vehicle diffusion on the number of accidents, as well as fatalities and injuries from the separate Visualization of the Traffic Accident Reduction Effects through Automated Driving and Driving Assistance project. After adjusting those using ITARDA traffic accident macro data, and also drawing upon the economic loss values by level of human injury made available by a Cabinet Office survey[(3)], we expressed effectiveness at reducing traffic accidents as a monetary value. The simulation in the separate project was conducted using the diffusion simulation results (dynamic model) from our research project.

There are two major differences in the social benefits brought by active safety (e.g., driving safety support systems, automated driving) and passive safety (e.g., airbags) technologies. The first is that while both types of technology help mitigate the severity of physical injury to the occupants, active safety technology also features the external economy of mitigating physical damage to the other party in an accident. The second is that on the flip side of mitigating damage to the other party in an accident, the use of active safety technology also lightens the psychological burden (non-monetary loss) of the party who causes the accident. The first benefit can be estimated using the amount of economic loss per traffic accident victim obtained from the Cabinet Office survey and the decrease in the number of accident victims resulting from the diffusion of automated driving. However, the second benefit cannot be measured since there is no existing value representing the economic loss per victim sustained by the party who causes the accident. The fact that automated driving prevents people from causing accidents is an extremely crucial aspect of assessing its value. Consequently, a web questionnaire was used in this research project to estimate the psychological burden (non-monetary loss) of the party who causes the accident.

The questionnaire consists of a survey applying to the party who causes the accident and another survey applying to the victim. The survey applying to the party who causes the accident uses a double bounded dichotomous choice to assess WTP (for one year of use) for a device that reduces the probability that an error by the driver (assumed to be 100% at fault) will cause the death of the victim (only one person assumed) by 50% (or 90%) in a collision involving two four-wheeled vehicles. Conversely, the victim survey inquires about WTP for a device that reduces the victim's own risk of dying by 50% (or 90%) in a collision between two four-wheeled vehicles caused by the other driver's error (in which the victim has no fault). The analysis of the results demonstrated that there was no major difference in the WTP median for each case. In this research project, we incorporated the results of those survey in expressing the effectiveness of automated driving at reducing traffic accidents in terms of monetary values.

(2)Effectiveness at Reducing Traffic Congestion and CO_2 Emissions

We ran an on-road simulation to estimate effectiveness at reducing traffic congestion and its attendant CO_2 reduction effect.

The simulation defined prerequisites for behavior characteristics or parameters such as lane changing conditions and determination, and response delay time when an automated vehicle is following or driving freely and took future transportation demand and the rate of automated vehicle diffusion set in the simulation (dynamic model) into account. At the same time, it incorporate the results of the development and validation of local traffic CO_2 emissions visualization technology evaluation concerning the impacts of introducing automated driving conducted during the first phase of SIP.

Specifically, as shown in Fig. 4, we ran a two-stage simulation accounting for the diffusion of automated driving, that first estimated the respective basic unit of reduction for congestion and CO_2 emissions, and expanded those estimates nationwide.

The basic unit estimates covered both expressways and general roads. For expressways, reduced congestion is mainly anticipated in sag sections, and we ran the simulation on applicable two- and three-lane segments in each direction. The choice of three-lane segments, in particular, was based on segments for which a considerable amount of data was acquired in the development and validation of local traffic CO_2 emissions visualization technology from the first phase of SIP–Automated Driving for Universal Services. In addition to estimating the CO_2 emissions reduction effect of automated driving, trial calculations of CO_2 emissions reduction effect that account for the diffusion of electric vehicles and the differences in CO_2 emissions reduction effect between each type of electric vehicles were conducted.

For expressways, the top 30 segments from the expressway traffic conditions ranking (2018) reported by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) were chosen to expand the estimate nationwide with several headway assumptions and anticipated diffusion rates. Similarly, for general roads, we focused on the subset of roads, including signalized intersections, corresponding to the Logistically-Important Roads (national highways under MLIT jurisdiction and high-standard arterial highways) to expand the estimate for various anticipated diffusion rates.

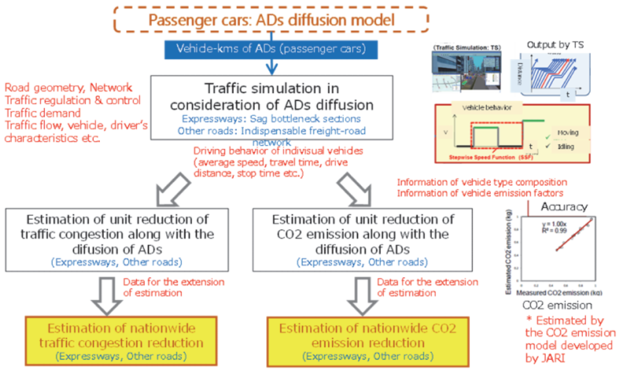


Fig. 4: Method for Estimating Effectiveness at Reducing Traffic Congestion and CO_2 Emissions

3.2. Analysis of Impact on Transportation Services

This section covers the themes of securing mobility for vulnerable road users, as well as in depopulated areas or other regions with poor transportation, mitigating the driver shortage for logistics services, and changing consumer choices for transportation, including vehicle ownership and use. The outcomes for the theme of changing consumer choices for transportation, including vehicle ownership and use have already been presented in Section 2-(2). Therefore, the themes of securing mobility for vulnerable road users as well as in depopulated areas or other regions with poor transportation and mitigating the driver shortage for logistics services are presented below.

(1) Securing mobility for vulnerable road users as well as in depopulated areas or other regions with poor transportation

Cases of the declining birth rate and migration of young people to cities, along with deteriorating business conditions and resulting withdrawal of private companies are forcing local administrations to take over services originally provided by those companies are frequently observed in semi-mountainous regions. Tasks such as traffic safety education, public relations, and crime prevention patrols, for example, which are carried out by neighborhood associations or local resident groups in cities, often turn into local administration services in semi-mountainous regions. Such administrative services involve extensive labor and expenses, and since local administrations face the same severe shortage of labor as corporations and residents, it is difficult to imagine that services currently handled by local administrations are highly sustainable. This makes finding ways to save on labor and costs to maintain administrative services one of the most pressing issues for semi-mountainous regions. This research project focused on the applications and relevant fields in which automated driving technology could be introduced in semi-mountainous regions, as well as on expectations concerning its use, from the standpoint of administrative services, and studied the actual usage of the vehicles employed for those services. In addition, interview surveys with local government staff in semi-mountainous regions were conducted to examine the effects and issues stemming from the introduction of automated driving technology.

(2)Mitigating the Driver Shortage for Logistics Services

Based on several GDP trend assumptions, we estimated truck driver supply and demand at a point in the future and calculated the shortage of drivers for the logistics services from the difference between the two. We then defined hypothetical automated vehicle adoption and deployment scenarios and estimated how much they would mitigate that shortage.

Specifically, we started by estimating the supply of drivers in logistics services based on the proportion of people who will continue to work as truck drivers by age category and the proportion of young people who will be employed (new driver employment rate). Next, to estimate the future demand for truck drivers, we calculated the amount of production and import for total goods and for goods by category based on future GDP forecasts, and estimated the volume of generated freight from those amount. This value was then used to obtain a future freight shipment tonnage value, as well as the vehicle-kilometers traveled by trucks.

Based on the Public-Private ITS Initiative/Roadmaps 2019 we then defined deployment scenarios for automated driving logistics services as shown in Table 2 and estimated the amount of travel and the number of drivers automated driving could replace.

Finally, we estimated the economic effects of mitigating the driver shortage through automated driving. In concrete terms, we set the amount of production and import goods in a situation imposing constraints on transport capacity due to a shortage of drivers as a reference, and defined the economic effect as the estimated improvement in amount of production and import goods when automated driving was added to normal trucks driving on expressways to mitigate the driver shortage.

Table.2: Automated Driving Diffusion Scenario for Logistics Services

Scenario		2025	2035	2040
1	Fully automated driving of trucks on some specific sections of expressways	Commencement	○ Achievement	
2	Fully automated driving of trucks on expressways with 4 lanes and more		○	
3	Unmanned autonomous driving delivery service in specific areas (remote areas)	Commencement	○ Achievement	
4	Unmanned autonomous driving delivery service in specific areas (all areas except urban and sub-urban areas)		○	○
5	Fully automated driving of trucks on major ordinary highways			○

3.3. Analysis of Impact on Industry & Society

This section describes the themes of the impact of changes in vehicle ownership patterns on the automotive industry and all industries and contribution to productivity.

(1) Impact of changes in vehicle ownership patterns on the automotive industry and industrial sector as a whole

Realizing automated driving requires installing many sensors and a lot of software, and production requires inputs that differ from those of traditional vehicles. This research project considered electrification in addition to automated driving. We referenced the methods from prior research(3) on electric vehicles, and used an input–output table to analyze how the changes in automobile component parts mandated by automated driving and electrification will impact the automotive industry and the Japanese economy.

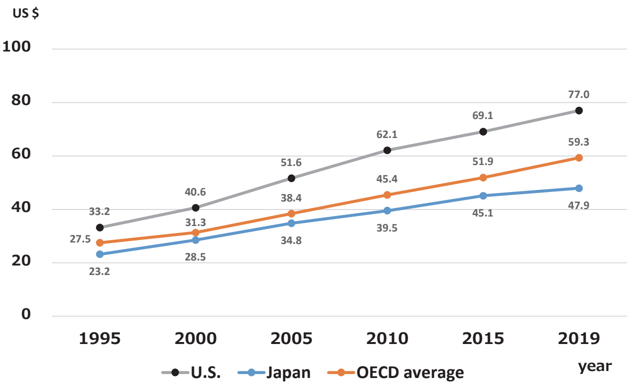
We started by identifying the parts required by automated driving and electrification along with their production sectors, and estimated the cost increases or decreases by automated vehicle category, type of electrification, and production sector. The number of vehicles by automated vehicle category and type of electrification obtained from the parts cost information and the diffusion simulation (dynamic model) was then used to derive an input coefficients table for an input–output table that accounts for future automated driving and electrification. The input coefficients table was then used to analyze the impact of automated driving and electrification on the amount of production and employment for the passenger vehicles, motor vehicle parts and accessories sectors as well as the overall Japanese industrial sector. We also performed a sensitivity analysis for changes in the costs of electrification and automated driving.

(2) Contribution to increasing productivity

Technological progress and innovation are critical to realizing the sustainable increase in labor productivity required to achieving sustainable growth when the population is declining. Figure 5 shows labor productivity (value added per hour worked) for the U.S., Japan, and OECD countries as a whole from 1995 to 2019. Although the data shows there was little difference between Japan, the U.S. and OECD countries as a whole in 1995, the gap grew progressively in after that. In 2019, the level for Japan (47.9 USD) stagnated at 62.2% that of the U.S. (77.0 USD) and 80.8% that of OECD countries as a whole (59.3 USD).

According to economic theory, improving labor productivity requires either increasing the capital–labor ratio (the amount of capital per worker), or raising total factor productivity (TFP) through technological progress or innovation. We therefore analyzed the effectiveness of automated driving at increasing the labor productivity and TFP of the Japanese economy. Factors that enhance the TFP increase rate are typically classified as changes in improving capital quality, improving labor quality, or improving business efficiency. Automated driving is expected to help improve TFP primarily through the improvement in capital quality factor. As noted in Section 3.2 (2) Mitigating the Driver Shortage for Logistics Services, the introduction of SAE level 4 automated driving would enable automated vehicles to replace the missing drivers, which unquestionably corresponds to improving capital quality. In this research project, we used the results from Section 3.2 (2) Mitigating the Driver Shortage for Logistics Services and estimated the rise in labor productivity and TFP brought about by the introduction of automated driving separately for commercial and private uses.

On a different front, mixed transport of passengers and goods by automated taxis represents an example of improving business efficiency. If we postulate that regulatory conditions are established and allow offering the transport of both passengers and goods, automated taxis could make use of an advanced dispatch system to move both people and goods efficiently in a single vehicle. This would primarily result in improved business efficiency raising TFP.



Note—Unit: Purchase power parity conversion in USD
Source: Based on Attachments 8, 9 and 10 in International Comparisons of Productivity by the Japan Productivity Center.

Fig. 5: International Comparisons of Labor Productivity (Value Added per Hour Worked)

4 Conclusions

This article presented an overview of the automated driving diffusion simulation and socioeconomic impacts analysis methods developed in the context of the research on the impacts of automated driving including traffic accident reduction carried out from 2018 to 2021. Moving forward, SIP-adus will use these outcomes to inform the public about the specific effects of automated driving on society and the economy.

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4 A Society with Automated Driving

(2) Public Acceptance of Automated Driving

Visualizing Effectiveness at Reducing Traffic Accidents—Enhancing Simulation Accuracy—

Hiroyuki Ota, Nobuyuki Uchida, Akito Adachi and Sou Kitajima (Japan Automobile Research Institute)

Fostering social acceptance is necessary for the smooth introduction and use of automated vehicles and vehicles providing driver assistance. In this project, we reproduced the traffic environment of selected model cities using a multi-agent simulation of the perception, recognition, decision-making, and actions of various traffic participants (developed in a project[1] in the first phase of SIP-Automated Driving for Universal Services). We then integrated driver distraction and other factors that cause accidents in the simulation to recreate real-world accident conditions. We also used the automated driving (driver assistance) system deployment scenarios for every five years from 2015 to 2050 provided by the Socioeconomic Impacts of Reducing Traffic Accidents project to estimate effectiveness at reducing traffic accidents. Since those deployment scenarios differ for each vehicle classification, we further subdivided those classifications and defined rates of automated driving (driver assistance) system market propagation separately for categories such as passenger car, bus, and truck. The nationwide effectiveness at reducing traffic accidents was estimated from traffic accident statistics using the ratio of accident reduction calculated using the simulation applied to model cities.

1 Project Overview

As social expectations surrounding the commercialization and market propagation of automated driving and driver assistance technologies rise, it is necessary to foster social acceptance to enable the smooth introduction and use of vehicles featuring those technologies. According to the Public-Private ITS Initiative/Roadmaps 2019[2], "Traffic participants will need to improve their acquisition of knowledge and level of understanding with respect to the use of automated driving vehicles irrespective of whether or not they personally use automated driving vehicles. We expect that correct knowledge of automated driving vehicles can help prevent accidents caused by overconfidence in or misunderstandings of automated driving functions and lead to the securing of social acceptance on the part of society as a whole."

In this project, we used a traffic environment agent-based simulation to calculate the effectiveness of automated driving and driver assistance technologies in the model cities defined in Section 4-(1) of this article. We estimated the nationwide effectiveness at reducing traffic accidents in accordance with the market propagation of vehicles equipped with those technologies, and looked for outcomes that would help foster social acceptance.

2 Simulation Overview

Raising the accuracy of the estimation of the effectiveness at reducing traffic accidents calls for incorporating behavior models that include traffic participant (driver, pedestrian, bicycle) errors and other accident factors into the simulation as faithfully as possible. In other words, the traffic environment simulation used in this project consists of a multi-agent simulation involving entities (agents) that perceive, recognize, make decisions, and act autonomously and influence one another's behavior, as shown in Fig. 1.

Figure 2 illustrates the process of building the simulation execution environment for one model city (Tokorozawa). A several square kilometer area containing the main parts (e.g., arterial roads, railway stations, city hall and city offices) of the model city were selected, and the road network for that area was extracted from satellite images (a). Next, data from the national road and street traffic situation survey (road traffic census) conducted every five years by Ministry of Land, Infrastructure, Transport and Tourism (MLIT) was used to investigate the volume of traffic in the main roads within the selected area (b). Incorporating behavior mistakes leading to traffic accidents in the driver and pedestrian agents then makes it possible to reproduce accidents. The reproducibility of the traffic accident conditions can be confirmed by comparing the accident locations collated in the simulation with the actual locations of accidents released by the prefectural police (c). Following these makes it possible to build a simulation execution environment to estimate detailed accident reduction effectiveness for each model city.

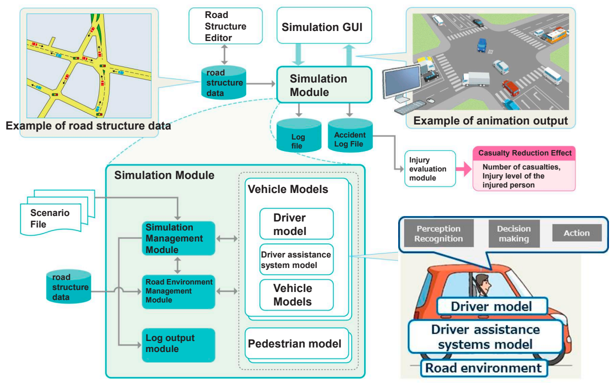


Fig. 1: System Configuration

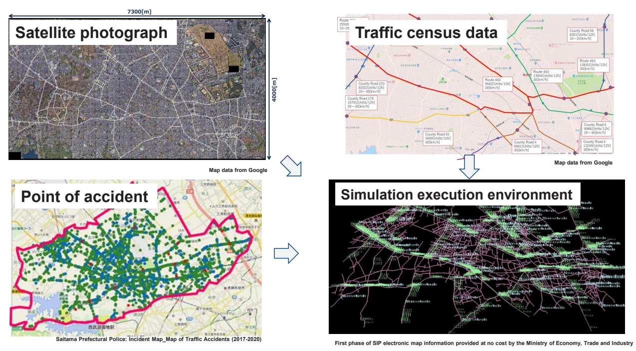


Fig. 2: Overall Visualization of Simulation

3 Traffic Participant Behavior Models

We defined the various traffic participant (driver, pedestrian, bicycle) models and the automated driving (driver assistance) system model in detailed as described in subsections (1) to (3) below to enhance the validity of the traffic accident reduction effectiveness estimate.

(1)Driver model

In this project, we used a driver model built to reflect the perception, recognition, decision-making, and action behavioral processes of the driver (see Fig. 3). We designed the perception and recognition processes to take the direction of the driver's line of sight (visual field) into account and retrieve position, speed, and other information about vehicles or pedestrians within that visual field. For distracted driving, one of the factors in traffic accidents, we defined intervals and durations for instances of distraction, and represented it by stopping the retrieval of information on the position and speed of vehicles and pedestrian during that time frame. One example of the decision process involves determining whether to speed up or slow down based on the relative speed of the preceding vehicle and the following distance. The action process then operates the accelerator, brakes and steering wheel in accordance with that decision. We also assigned a certain probability of driver error for each of the perception, recognition, decision, and action processes.

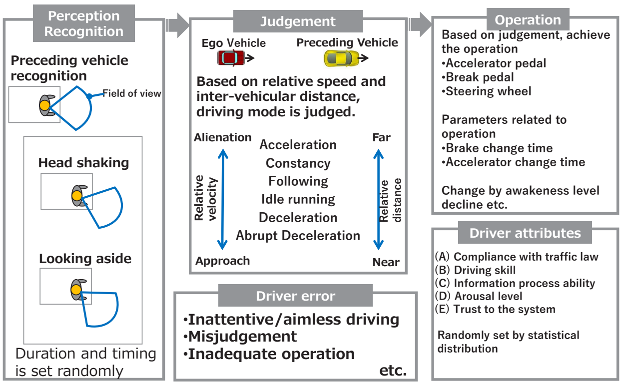


Fig. 3: Driver Model

(2)Pedestrian and bicycle models

We implemented pedestrian models reproducing not only for the highest fatality case of pedestrians dashing out to cross a single stretch of road (see the implementation of the speed and angle of crossing in Fig. 4), but also for the next highest fatality case of crossing at intersections. Intersection crossing pedestrian accidents involving factors such as jaywalking pedestrians, pedestrians ignoring the pedestrian traffic signal, and drivers making a right or left turn failing to notice the pedestrian are generated at a given probability.

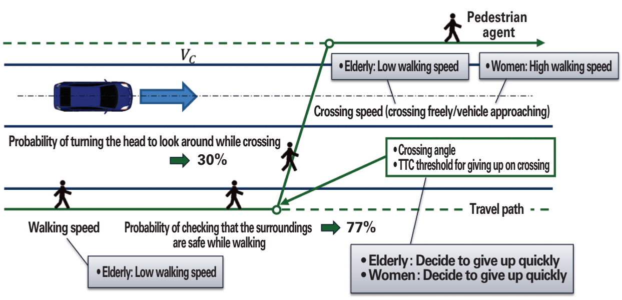


Fig. 4: Model for Pedestrian Dashing Out to Cross a Single Stretch of Road

The bicycle model only applies to accidents where the bicycle is the victim, and simulates the particularly frequent cases represented by frontal collisions, as well as both left- and right-turn accidents.

(3)Automated driving (driver assistance) system model

Figure 5 shows the activation conditions for the automated driving (driver assistance) system.

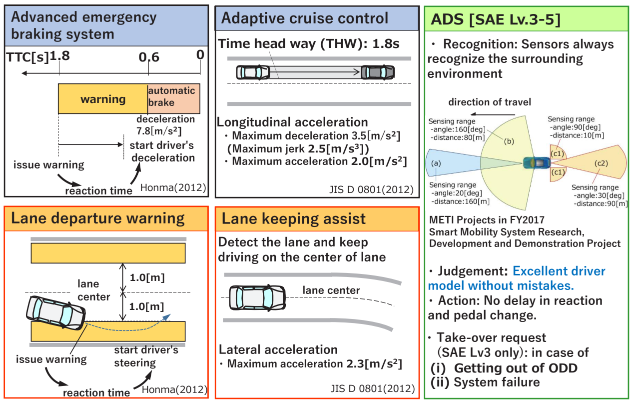


Fig. 5: Automated Driving System Activation Conditions

For the collision mitigation braking system, we use the paper by Ryohei Homma et al.[3] to define the activation conditions. A warning is emitted when the time to collision (TTC), which is the distance to the preceding vehicle divided by the relative speed of the two vehicles reaches 1.8 [s]. The driver agent starts slowing down after a response delay accounting for the driver's response to that warning has elapsed. If the driver agent does not react (due to a low alertness state such as drowsiness, for example), the model was designed to activate the automatic braking system when the TTC drops to 0.6 [s], with the maximum deceleration for automatic braking set to 7.8 [m/s^3]. The activation conditions for the constant speed cruising and maintaining following distance functions were set in accordance with stipulations in the Japan Industrial Standards (JIS D 0801)[4]. Acceleration and deceleration are applied to control the relative speed with the preceding vehicle to obtain a time headway (THW) of 1.8 [s], which is calculated by dividing the distance to the preceding vehicle by the speed of the driver's vehicle. Based on the stipulations in the standard, acceleration values in the longitudinal direction were set to a maximum deceleration of 3.5 [m/s^3], a maximum additional acceleration of 2.5 [m/s^2], and a maximum acceleration of 2.0 [m/s^2]. The lane departure warning is triggered when the vehicle deviates from the center its driving lane by 1 meter or more toward either side, and as with collision mitigation braking, the driver agent starts steering after a response delay based on response characteristics. The activation conditions for the lane-keeping assistance function were set in accordance with the stipulations for performance on curved roads from the same standard[4] used for the above constant speed cruising and maintaining following distance functions. The standard categorizes performance from Class I to Class IV. The curve radius the system can handle is 500 [m] for Class II, 250 [m] for Class III, and 125 [m] for Class IV. For this project, the vehicle is assumed to be equipped with a Class III system, and the maximum acceleration applied in the lateral direction to keep the vehicle near the center of the lane was set to 2.3 [m/s^3].

The automated driving system model operates similarly to the driver agent, using sensors for perception and recognition, a computer for decisions, and actuators to take action. The sensor configuration, detection angle, and detection range examined in a project commissioned by the Ministry of Economy, Trade and Industry[5] served as a reference to define forward (long range), forward (peripheral), rearward (proximal), and rearward (medium range) perception and recognition. A model corresponding to an exemplary driver that does not make mistakes was used for the decision process, and the implementation of the action process removed the response time and pedal switching delay taken into account for the driver agent.

We used existing surveys and research involving drivers of vehicles with already commercialized level 2 driver assistance[6] as a basis for defining the specifications for the handover of driving operations by an automated vehicle with level 3 automated driving (driver assistance) systems. As shown in Fig. 6, we postulated that the take-over request from the automated driving system is made ten seconds before exiting the ODD. A minimal risk maneuver (MRM) was set to activate ten seconds after the handover request was issued for all cases involving overconfident drivers who do not take over driving from the system. The MRM was defined to slow down and stop using a fixed steering wheel angle with a maximum deceleration (2.94 [m/s^3])[7][8] that does not result in sudden braking.

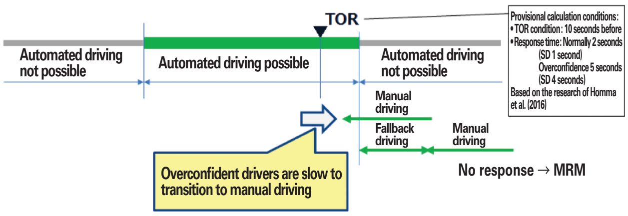


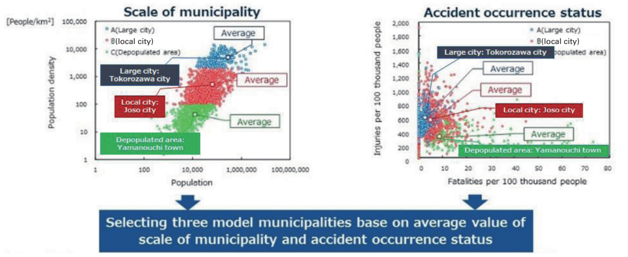
Fig. 6: Specifications for Driving Operation Take-Over by Level 3 Automated Vehicle

4 Preparing the Simulation Data and Defining the Execution Conditions

Subsection (1) presents the selection of model cities, and subsections (2) to (8) describe the preparation of simulation data and definition of execution conditions used to simulate the different market propagation rate of automated driving (driver assistance) systems for each vehicle classification.

(1) Selection of Simulation Model Cities

In this project, we selected representative model cities on which we ran simulations. The results were used as the basis to estimate nationwide effectiveness at reducing traffic accidents. Specifically, we referred to the Mid-and Long-Term Mobility Vision (2018) published by the Mid- and Long-term Mobility Vision Study Group of the Japan Automobile Manufacturers Association (JAMA) and classified all municipalities into large cities, local cities, or depopulated areas based on their scale and traffic accident conditions. The municipalities with the most average characteristics in each classification (Tokorozawa in Saitama as the large city, Joso in Ibaraki as the local city, and the town of Yamanouchi in Nagano as the depopulated area) were selected as model cities (see Fig. 7).



A (large city) candidates

Prefecture	Municipality	Population	Population density
Saitama	Tokorozawa	34.2	4,750
Kanagawa	Hiratsuka	26.1	3,846
Saitama	Koshigaya	32.3	5,411

B (local city) candidates

Prefecture	Municipality	Population	Population density
Yamaguchi	San' yo-Onoda	6.5	485
Ibaraki	Joso	6.5	529
Nagano	Chikuma	6.2	518

C (depopulated area) candidates

Prefecture	Municipality	Population	Population density
Aomori	Ajigasawa	1.1	33
Nagano*	Yamanouchi	1.4	51
Akita	Gojome	1.1	49

*No statistics were available to investigate accident locations in Yamaguchi and Aomori. Therefore, Ibaraki and Nagano, which had such statistics, were chosen.

Fig. 7: Selection of Model Cities

(2) Selection of Vehicle Models

As shown in Fig. 8, we defined vehicle models per classification that match the deployment scenarios provided by the separate Socioeconomic Impacts of Reducing Traffic Accidents project.

Mini bus

	Unit	Value
Length	[m]	6.995
Width	[m]	2.065
Weight	[kg]	3,710

Light-passenger car

	Unit	Value
Length	[m]	4.495
Width	[m]	1.745
Weight	[kg]	1,310

Mini-passenger car

	Unit	Value
Length	[m]	3.650
Width	[m]	1.665
Weight	[kg]	910

Bus

	Unit	Value
Length	[m]	11.99
Width	[m]	2.49
Weight	[kg]	13,180

Ordinary-passenger car

	Unit	Value
Length	[m]	4.910
Width	[m]	1.800
Weight	[kg]	1,690

Mini Truck

	Unit	Value
Length	[m]	1.475
Width	[m]	2.065
Weight	[kg]	350

Light Truck

	Unit	Value
Length	[m]	4.690
Width	[m]	1.695
Weight	[kg]	2,000

Motorcycles

	Unit	Value
Length	[m]	1.990
Width	[m]	0.710
Weight	[kg]	167

Special Vehicle

	Unit	Value
Length	[m]	4.910
Width	[m]	1.800
Weight	[kg]	1,690

Ordinary trucks

	Unit	Value
Length	[m]	5.280
Width	[m]	2.080
Weight	[kg]	2,770

Bicycles

	Unit	Value
Length	[m]	1.850
Width	[m]	0.580
Weight	[kg]	20

Fig. 8: Vehicle Models by Classification

(3) Definition of Traffic Regulation Information

We set the map data by applying geodetic (coordinate) conversions to the traffic signal (including pedestrian signal) display information provided by the National Police Agency (NPA) (see Figs. 9 and 10).

Fig. 9: Locations with Traffic Signal Display Information
(for Tokorozawa, Saitama)

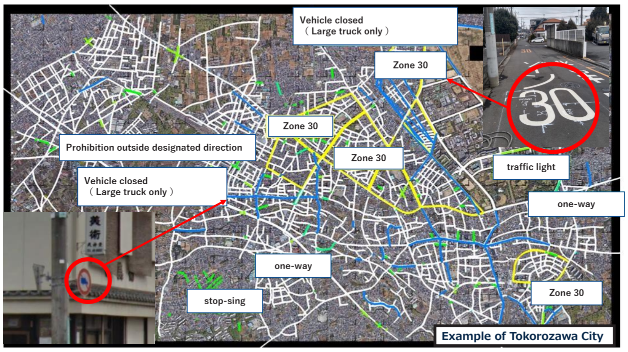


Fig. 10: Defining Traffic Regulation Information in the Map Data for the Simulated Region (Tokorozawa, Saitama)

(4) Setting the Speed Limit and Actual Speeds

In running the simulation, we had automated vehicles drive at or below the speed limit. However, as shown in Fig. 11, we defined both the speed limit and actual speed in the map lane information to have driver-operated vehicles move at their actual speeds. The speed limits were set using the values provided by the NPA, and the actual speeds from that agency's 2008 report on research concerning how to determine the speed limit. As shown in Fig. 10, Tokorozawa also has a 30 km/h zone, in which the speed limit was set to accordingly.

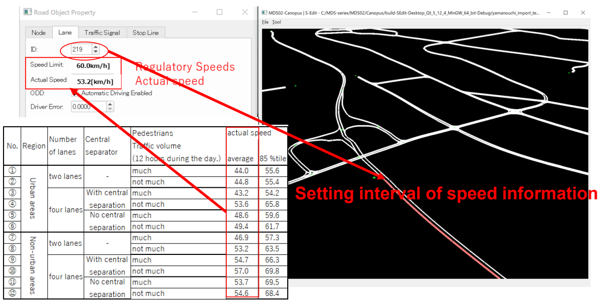


Fig. 11: Defining the Speed Limit and Actual Speeds in the Road Informatio

(5) Setting the Pedestrian and Bicycle Information

We investigated the accident conditions and locations in data released by the prefectural police for each model city, and define locations with a high accident frequency as paths traveled by pedestrians and bicycles. We also conducted on-site surveys of the volume of traffic to acquire the base data necessary to define the volume of traffic for bicycles and pedestrians, and entered the collated results in the map data (see Fig. 12).

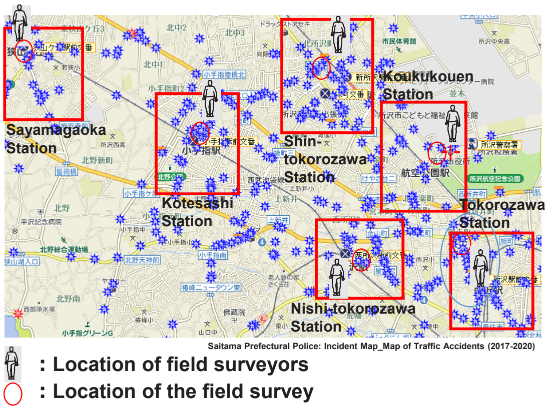


Fig. 12: Locations of Pedestrian Accidents and Volume of Traffic Surveys

(6) Setting the Volume of Traffic for the Model Cities

In this project, the National Road and Street Traffic Situation Survey of Origin Destination of Automobiles (the OD survey) and the Statistics of Motor Vehicles Owned published by the MLIT were used as the basis to calculate the volume of traffic conversion by vehicle classification using the procedure presented in Fig. 13. The road traffic census used in the past classified vehicles as either ordinary or large vehicles, but the vehicle classifications used in the OD survey and the statistics of motor vehicles owned were considered to obtain more accurate results. For the simulation, we distributed the volume of traffic from the road traffic census into a total of ten classifications (see Fig. 14)

Note: The O and D in OD stand, respectively, for origin and destination. In this project, those terms are used to identify the point where traffic participants (vehicles, pedestrians, bicycles) enter or leave the simulation.

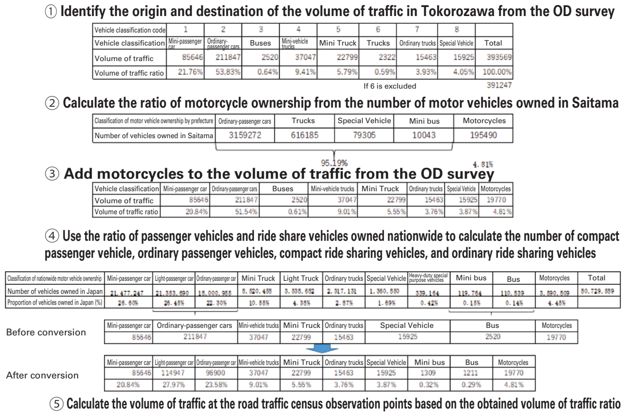


Fig. 13: Procedure for Distributing the Volume of Traffic Based on the OD Survey

2015 National Road and Street Traffic Situation Survey Basic—General Volume of Traffic Survey—Table by Location

	Route		Name of volume of traffic observation point	Volume of traffic by vehicle time over 12 daytime hours (Total in both directions)			Volume of traffic by vehicle time over 24 hours (Total in both directions)		
	Route number	Route name	Address	Compact vehicles (Vehicles)	Large vehicles (Vehicles)	Total (Vehicles)	Compact vehicles (Vehicles)	Large vehicles (Vehicles)	Total (Vehicles)
①	463	National Route 463	437-5 Ushinuma, Tokorozawa	11488	2447	13935	15612	3340	18952
②	463	National Route 463	14-14 Yurakucho, Tokorozawa	11513	2431	13944	15654	3310	18964
③	463	National Route 463	2-4-12 Nishitokorozawa, Tokorozawa	8014	1028	9042	10464	1471	11935
④	463	National Route 463	Ahead of 7-549, 3-chome, Hayashi, Tokorozawa	23183	2317	25500	31789	4931	36720
⑤	463	National Route 463	Ahead of 6-77, 1-chome, Higashisayamagaoka, Tokorozawa	12698	965	13663	16681	1764	18445
⑥	4	Tokyo Metropolitan Road and Saitama Prefectural Road Route 4	125 Kitaakitu, Tokorozawa	11785	1464	13249	15551	2203	17754
⑦	4	Tokyo Metropolitan Road and Saitama Prefectural Road Route 4		6133	828	6961	8801	1292	10093
⑧	6	Saitama Prefectural Road Route 6	1286-7 Kamiyasumatsu, Tokorozawa	8737	1249	9986	11511	1770	13281
⑨	50	Saitama Prefectural Road Route 50	Ahead of 34-258 Kitaiwaoka, Tokorosawa	8719	649	9368	12243	914	13157
⑩	55	Saitama Prefectural Road and Tokyo Metropolitan Road Route 55	Ahead of 2190 Kamiyamaguchi, Tokorozawa	4926	674	5600	7008	976	7984
⑪	179	Saitama Prefectural Road and Tokyo Metropolitan Road Route 179	Ahead of 1746 Kojiya, Tokorozawa	8920	1781	10701	12496	2661	15157
⑫	223	Saitama Prefectural Road Route 223	1-2421 Nishisayamagaoka, Tokorozawa	7142	1060	8202	9306	1439	10745

Volume of Traffic Based on the OD Survey (Final Values Used in Simulation)

		Mini passenger vehicles	Compact vehicles	Ordinary vehicles	Compact ride sharing	Ordinary ride sharing	Mini-vehicle trucks	Compact trucks	Ordinary trucks	Special-purpose vehicles	Motorcycles
	Total	20.84%	27.97%	23.57%	0.32%	0.29%	9.01%	5.55%	3.76%	3.87%	4.81%
①	14639	3050	4094	3451	47	43	1319	812	551	567	705
②	14649	3052	4097	3453	47	43	1320	813	551	568	705
③	9499	1979	2656	2239	30	28	856	527	357	368	457
④	26789	5582	7491	6315	85	79	2414	1486	1008	1038	1290
⑤	14353	2991	4014	3384	46	42	1294	796	540	556	691
⑥	13918	2900	3892	3281	44	41	1254	772	524	539	670
⑦	7313	1524	2045	1724	23	22	659	406	275	283	352
⑧	10491	2186	2934	2473	33	31	946	582	395	406	505
⑨	9841	2051	2752	2320	31	29	887	546	370	381	474
⑩	5883	1226	1645	1387	19	17	530	326	221	228	283
⑪	11242	2342	3144	2650	36	33	1013	624	423	436	541
⑫	8616	1795	2410	2031	27	25	777	478	324	334	415

Fig. 14: Volume of Traffic Used in the Tokorozawa Simulation

(7) Setting the Traffic Accident Statistics

We converted the traffic accident statistical data obtained from the Institute for Traffic Accident Research and Data Analysis (ITARDA) into the vehicle classifications presented in Fig. 8, and recalculated the figures. We then defined execution parameters that reproduced the accident ratio obtained from those recalculated figures in the simulation. Note that the simulation used in this project only covers the eight types of accidents shown in red among the 29 types of accidents in the ITARDA categories shown in Fig. 15.

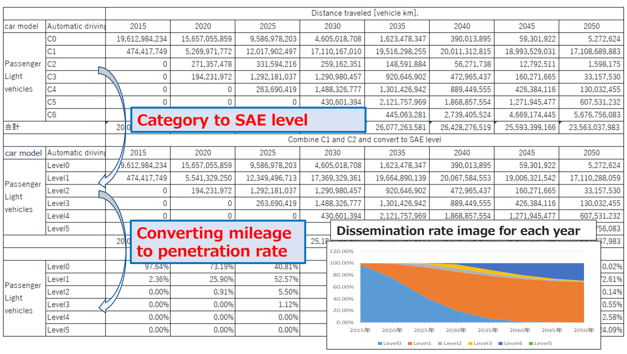
Category	Subcategory
Vehicle-to-pedestrian accidents	Driving toward pedestrian, driving behind pedestrian, crossing at a crosswalk*, crossing near a crosswalk, crossing elsewhere, playing in the roadway, working in the roadway, stopped in the roadway, lying down on roadway, other
Vehicle-to-vehicle accidents	Head-on collision, rear-end collision, intersection collision, overtaking, changing course, passing oncoming vehicle, left turns, right turns, crossing, overturning, reversing, other
Single-vehicle accident	Collision with a stationary object, collision with parked vehicle, driving off the road, rolling over, other
Train accidents	

* Only when crossing the crosswalk at an intersection.

Fig. 15: ITARDA Accident Categories

(8) Setting the Deployment Scenarios

The market propagation rate of automated driving (driver assistance) systems was calculated from the deployment scenarios provided by the separate Socioeconomic Impacts of Reducing Traffic Accidents project. Those deployment scenarios are not classified by SAE automated driving levels, and are defined in terms of traveling distance rather than market propagation rate. We applied a conversion to the SAE level rate of market propagation on the premise that automated driving (driver assistance) systems have propagated proportionately to traveling distance (see Fig. 16). However, predicting the market propagation rate for SAE level 5 using the provided deployment scenarios is difficult at this stage, and the propagation rate by 2050 was assumed to be 0[%].



		Distance traveled [vehicle km].							
car model	Automatic driving	2015	2020	2025	2030	2035	2040	2045	2050
Passenger Light vehicles	C0	19,612,984,234	15,657,055,859	9,586,978,203	4,605,018,708	1,623,478,347	390,013,895	59,301,922	5,272,624
	C1	474,417,749	5,269,971,772	12,017,902,497	17,110,167,010	19,516,298,255	20,011,312,815	18,993,529,031	17,108,689,883
	C2	0	271,357,478	331,594,216	259,162,351	148,591,884	56,271,738	12,792,511	1,598,175
	C3	0	194,231,972	1,292,181,037	1,290,980,457	920,646,902	472,965,437	160,271,665	33,157,530
	C4	0	0	263,690,419	1,488,326,777	1,301,426,942	889,449,555	426,384,116	130,032,455
	C5	0	0	0	430,601,394	2,121,757,969	1,868,857,554	1,271,945,477	607,531,232
	C6					445,063,281	2,739,405,524	4,669,174,445	5,676,756,083
合計		[illegible]				26,077,263,581	26,428,276,519	25,593,399,166	23,563,037,983

Category to SAE level

		Combine C1 and C2 and convert to SAE level							
car model	Automatic driving	2015	2020	2025	2030	2035	2040	2045	2050
Passenger Light vehicles	Level0	19,612,984,234	15,657,055,859	9,586,978,203	4,605,018,708	1,623,478,347	390,013,895	59,301,922	5,272,624
	Level1	474,417,749	5,541,329,250	12,349,496,713	17,369,329,361	19,664,890,139	20,067,584,553	19,006,321,542	17,110,288,059
	Level2	0	194,231,972	1,292,181,037	1,290,980,457	920,646,902	472,965,437	160,271,665	33,157,530
	Level3	0	0	263,690,419	1,488,326,777	1,301,426,942	889,449,555	426,384,116	130,032,455
	Level4	0	0	0	430,601,394	2,121,757,969	1,868,857,554	1,271,945,477	607,531,232
	Level5								[illegible]
		[illegible]			[illegible]				[illegible]
Passenger Light vehicles	Level0	97.64%	73.19%	40.81%					0.02%
	Level1	2.36%	25.90%	52.57%					[illegible]
	Level2	0.00%	0.91%	5.50%					0.14%
	Level3	0.00%	0.00%	1.12%					0.55%
	Level4	0.00%	0.00%	0.00%					2.58%
	Level5	0.00%	0.00%	0.00%					[illegible]

Fig. 16: Conversion form Deployment scenarios to Market Propagation Rates

5 Confirming the Simulation Results

Effectiveness at reducing traffic accidents was estimated by following processes (1) to (4) below. Processes (1) and (2) are designed to verify whether the simulation appropriately reproduces the real world volume of traffic and accidents.

(1) Verifying Volume of Traffic Reproducibility

As shown in Fig. 17, the volume of traffic in the model cities (Tokorozawa in Saitama, Joso in Ibaraki, Yamanouchi in Nagano) was confirmed to match the volume of traffic measured at the observation points in the road traffic census from both the standpoints of volume and vehicle mixture ratio.

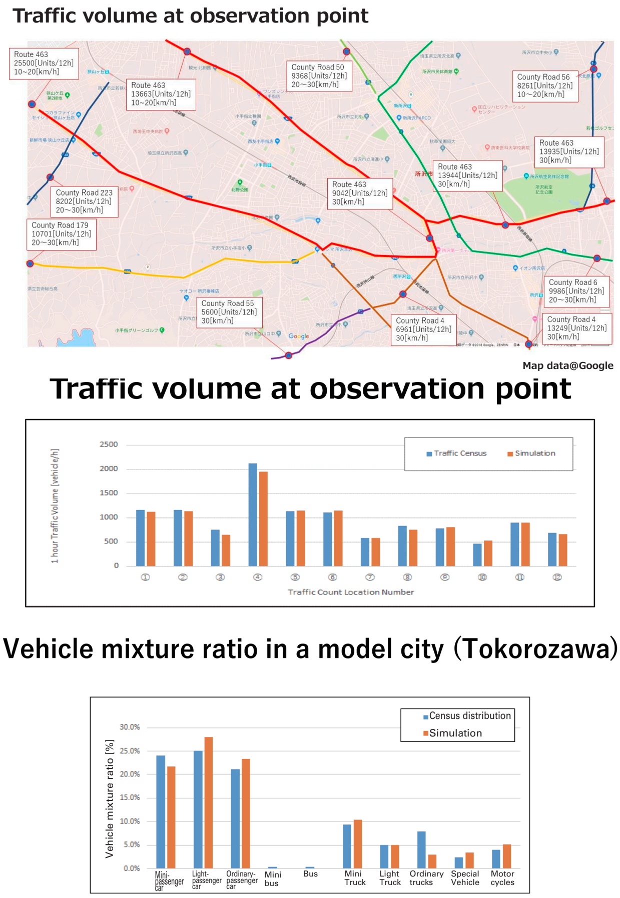


Fig. 17: omparison of Volume of Traffic at the Observation Points

(2) Verifying Accident Conditions Reproducibility

We compared the traffic accident statistics from ITARDA, the traffic accident location data released by each model city, and the results of accidents in the simulation, and confirmed that the results of the simulation closely match the actual circumstances in terms of both the frequency of accidents and their locations (see Fig. 18)

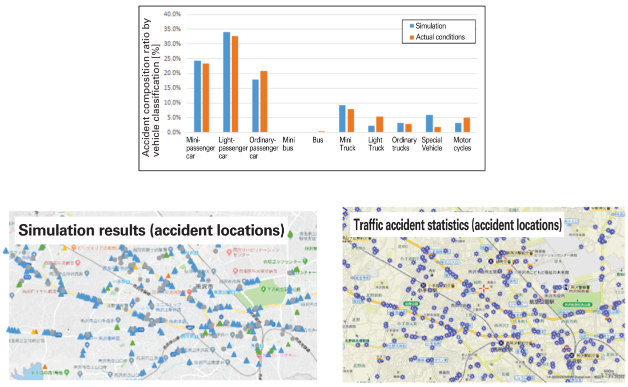


Fig. 18: Comparison of Traffic Accident Conditions (Tokorozawa)

(3) Calculation of Traffic Accident Reduction Achieved by Automated Driving (Driver Assistance) Systems

Figure 19 shows the reduction in traffic accidents achieved relative to the number of traffic accidents 2015 in the large city model (Tokorozawa) when the simulation was run with the automated driving (driver assistance) system market propagation rate.

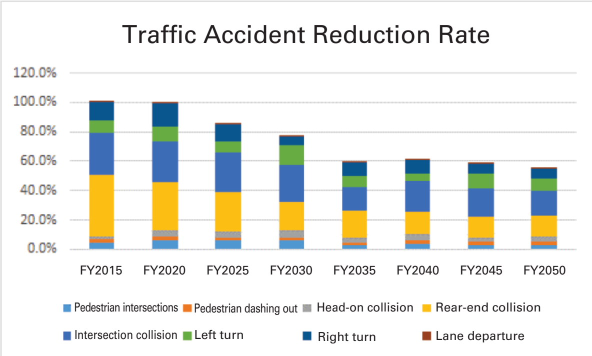


Fig. 19: Calculation of Traffic Accident Reduction Coefficient for Tokorozawa

(4) Estimating the Nationwide Traffic Accident Conditions

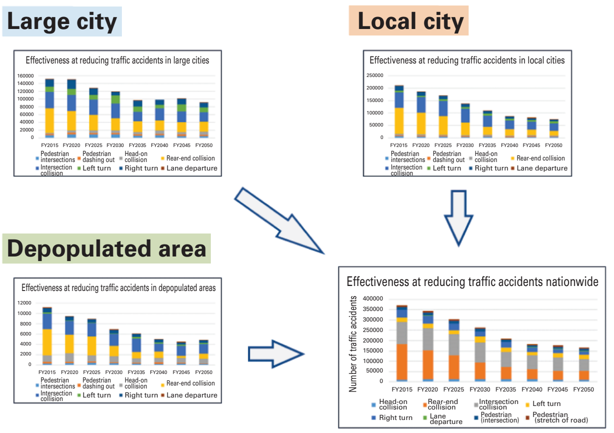


Fig. 20: Nationwide Estimate Based on the Number of Traffic Accidents in the Model Regions

Using a method similar to the one described in Section 5 (3), we first calculated the reduction in traffic accidents for each of the model cities (large city, local city and depopulated area) selected in this project. Based on the premise that those each of those values were representative of the model regions for municipalities in all of Japan, we integrated them with the number of accidents for each region in the country to obtain the nationwide estimate of traffic accident conditions presented in Fig. 20.

6 Conclusion

In this project, we validated the appropriateness of the simulation using real volume of traffic and accident statistical data. Using this simulation as a basis, we also demonstrated that the effectiveness at reducing traffic accidents achieved by introducing automated driving (driver assistance) systems could be estimated with a high degree of accuracy by assigning the prerequisites from traffic regulation information as well as from the deployment scenarios for such systems provided by the Socioeconomic Impacts of Reducing Traffic Accidents project. The next step will be to estimate the effectiveness at preventing accidents for each automated driving deployment scenario for the purpose of evaluating socioeconomic impact in the context of the project that assesses the impact of automated driving on society and the economy and researches policies to promote its market propagation.

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