Current Status and Future Outlook of Automated Driving

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1. INTRODUCTION

Various studies on automated driving are underway in the automotive field, and it is thought that many aspects of these moves are also applicable to autonomous ships. Therefore, this paper describes the current status and future outlook of automated driving of automobiles in the hope that this may serve as a useful reference when studying autonomous ships.

2. OVERVIEW OF AUTOMATED DRIVING

2.1 Background

Growth Strategy 2017 presents a broad vision of efforts in automated driving with the aims of "Realization of Mobility Revolution" and "Extension of Healthy Lifespan" [1).

The image of the mobility revolution consists of four items, (1) Truck platooning (convoy-type truck transportation), (2) Unmanned automated driving to provide human mobility services (Mobility as a Service: (MaaS), (3) Package delivery using drones and (4) Autonomous ships, targeting demonstration of each of these items by 2020. In the automotive field, demonstrations of (1) Unmanned travel by following vehicles on an expressway and (2) Unmanned automated driving using an abandoned rail line have been carried out, and the targets were achieved. Other efforts in the Growth Strategy 2017 included "Experiments Ahead of the World," "Strategic Collection and Use of Data, Expansion of Cooperating Fields" and "Development of Systems looking to International Inter-system Competition." Many of these aims have also been realized.

Growth Strategy 2018, which was published the following year, placed even greater emphasis on automated driving for " Manpower shortage due to migration and the logistics revolution and Reducing the number of vulnerable persons" [2)].

2.2 Questions concerning Automated Driving

(1) When will fully automated driving be realized?

It is considered that it will not be possible to realize fully automated driving which enables travel in any environment in the near term due to the high degree of difficulty involved. On the other hand, automatic travel in restricted areas and spaces can be realized almost immediately if funding is available. In this case, a separate study will be necessary to determine the appropriate level of funding.

(2) How will popularization of automated driving change society?

It is reasonable to think that the current relationship between people and automobiles will change. For example, if a passenger can call an unmanned automated taxi simply by using a smartphone app, it may be cheaper to travel by taxi than to own and drive a car oneself. In the future, this might mean the end of the current concept of private ownership of automobiles.

(3) What are the differences between automated driving in Japan and other countries?

In Japan, there are strong expectations for unmanned operation of commercial vehicles (buses, trucks) due to a remarkable shortage of drivers. For this reason, I think that unmanned commercial vehicles will be realized in Japan at an earlier date than in other countries.

2.3 Methods for Realizing Automated Driving

There are basically two methods for realizing automated driving, infrastructure coordination and autonomous technology. Infrastructure coordination is a method in which various types of equipment are installed in the infrastructure, and the vehicle travels automatically while communicating with that equipment. Autonomous technology means the vehicle travels autonomously, without depending on the infrastructure, by using various types of sensors installed on the vehicle itself.

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Looking back on history, in the 1990s, the main approach was infrastructure coordination, for example, using magnetic nails embedded in the roadway, and in 1996, Japan led the world in demonstrating vehicle platooning using magnetic nails on the Joshin-Etsu Expressway before that highway was opened. However, this kind of project was not continued beyond that point, as it would have been difficult to create the same magnetic nail infrastructure throughout the country due to its extremely high cost. After 2010, autonomous technology became the main stream thanks to active research in response to unmanned automated driving contests for military purposes conducted by the Defense Advanced Research Projects Agency (DARPA) in the United States and the construction and operation of the Google self-driving car in 2012. But there was a strong sense that the Google project was a demonstration, rather than product development with the aim of social implementation, because the LiDAR sensors installed on the Google self-driving car were very expensive at the time.

In spite of an ongoing argument about whether infrastructure coordination or automated driving is the better approach for realizing automated driving, it is thought that automation will be realized in the near future, while also controlling costs, by skillful use of infrastructure coordination and automated driving. For instance, on predetermined routes traveled by regular buses or scheduled trucks, it would be possible to utilize infrastructure coordination by constructing the necessary infrastructure only on those sections.

2.4 Social Issues

Japan currently has the world's highest percentage of older persons, at 28.7 %, and this is forecast to exceed 30 % in 2030 and reach 40 % by 2055. As the working-age population decreases, a corresponding increase in productivity will be necessary in order to maintain the country's GDP. It also goes without saying that the costs of social security, medicine and nursing care increase as the population continues to age.

The "Grand Design of National Spatial Development towards 2050" prepared by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) summarizes the outlook for Japan's future [3)]. To mention examples from that document, it is generally thought that Japan's population will gradually decrease, and will fall below 100 million in 2050. Furthermore, the distribution of that population will be concentrated in large metropolitan areas such as Tokyo and Nagoya, and 20 % of the currently inhabited grid squares will become uninhabited.

Accompanying the increased number of older drivers in recent years, accidents caused by older drivers have become a social problem. As countermeasures, the National Police Agency is studying the possibility of training for older persons, and in the future, the introduction of a practical driving skill test. Community buses and demand-responsive transport sponsored by local governments are available for persons who have returned their driver's license, but in reality, those systems are still inadequate. Heightened expectations are placed automated driving as a means of solving these issues.

3. CURRENT STATUS OF AUTOMATED DRIVING

3.1 History of Automated Driving

Efforts related to automated driving have been underway since the 1970s. In Japan, automated driving experiments were conducted, for example, by the Mechanical Engineering Laboratory, Agency of Industrial Science and Technology (now the National Institute of Advanced Industrial Science and Technology, AIST) under the Ministry of International Trade and Industry (MITI). In 1977, a vehicle called an "intelligent car" was built, and was capable of recognizing the white line on roadways by using an onboard camera.

In the 1990s, automated driving was possible by following a route marked by magnetic nails embedded in the pavement, and as mentioned previously, a demonstration of automatic vehicle platooning was carried out on the Joshin-Etsu Expressway in 1996, before the highway was opened to traffic.

Around 2000, Toyota developed a "platoon" system for buses called IMTS (Intelligent Multimodal Transit System), which was first operated commercially at EXPO 2005 in Aichi, Japan.

In 2004, the above-mentioned DARPA in the United States held a competition called the "Grand Challenge" in which vehicles travelled autonomously without using infrastructure coordination. Initially, this contest was held in the desert, the vehicles were quite large, as shown in Photo 1, and the vehicles used were quite different from ordinary cars. Later, the name was changed to Urban Challenge, and the contest was conducted with ordinary automobiles equipped with various sensors in a setting simulating an urban area. Photo 2 shows vehicles used in the Urban Challenge.

In 2012, Google Inc. of U.S. started public road testing of driverless vehicles.

Photo 1　Vehicle used in Grand Challenge [4)]

Photo 2　Vehicles used in Urban Challenge [5)]

In Japan, then-Prime Minister Abe took test rides in self-driving cars developed by three companies in 2013, and declared that the country would devote effort to automated driving. In the years that followed, Japan put great effort into the development of automated driving, and a series of demonstration tests were conducted widely in all parts of the country between 2017 and 2019 [6) 7)]. Figure 1 shows the main demonstration tests carried out in Japan in and after 2019.

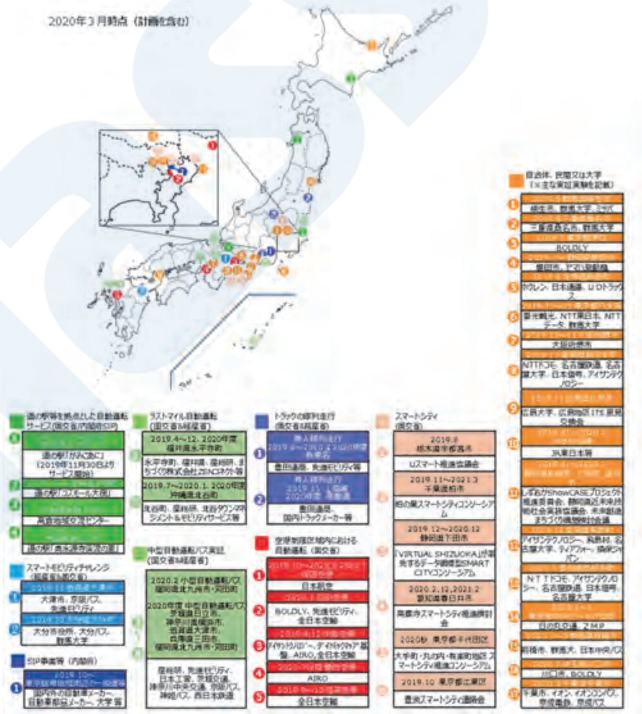

Figure 1　Main demonstration tests of automated driving conducted in and after 2019 (Japanese) [7)]

3.2　Classification of Driving Automation Levels

Driving automation is generally classified according to the definitions of the six levels of driving automation established by the Society of Automotive Engineers (SAE), as shown in Table 1. The image of automated driving held by many people corresponds to Levels 4 and 5.

In Level 1, either forward/backward operation (acceleration/deceleration) or right/left operation (steering) is automated. In Level 2, both forward/backward and right/left operations are automated, but up to Level 2, driving is performed primarily by the driver, and the driver bears the responsibility (liability) for driving. Therefore, Levels 1 and 2 should be understood as advanced driver assistance systems.

At Level 3, the automated driving system operates within a range that satisfies certain specific conditions, but when the conditions exceed that range, driving operation is turned over to the driver. However, many experts have raised questions whether operational authority can be transferred appropriately from the automated driving system to the driver (that is, how many seconds should be allowed for the transfer of driving authority). The National Police Agency requires the driver to take over operation of the vehicle immediately in situations where a transfer of authority is necessary, but under the MLIT guidelines, the vehicle must be stopped safely if this is not possible.

At Levels 4 and 5, driving is performed primarily by the automated driving system and not by the driver. Early realization of Levels 4 and 5 under the mixed traffic conditions of public roads is not possible due to the high degree of technical difficulty involved, but it is thought that these higher levels can be realized relatively easily assuming a combination of dedicated space or restricted space and low speed.

Table 1 Levels of driving automation [8)]

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	You **are driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You **are not driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			**These are automated driving features**		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/ acceleration support to the driver	These features provide steering AND brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering OR • adaptive cruise control	• lane centering AND • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

3.3 Purpose of Automated Driving

(1) Safety

Human error is considered to be the cause of 90 % of traffic accidents. The purpose of automated driving is to prevent such traffic accidents due to human error. In Japan, implementation of automated driving began from expressways, and Level 3 was realized in 2021, although with conditions during congested periods on expressways. However, if priority is placed on reducing the aforementioned accidents caused by older drivers, reducing driving mistakes by older drivers by focusing on driver assistance, rather than automated driving, is also a possible approach that contributes to safety.

(2) Driver shortages

With the population of Japan in the process of decreasing, there is a remarkable shortage of drivers, especially for buses, taxis and trucks. Therefore it has been increased that the expectations for unmanned driving by automated driving, which does not require a driver. Particularly in under-populated areas, development is being promoted, while continuing to pursue Levels 4 and

5 and truck platooning on expressways (lead truck with driver, following trucks unmanned). Development is not limited only to unmanned driving, but also includes remote monitoring and remote operation. In Level 2, the remote operator bears the responsibility (liability) for driving. Since there is no reduction in the number of drivers if one remote operator monitors one remote vehicle, the aim is to develop a system which makes it possible for one person to monitor multiple vehicles.

(3) Added value

As the significance of automated driving, the ability to do other work while traveling, rather than simply driving the automobile, is considered important in other countries. Naturally, the ability to do other work while traveling increases work productivity. Moreover, if a long-distance driver can rest during traveling time while not actually driving the vehicle, this will also lead to improvement of work conditions. Effectiveness can be increased further if it is possible to enhance the added value of connected cars by installing automated driving systems to other vehicles. Automated driving is also expected to contribute to urban development. If all automobiles are automated, it is thought that the existing road space can be redistributed based on a review of the relationship between traffic volume and road capacity, thereby contributing to effective use of surplus land. For example, if the concept of private ownership of automobiles is eliminated, parking lots will no longer be necessary, and that space can be utilized effectively. It will also become possible to manage expressways with fewer lanes, and that space can be used for solar panels or bicycle roads. (See Figs. 2 and 3; driving automation eliminated the need for the roadway areas shown in red.)

Figure 2 Image of use of parking lot [9]

Figure 3 Image of use of surplus lanes of expressway [9]

3.4 Efforts by Japan to Realize Automated Driving

The Japan Economic Revitalization Secretariat of the Cabinet Secretariat organized a Public-Private Council for Automated Driving, which held discussions with the participation of the related ministries and agencies, the private sector and experts. Improvement of the legal system is necessary for social implementation of automated driving, this issue was discussed in the Council. In response to this, early improvement of the system has been realized thanks to a prompt response by the related ministries and agencies in line with the requests of the private sector and experts. Legal provisions were incorporated in various laws, including the Road Transport Vehicle Act and the Road Traffic Act, and in matters related to liability, the Act on Securing Compensation for Automobile Accidents, etc. In addition, automated driving systems were defined in the revisions of the Road Traffic Act and the Road Transport Vehicle Act in 2019.

In order to avoid the so-called “Galapagos syndrome,” in which the legal system in Japan evolves in way that is incompatible with the systems in other countries, discussions are in progress in the United Nations under Japanese leadership, and there is a trend toward the creation of international standards in the form of the skillful incorporation of Japan’s arguments.

On the other hand, even assuming progress in technological development and improvement of the legal system in a way that enables use of automated driving, whether automated driving is actually accepted by society is also extremely important. In other words, it is important to ensure social acceptance, including not only the persons who use self-driving vehicles, but also other persons who may be affected.

Although the Public-Private ITS Initiative / Roadmaps 2018 [6] set targets up to FY 2020, almost none of those goals were realized by that date. Therefore, in the Public-Private ITS Initiative / Roadmaps 2020 [7] efforts for the future during the 2020 decade are divided into short-, medium- and long-term, how the efforts in each timeframe should be realized is summarized. METI, MLIT and other related parties are grappling with various projects with large budgets toward realization of this Roadmap.

3.5 Safety Standards for Automated Driving

In considering automated driving, how to create standards and ensure compliance with those standards is important. First, MLIT established Safe Technology Guidelines for Self-Driving Vehicles [10] to specify the safety targets for standards. As a basic concept, since the goal is a society in which the system theoretically causes 0 accidents resulting in personal injury or death, avoiding accidents with objects that are foreseeable and avoidable was set as a target. However, because the allowable range of what is “foreseeable” differs depending on the country, there are divisions on this issue, even in international forums.

Revision of the Road Transport Vehicle Act is necessary for actual practical application of Level 3 or higher, Therefore, the proper form of accuracy necessary for comprehensively securing safety from the self-driving vehicle design and production processes to the use process was studied in a subcommittee of the Transportation Policy Council [11].

4. FUTURE OUTLOOK

4.1 Recognition of the Current Condition

Because a condition in which a driver is present and can take over driving at any time is regarded as Level 2, demonstration tests can be carried out easily on public roads. Even in case a driver is not present in the driver’s seat, demonstration tests can be conducted if remote monitoring and remote operation is possible. A license plate number can be issued, even if the vehicle is not equipped with a steering wheel or pedals, and a demonstration test can be conducted, then it can be considered the vehicle is compatible with the security standards, provided remote monitoring and remote operation is possible and the necessary conditions are satisfied. Thus, Japan is an environment in which demonstration tests can be carried out easily when the automated driving system is considered Level 2.

Moreover, it can be said that Japan possesses a technology level which is capable of achieving full automated driving if the necessary funding is available and the environment is simple.

At present, various studies on cost reduction and adaptation to complex environments are being carried out, and the problem of liability is under study. A response to legal and regulatory issues is also in progress in accordance with the Outline of Institutional Development of Automated Driving [12].

4.2 Legal Framework

Within the range of Level 2 demonstration tests, the current legal framework has been arranged in a form in which it is possible to conduct tests even with vehicles without a driver’s seat. In the case of remote monitoring, 1 : 3 demonstration tests (1 remote operator : 3 vehicles) have already been completed, aiming at the time when 1 : 1 becomes 1 : N. Discussions on the final form of the system of liability will begin from the present. If Level 4 or higher is achieved, remote monitoring will not be necessary under normal conditions. Although AI is expected to progress to a level where that can be achieved, it is difficult to discuss theories of liability without seeing a condition that sufficiently achieves that level in the technical aspect.

In the legal framework, opinions are divided on the extent to which safety should be required. Requiring a level that prevents accidents caused by the other party is a high hurdle. It is not possible to design products unless a certain direction is set for equipment reliability requirements, and in international competition, it is necessary to consider where the target level and speed of achievement should be set.

On the other hand, development of safety standards and certification and auto inspection requirements for vehicles with advanced driver assistance and automated driving functions are also progressing, as Level 3 has become possible under the revisions of the Road Traffic Act and Road Transport Vehicle Act. The necessary conditions for conducting a transportation business have also been summarized.

4.3 Future Image

Up to 2020, commercialization of Level 3 during congested periods on expressway, Level 3 in limited spaces, and construction of a technology for truck platooning were realized. However, it is still difficult to realize automated driving on local roads even at Level 2. In addition to improvement of maps, various agreements will be necessary for this.

How Level 3 will develop is unknown, but for the time being, an extension of the range of operation on expressways is considered likely. The image of commercialization of remote monitoring and remote operation at Levels 4 and 5 is also unknown.

In commercial vehicles for which personnel costs can be reduced, and in privately-owned passenger cars, how money is spent on sensors and other equipment will change. In addition, a roadmap to around the year 2030 has been prepared [13] in the Subcommittee on Business Discussions on Autonomous Driving Technologies, while continuing to study the outlook for work on treaties and standards, social acceptance and other issues. (See Fig. 4).

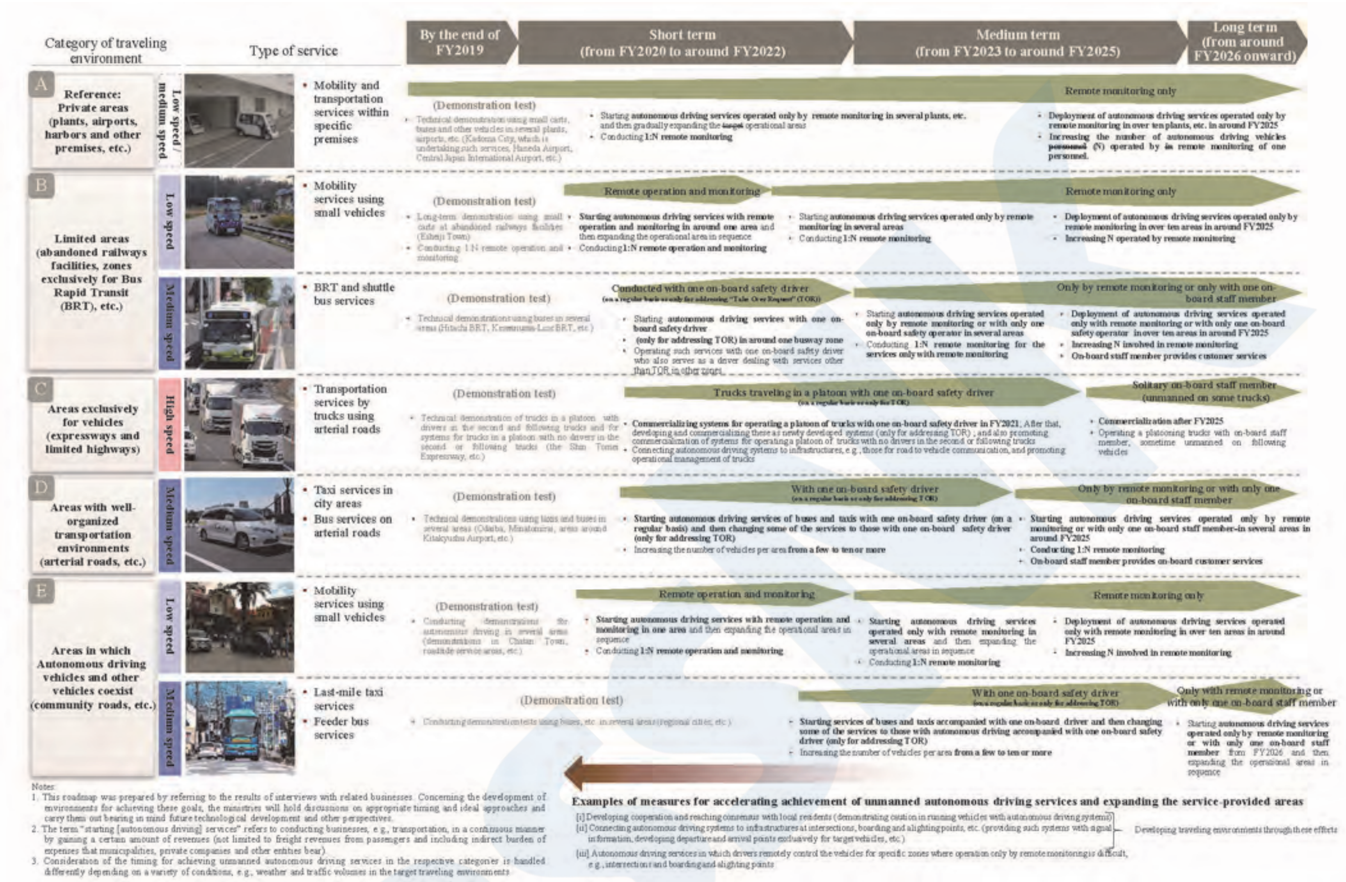

Figure 4 Roadmap for Deployment of Autonomous Driving Services [13]

4.4 Future of the Automobile Industry

The region of automated driving technology will expand to mobility services and public transportation services, and to urban development. On the other hand, with the rise of connectivity, competition for territory with the ICT industry will also begin. Although emerging competitors still do not possess the technologies necessary to move an automobile weighing 1 ton or more safely at a speed exceeding 100 km/h, or the technologies that support high reliability and durability, this is no reason for complacency. While technology will evolve rapidly, the people who use that technology will not necessarily evolve at the same pace, but rather, may regress due to aging and other factors. The time is coming when the automobile industry must consider whether its current simple business model of merely building and selling cars is sufficient.

4.5 Methods of Utilizing Automated Driving

Even with Level 2 functions, automated driving can play an important role in securing safety through driver assistance.

On the other hand, there are various hurdles to unmanned driving for labor saving. Unmanned automated driving will begin from deployment in limited locations where it is possible. In spite of the strong expectation that unmanned driving will make labor costs unnecessary, the cost of driving automation is high. Thus, it is necessary to examine whether a business model based on automated driving is feasible or not.

Automated driving is merely simplifies the means of transportation. What is important is not simply developing a more advanced means of mobility, but utilizing it to vitalize human mobility and logistics. From this viewpoint, it can be said that the most important aim of automated driving technology is the development of attractive cities and towns.

4.6 Directions in Urban Development

Even assuming automated driving technology progresses and a legal framework which is capable of responding to the challenges of that technology is developed, how to achieve social implementation, including the cost aspect, is important. As Japan's population decreases in the years to come, it is difficult to think that simply using automated driving by itself will create a better society. This suggests the need for sustainable urban development which enables easy use of self-driving vehicles, or utilizing automated driving to make people's lives easier even assuming a declining population. This will be difficult to realize unless we create a grand design of how driving automation should be utilized as one means of transportation in urban development.

4.7 Summary

If our descendants look back on history 50 or 100 years from now, the current period will probably be considered a major turning point in the field of mobility. In the years to come, there is no question that electrification of automobiles will progress and great advances will be made in automated driving and connected cars. On the other hand, there are points that require a response to a mature society and a society with a declining population, and cannot be addressed simply by technical development. Because the population of Japan will inevitably decrease to less than 100 million persons around the year 2050, it is necessary to develop a grand design that enables an affluent life for the population of ca. 80 million within the range of a certain part of the country's land. As part of this, it is important to present a precise vision of the future of mobility, to have the automobile industry play the role of a mobility services industry that supports everyday life, and to create a trend in which the national government also supports this goal.

5. CONCLUSION

This paper has described automated driving in the automotive field, centering on its outline and purposes, history to date and outlook for the future. On the other hand, it can perhaps be said that the issues confronting automated driving of automobiles are the same as those in the field of autonomous ships. For example, this paper has described the three issues of safety, labor shortages and added value as purposes of automated driving of automobiles, but these also apply to the maritime industry. It is generally said that about 80 % of maritime accidents are the result of human factors (improper maneuvering, inadequate lookout, etc.). Where labor shortages are concerned, aging of crew is progressing, and particularly in the case of coastal ships, crew shortages are expected to become a real problem. Moreover, due to the diverse range of crew duties on ships, which include maneuvering, lookout, propulsion and power system management, and cargo management, the burden on crew is large, and there is a great need for technologies that contribute to improvement of the working environment. Thus, autonomous ship technologies are also expected to provide a means of preventing accidents, solving labor shortages and improving the working environment.

In recent years, multiple development projects in connection with autonomous ships have also been started, represented by demonstration projects of MLIT and the Nippon Foundation's unmanned ship project, MEGURI 2040, and it is thought that the development of regulations and technological development aiming at implementation will also progress at an ever faster pace in the future. Although the path to realization may not be easy, it is hoped that the example of automated driving for automobiles introduced in this paper will be of assistance when studying autonomous ships.

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