Technical studies on driverless automatic train operation in Japanese subways

---Japanese challenge in the 21st century---

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Summary

The Japan Subway Association (JSA) has been continuously surveying the trend of automatic driving technology in and outside of Japan and studying the technology of physical isolation from danger and sensors for automatic fire and forward detection. This paper presents an overview of the studies and provides an opportunity for information sharing and discussion with international technical experts in the field of automatic train operation in railways.

Keyworts: Subway, Driverless Train Operation (DTO), Automatic Train Operation (ATO), Grade of Automation (GoA), safety forward monitoring

1 Introduction

Urban railroads, especially subways in large cities, have played an important role throughout the 20th century due to the concentration of population in large cities and the long commuting times characteristic of Japan's large cities, where many commuters use them every day. In Japan, the aging of the population is accelerating with the onset of Japan's economic recession. In addition, the country has entered a phase of long-term population decline that peaked in 2008 [1]. As the working population declines, it is expected that there will be difficulty in simultaneously reducing the number of subway operators and the long-term contraction of passenger transportation demand. It is an important issue today to make subway operations sustainable by reducing operating costs while maintaining safety and the attractiveness of transportation services.

During the 1990s, while investigations and technical studies were being conducted based on numerous examples from overseas, concrete discussions on the introduction of driverless train operation (DTO) to Japanese subway lines were not conducted seriously, with the only exception of a feasibility study in Fukuoka City in the early 2000s. The only exception was a feasibility study for Fukuoka City in the early 2000s. Today, Automatic Train Operation (ATO) technology for realizing DTO is suddenly attracting attention, while being aware of the social background mentioned above, during the transition period to the Japanese government. In addition to the study conducted by the Japan Subway Association (hereinafter referred to as JSA), which is introduced in this paper, various discussions are being held by several railroad companies and governmental study groups, aiming at test operations and the establishment of technical standards [2] presently.

The automation of train operation will reduce the number of operating experts by using information and communication technology, thereby reducing daily operating costs, and freeing up operating plans from constraints such as crew arrangements, thereby enabling flexible response to changes in train demand. In addition, the system is expected to provide further values that only fully automated operation can provide, such as the implementation of energy-saving operation [3], which is difficult to achieve manually, and the sustainability of operations under social unrest, such as the threat of infectious diseases, which is currently an issue.

As we enter the year 2020, the global threat of COVID-19 infection prevention has led to curfews, a rapid shift to online lectures and remote meetings for business, and the loss of foreign visitors who had been compensating for the recent decline in population and preventing the decline in demand from surfacing. The sudden stagnation of economic activity caused by these factors has led to the deterioration of many railway operators.

Today, there is a situation in which railway engineers cannot devote enough effort to future-oriented technical studies. For this reason, the technical study of fully automated train operation is also falling behind the initial schedule. It is unknown when and how the abnormal state of society that we are currently experiencing will return to normal daily life. This means that the shrinking demand for transportation, which was previously considered a long-term issue, and the challenge of balancing lower costs with the sustainable provision of high-quality and safe transportation services have suddenly become urgent issues for railway operators.

This report first summarizes the history of the study on the introduction of DTOs [4], which has been continuously carried out at JSA since the beginning of this century. Then, referring to international trends in the application of automatic train operation technology to urban railroads, we will present an overview of the studies currently being conducted by JSA experts, including a survey of trends in automatic train operation technology, methods for physically isolating passengers from danger, and sensors for automatic fire and forward monitoring, to provide an opportunity for information sharing and discussion with international experts in railroad operation technology.

2 Automated Driverless Train Operation: Historical Background

UTO (Unattended Train Operation), which does not require a driver or crew, was first put to practical use in the Kobe Port Liner, which opened in 1984. Later, UTO became popular in Japan as the Automated Guided Transport (AGT), a new urban elevated track transportation system that was developed uniquely in Japan, including the New Tram in Osaka, Yurikamome in Tokyo, Yokohama Seaside Line, and Nippori-Toneri Liner.

On the other hand, in the 1980s, fully automated driving was realized in other countries, such as VAL, a light urban rail system in Lille, France in Figure 1, somewhat later than in Japan.

The following is a summary of the characteristics of the automatic train operation of these AGTs.

Figure. 1 Oversee technical visit to VAL at Lille, France, from JSA in 2001

Fig. 2 Nanakuma-line at Fukuoka city designed for the first commercial realization of DTO in Japanese subways

(1) In Japan, the UTO and DTO were the first to be realized in a "new transportation system" with an elevated structure.

(2) In the above systems, elevated tracks are physically isolated from the outside world, and evacuation guidance can be implemented relatively simply.

(3) The design of Japanese "new transportation system" is based on the assumption that the system will not break down or stop between stations.

The development of automatic train operation technology for one-man urban transportation has been, and continues to be, actively pursued. However, the practical application of DTO/UTO to railroads, including subways, has not been studied for a long time in the Japanese railroad business with the aim of practical application.

3 International Technical Standardization of Automatic Train Operation and Grade of Automation: GoA

As is clear from the underground section of the VAL in Lille, France in section 2, the subway has conditions that make it easy to introduce fully automated driving: DTO/UTO, in that it is easy to prevent the outside world from entering the track. For this reason, commercial subway operation of UTO was realized on Line 14 of the Paris Metro, which opened in 1998.

As the use of UTO in urban transportation such as subways continues to advance, the international technical standard IEC 62267 Railway applications - Automated urban guided transport (AUGT) - Safety requirements (the corresponding European standard is EN 62267, and the Japanese standard is JIS E 3802) [5] was published in July 2009. In the standard, the following four levels of GoA (Grade of Automation) were defined.

(1) **GoA-1 is a normal urban train operation system** in which the driver operates the train under the protection of a traditional signal security system.

(2) **GoA-2: Semi-Automatic Train Operation (STO)**: A so-called "one-man ATO" in which the driver is on board, but the driver only decides when to start automatic operation and the ATO performs the actual operation control. This is an operation method that has been widely used in Japan, mainly in subways.

(3) **GoA-3: Driverless Train Operation (DTO)**: A form of train operation in which one or more non-driving attendants are assigned to each train for non-driving purposes, such as ensuring safety in the cabin, guiding passengers, and guiding passengers to evacuate in case of trouble.

(4) **GoA-4: UTO (Unattended Train Operation)**: A form of train operation in which attendants are not on board as described above. The driverless operation that has been proven overseas, mainly in subways, is classified as this UOT=GoA-4. In addition, many

AGTs in Japan, starting with the aforementioned Kobe Port Liner, also belong to the GoA-4 category.

As introduced by the author and others in 2018 in the IEEJ literature in Japan [6], *etc.*, and shown in many public documents on the Internet, urban transportation using UTO/DTO has been widely put to practical use in Europe, mainly in subways, and its route length has increased remarkably in recent years.

For example, Bombardier, a company based in Canada and Central Europe that combines linear drive and automated driving, which is closely related to the author's research field in the field of urban transportation, is actively developing international business in urban transportation packages [7].

4 Study on the possible applications of Automatic Train Operation at the JSA

4.1 Early efforts at JSA

In Japan, subway operators, led by the Japan Subway Association, have been studying the possibility of driverless operation of subways for the past decade or so. In particular, the Japan Subway Association established the Next Generation Subway System Research Committee (chaired by Professor Eisuke Masada of Tokyo University of Science at the time) in 2001 with the aim of opening the aforementioned Fukuoka City Nanakuma Line in February 2005. The committee intensively discussed the possibility of improving safety, convenience, comfort, and economy through the creation of attractive station spaces and the full-scale introduction of driverless operation.

Thus, a report [4] was submitted in June 2002, stating that a DTO subway is technically feasible and has advantages in terms of economy, passenger safety, and convenience if evacuation guidance measures in case of fire in the tunnel section are systematically organized and countermeasures are considered. Following this, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) convened a study group on driverless operation, and in March 2005 compiled a report entitled "Study on Issues and Countermeasures for Operation Systems in Subways.

The reason why the practical use of DTO in subways has been considered difficult compared to the early realization of AGT is that it is difficult to respond to fires in tunnels and to guide evacuation without a crew member in the car.

After these studies, the Fukuoka Municipal Transportation Bureau's Nanakuma Line, shown in Figure 2, was constructed as Japan's first DTO for a large-volume urban subway and started its commercial operation in 2005. It was designed on the premise that the train would be operated with an attendant at the head of the train (recently called GoA-2.5 in Japan) who would perform emergency stop operations (not specified in international standards). Under international standards, this system is classified technically as GoA-3 as an automatic train operation system.

However, the current operation of the Fukuoka Municipal Transportation Bureau's Nanakuma Line is essentially a GoA-2 one-man ATO, as shown in Figure 2, with a qualified driver on the front of the train. For this reason, the highest level of automation in general railroad operation in Japan at present is still only GoA-2, and it must be said that Japan is still behind other countries including our Asian friends*, e.g.,* Malaysia, Singapore, China and Korea.

Aware of the above problems, JSA has been working to explore the possibility of realizing our own DTO in domestic subways and its use in energy-efficient driving [3]. In this way, JSA has continued steady technical investigations, including overseas technical investigations, in the form of internal working groups.

Figure 3 Canadian UTO: SkyTrain in Vancouver

Figure 4 French UTO subway No.1

4.2 Case studies from overseas technical surveys by the Japan Subway Association

4.2.1 Canada: Vancouver SkyTrain

In December 2008, JSA visited Bombardier [7] in Canada to discuss the international standardization of linear induction motors for driving railroad cars, and also visited

Translink in Vancouver, which operates SkyTrain shown in Figure 3. JSA visited Translink in Vancouver, which operates SkyTrain shown in Figure 3, to conduct technical research on both linear motor applications and driverless automated driving, and to exchange opinions with overseas operators.

4.2.2 France: Subway in Paris

In 1998, the Paris Metro Line 14 was the first in the world to put UTO, a fully automated subway system, into practical use, attracting much attention. It has the following features.

(1) The Paris Metro (RATP) developed and introduced driverless operation with the main objective of saving labor and energy.

(2) In the case of Line 14, fully automatic operation was achieved on an operation security system using traditional track circuits. After that, the technology developed there was successively applied to the UTO of subway line 1, as shown in Figure 4.

(3) The deployment of the above technology in the subway line 1 was carried out at the same time as the plan to change the train control system to CBTC (communication-based train control).

4.2.3 Germany: Subway in Nuremberg

The system was introduced in stages as the existing subway line 2 and the newly built line 3 in the city of Nuremberg over the course of 2008-2009. This automatic train operation system is based on Siemens' proposal and technology. As shown in Figure 5, the UTO system is characterized by the fact that it enables safe train operation without any platform doors. The system is equipped with an advanced ground-based sensor system that detects falls from platforms using lasers, *etc.,* and all trains are equipped with forward obstacle detection and highly reliable onboard derailment detection sensors on all axes of the train. The UTO continues to operate under difficult operating conditions, with trains of two or four trains in length and a mix of old and new models, and is equipped with advanced functions unique to fully automated train operation, such as high frequency operation at 100-second intervals, robustness against minor disturbances, and energy-saving operation. The system has shown results in reducing the number of trains required and operating energy consumption by saving the labor of 95 drivers and improving operating efficiency.

Figure 5 German UTO Subway No. 2 at Nuremberg, without any platform doors

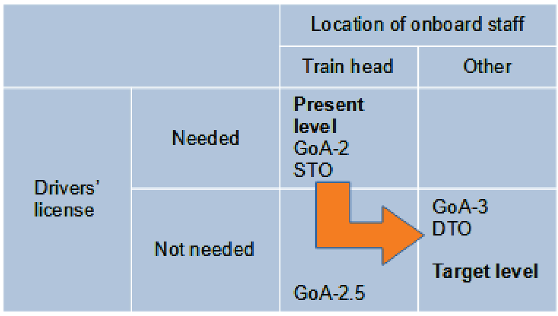

Figure 6 Step -by-step investigation map for multiple DTO/UTO investigation levels at JSA.

4.3 Proactive Technical Investigations mainly at JSA in Recent Years

Since February 2014, the Subcommittee on Research and Study of Operation Systems in Subways (Research and Study of Driverless Operation in Subways) has been established, and since April 2018, the Research and Study Committee on Research and Study of Operation Systems in Subways has been established, where neutral researchers and multiple operators are promoting discussions on comprehensive technical research and system design.

With the study map shown in Figure 6 in mind, and with a view to the future realization of UTO subways in Osaka, Tokyo, and other areas, we have also determined the trends of the Ministry of Land, Infrastructure, Transport and Tourism's Study Group on Automated Railroad Operation Technology (2), and have compiled a list of measures for fostering safety and security at each level of automation and DTO/UTO from the perspective of users and the general public. In addition to the above, we have been working on the UTO/DTO. In addition to this, as part of the discussion on the feasibility of UTO/DTO, we have been investigating and studying the requirements for station platform fences, the requirements for sensor systems for fire and smoke, and the clarification of the roles of crew members and operation commands, mainly from a technical perspective.

In the investigation of sensor systems, we visited domestic and foreign manufacturers of sensors and disaster prevention monitoring systems with proven track records in highways and tunnels, as well as their agents, and conducted a summary survey, including demonstration visits, of current technologies in smoke detection sensors for tunnel disaster prevention, smoke, heat, and light monitoring of highways, *etc.*, and exchanged opinions on the suitability of these detection methods for railroad tunnels.

The main roles of the sensor system are fire and smoke detection, and prevention of contact with obstacles on the track and overhead wires, *i.e.*, safety forward monitoring.

In addition, we are trying to deepen our understanding of the technical level and applicability of sensor systems in the present and future by inspecting the premises of subway stations, where these monitoring systems are applied, in order to specifically organize information on the installation status of turnouts, space, illumination, wind speed, *etc.*, and by exchanging opinions among manufacturers and operators.

In the future, with the cooperation of sensor manufacturers and operators, we will set up some specific test items, and proceed with discussions on the detection of obstacles and people by sensors, the necessity of detecting fire phenomena with a small amount of smoke, which have not been successfully detected in basic experiments to date, and the feasibility of such sensing, while also conducting basic performance verification tests of existing sensors.

In addition, through interviews with elevated urban railroad operators who have experience with UTOs, we will gather information on the role of attendants, the concept of safety evaluation, and methods for ensuring passenger safety in the event of abnormalities. We will also conduct a detailed analysis of subway operation practices to date, with the aim of identifying operational issues, such as the division of roles among attendants, command staff, and command systems, and formulating safety evaluation methods for the practical application of DTOs and UTOs in Japanese subways.

Figure 7 summarizes and visually and comprehensively explains the history of the study for the introduction of driverless operation in the Japan Subway Association since 2001.

JSA is testing a smoke sensor used in highway tunnels to detect fires in tunnels, a camera in the front head of the vehicle, and a LiDAR (Light Detection and Ranging) sensor for detecting obstacles in tunnels, which drivers may have noticed so far, starting in FY2020.

The sensor at the train-head is considered to be difficult to obtain sufficient sensitivity for braking distance as a sensor for obstacle detection in a dark tunnel. As for LiDAR sensors, while their performance is currently highly evaluated for obstacle detection, the cost of installing them in trains is considered too high.

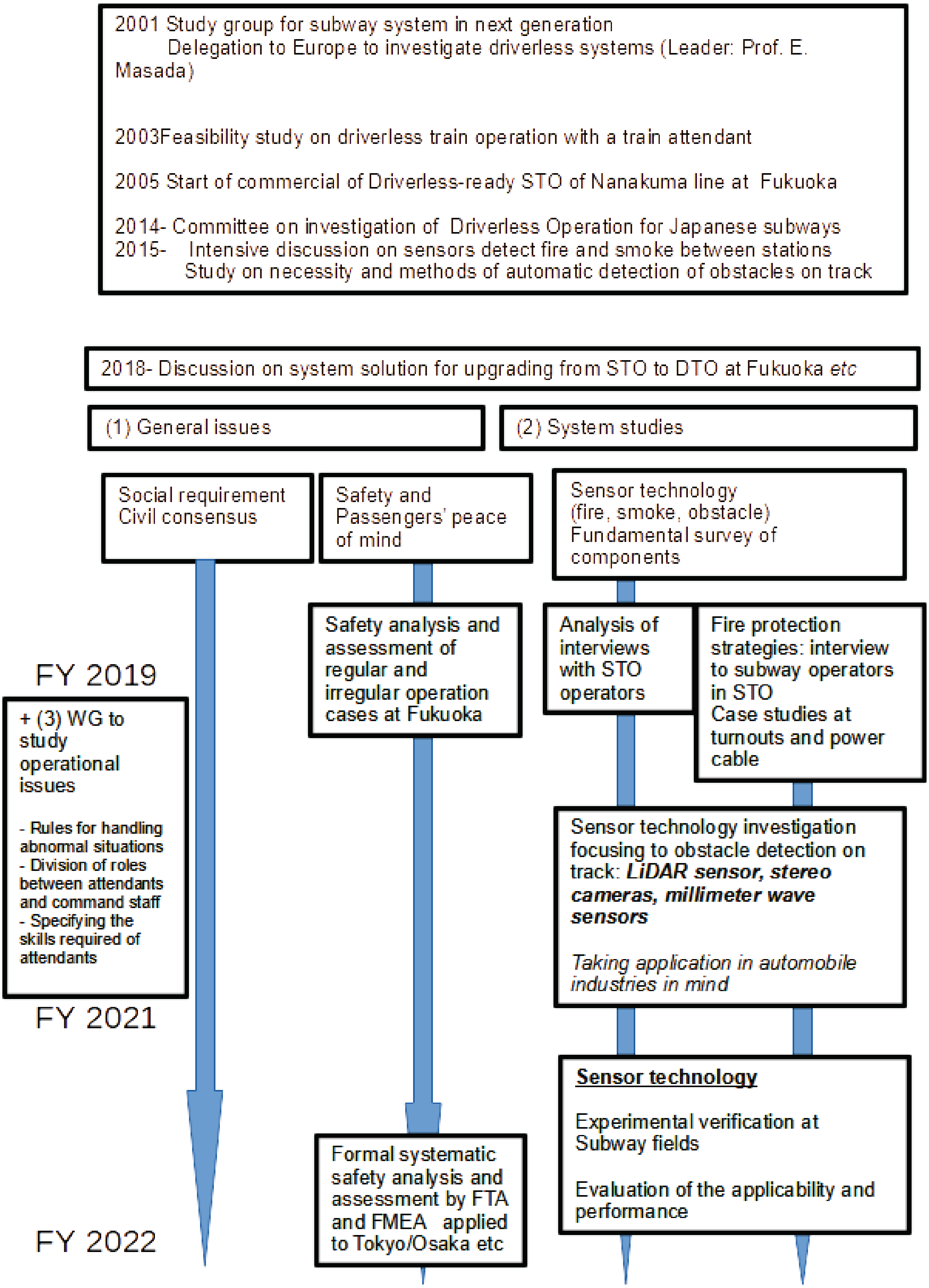

Figure 7 Chronological summary of DTO/UTO-investigating efforts at JSA

For example, we are studying the application of LiDAR sensors at open sections for urban railways. For the purpose of studying the application to such railways, we are studying to detect the reflector of a sign and its distance from the reflector on the ground in real time using a relatively inexpensive LiDAR sensor[8]. By combining this system with position detection by using satellites, we are attempting to demonstrate the possibility of compensating for the uncertainty and variability of information measurement by satellite positioning and accurately detecting train positions free from costly ground signaling equipment. One of such tests is shown in figure 8.

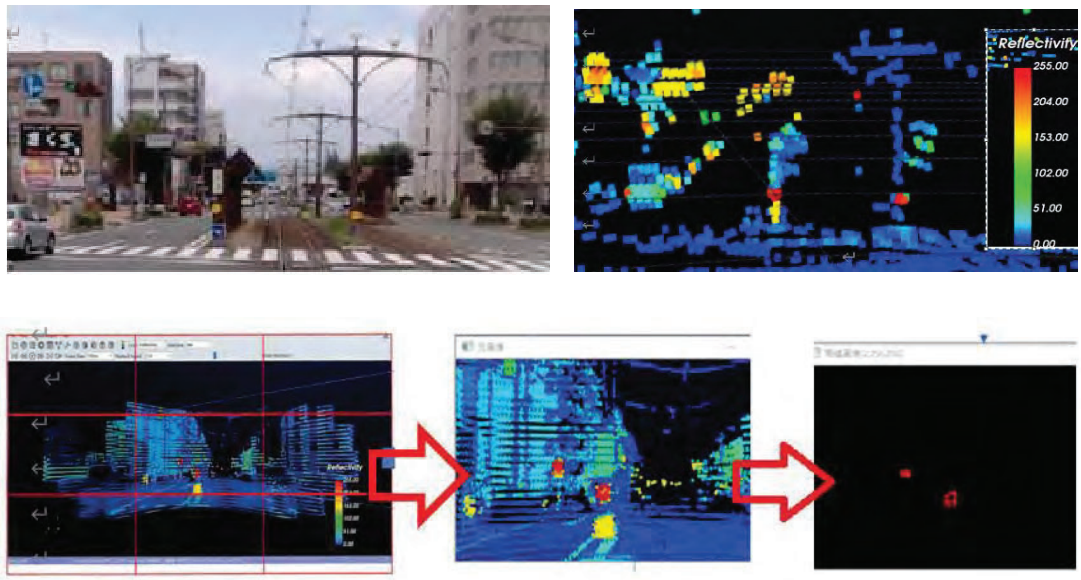

Figure 8 Comparison of picture by a Web-camera and a LiDAR sensor and a trial to extract of reflective sign plates from foreground scenery.

In spite of such technical efforts, the difficulty is being increasingly recognized to replace the function of detecting abnormal events by the driver due to the current technical level of commercial sensors. In addition, the impact of COVID-19 is making Japanese railway business difficult, and technical R&D resources are being strongly constrained. On the other hand, awareness of the importance of the driverless operation in the medium to long term is increasing.

For this reason, the following discussions are underway in expert study groups (as of the beginning of November 2021, when this report is being written), in order to position the concept of "safety assurance in replacing a driver" and the role of sensor systems at a currently available technical level.

The basis of conventional safety assurance for general railways with drivers, which are the criteria for "non-worsening than status quo" are as follows:

(1) Safety between trains is ensured by ground and on-board equipment such as automatic train closures and ATC;

(2) Disturbances are dealt with by physical protection of the track space such as protective fences and platform fences;

(3) Entry of people is prevented by legal prohibitions;

(4) Abnormal events, such as natural disasters, are dealt with in a systematic and proactive manner by notifying drivers in advance, imposing restrictions on operations, limiting speed, and planning planned suspensions of operations, *etc.*; and

(5) Facilities, rolling stock, and other equipment are strictly managed under statutory regulations for construction and maintenance.

While it is true that the driver plays an important role in ensuring safety, the legal obligation of the driver to detect obstacles on the track and avoid danger is not stipulated in Japanese railway regulations. In practice, when a danger is detected within the driver's visual range, he does his best to prevent accidents and mitigate damage. However, this can be understood as an "act of self-defense" to avoid the danger to the driver's own life. Therefore, it is difficult to objectively define the level of forward obstacle risk avoidance by train drivers, which is a guideline for the technological development of sensor systems, as described in the previous paragraphs, or to define the requirements for forward monitoring sensors, *etc*. that are equivalent to the level of forward obstacle risk avoidance.

Therefore, it is not appropriate to have onboard sensor systems playing the main role in ensuring safety by monitoring obstacles in front and avoiding the risk of collision, and they should be recognized as a supplementary measure. Instead, safety assurance in GoA3 and above should be achieved by comprehensive measures described in (1)-(5) above, so that practical use of driverless operation in a Japanese heavy rail will be possible for the first time, while avoiding an extreme increase in investment costs for onboard as well as wayside equipment.

5 Conclusions

In the early 2000s, JSA's driverless operation study for the Fukuoka Nanakuma Line was affected by serious tunnel fires in South Korea and Austria, and despite the enthusiasm of the people involved, there are bitter memories of the fact that the promotion of automation was forced to be only partial. From the year 2020, various difficulties are being felt worldwide in terms of the business of public transportation, such as restrictions on urban life due to the threat of infectious diseases, catastrophic economic impact on transportation projects, and changing lifestyles in the midst of rapidly moving business and educational activities online. However, in the midst of positive approaches to new lifestyles, the examination of DTO/UTO conversion at JSA, which has been leading the way in the Japanese railroad industry, is gaining importance. In other words, the value of promoting the automation of subway operations will contribute to the realization of secure subway operations and sustainable management under a new lifestyle that maintains distance between people in a declining population. Without forgetting that what is required to fundamentally support the safety and reliability of automated driving systems in daily operations is the power of engineers who have a good understanding of operations and equipment, I intend to more actively promote discussions in JSA committees with the following key issues in mind.

(1) Establishing and guaranteeing the ability of OCC to determine the train position and speed with a high degree of reliability.

(2) Establishment and verification of a safety assurance function that does not require direct human monitoring.

(3) Ensuring safety and security during evacuation guidance by attendants and patrolmen, and promoting social acceptance.

(4) Establishing a social consensus on automated driving safety evaluation, and

(5) Consideration of the social impact of infectious diseases: on-board safety in terms of health management and hygiene of operator personnel under threat of infection.

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