MEASURES FOR ENSURING THE SAFETY AND SECURITY OF AUTOMATED OPERATION OF PUBLIC TRANSPORTATION IN JAPAN

TAKESHI MIZUMA
Department of Advanced Energy, University of Tokyo, Japan

ABSTRACT
The technology of automated driving has been making rapid strides in the automobile sector and is quickly moving toward becoming a reality. However, automated driving technology was first implemented in the railway field in the 1970s (mainly as a new type of transportation system), and its safety requirements were stipulated through the International Electrotechnical Commission. In this paper, we describe the safety procedures of automated driving that have been adopted in Japan's public transportation system (railway sector) and explain the techniques for ensuring the security of this technology in the railways of the future and in the incorporation of advanced automated driving technology in the automotive field.
Keywords: automated train operation, safety, security, autonomous driving, RAMS.

1 INTRODUCTION

Automated driving is used to describe the system known as Automated Urban Guided Transport by the International Electro Committee (IEC), and is applied to vehicles that self-propel along an assigned track. The automated operation of trains in Japan has a long history. It began in 1976 with automated forwarding in the car shed of the Tozai Line in Sapporo, with full-fledged operation beginning in 1981, with the Port Liner in Kobe and the New Tram in Osaka. Initially, automated driving using rubber tires on elevated tracks became popular as a new transportation system; in 2005, however, the automated operation of subway trains according to international standards was introduced in the Nanakuma line in Fukuoka. Studies are now being made to examine whether an automated operation is possible in older lines.

This paper first defines the automated driving of trains and describes its safety requirements. We then go on to discuss the relationship with the automated driving technology used in automobiles, and the issues involved in applying this technology to railways, and finally reflect on the future course of the automated driving of trains.

This paper is the first application of safety analysis on driverless train operation to subways in Japan. Through our hazard and risk analysis, driverless train operation has realized practical use in Japan.

2 HISTORY OF AUTOMATED DRIVING IN JAPAN

Table 1 shows the history of automated driving in Japan. The term "automated driving" used in this paper focuses on driving using automated train operation (ATO). The widespread use of automated operations through ATO, principally in subway trains, has been well established. In the table, STO refers to semi-automated train operation, DTO is driverless train operation, and UTO is unattended train operation, as stipulated in IEC 62267 (international standard for safety requirements of automatic operation). Under the international standard, DTO and UTO are regarded as automated operations.

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Table 1: Present status of (unmanned) automated driving in Japan.

Implementation year	Railway authority	Type	Route	Grade of automation	Remarks
1976	Sapporo city	Subway	Tozai line	UTO	Rubber tires, only in depot
1977	Kobe city	Subway	Seishin	STO	Conventional railway
1981	Kobe city	NTS	Port liner	UTO	With platform screen doors
	Osaka city	NTS	New Tram	UTO	With platform screen doors
	Fukuoka city	Subway	Airport	STO	With half height platform
1985	Kitakyushu city	Monorail	Kokura	STO	Now change to manual (NTO)
1987	Sendai city	Subway	Nanboku	STO	Conventional railway
1988	Kobe city	Subway	Hokushinkyuko	STO	Through to Seishin line
1989	Nagoya city	Subway	Sakuratorie	STO	Conventional railway
	Yokahama city	NTS	Kanazawa hakkei	UTO	With platform screen doors
1990	Kobe city	NTS	Rokko island	UTO	With platform screen doors
	Osaka city	Subway	Tsurumiryokuchi	STO	Linear motor subway
1991	Tokyo metropolitan	Subway	Oedo	STO	Linear motor subway
	Tokyo metro	Subway	Nanboku	STO	With platform screen doors
1995	Tokyo metropolitan	NTS	Yurikamome	UTO	With platform screen doors
1997	Kyoto city	Subway	Tozai	STO	With platform screen doors
1998	Tokyo metropolitan	Monorail	Tama	STO	With half height platform
2000	Tokyo metropolitan	Subway	Mita	STO	With half height platform
2001	Saitama	Subway	Saitama kosoku	STO	Through to Nanboku line
	Kobe city	Subway	Kaigan	STO	Linear motor subway
	Disney	Monorail	Maihama	DTO	With half height platform
2005	Fukuoka city	Subway	Nanakuma	DTO	First DTO subway in Japan
	Aichi prefecture	Maglev	Linimo	DTO/UTO	DTO in tunnel/UTO outside
2006	Osaka city	Subway	Imazatosuji	STO	Linear motor subway

Table 1: Continued.

Implementation year	Railway authority	Type	Route	Grade of automation	Remarks
2007	Yokohama city	Subway	Blue line	STO	With half height platform
2008	Yokohama city	Subway	Green line	STO	Linear motor subway
	Tokyo metro	Subway	Fukutoshin	STO	With half height platform
	Tokyo metro	Subway	Marunouchi	STO	With half height platform
	Tokyo metropolitan	NTS	Nippori Toneri	UTO	With platform screen doors
2010	Tokyo metro	Subway	Yurakucho	STO	With half height platform
2012	Sapporo city	Subway	Nanboku	STO	Rubber tire subway
2014	Tokyo metro	Subway	Chiyoda	STO	With half height platform
2015	Osaka city	Subway	Sennichimae	STO	With half height platform
	Nagoya city	Subway	Higashiyama	STO	With half height platform
	Sendai city	Subway	Tozai	STO	Linear motor subway
2016	Sapporo city	Subway	Toho	STO	Rubber tires and platform fence

Table 2 shows the operation modes specified by IEC 62267 and their roles. The basic functions of a train operation are defined, and those functions that are carried out by the driver are marked with an x, whereas the functions performed by the system are denoted with an S. The difference between STO and DTO is that, although the driving and maintenance of the security of an operation are carried out by the system in both cases, track monitoring is conducted by the system with DTO, and by the driver with STO. With UTO, the operation of running a train and the security function of detecting and managing abnormalities are also performed by the system, in addition to the functions of the system used with DTO.

Automated driving has been progressively introduced into Japanese trains, mainly in subway trains running on assigned tracks without railroad crossings and in the New Transport System. However, in subway trains, it was developed as an STO, in which the driver also monitors the track for evacuation guidance inside the tunnel. In the New Transport System, it progressed more as UTO because the system can easily monitor the tracks, which are elevated, and evacuation guidance is relatively easy, particularly owing to the use of a guide-rail system.

However, with the call for labor saving techniques and advancements in sensor technologies, automated track-monitoring and responses to emergency situations have become possible to a certain extent, resulting in a move toward the use of DTO in subway trains, as was implemented in the Nanakuma Line of the Fukuoka City Transportation Bureau. For this reason, the design of the trains is such that the system can respond to emergency situations by means of a derailment detection device mounted on the train or using

Table 2: The operation modes specified by IEC 62267 and their roles.

Basic functions of train operation		TOS Train on sight	NTO Non-automated train operation	STO Semi-automated train operation	DTO Driverless train operation	UTO Unattended train operation
Assurance of safe driving	Assurance of safe route	×	S	S	S	S
	Assurance of safe distance	×	S	S	S	S
	Assurance of safe speed	×	×/S	S	S	S
Driving	Control of acceleration/deceleration	×	×	S	S	S
Supervising the track	Protection of collisions with obstacles	×	×	×	S	S
	Protection of collisions with persons	×	×	×	S	S
Supervising of passengers' movement	Control of vehicle doors	×	×	×	×	S
	Protection of passengers' movement between platform and vehicle	×	×	×	×	S
		×	×	×	×	S
	Confirmation of safe start	×	×	×	×	S
Train operation	Set and cancel of train operation	×	×	×	×	S
	Supervising the train situation	×	×	×	×	S
Confirmation of detection and management in emergency	Train diagnoses, fire and smoke detection, derailment detection, evacuation and supervising of emergency and report	×	×	×	×	S and/or staff in OCC (operation control center)

a function that makes the train automatically pass through a station without stopping in the event of a fire in the station (see Fig. 1).

3 RESULTS OF METHOD FOR ENSURING SAFETY AND RELIABILITY IN AUTOMATED DRIVING OF TRAINS IN JAPAN

Automated operation in Japan is implemented through the ATO of an Automated Train Control (ATC) system and is a safe and stable system because ATC ensures high safety and reliability. The idea is that, even if the ATO becomes out of control owing to a breakdown or malfunction, the brake will be safely applied by the ATC and the train will be brought to a stop. The same concept is present in foreign countries as well. Even with the Safety Integrity Level (SIL) stipulated by IEC 62278, the SIL requirement for an ATC is typically 4, (the probability of a dangerous failure per hour is 10^{-9} to 10^{-8}, and in railways that require the highest level of safety integrity, this is referred to as a fail-safe), whereas the SIL requirement for ATO is 2 in many cases (the probability of a dangerous failure per hour of 10^{-7} to 10^{-6}). However, in the idea as conceived by Japanese railway operators, both ATO and an ATC use the same computer, and hence both of them are often designed with SIL 4 as their aim, thereby ensuring high safety and reliability.

Figure 1: Example of DTO in Japan (Nanakuma Line of Fukuoka City Transportation Bureau equipped with derailment detection device).

Under these circumstances, we put safety analysis into the following system. The method used FMEA (Failure Mode and Effect Analysis) and FTA (Fault Tree Analysis) as our safety policy. At first, through FMEA, the top priority unsafe phenomena were extracted, and FTA was executed against these unsafe phenomena.

Our safety index is to secure the same safety as the present Japanese safety in railways. Therefore, 10–12/h of unsafe probability is the general criteria in our analysis. To realize these criteria, multi safety corrective actions were accepted and multilayer failure mode were assumed for these FTAs. This is the major difference with other safety analysis in Europe.

4 EXAMPLE OF SAFETY ANALYSIS FOR AUTOMATED OPERATION (DTO) IN JAPAN

We next describe a safety analysis for DTO conversion of subway trains that was carried out in the Nanakuma Line of Fukuoka. Our analysis was carried out according to the following process.

First, functions of driver's business details were picked up and these functions were assigned by the system. Therefore, we formulated an alternative table of automated driving tasks, and ascertained the roles of the crew and system in the existing STO and for the case of DTO conversion (see Table 3). We then made a list of probable hazards (dangerous events) and created a corresponding table (manual, STO, DTO, and UTO) for these hazards. The results show that the same degree of safety can be secured with DTO as with the conventional driving of subway trains, and that this is an example that can be put to practical use (see Table 4). Tables 5 and 6 show the on-board equipment and ground equipment installed for DTO conversion. The derailment detection device, the function of passing through a station during an emergency situation, and smoke eliminating equipment that makes evacuation easy are some of the design functions that are consciously included in DTO conversion but are not present in the conventional operation of subway trains. This method also conforms to the risk analysis method of IEC 62267, and can be said to be a DTO that adheres to international standards.

Table 3: Example of risk and hazard analysis results for automated operation carried out by Fukuoka City Transportation Bureau (study of division of function).

Business details	Functions	Realization by STO			Realization by DTO			
		Staff	System	Operation command	Operation command	System	OCC	Maintenance and patrol
Inspections	Enter and depart inspection	○						○
Operation and driving	Shunting	○				○	○	
	Open and close of train doors	○				○	○	
	Start control	○				○	○	
	Driving (ACC, DCC and stopping)	△	○			○	○	
	Train distance		○			○		
	Driving arrangement			○	○		○	
	Route control			○	○		○	
Confirmation and supervising	Forward supervising	○				○		
	Platform door supervising	○				○		
	Constant stop supervising	○				○	○	
	Signal confirmation	○				○		
	Equipment supervising	○				○	○	
Correspondence to passengers	Corresponding	○				○		○
	Information	△					△	
Communication and report	Notification of in/out inspection	○	○		○			○

Note: Through safety analysis, ○ means the approved the function by system or OCC instead of staff for DTO; △ means partially performed.

Table 4: Examples of ground facilities for automatic driving studied by Fukuoka City Transportation Bureau.

	Hazard	Manual operation	Automatic operation	Unmanned operation			
			STO	DTO	Evaluation	UTO	Evaluation
While running	Rear-end collision, collision	ATS, ATC	ATC	ATC	○	ATC	○
	Derailment	Driver (crew)	Driver (crew)	System	○	System	○
	Train car separation	Driver (crew)	Driver (crew)	System	○	System	○
	Stopping between stations	Driver	Driver	System and Tour operator	○	System	○
	Irregular stop position	Driver	Driver	System	○	System	○
	Not starting	Driver and relief operation	Driver and relief operation	Relief operation	○	Relief operation	○
	Vehicle equipment failure	Driver	Driver	System	○	System	○
	Fire on the train	Driver (crew)	Driver (crew)	Tour operator	○	System	?
	Fire in the tunnel	Driver (crew)	Driver (crew)	Tour operator	○	System	?
	Power outage	System and crew	System and crew	System and Tour operator	○	System	○
	Terrorism, crime	Crew	Crew (driver)	Tour operator	○	System	△
Station	Station fire	Station attendant	Station attendant	System (OCC)	○	System (OCC)	○
	Power outage at station	Station attendant	Station attendant	System (OCC)	○	System (OCC)	○
	Disaster (earthquake, flood)	Station attendant	Station attendant	System (OCC)	○	System (OCC)	○
	Platform door failure	Station attendant	Station attendant	System (OCC)	○	System (OCC)	○
	Caught between doors	Crew	Crew (driver)	System	○	System	○
	Caught between platform and train	Crew	Crew (driver)	System	○	System	○
	Falling in the track	Driver (crew)	Driver (crew)	System	○	System	○
	Getting hit by train	Crew	Crew (driver)	System and Tour operator	○	System	?
	Examples in Japan	Major subways, Tokyo Metropolitan Area conventional lines, Shinkansen	Subway	Fukuoka City, Nanakuma Line, Linimo, NTS		NTS (Rubber tired System)	
	Examples in foreign countries	Conventional lines, high speed rail (several)	Subway	Subway, NTS (many cases)		Subway, NTS (many cases)	

Table 5: On-board equipment at time of DTO introduction.

Equipment	Apparatus	Functions	STO	DTO
Equipment for driving	ATO	Back up for location detection	System	System
		Communication of train stop between stations	Driver	System
			Driver	System
		re-power running command from OCC	Driver	System
		Inching command	System	System
	Brake	Security brake	System	System
		EB in case of insufficient brake	S/Driver	System
	Train doors	Detection of passengers caught	System	System
		Automatic door opening and closing	System	System
		After several useless door opening, report of keeping door open	×	System
				System
		EB at the time of door opening during operation	×	System
				System
Equipment for safety	Train communication	Alarm signal transmit	System	System
		EB at reception of alarm signal	System	System
	Data communication	Communication between OCC and signaling system	×	System
				System
		Dual system and battery back up	×	System
	Obstruction detection	Report to OCC in case of detection	Driver	System
	Derailment detection	Brake and report at time of detection	Driver	System
Equipment for information	In-train automatic announcement	Next stop and arrival announcement	System	System
		Emergency automatic announcement	Driver	System
	In-train guidance display	Next stop and arrival information	System	System
		Emergency guidance information	×	System
	Lighting	Emergency lighting over 30min.	System	System

Table 6: Ground equipment at time of DTO introduction.

Equipment	Devices	Functions	STO	UTO
Signal related equipment	Operation control	Start command, inhibiting control	×	System
		Supervising of train conditions	Staff	System
		Abnormal alarm of train stop position	×	System
		Train passing in case of station abnormality	Drivers	System
	ATO	Communication with onboard ATO devices	System	System
	Limit obstacle detection	Setting with specific sections	System	System
		ATC stop after detection	System	System
	Train communication	Communication between train and OCC	System	System
		Automatic alarm signal transmits at time of earthquake	System	System System
		Alarm signal transmit at time of train stop with doors opening	×	System System
	Data communication	Redundancy	×	Dual
		Train stop	×	System
		Train failure information reception	×	System
Safety equipment	Screen platform doors	Obstacle sensors, passenger caught detection	System	System System
		anti-Interlock switch between train and platform doors	×	System System
		Interlock between train and platform doors	System	System
		Supervising of door opening and closing	System	System
Disaster protection and evacuation	Tunnel lighting	Sufficient illumination during evacuation	System	System
	Broadcast	Transmit from OCC to station	System	System
	Guidance display	Display of abnormal guidance in station	System	System
		Display of abnormal guidance in train	System	System
	Smoke exhaust	Smoke exhaust with easy evacuation	△	System

5 METHOD OF ENSURING SAFETY WITH AUTOMATED DRIVING TECHNOLOGY OF AUTOMOBILES

With safety improvement measures aiming at zero accident fatalities, the automated driving technology of automobiles in Japan has been making progress with the advancement of its Information Technology System (ITS) and Advanced Safety Vehicle (ASV) technology. Table 7 shows the levels of automatic driving indicated in the SIP Automatic Driving System

Research and Development Plan of the Cabinet Office. Currently, the automatic operation system is at the level 2 stage, which is a combination of independent technologies of collision damage mitigation braking, lane-keeping assistance technology, and lane-keeping support control technology. It might be said that this approaches very close to level 3, in which accelerating, steering, and braking are all performed by the system, and the driver needs to respond only when requested by the system. An example of an automated driving technique, as indicated in the 5th ASV Promotion Plan of the Ministry of Land, Infrastructure, and Transport, is shown for reference.

Fig. 2 shows an example of the evaluation method including security in the automated operation of an urban transportation system. A Reliability, Availability, Maintainability and Safety (RAMS) evaluation and a security evaluation are considered very important and serve as useful references in complying with international standards.

6 CONCLUSION

Automated operations (known as DTO and UTO in the international standards) have been implemented in the Japanese railway system, as part of the New Transport System. However, they have not been very highly regarded in conventional trains because of issues including accidents after a platform collapse and at railway crossings, or in ensuring a sense of security during evacuation guidance. However, the rapid progress in automated driving technologies in automobiles, and problems such as labor shortages owing to a declining birthrate and an aging population, have led to studies being conducted on the application of automated driving in the field of conventional railways. In this regard, although utilizing the automated driving technologies in automobiles is important from the viewpoint of cost saving, it goes without saying that ensuring the safety and security of the traditional system is also an essential prerequisite. Therefore, practical application of an automated operation incorporating state-of-the-art technology, while ensuring the safety and reliability of a conventional railway system, is desirable. In this paper security design is described but further study of security problems being undertaken now.

Table 7: The levels of automatic driving indicated in Japan.

<table>
<tr><th>Automatic operation level</th><th>Description</th><th colspan="2">The system that performs these functions</th></tr>
<tr><td>Level 1</td><td>The system performs one of the operations of acceleration, steering, and braking</td><td colspan="2">Safe driving support system</td></tr>
<tr><td>Level 2</td><td>The system performs more than one of the operations of acceleration, steering, and braking</td><td rowspan="2">Semi-automated driving system</td><td rowspan="3">Automatic driving system</td></tr>
<tr><td>Level 3</td><td>The system performs all the operations of acceleration, steering, and braking and the driver responds, when requested by the system</td></tr>
<tr><td>Level 4</td><td>All the operations of acceleration, steering, and braking are performed by an entity other than the driver, and the driver is not involved at all</td><td>Fully automated driving system</td></tr>
</table>

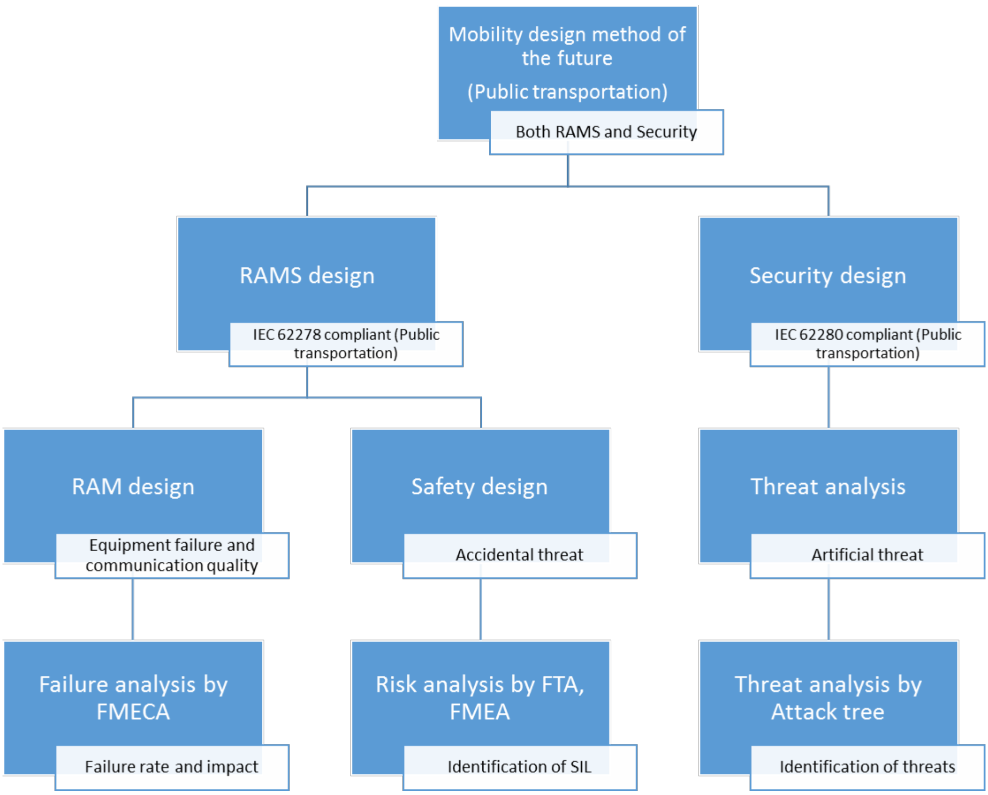

Figure 2: Example of the evaluation method including security in the automated operation of an urban transportation system.

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