Special feature article

Global Trends in Radio-based Train Control Systems

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1 Introduction

Development and deployment of ERTMS/ETCS, CBTC, PTC, and other train control systems that use radio communications is going forward outside Japan. Such train control systems that use radio communications are at the core of innovative technologies for signalling, rolling stock control, and transport systems, and it is important to identify the status of their development and their backgrounds.

This article will cover the current state of and issues with train control systems that use radio communications outside Japan as well as expectations for future train control systems in Japan.

2 Train Control Systems Using Radio Communications

2.1 Deployment of ERTMS/ETCS

Development of the European Train Control System (ETCS) started in the 1990s. The aim of that system is smooth train operation over borders, i.e. interoperability, achieved by a homogeneous train control system in Europe, where systems differed country by country. In 1996, a directive on interoperability was established, and the European Railway Traffic and Management System (ERTMS) including operation control was stipulated for ETCS as a train control system with that directive.

ERTMS/ETCS is classified into application levels from 1 to 3 to allow easier introduction in stages. Level 1 achieves automatic train protection (ATP) functions, and these functions are carried out by Eurobalise transponder beacons and onboard equipment. Level 2 achieves a cab-signalling-based train control system using GSM-R radio communication that is mobile phone radio communications provided with a specific frequency for dedicated railway use. Both levels use track circuits to detect trains. Level 3 achieves Level 2 functions with GSM-R radio communication alone, without the use of track circuits. It was introduced on local lines in Sweden in 2011, but system development for major trunk lines has not yet started.

ETCS applies to train control systems, and ERTMS includes train control systems and train operation control systems. In actuality, however, the operation control part has not been formed yet.

Level 2 ERTMS/ETCS has been introduced in places such as Italy (2005), Switzerland (2007), Spain (2006), and the Netherlands (2006). ERTMS/ETCS was introduced at an early stage in Italy because improvements were needed in existing track circuits and train control systems with the change

Profile

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1953	Born in Hokkaido
1973	Graduated from Department of Electrical Engineering, Hakodate National College of Technology
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of the power feeding system there from DC to AC. And in Switzerland, a train control method was needed for faster speeds and shorter travelling time to allow better train connection at hub stations in line with the Bahn 2000 plan.

Germany and France, however, are not as assertive in introduction of ERTMS/ETCS. Germany has its own LZB train control system by crossed inductive wires on its high-speed rail network and France its TVM430 train control system by track circuits, and the lifetime of the equipment for those will not be reached for some time. Introduction will be mandatory in the future with the interoperability directive, so ERTMS/ETCS is expected to be gradually introduced in Europe. ERTMS/ETCS Level 2 is planned for introduction in the outskirts of London in the UK, and this will be covered later in the article.

Existing onboard and wayside systems cannot be replaced all together when introducing ERTMS/ETCS to other than new lines, so measures need to be taken for that migration. At such migration, the existing train control system needs to be operated concurrently with ERTMS/ETCS for a certain period of time, so the onboard ERTMS/ETCS is given a specific transmission module (STM) to convert information from the existing wayside equipment. Also, software becomes more complex due to the diversity of requirements in individual countries. In the Swiss example, continuous speed check patterns are emitted only in locations with turnouts, and speed check patterns to stop trains are not emitted in locations without turnouts. This Limited Supervision (LS) is used to avoid the need for laying new cable to beacons and to reduce cost. It should be noted that major software errors were reported in Switzerland where this has started to be used.

In terms of ERTMS/ETCS software management, preparation is underway for baseline 3, which has compatibility with system requirements specifications (SRS) version 2.2.2d used up to now and new additional corrections. With baseline 3, the Swiss-proposed LS functions and level crossing control functions were added, brake patterns were modified, STM specifications were modified, and other changes were made. And in terms of ERTMS/ETCS onboard device software, a project aiming to reduce costs by joint development as open source was started in 2012 by Deutsche Bahn.

For GSM-R, which is positioned as a previous-generation data transmission technology, areas such as line capacity improvement through the GPRS data packet exchange method are being studied. Methods to reduce the effect on ERTMS/ETCS data transmission by GSM-R in emergency communications are also being studied.

In China, CTCS Level 2 with stop pattern generation to block boundary by transponder and emergency stop signal transmission by track circuit was introduced between Tianjin and Beijing. However, CTCS Level 3 with functionality similar to ERTMS/ETCS Level 2 is currently being deployed.

2.2 Deployment of CBTC

Communications-Based Train Control (CBTC) is a train control system for a broad range of urban transport systems such as subways, new transport systems, and airport access systems. CBTC standards include IEEE Std. 1474.1:2004, which requires as its definition…

- Detection of train location from onboard
- Continuous train-to-wayside and wayside-to-train data communications
- Determination and protection of stop limits by failsafe onboard and wayside devices

The systems of Automatic Train Protection (ATP), Automatic Train Operation (ATO), Automatic Train Supervision (ATS), and data transfer are included as elements composing CBTC.

The aim of ERTMS/ETCS is interoperability within Europe, so items down to interface specifications are determined in detail to allow common utilization of components regardless of their manufacturer. With CBTC, however, the system functions and composition and the data transfer methods differ by manufacturer even though there are recommended design standards. System compositions, including operating density, appropriate for the conditions of individual lines become possible, but the lack of commonality between systems means handling must be done individually if through service between lines is needed.

The first CBTC was achieved in the 1980s. Today, many of its systems, including unmanned operation, are in use outside Japan.

2.3 Development of PTC

The Rail Safety Improvement Act (RSIA) was passed by the US Congress in 2008 in response to three major accidents in 2005 and multiple incidents before and after that year. RSIA mandates that Positive Train Control (PTC), a system to prevent train collisions and excessive speeds, be introduced to major lines by the end of 2015. PTC requires ability to handle items such as through service to other lines. In other words, it requires interoperability in the USA where much through service is implemented, especially for freight trains.

Two types of systems are currently being developed for PTC. One is Advanced Civil Speed Enforcement System (ACSES) by conventional track-circuit-coded and transponders. The other is Interoperable Electronic Train Management System (I-ETMS) with position detection by GPS and 220 MHz band radio transmission.

With such conditions to deal with, development and deployment of PTC is not necessarily progressing smoothly.

One reason pointed out is that, despite the short deadline for introduction in 2015, specifications are not sufficiently disclosed by manufacturers to introduce PTC that can achieve the interoperability required by the law. This is because the major railway companies contract with only one manufacturer each for PTC on their individual lines.

With ERTMS/ETCS in Europe, introduction was mandated by the interoperability directive in 1996. Technical development, however, started at the beginning of the 1990s, proving the need for much time and manpower to be expended for introducing ERTMS/ETCS. This includes studies on migration from individual countries' existing systems.

Train control systems have an appropriate system scope and lifespan. By focusing mainly on interoperability, there is little room for flexibility. Yet, if functions effective for railway management cannot be added, the new system will have little appeal.

3 Handling of Urban High-density Operation Sections

As previously mentioned, ERTMS/ETCS has been mandated by interoperability directives for introduction on major lines in the EU. Level 2 has been introduced on major high-speed trunk lines and Level 1 on quasi-trunk lines, and there are various projects for through service from trunk lines by trains equipped with ERTMS/ETCS in urban high-density operation areas. The top objective of ERTMS/ETCS is interoperability, so whether or not 24 to 30 trains per hour can be operated in urban high-density operation sections or what sort of handling is needed if that many trains cannot be operated are major issues with ERTMS/ETCS.

There are two projects in London for which work is underway with an aim to start use in 2018: Thameslink and Crossrail. With Thameslink, trains equipped with ERTMS/ETCS Level 2 will merge in central London from multiple lines connecting north and south London in a 4-km/four-station section. High-density operation of 24 trains per hour (equipment limit of 27 trains per hour) will be conducted there. Crossrail, similarly, will have high-density operation of 24 trains per hour (equipment limit of 30 trains per hour) in a 10-km/six-station section with multiple lines from east and west London.

Different methods were selected at Thameslink and Crossrail for high-density operation in the merging sections in central London. For Thameslink, ATO is added to ERTMS/ETCS to minimize fluctuation in travel time with manual operation by drivers and to allow reduced headway. On the other hand, for Crossrail, the two systems of ERTMS/ETCS and CBTC are equipped to trains, with the onboard device switched to CBTC in merging sections and automatic operation conducted to handle high-density operation.

Reasons for switching the onboard device to CBTC with Crossrail are risks such as the following:

- While CBTC has a substantial track record with high-density operation, there are development risks associated with adding an ATO function to ERTMS/ETCS such as addition of transfer data to GSM-R and compatibility of ERTMS/ETCS protection patterns and ATO control patterns.
- For future plans, equipment must be able to handle operation density of 30 trains per hour.
- Full-size platform gates must be installed in the Crossrail merging section (underground), but the current delay of up to 12 seconds with GSM-R will not allow control to open and close gates at the appropriate timing for trains operating automatically.

Also, the situations surrounding the two projects differ. For example, they have separate infrastructure management organizations, and a new operation control center will be built for Crossrail while existing facilities will be used for Thameslink. Moreover, cell size will be 1 to 2 km and low antennas set up as measures for GSM-R for high-density operation with Thameslink. Also, measures are taken where block boundaries are set extending past track circuit boundaries.

Similar issues have also come up with the Bosporus Strait at Istanbul, the Madrid Metro, and other locations. In the case of Istanbul, two overlapping systems—ERTMS/ETCS Level 1 and CBTC—will be set up in the 14-km/four-station section of the strait tunnel.

Handling of high-speed operation sections for ERTMS/ETCS is currently decided by considering the individual conditions at the time. Drawbacks of switchover delay and capacity have been pointed out for GSM-R, and those are key factors in such high-density operation sections. ERTMS/ETCS Level 3 has moving blocks, and the method of handling in high-density operation sections is assumed to be different than at present, but information transfer capacity and speed increase for radio systems will be more important.

While sufficient consideration has not yet been made in ERTMS/ETCS for operation control systems, a new operation control system different from current CBTC could be achieved for trunk lines, suburban lines, and city center merging sections if individual train position and speed information gained with Level 3 is applied. In particular, Japan's ATACS is equivalent to Level 3, and early formation of a high-level operation control system is expected.

4 Train Control System Development and Related Research: INESS Project

In Europe, the Integrated European Signalling System (INESS) project was conducted for three years from 2008 with support of the European Commission and the participation of UIC, major European railway operators, manufacturers, universities and others. The project objectives were clarifying specifications for new interlocking devices compatible with ERTMS/ETCS and reducing procurement costs so as to effectively deploy ERTMS/ETCS. Items studied in the project were (a) division of functions between common European core interlocking functions and subsystems including Radio Block Centers (RBC) and operation control systems, (b) business models for interlocking device deployment, and (c) tests for authentication and safety cases (safety verification documents). Specifically, detailed studies were conducted by eight work-streams handling project management, business models, system design, generic requirements, function architecture, testing and commissioning, safety case processes, and dissemination and training.

Such a basic project has significant meaning. The safety case in particular is important, as it is necessary for safety authentication. But the details are not always clear, leading to much labor and costs being incurred. Costs to gain authentication are said to be 10% of system development costs. Describing and deploying safety requirements by Goal Structuring Notation (GSN) as shown in Fig. 1 is a method being studied for verifying safety through the safety case process.

With GSN, Arg 0 is the top safety requirement. That is resolved into more specific lower requirements while adding explanations by C to St elements such as strategy, criteria, and reference to express the requirement being fulfilled. In the end, it attempts to show the justification of the bottom safety requirement by Ref and, as a result, the justification of the top safety requirement.

In INESS, the notation method and standardization for interfaces between interlocking device subsystems are being studied in addition to safety cases. Those will continue to be studied in Germany.

In this way, joint efforts in systemizing the foundational parts common to train control systems in a larger framework are important, and studies should not stop at just ERTMS/ETCS. This is also necessary in Japan.

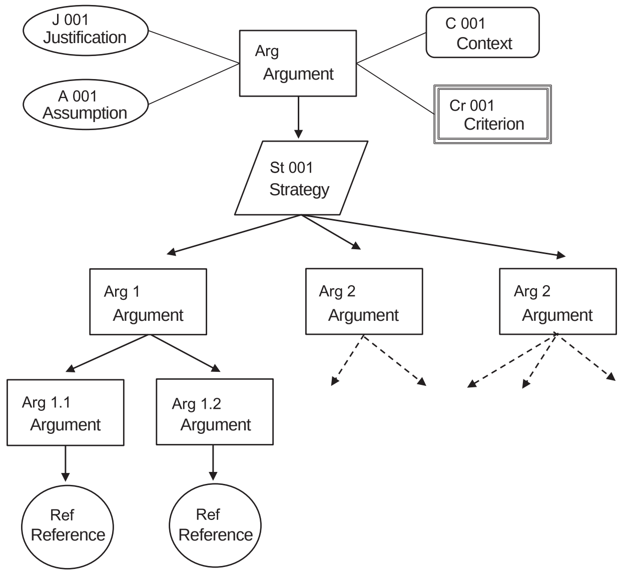

Fig. 1 Deployment of Safety Requirements by GSN

5 Conclusion

Train control systems are important systems in going forward with management strategies. By applying radio communications to train control systems, cost reduction as well as new functions effective in management strategies are expected to be achieved. In particular, a highly functional transport system different from those up to now may become possible with the ability to constantly identify the location and speed of individual trains. In order to achieve that in Japan, we must identify the status of development outside Japan for train control systems using radio communications, understand the conditions placed on those and the results and measures aimed for, and make considerations that reflect the situation in Japan.

We also need to systemize the foundational parts common to train control systems in Japan as is seen with the INESS project in Europe.