Latest Train Control and Management System Technologies for Improving Safety and Maintainability

Whereas the primary function of TCMSs when they were initially introduced was to transmit and display fault information of onboard equipment, the systems have since undergone progressive functional enhancements including not only powering and braking commands during train operation, but also commands for passenger information, air conditioning, and other service equipment. Hitachi was an early adopter of broadband communication standards and developed the Synaptra series as a TCMS capable of satisfying a wide range of requirements, incorporating the system into a variety of trains supplied in both Japan and other countries over recent years. This article describes the history of TCMS development and where the systems have been used, also summarizing their current specifications and functions and reviewing directions for future development.

Satoru Ito
Takayuki Suzuki
Keishi Suzuki
Keita Suzuki

1. Introduction

Hitachi's train control and management system (TCMS) has undergone ongoing enhancements to its functions and performance since it first entered commercial use in 1990, a trend that has only been accelerated by the advance and spread of information technology (IT) over recent years. Moreover, in addition to the onboard systems themselves, further functional improvements are also being made through cooperation with trackside systems using wireless and other forms of communication.

This article describes the history of TCMS development, summarizes current TCMS specifications and functions, and reviews directions for future development.

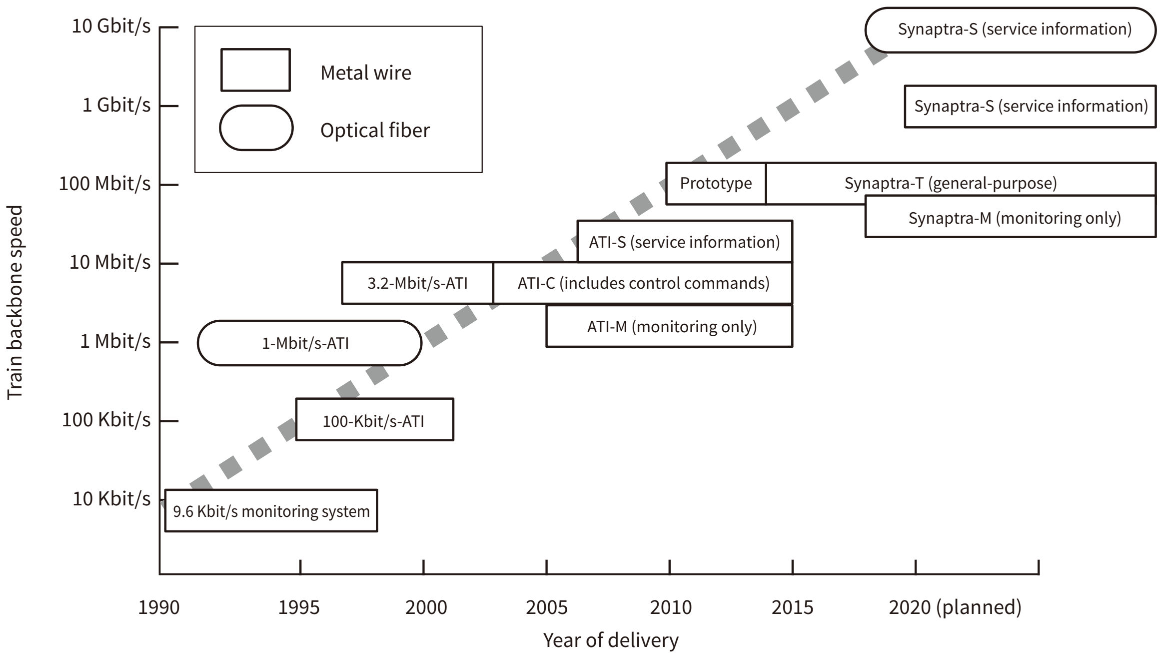
2. Development History and Past Applications

2. 1 Development History and Product Range

The transmission speeds achieved by the train backbone network that TCMSs use to send information between vehicles have increased over the years in step with the expansion in functional requirements,

Figure 1 — History of TCMS Development by Hitachi

The incorporation of new functions has increased the speed of train backbone networks over the years at the approximate rate of a 10-fold increase every five years. It is anticipated that this trend will continue.



TCMS: train control and management system ATI: autonomous decentralized train integrated system

typically rising by a factor of 10 every five years (see **Figure 1**).

The transmission speed of the train backbone used by the monitoring systems first installed in 1990 was 9.6 kbit/s. The main function of these systems was to display information about onboard equipment faults on the cab screen. As further enhancements were added aimed at reducing the amount of wiring and consolidating onboard equipment, including control commands for operations such as powering and braking, and commands for passenger information, air conditioning, and other service equipment, and also more extensive fault detection and automatic testing, the name "autonomous decentralized train integrated system" (ATI) was applied.

The transmission speed of the ATI train backbone was 3.2 Mbit/s, and while this was initially considered to be comparatively fast for a metal-wired system that can operate in the environment found on trains, the required transmission speeds progressively increased toward the limit as the functional requirements expanded and more equipment was connected. Meanwhile, debate continued about using an Ethernet-based onboard communication standard (currently IEC 61375) and Hitachi was among the first to adopt this technology, developing a TCMS that used 100-Mbit/s Ethernet.

Since commencing trial operation of a prototype in 2010, Hitachi has developed versions of the product using a variety of equipment configurations with a number of different customers in Japan and other countries and applications in mind, with the first product deliveries occurring in 2015. Called "Synaptra" (an amalgamation of "synapse" and "train"), the system is being used in a number of applications in Japan and other countries (see **Figure 2** and **Figure 3**).

The current version of Synaptra is a general-purpose system (Synaptra-T) capable of transmitting a variety of different data packets (for control commands, monitoring, and services) over the same hardware. The train backbone is primarily designed to have a dual-network configuration for redundancy, with one network being used exclusively for control commands and the other carrying packets for both control commands and monitoring. It can also be configured, however, as a single-network train backbone that only

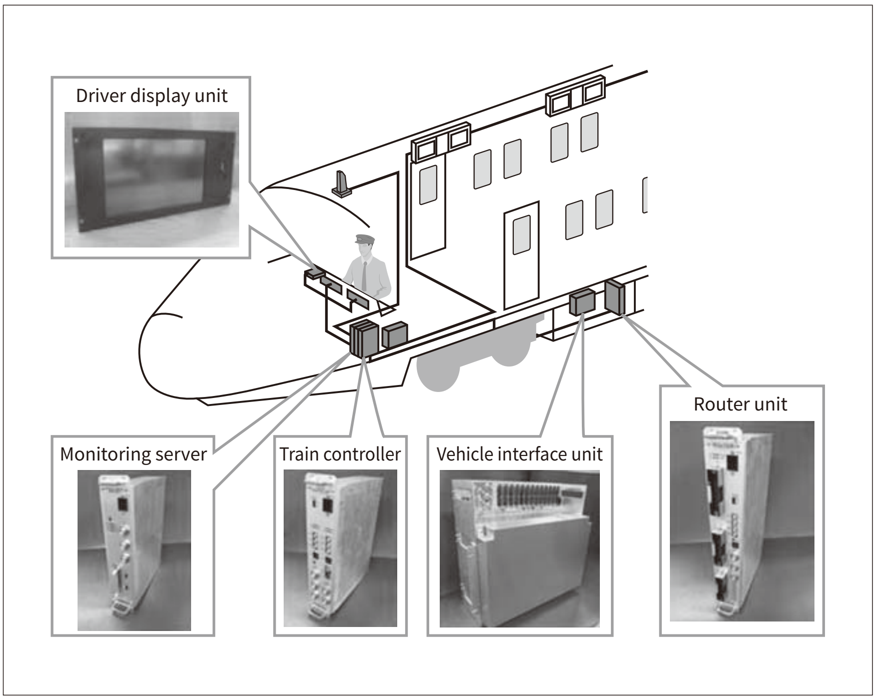
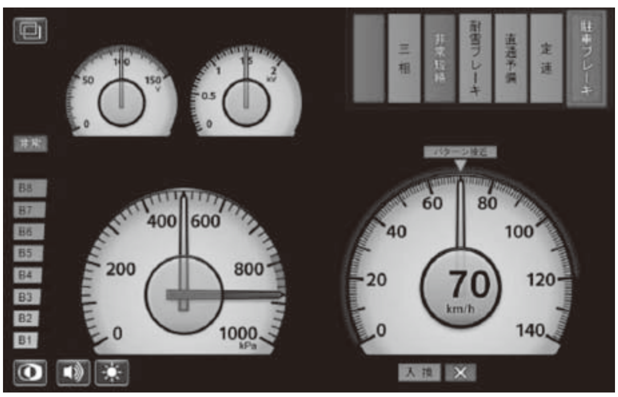


Figure 2 — Basic Synaptra Components and Configuration
As each component has its own hardware, allowing systems to be configured flexibly to suit different objectives.

carries monitoring data packets, with an additional (100 Mbit/s) network for services, or with separate control and monitoring networks.

Hitachi is also working on developing Synaptra into a series of different products to allow for detailed customization to suit the different uses and circumstances of each application. This product range includes Synaptra-M (100 Mbit/s), which is designed specifically for monitoring applications and has a simplified configuration while still providing all of the monitoring functions available on the current Synaptra system, and Synaptra-S (1 Gbit/s or 10 Gbit/s), which supports the transmission of large volumes of service data such as videos and transmission logs. These different versions have the flexibility to suit a variety of different requirements, including the ability to be used alongside the current Synaptra-T system.

Figure 3 — Synaptra Meter Screen
Meters and indicators are displayed in a way that makes them easy to view while driving. Screen operation is designed to ensure that meter needle movement is smooth so that it looks natural to drivers.



2. 2 Major Projects and Functions in Recent Years

This section describes some typical examples of Synaptra installations supplied over recent years.

(1) Class 800/801 train for the UK Intercity Express Programme (IEP)

The base configuration of the IEP trains, which commenced delivery in 2014 as replacements for express trains in the UK, included a dual-network Synaptra system. The system supports the full range of functions for trainset lengths of between five and 12 cars and also for two trainsets coupled. It also supports the minimal set of functions required for train operation when running four trainsets coupled, a configuration used for out-of-service trains (see **Figure 4**).

Although a wide range of train variants exist fitted with different numbers and types of onboard equipment depending on the lines and services they are used on, these differences are handled as far as possible by using software settings, with standardization of carbody wiring where possible.

Synaptra also works with other functions, including a safety door operation (SDO) function that designates which doors are permitted to open based on platform length, automatic power change-over (APCo) for switching between electric and diesel, the driver advisory system (DAS) that supports energy efficiency and routine operation, and the seat reservation system (SRS). Most of these are data-driven functions that work using databases received from offboard servers.

Similarly, fault and status information from the train is transmitted to trackside systems in real time and used to support operations and maintenance.

The trains commenced commercial operation in October 2017 on the Great Western main line (GWML) that runs west from London, and are also scheduled to be introduced on the East Coast main line (ECML) from the end of 2018. Orders for the same class of trains have also been received from other railway operators and deliveries are proceeding without major issues.

(2) Class 385 electric multiple unit (EMU) for Abellio ScotRail (ASR) in the UK

Synaptra is also used on this class of trains that commenced commercial operation in Scotland from July 2018 (see **Figure 5**).

Although the functional requirements and connected equipment on these commuter trains differ considerably from the IEP express trains described above, the development period was shortened by using the same hardware and handling the differences in software. Synaptra supports the full range of functions for up to four trainsets coupled, with each trainset being made up of either three or four cars.

(3) 20000 series EMU for Sagami Railway Co., Ltd. (Sotetsu)

The new class of EMU for direct city center services in preparation for the mutual direct train service between the Sotetsu and Tokyu Lines planned for FY2022 was completed in FY2017, the centenary of the Sagami Railway Group (see **Figure 6**).

The trains use Synaptra in a three-network configuration, made up of a dual-network train backbone for redundancy and an additional service network.

The cabs are fitted with two display units, replacing the analog meters and indicators used in the past. This

Figure 4 — Class 800/801 Trains for UK Intercity Express Programme (IEP)

The trains incorporate a large number of data-driven functions that work using databases received from offboard servers. Similarly, fault and status information from the train is transmitted to trackside systems in real time and used to support operations and maintenance.

Figure 5 — Class 385 EMU for Abellio ScotRail (ASR) in the UK

The development period was shortened by using software to handle the differences between the functional requirements and connected equipment on these commuter trains and those on the IEP express trains.

Figure 6 — 20000 Series EMU for Sagami Railway Co., Ltd.

The cabs were kept simple by designing them with the aim of consolidating, in the display unit, the various indicators that will be needed for the shared sections of track in future city center services.

Figure 7 — 20400 Series EMU for Tobu Railway Co., Ltd.

Retrofitting of Synaptra was facilitated by connecting existing equipment via interface units to avoid having to modify any of it.

has resulted in a simple cab layout designed with the aim of consolidating the various indicators that will be needed for the mutual direct train service in future direct city center services.

(4) 20400 series EMU for Tobu Railway Co., Ltd.

The new 20400 series EMU were created to repurpose the 20000 series EMU used for mutual direct services on the Tokyo Metro Hibiya Line (with a fixed eight-car trainset configuration) for use on the Tobu Utsunomiya Line and north of Minami-Kurihashi Station on the Tobu Nikko Line, with modifications being made to allow a four-car trainset configuration (see **Figure 7**). The EMU has been fitted with Synaptra systems to replace the existing monitoring systems. The amount of modification work that needed to be done was reduced by consolidating the hardware on the leading car. In terms of functionality, the new system features additional control functions to support single-driver operation as well as display of vehicle status and fault information. Installation of Synaptra on the trains was also facilitated by using interface units to connect existing equipment, thereby avoiding the need for equipment modifications.

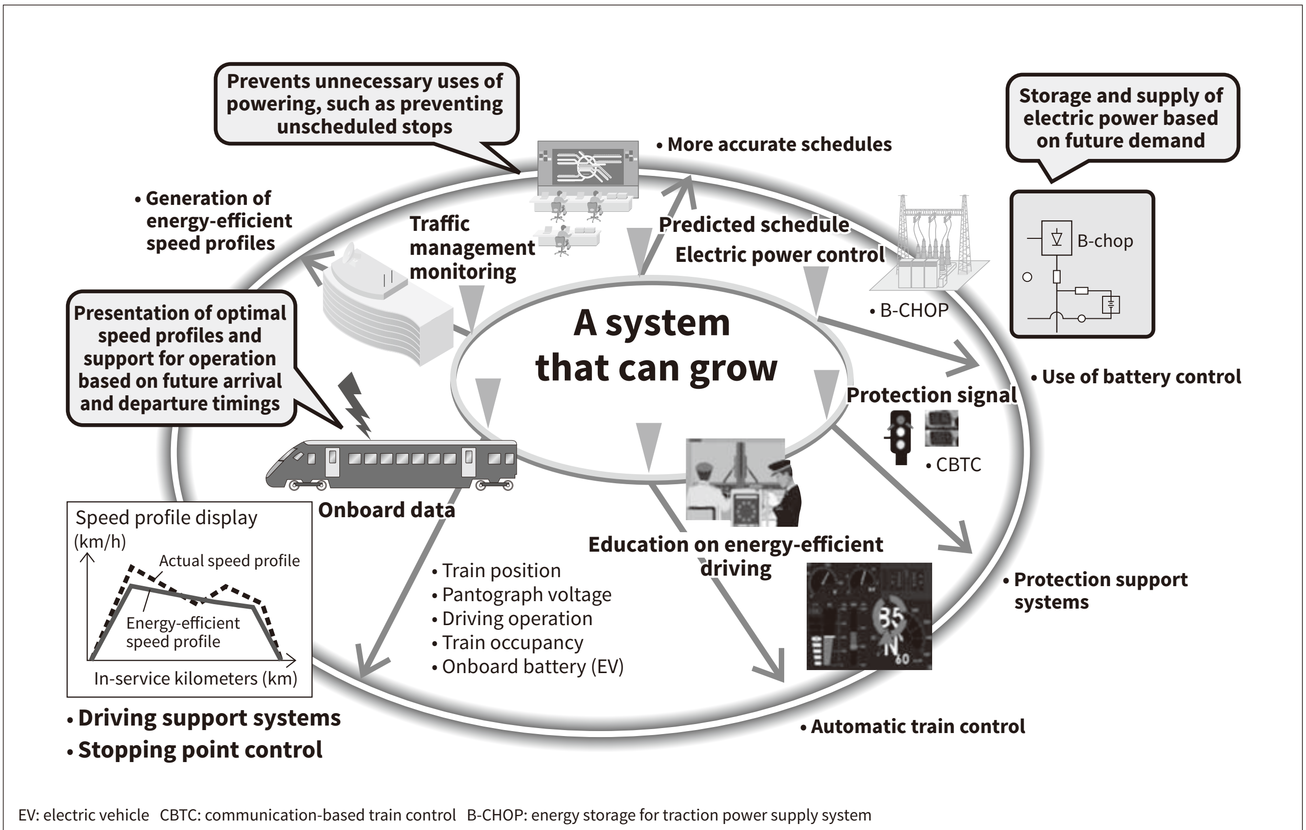
3. Future Developments

3. 1 Applications for Improving and Supporting Energy Efficiency

Measures for reducing the load on the environment are also important for trains. Whereas efforts to date

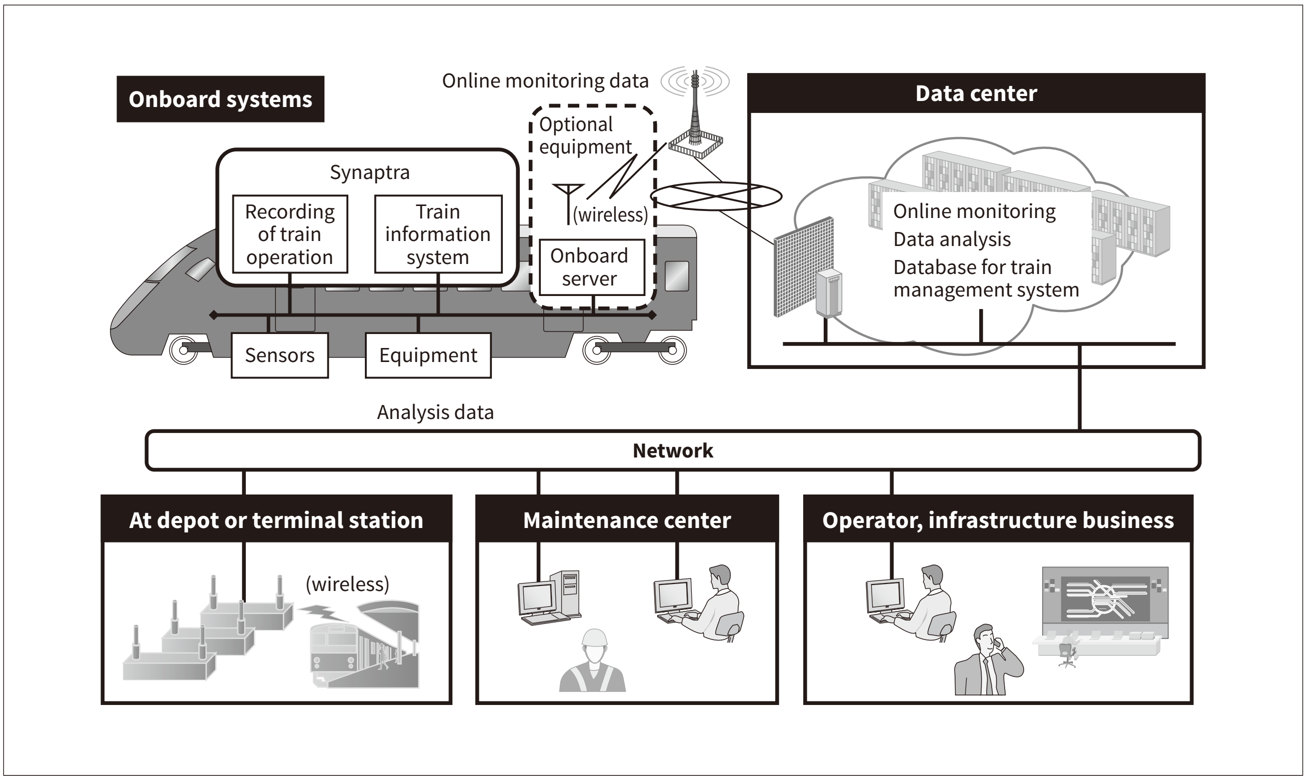
Figure 8 — Energy Management for Railway Systems

Optimal energy management across the entire railway network can be achieved through integration of trains with trackside systems.



EV: electric vehicle CBTC: communication-based train control B-CHOP: energy storage for traction power supply system

Figure 9 — Block Diagram of Online Monitoring System
Condition and fault information for onboard equipment sent via wireless communications to trackside systems can be used to support operation and make maintenance more efficient.



have sought to improve energy efficiency by reducing the weight or improving the efficiency of individual items of equipment, work is now progressing on energy savings achieved through system interoperation, taking advantage of the ease of exchanging information between the TCMS and trackside systems made possible by advances in information and communications technology. One example is the implementation of functions for ensuring energy efficiency that work by sending information to each train about train movement commands derived from the integrated operation of traffic management and power system management so that each train's TCMS can use this information as a basis for generating its speed profiles (see **Figure 8**).

3. 2 Maintenance

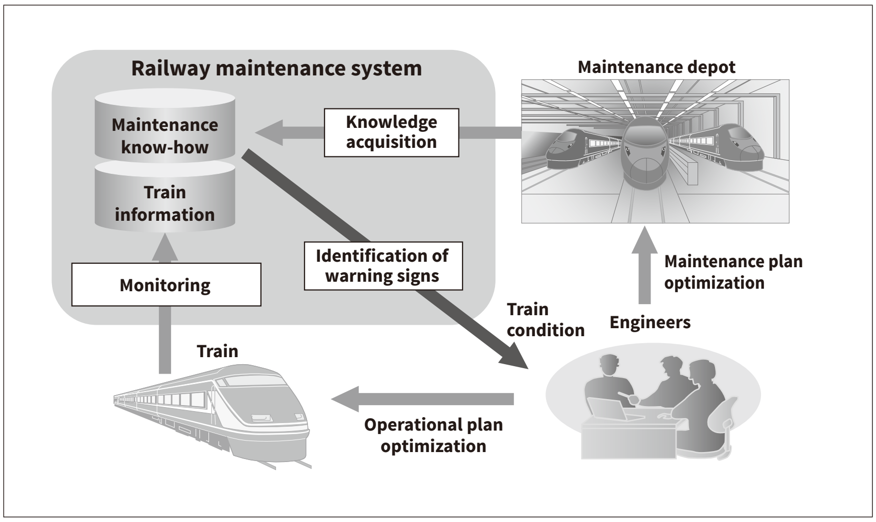
The primary approach to maintenance in the past has been to conduct periodic inspections to ensure that equipment satisfies the requirements of various laws and directives, and to maintain the equipment to ensure that it remains up to standard.

However, by utilizing advances in TCMSs and in information and communication technology, Hitachi is already operating onboard-trackside integration systems that collect important data from onboard equipment in a server on the train and then forward it to an offboard server for storage (see **Figure 9**).

Being able to continuously acquire operational data from in-service equipment has the potential to reduce maintenance costs by using recently collected operational data for inspection results and to prevent service interruptions due to faults by using condition monitoring to deal promptly with performance degradation. Plans for the future include functions that make it easy for knowledgeable staff to use the collected data to identify what maintenance work is needed and improvements to the human-machine interface. Hitachi also plans to achieve reliable operation and further reliability improvements through measures such as the use of artificial intelligence (AI) and the development of techniques for structuring knowledge that involve the systematic collection of information on how to go about fault analysis and response rather than just rules of thumb (see **Figure 10**).

Figure 10 — Diagram of Maintenance Support System with Integration of Onboard and Trackside Equipment

In addition to its use for maintenance, data from trains can also be collected and analyzed and used for fault analysis or to make responses more efficient.



4. Conclusions

It is anticipated that TCMSs will become even more important in the future as a means of implementing train functions and as a portal to a wide variety of functions connected to trackside systems. Hitachi intends to continue developing systems and functions that meet the needs of the market to contribute to operations and maintenance at railway companies and to improving service to passengers.

References

1) M. Hata et al., “Train Management System Technologies by Hitachi, Ltd.,” Rolling Stock & Technology, 242, (Dec. 2016) in Japanese.
2) N. Yamamoto et al., “Development of Train Management System (TMS) for the UK,” Proceedings of 52nd Railway Cybernetics Symposium of Congress of Japan Railway Cybernetics (Nov. 2015) in Japanese.
3) M. Sekine et al., “Sagami Railway 20000 Series DC Train,” Rolling Stock Technology, 255, (Mar. 2018) in Japanese.

Authors

Satoru Ito
Train Control and Management Systems Design Department, Train Electrical Systems Design Department, Mito Rail Systems Product Division, Railway Systems Business Unit, Hitachi, Ltd. *Current work and research:* Technical management of train control and management systems. *Society memberships*: The Institute of Electric Engineering of Japan (IEEJ).

Takayuki Suzuki
Train Control and Management Systems Design Department, Train Electrical Systems Design Department, Mito Rail Systems Product Division, Railway Systems Business Unit, Hitachi, Ltd. *Current work and research:* Management of train control and management systems design planning.

Keishi Suzuki
Rolling Stock Engineering Department, Rolling Stock Systems Division, Railway Systems Business Unit, Hitachi, Ltd. *Current work and research:* Engineering of onboard systems for trains.

Keita Suzuki
Train Control and Management Systems Design Department, Train Electrical Systems Design Department, Mito Rail Systems Product Division, Railway Systems Business Unit, Hitachi, Ltd. *Current work and research:* Management of train control and management systems design.