Network-based Signaling Development: Progress and Future Outlook

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JR East has developed a network-based signal control system for station yards whereby signal house logic controllers and the station yard signaling devices are connected via an optical network and control is done by data. The purpose of this system is to improve ease of work in signal installation and lighten the burden of field tests. It was put into practical use for the first time at Ichikawa-Ono station on the Musashino Line in February 2007. We are currently aiming to innovate other signaling systems while deploying the system. That involves developing and introducing a network-based signal control system for automatic block signals that applies the developed technologies to automatic block signals, development for practical use of station yard logic controllers to improve overall signaling system reliability, and researching application to level crossings.

1 Introduction

Conventionally, control of signals and motor points in the station yard has been by laying signal cable (metallic cable) from interlocking equipment and other logic equipment in the signal house to signaling devices in the field to control those by voltage control. That meant replacing or making improvements to the signaling system involved laying a huge volume of cable from the signal house to individual field devices along with many times that work in cable core wiring as well as connection tests and the like over a long period of time for checking. As a result, construction in larger station yards is complex and difficult, and mistakes in construction could lead to transport disorders. We thus conducted development of a system based on a new concept whereby signaling devices such as signals and motor points in the station yard are connected to a logic controller in the signal house and signaling devices are controlled by digital data transfer. By introducing this system, we hope to achieve a reduction in the amount of cable laid, lighten the burden of wiring diagram creation and wiring work, and simplify connection tests. As a result, we expect to be able to reduce the risk of disruptions due to mistakes in construction (Fig. 1). JR East calls a signal control system based on this concept a "network-based signal control system," and we aim to innovate signaling systems by phased technical development and introduction to practical use.[1)]

This article provides an overview of network-based signal control system development in chapter 2. Chapter 3 gives an overview of and explains the major technical development elements of the network-based signal control system for station yards, network-based signal control system for automatic block signals, station yard logic controllers, and network-based level crossing control.
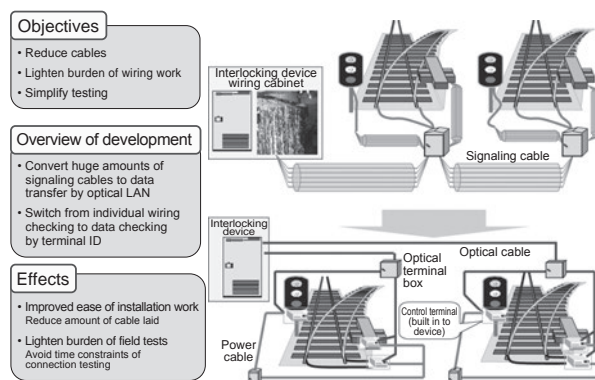

Fig. 1 Concept of Network-based Signal Control System

2 Overview of Network-based Signal Control System Development

2.1 Concepts of Developing and Introducing Technologies

With network-based signal control systems, we conducted four-staged development in steps from a perspective of achieving the ideal network for the future while keeping in mind introduction of the system to practical use as early as possible. In this, we introduced systems to practical use as their technologies were established (Fig. 2).
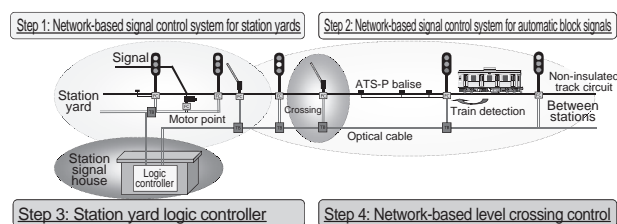

Fig. 2 Development Steps of Network-based Signal Control System

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2.2 Concepts of Development Processes

Elemental technology development to achieve the concepts of a network-based signal control system started in 2002, and basic research on the network method, the method of achieving field controllers, and countermeasures against lightning damage was completed by fiscal 2003. A decision was subsequently made to put a network-based signal control system into practical use as a physical measure to solve trouble leading to delay in construction to relocate track on the Chuo Line, which occurred in September 2003. Full-scale technical development thus started in fiscal 2004. By starting technical development for steps after the network-based signal control system for station yards in parallel when their prospects came into view, we were able to reduce the overall number of processes (Fig. 3).
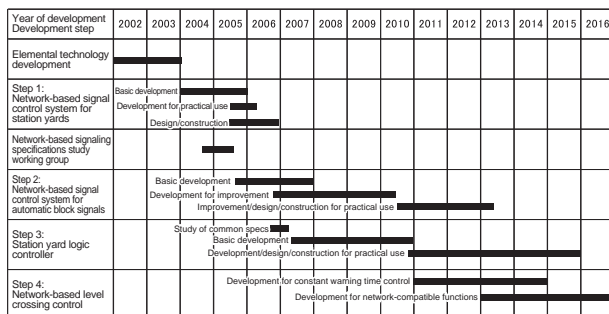

Fig. 3 Overall Development Processes for
Network-based Signal Control Systems

2.3 Status of Development

The objectives and current status of the individual steps are as described below.

(1) Network-based signal control system for station yards
· Reduce cables and improve ease of work in signal installation by switching to an optical network.
· Lighten the burden of wiring work by digital data transfer.
· Reduce field testing by conducting preliminary tests in the factory.

The system was put into practical use at Ichikawa-Ono station on the Musashino Line in February 2007, and currently construction is underway to introduce it to Shin-Narashino and Soga stations as part of the Keiyo Line simplification and integration project. Planning is underway for introducing it at replacement of interlocking equipment due to aging at major stations in the greater Tokyo area.

(2) Network-based signal control system for automatic block signals
· Reduce cables and improve ease of work in signal installation by switching to an optical network.
· Improve reliability by centralized control of signaling devices for automatic block signals.

Construction is underway for introducing as part of the Keiyo Line simplification and integration project (Tokyo to Soga).

(3) Station yard logic controllers
· Improve reliability by reducing the number of logic controllers.
· Simplify renovation of interlocking at the work such as installing and removing signals.

· Lighten the burden of planning work.

Development for practical use is currently underway at the Tokyo Electrical Construction and System Integration Office. We plan to commence using the first station at around the beginning of fiscal 2016.

(4) Network-based level crossing control
· Improve efficiency of level crossing control by means such as optimizing crossing warning time.
· Monitor and maintain remotely.

3 Technical Development of Network-based Signal Control System

This section introduced technical development in the individual development steps of for network-based signal control systems.

3.1 Network-based Signal Control System for Station Yards

The basic technologies for network-based signal control systems were established in this development step. The following are typical examples.

3.1.1 Achieving Data Control of Signaling Devices

Fig. 4 shows a configuration diagram for a network-based signal control system. A Field object Controlled Processor (FCP) is set up in the signal house for batch processing of signaling devices control logic. The FCP determines details of control for applicable signaling devices by control data from interlocking equipment and display data of related signaling devices. Control data for individual signaling devices is transferred as digital data. The Field Controller (FC) built in to the signaling devices has intelligence with which it extracts data intended for it from received data, confirms the soundness of data, and interprets control instructions in the data for electronic control such as lighting signals and operating motor points.
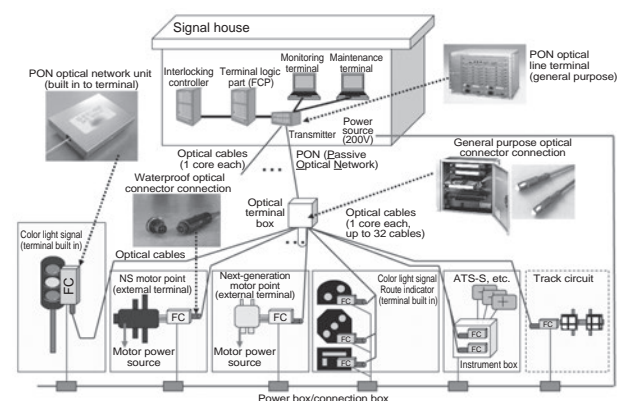

Fig. 4 Configuration of Network-based Signal Control System

Wiring and control logic are separated in the method of control by data. At FC replacement, only whether communications with the FC is possible by the terminal ID set to the FC needs to be checked, and control conditions do not need to be tested. Also, information to stipulate the action mode of the signaling devices is included in the data. For example, equipment contributing to running can exist concurrently on the same network with equipment for maintenance (Fig. 5).
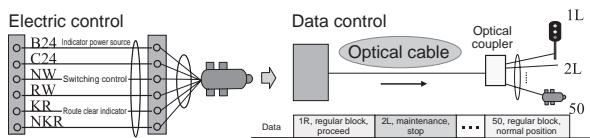
Fig. 5 Comparison of Electric Control and Data Control

The basic concept of the issue of securing safety of signaling device control by transmission is to identify all errors that occur in the transmission line. Setting up a mechanism to detect those and to act safely in the fail-safe devices at both ends of the transmission line is described in the IEC 62280 international standard.[2] This system uses general-purpose IP networks, and network devices are "black boxes" not open to modification. Therefore, there is no way to analyze in detail the impact of device failure and identify errors that occur in the transmission line. However, errors that occur in an IP network can be qualitatively classified as data errors, recipient errors, and time errors. So, we have developed technology to detect those errors and equipped FCPs and FCs with those.[3]

3.1.2 Adapting to Environments Along Railways

In this system, electronic devices are built in to signaling devices along rail lines, so adapting them to the difficult environment there becomes an issue. We thus set reference values (Table 1) for environmental durability based on JIS or international standards for railways and conducted tests. In particular, we have little knowledge in countermeasures near tracks against electromagnetic noise from motor cars, so we addressed this as an important issue affecting the success or failure of putting the system into practical use.

Table 1 Major Environmental Conditions of Field Controller

Environmental phenomenon		Test condition
Lightning surge	Power line	30 kV (1_o 2/50 μs, 10/200 μs, 10/1000 μs)
	Signal line	20 kV (1_o 2/50 μs, 10/200 μs, 10/1000 μs)
Electromagnetic noise (EMC)		According to IEC 62236-1, 2, and 4
Ambient temperature in use		– 10 to +60 ºC (according to JIS-E 3019 and 3020)
Vibration characteristics		10 to 500 Hz (1 G or greater) (according to JIS-E 3014 type 2)

The following introduce specific examples of countermeasures against lightning damage and electromagnetic noise.
(1) Countermeasures against lightning damage
Fig. 6 shows countermeasures against lightning damage. The benefit of this method is that the signal chassis or instrument box have a potential of zero (reference potential), so uniform surge protection characteristics can be gained regardless of the presence or lack of grounding or the size of the ground resistance.
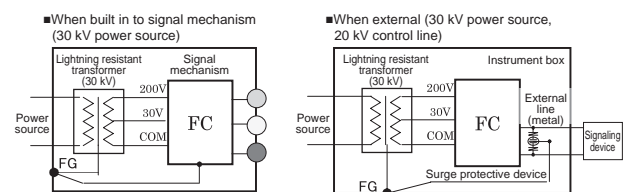

Fig. 6 Method for Countermeasures against Lightning Damage

(2) Countermeasures against electromagnetic noise
Generally, CPUs become more susceptible to electromagnetic noise as they become more energy efficient and faster. With fail-safe computers in particular, taking countermeasures against noise is an important issue in increasing reliability because those are force-stopped in temporary malfunctions due to noise. For noise tolerance, requirements in the IEC-62236-4[4] international standard for electromagnetic compatibility (EMC) in a railway environment must be met. Reference values for tolerance to noise intruding from power lines are shown in Table 2 as an example of test criteria.

Table 2 Reference Values for EMC Testing (Example of Power Line)

Environmental phenomenon	Reference value	Units
Radio frequency common mode	0_o 15-80 10 80 150	MHz V %AM (1 kHz) Ω
Electrical fast transient/burst	±2 5/50 5	kV (P-P) Tr/Th ns Repetitive frequency kHz
Surge	1_o 2/50 ±2 ±2 ±2	μs kV (common mode) kV (differential mode) kV (diff mode unbalanced system)

3.1.3 Development of a Remote Monitoring and Control System

Network-based signaling systems have control terminals built in to the field signaling devices, so if a malfunction occurs, much time is require to find the cause and conduct repairs. For that reason, there is concern of large-scale transport disruptions occurring. We thus decided to develop a monitoring and control system via the network for quick identification of failure locations by enhanced monitor/journal information, remote resetting when control terminals fail, stopgap restoration by switching networks, and software replacement in cases such as program problems. Monitoring devices for signal control systems had existed from before, but new monitoring devices were provided new each time a new system was introduced to enhance monitoring items, and this in turn made monitoring work more complex. In light of this, we developed an integrated remote monitoring and control system that uses ICT to monitor all signaling and system devices and reset them remotely. The main characteristics of those are as follows.

· Achieve a large-scale, large-capacity monitoring network configuration through general-purpose network technology.
· Enable real-time accumulation of monitoring information through general-purpose RDB technology.
· Allow easy addition of new signaling devices monitoring functions by standardization through SQL procedures to reference monitoring information (Table 3).
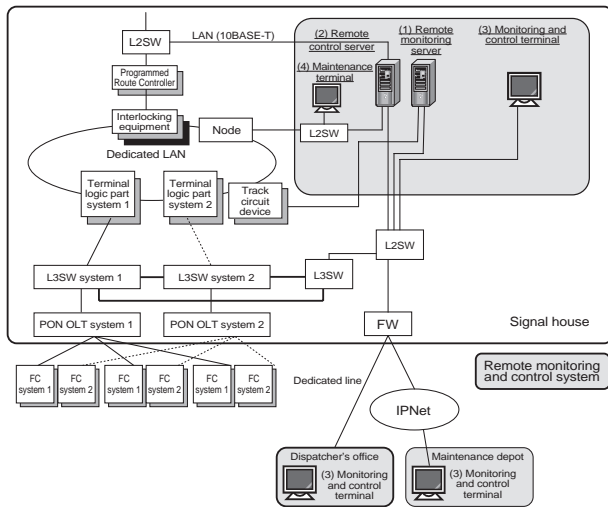
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Fig. 7 Configuration of Remote Monitoring and Control System

Table 3 Devices Related to Remote Monitoring and Control System

No.	Device	Functions
(1)	Remote monitoring server	Function to accumulate current status information of signal devices and communications equipment and to notify monitoring and control terminal of failures
(2)	Remote control server	Remote control of signal devices based on instructions from monitoring and control terminal
(3)	Monitoring and control terminal	Function to display warning and status information at signal device failure and to perform remote control and journal obtaining
(4)	Maintenance terminal	Adding and deleting FCs and changing programs

3.2 Network-based Signal Control System for Automatic Block Signals

This section gives an overview of and the status of implementation for the network-based signal control system for automatic block signals.

3.2.1 Overview of Network-based Signal Control System for Automatic Block Signals

Signaling devices such as block signals, track circuits, ATS-P, and ATS-S are located at points between stations. Conventionally, those are devices separated by their individual functions with control logic formed mainly by signal relays (Fig. 8 (a)). Such a system configuration has the following issues.
(1) Simplex devices (no backup in case of failure)
(2) Complex relay connection logic and a huge amount of wiring work
(3) Information needed for maintenance only acquirable on-site

In fundamental signal system improvement on the Chuo Line for overcoming those issues, we worked to overcome issues 2 and 3 by centralizing in the signal house controllers that were spread out (Fig. 8 (b)). But, a huge number of signal cables have to be laid from the signal house to the individual devices, and those cables remain simplex. Thus, there is still room for improvement on issue 1. For the network-based signal control system for automatic block signals (Fig. 8 (c)), we are working to find solutions to the issues of signaling devices for automatic block signals, including issue 1, by connecting the logic controller in the signal house (LC: Fig. 9) and field controller along the

track (FC: Fig. 10) with optical cables to reduce the amount of metallic cables laid and make the system duplex.
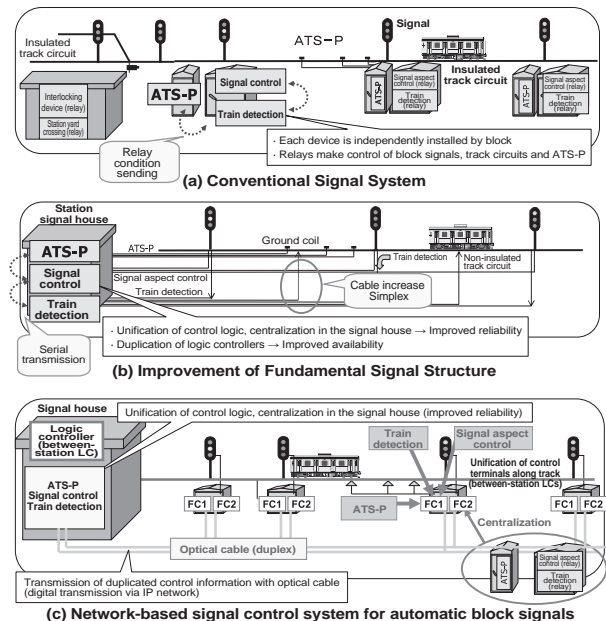

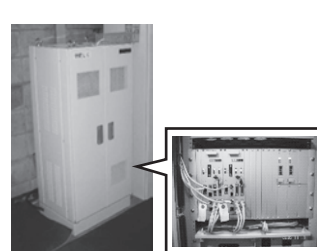Fig. 8 Systemization of Control of Signaling Devices for Automatic Block Signals

Fig. 9 LC   Fig. 10 FC

3.2.2 Application to the Keiyo Line Simplification and Integration Project

The network-based signal control system for automatic block signals was applied in the Keiyo Line simplification and integration project, and construction for introducing that is currently underway. Most of the electronic interlocking and ATS-P devices on the Keiyo Line are more than 20 years old, and they require replacement due to deterioration. And in the future, improvement of transport capacity will also be needed. We are thus planning to introduce a network-based signal control system when that replacement is done. A network-based signal control system for station yards (303-type) will be introduced at Narashino station (including the Keiyo Rolling Stock Center) and Soga Station, which have many routes. At other smaller stations, 602-type electronic interlocking equipment with the conventional control method will be introduced. Moreover, a network-based signal control system for automatic block signals will be introduced in a 43 km section between Tokyo and Soga stations (Fig. 11).

The processes for switchover work started with replacing aged interlocking devices in station yards from fiscal 2012. Later, upgrade of the system for automatic block signals and

improvement in the station yard reflecting transport capacity improvement will be conducted. In switchover of automatic block signals, the Keiyo Line will be separated into five construction sections where switchover will be done in steps until fiscal 2015.[6]
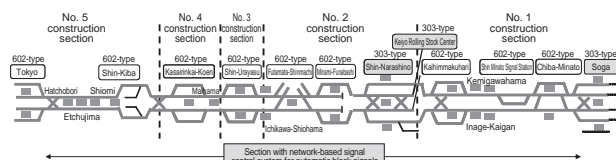

Fig. 11 Keiyo Line Simplification and Integration Project

3.3 Development of a Logic Controller for Station Yards

This section gives an overview of technical development for a logic controller for station yards.

3.3.1 Overview of Logic Controller for Station Yards

As we were aiming to put a network-based signal control system into practical use as early as possible, we set a development policy of incorporating a network-based signal control system as part of the 301-type electronic interlocking equipment (hereinafter, "301-type"), which already has a significant track record. The 301-type itself has an optical network and is of a configuration where ACP field devices controllers are connected. In the network-based signal control system for station yards, ACPs are replaced by Field object Controlled Processors (FCP), which process field devices logic only. That system configuration where field devices are controlled via an optical network other than S-LAN is not preferable in terms of reliability and cost. We thus believed that we should integrate these two types of logic controllers and networks (Fig. 12).[8]
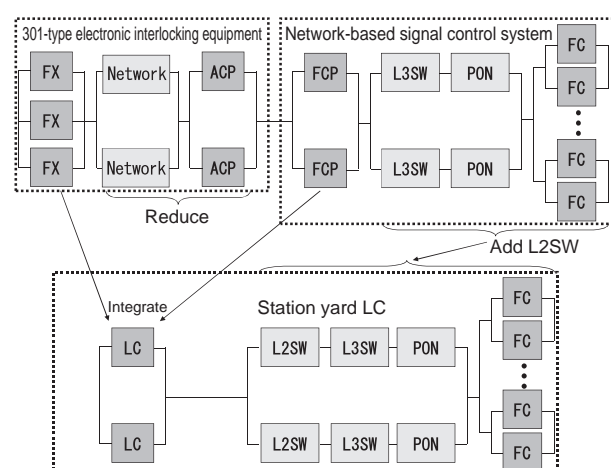

Fig. 12 Integration of Logic Part and Network in Network-based Signal Control System

Next, the signaling logic controller for station yards is composed of a logic part that determines the control information for signaling devices and multiple control parts that control devices according to the control information. Transfer of conditions between the logic part and control parts varies greatly from delivery of conditions by relays to real-time transfer and transfer using Ethernet. Moreover, various signal control functions such as interlocking and ATS are individually systemized, and interlocking operations are achieved between signaling devices through transfer of conditions by connecting those devices in various transmission routes. For that reason, the system configuration becomes complex, making design, construction, and testing difficult. Up to now, no matter how reliable individual devices may be, failure of some devices would affect the station as a whole, in effect making reliability of the system as a whole lower than that of individual devices.

In light of that situation, we are conducting development to integrate various signal control logic controllers the station yard into one set of fail-safe computers (signaling logic controller for station yards, station yard LC) and unify control of all signaling devices to control via a network (Fig. 13).
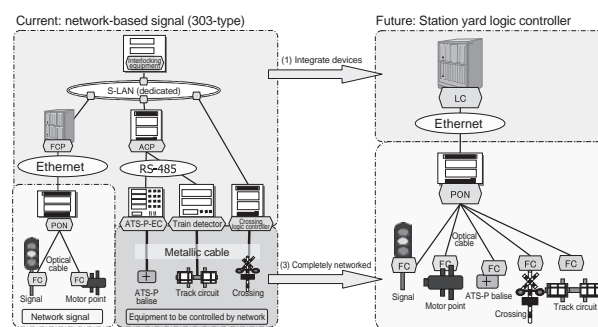

Fig. 13 Concept of Integrating Station Yard Logic Controllers

3.2.2 Issues in Logic Controller Integration

Multiple logic functions are integrated into a single device with the station LC, so there is concern of maintenance and troubles affecting a broad area. We thus developed a method to prevent the area affected from becoming too large.

Large transport disruption will occur if an interlocking device stops working, so we have to prevent interlocking functions from stopping due to troubles with supporting equipment control and other newly integrated functions not present in conventional electronic interlocking devices. We thus decided to revise the software configuration. To limit the affected area to the corresponding function in modification or troubles, independence between functions needs to be established. For this reason, we studied and assessed adopting a software architecture where logic processing is divided by functions as subsystems (Fig. 14).
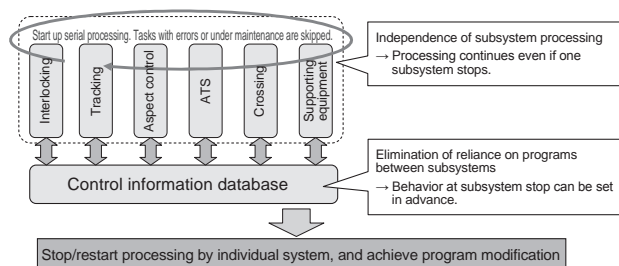
Fig. 14 Divided Software Configuration

With this software architecture, subsystems are unable to directly access the other subsystems. So, even if a software malfunction occurs, programs and data of other logic processing are prevented from being modified, thus preventing troubles from affecting other functions. And by making transfer of all data needed for control of multiple functions go through a common database, duplication of processing and data can be eliminated. Such an architecture allows for stopping and starting of processing and modification of programs by individual subsystem, thus increasing the durability of the software.

The signaling logic controller for station yards is currently in the final stages of technical development at the Tokyo Electrical Construction and System Integration Office. We plan to commence using the first station at around the beginning of fiscal 2016.

3.4 Network-based Level Crossing Control

The major issues in level crossing control are setting more appropriate alarm timing and making monitoring and maintenance more efficient. To set more appropriate alarm timing, information spread out along the railway line needs to be gathered at the level crossing controller. However, with conventional technology, a huge amount of metal cable needed to be laid and many relays used to build logic. A large capacity information network needs to connect level crossings with locations such as dispatch to make monitoring and maintenance more efficient, at high-speed.

Such issues could be overcome by incorporating level crossing control logic to network-based signal control systems, but many difficult technical issues stand in the way. So, assuming future network connection, we will gradually conduct development for software control at a higher level of constant warning time control of level crossings, for network-compatible level crossing controllers, and for remote monitoring and maintenance functions in an aim to solve problems in a comprehensive manner.

4 Conclusion

This article has covered development of network-based signal control systems and the status of putting those into practical use as efforts in innovating signaling by JR East. Technical development started on network-based signal control systems in 2004, and the final step of developing network-based level crossing control has not yet been completed. But by developing consistently step by step and putting systems in to practical use in individual steps, we have been able to continue with development without loosing pace. Such methods of developing and introducing technologies have also been adopted for the Autonomous decentralized Transport Operation control System (ATOS) in the greater Tokyo area, and we believe they are effective measures for successfully completing large-scale projects in this age of rapidly changing social environments. We also believe that network-based signal control systems will be the norm for next-generation transport system control infrastructure. They are also showing promise as wayside infrastructure of radio train control systems, so we are sure further development can be expected in the future.

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