Special feature article

Toward Innovation of Signal Systems

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In the history of railway signaling, signal equipment evolved with the development of electronics technologies from machines to relays, electricity, electrons, and computers. Especially, since the establishment of JR East, technological breakthroughs have enabled the establishment of innovative systems such as ATOS, COSMOS, and digital ATC with computer and network technologies.
Signal control at front-line train operations, however, still relied on wiring technologies, and this caused transport disruptions on the Chuo line in September 2003. We have been developing a new network signal control system as a measure to deal with this problem, and this paper describes what kind of research and development will be demanded now and in the future.

1 Introduction

Development of railway signal equipment follows a vicious circle pattern; new signal equipment is introduced after a major accident in order to avoid reoccurrence of the same kind of accidents, then a new accident that reveals blind spots of that new signal equipment occurs, and again, a new measure is implemented. In the early stage of signal equipment development, accidents triggered the introduction of new signal equipment to answer the question of how signal equipment should prevent accidents. Today, new systems are being developed based on the need to answer the question of how operation efficiency and customer service can be improved while maintaining safety. Control of signals and point switches installed at operation sites however had problems since they used old-style wiring technologies.
In this paper, I would like us to review the history of railway signal systems, discuss the innovative systems that have been created so far, including not only train operations but also transportation that have been carried out since the establishment of JR East. Then I would like to clarify the current signal system problems, and describe what future signal systems should be like.

2 History of railway signal systems

2.1 Early times

In early times, a flagperson on a horse secured safety by leading a train. As train speed increased and the number of track junction points increased, lookout men called "policemen" were located at key points, and these "policemen" enabled safe train operations by using hand signals indicating hazard (both arms up), caution (one arm up), or safe (one arm outstretched horizontally parallel to the ground). After a while, equipment that indicated such signals was installed at designated locations. This equipment was called a "semaphore signal," and it developed into a mechanical semaphore signal (Figure 1).
Furthermore, a block system was designed in order to ensure that more than one train does not enter a certain track section, a track circuit was designed to detect train locations, and an interlocking device was designed to establish a relationship between the opening direction of a turnout and a signal. These devices from the second half of 19th century established a basis for today's railway signal systems. They underwent a number of revisions and greatly contributed to the improvement of safety. As seen above, signal equipment has been introduced to secure safety and respond to the increase in transportation volume.

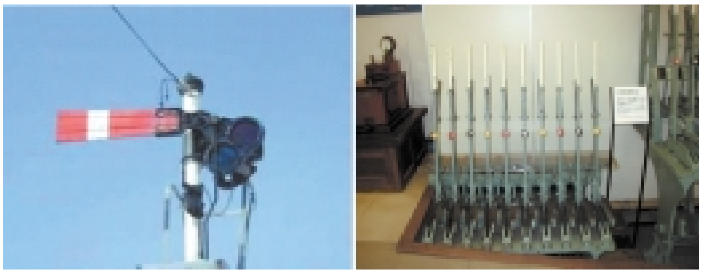

Fig. 1: Mechanical Semaphore Signal and Mechanical Interlocking Device

2.2 Mechanization of signal operation

First, equipment called "mechanical interlocking device" was invented in 1856 (Figure 1). This equipment mechanically establishes an interlock between a signal and a turnout. Wires and pipes move the signal and the turnout, and the signal can allow the train to proceed only when the turnout opens and the conditions allowed the train to proceed. Safety is secured in this way.
Since the mechanical interlocking device is not efficient due to the fact that it is manually operated and required much maintenance work, a "relay interlocking device" which uses electricity to operate relays was designed in 1929. This equipment uses combinations of relay circuits to lock and therefore control signals or point switches at relay contact points. The outstanding feature of this equipment is

that, even when multiple signals or point switches are installed along a single route, by operating a switch called a "lever," required switches can be automatically operated and signals were indicated.

2.3 Prevention of train operation errors

Since the number of accidents did not decrease simply by having train operators check the signals while operating the train, a driver's cab signal was designed and installed in order to let the operator know that the train was approaching a stop signal. Still, accidents caused by overlooking this signal occurred. As a response to this, an automatic train stop device (ATS), with a capability to automatically stop the train, was developed. This device was designed to prevent the above-mentioned type of accidents by automatically stopping the train before a stop signal. If the train operator overlooked or ignored the alarm, then the brake was automatically activated. ATS was introduced after the Mikawashima accident, and was installed on all Japan National Railway tracks by 1966.

This device, however, also had a flaw; once the train operator checked and confirmed the alarm, the alarm was cancelled, and if the train operator made some kind of mistake after the alarm was cancelled, train accidents still occurred. To solve this problem, a new type of ATS (ATS-P) was developed. Descriptions of this device will be provided later.

3 Further progress of signals

As we all know, transistors that were invented shortly after the war greatly changed our lives. Electronics technologies rapidly advanced from the middle of the 20th century, from relays to transistors, ICs, and computers. With these new technologies, many types of new signals and signal systems were developed and put into practical use.

3.1 Automation of lever operators

The interlocking device described above was installed at each station; therefore, each station needed to have a "device operator." At the same time, a "dispatcher" who would control train traffic by understanding the train operation status of the entire line was necessary. To meet both requirements, a centralized traffic control (CTC) device came into practical use, and this device allowed a dispatcher at the control center to remotely control switches and signals via interlocking devices installed at multiple stations.

Due to introduction of CTC, control of train operations on a certain line was centralized into the central command center, and then the operation efficiency was greatly improved. As the number of trains increased, however, processing by humans was not fast enough, and also, there was the limitation that operation errors could not be completely eliminated. For this reason, a program route control (PRC) was developed such that the above-mentioned human operations would be replaced by automatic route control in accordance with specified procedures (programs) based on train behavior, and that operation efficiency and reliability would be further improved.

3.2 Advancement of train control

In order to overcome the weakness of ATS, a train control system called Automatic Train Stop-Pattern Type (ATS-P) was developed, and it was capable of operating a train while comparing the train speed and its "speed patterns" for stopping the train before a stop light. Development of ATS-P was triggered by the derailment that occurred at Hirano station of the Kansai Honsen in 1973. It was originally a variable frequency type like ATS, but it was remodeled into the current ATS-P with a transponder because it had problems with the use of emergency brakes and the amount of information was insufficient. ATS-P was first introduced on the Keiyo line in 1988, and its installation plan was expedited up because a rear-end train collision occurred at Higashi Nakano station 5 days after ATS-P was first installed on the Keiyo line.

Meanwhile, since overlooking a signal on a high-speed train line or on a high-density train line will cause a serious accident, it is necessary to indicate inside the train the allowable maximum speed and automatically activate the brake in accordance with that indication. A device that realizes this is known as an automatic train control device (ATC). ATC was first installed on the Tokaido Shinkansen line in 1964 based on the understanding that it would be difficult to safely check wayside signals while the train was running at 200 km/h. As for the existing Japan National Railway (JNR) lines,

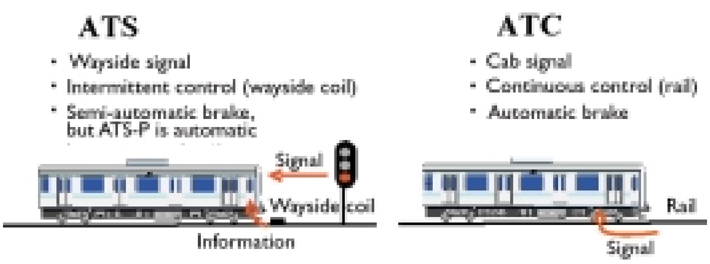

Fig. 2: Differences between the ATS and ATC Systems

of mixed operations with the Teito Rapid Transit Authority.

Compared to ATS with intermittent control, ATC executes continuous control and therefore trains can be safely operated even when the train operators do not correctly understand the signal, resulting in a dramatic improvement of safety.

3.3 Emergence of computerized interlocking

Although the conventional relay interlocking device operated by combining the turning on and turning off operations of a relay, an computerized interlocking device replaced switching elements, with no movable parts as seen in the conventional relay, with a microcomputer, and also it took advantage of hardware as well as software features to expand and diversify its features. Since interlocking settings could be changed by changing software settings, repair work became easier, and also, the interface with computerized devices such as a centralized traffic control device and an automatic route control device was simplified. Furthermore, the computerized interlocking device could be linked with train departure information displays or departure announcement functions, thus having a feature of expanding and diversifying its capabilities. As described above, since the computerized interlocking device was better than the conventional relay interlocking device, it was first installed at Higashi Kanagawa station in 1985, and since then, it has been actively installed at various train stations when their old relay interlocking devices were replaced.

4 Innovation of railway transportation

Upon privatization, JR East established the following three basic management policies; a "life-creating company" contributing to customers, areas, and society, a "future-oriented company" developing and effectively using the latest technologies, and a "company respectful of humans" achieving happiness for employees and their families. Through these policies, JR East raised the motivation to eliminate the bad habits of the predecessor JNR. Under this background, systemization was promoted in various fields, including management information systems. Systemization of transportation operations was one of the examples of such systemization aproach. JR East systemized the operations in the Tokyo area and reviewed the Shinkansen systems to increase speed and comfort, and started to develop systems for contributing to improvement of the level of service.

4.1 Emergence of integrated transportation systems

Transportation planning includes a series of tasks from creation of train operation plans to communication of the information of that plan, understanding of operation performance, and vehicle management. Most of these tasks used to be handled manually. Since a single mistake could lead to a train delay or an accident, double or triple checks were necessary, which in turn greatly increased the amount of work. For this reason, the Integrated Railway Operation System (IROS) was developed as a result of automation and systemization; transportation plans, which used to be created manually, were created with support of computers; and information such as train schedules and vehicle and crew operation plans was cited and organized for each station, crew organization, and maintenance section, and then transmitted online. This system contributed to speeding up of planning department operations and also to a decrease in the number of errors.

4.2 Innovation of transportation management in the Tokyo metropolitan area

Establishment of an ideal work environment has been demanded in order to provide services suitable for an era of technological innovation. Such an environment requires the following things: provision of detailed traveler services in case of disruptions in train schedules, a function to return to normal train schedules as quickly as possible, securing of safety, reduction of command operation, improvement of command operation efficiency, labor saving in station operations, and management of maintenance work.

It was extremely difficult to automate transportation management in the Tokyo metropolitan area, because train operations are very dense and complicated. A Tokyo metropolitan area transportation management system was developed with the objectives of labor-saving in station operations, securing of safety, and provision of a detailed traveler guidance system. This Autonomous Decentralized Transport Operation Control System (ATOS) was first introduced in 1996 on the Chuo line, and then on the Yamanote and Keihin Tohoku lines in 1998. Currently, its use has expanded to 18 lines with a total distance of approximately 910 kilometers (Figure 3).

We have installed computers at each station, adopted a distributed autonomous system that would allow each station to have control capability, and connected the central system and station systems via a 100 Mbps high speed optical transport network, such that each station could autonomously control trains based on train schedule data transmitted from the central system. With such a configuration it was possible to achieve high responsiveness, which is a requirement for high-density train operation lines. In the Tokyo metropolitan area, introduction of ATOS greatly improved information communication efficiency and workability compared to the times when CTC or PRC was used.

4.3 Total systemization of the Shinkansen line

The Shinkansen Traffic Control System (COMTRAC) was already installed on the Tohoku Shinkansen and Joetsu Shinkansen lines when they started operation, but COMTRAC could not be applied to some of the new projects such as planned Hokuriku Shinkansen line. COMTRAC had other problems: it displayed the train operation status on its large, integrated display board, and therefore, the system required a lot of space; cooperation between dispatchers was not smooth; and it had no scalability for installation at new stations. Therefore, it was determined that COMTRAC must be redesigned into a CRT-base command system. At that point, networking of the entire Shinkansen-related operations, information sharing and centralization, and introduction of a distributed autonomous operation management system for risk diversification and response improvement were planned at the time of replacing the old systems with new systems. As a result, the use of the new Computerized Safety, Maintenance and Operation Systems of Shinkansen (COSMOS) started in 1995 (Figure 3).

COSMOS is a total system comprising eight sub-systems: the transportation planning system, the operation management system, the railway compounds work management system, the maintenance work management system, the vehicle management system, the equipment management system, the centralized information management system, and the power system. Information is distributed from the center to stations, crew district offices, car depots, and maintenance sections via a high-speed digital line. Furthermore, PRC at each station executes train route control and displays train departure times on electrical signboards based on the train schedule sent via this high-speed digital line, and also broadcasts guidance announcements to platforms and the concourse.

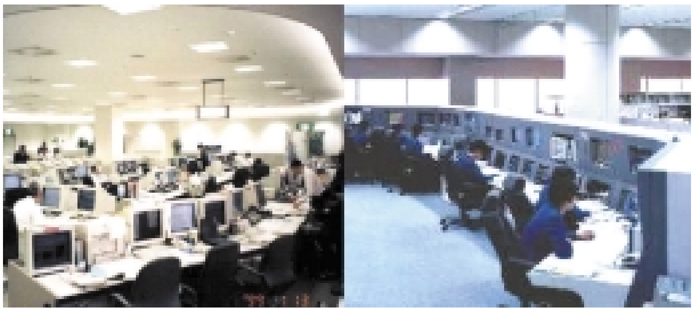

Fig. 3: Command Room of COSMOS (left) and ATOS (right)

4.4 New type of train control

In 1990, shortly after JR East came into existence, "Next-Generation Signal Communication Examination Committee" was established with the participation of external intellectuals in order to examine the signal communication system to be used in the next generation. As a result of examination of a signal communication system suited to play an important role in the next generation from various perspectives such as safety, reliability, maintainability, and operations, an image of a radio train control system with no track circuits, in other words, an image of an onboard information transmission and autonomous control system was established. However, after discussing whether or not this system should be implemented immediately and installed at the time of ATC update on the Yamanote and Keihin Tohoku lines, it was determined that a new ATC with track circuits would be used for these lines.

4.4.1 Development of a new ATC

The conventional ATC used old relay circuit-based technologies developed at the time when the Tokaido Shinkansen was established, and therefore, it was not possible to increase the number of trains, it was uncomfortable to ride the trains since braking was always sudden, and the long, large, thick and heavy ground-based equipment required a lot of investment.

For an ideal train control device to stop a train at a place to be in front of stop signal, the only information that is necessary is "where to stop" and "the distance to the stop point." Therefore, what should be done is to transmit information to the train regarding where it should stop. The train can always access its own location information, calculate the distance to the stop point, and apply an appropriate level of braking while taking curves and slopes into consideration. This is how the newly developed digital ATC (D-ATC) works (Figure 4). One of the features of this D-ATC system is that it enables high-density train operation with single-stage brake control and the onboard self location recognition function since these functions allow shortening of train intervals. Another feature of the system is that it is a slim and low-cost wayside device due to the use of general-purpose information devices and a distributed system. Furthermore, along with the improvement of vehicle acceleration capabilities, this system has sufficient flexibility to shorten time intervals without changing the wayside device settings. As a result, not only is the new ATC cheaper than the existing ATC, but also the new ATC can reduce the operation time interval from the existing ATC's 2 minutes and 30 seconds to 2 minutes and 10 seconds.

This system was put into practical use on part of the Keihin Tohoku line in December 2003, and also construction work has now been carried out in order to expand its application to the Yamanote line and the rest of the Keihin Tohoku line. Also, DS-ATC where the "S" stands for "Shinkansen" was developed based on the decision to install ATC when the Tohoku Shinkansen line was extended to Hachinohe, and DS-ATC has been used between Morioka and Hachinohe since the start of the Hachinohe Shinkansen operations in December, 2002. Currently, ATC replacement work is being carried out in order to replace ATC installed on the Tohoku Shinkansen and Joetsu Shinkansen lines with a system that is integrated with an electronic interlocking system.

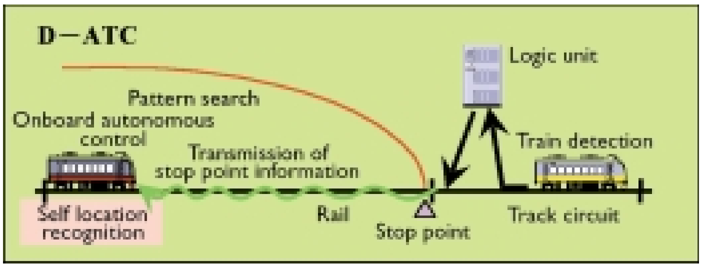

Fig. 4: Overview of D-ATC operation

4.4.2 Development of ATACS

Following direction given to "Next-Generation Signal Communication System Examination Committee", examination and development of a new, radio-based train control system (ATACS) with no track circuits started in 1995 (Figure 5). ATACS had a great advantage in that it could flexibly meet transportation improvement needs such as the removal of signal equipment like track circuits and signals installed around tracks, and cancellation of the division of block sections since it was not necessary for shortening the operation intervals or improving train speed. Field trials of the system were carried out through three terms. The trials conducted in the third term were prototype tests, and a model closely resembling the actual system was tested for its safety and reliability from October 2003 to February 2005. Since track circuits were not used but radio was used instead in this new train control system, the ATACS system evaluation committee was convened to evaluate safety and train operations. As a result, this system has been evaluated as being at the practical use level.

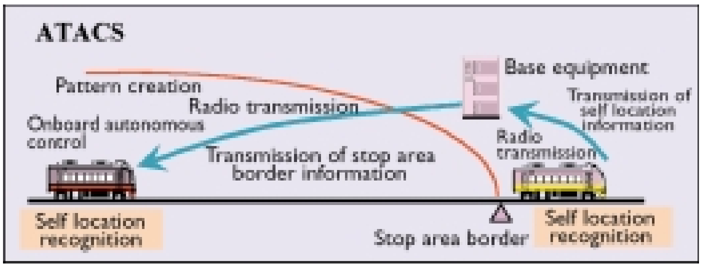

Fig. 5: Overview of ATACS

5 Problems with signals

Since the establishment of JR East, systemization was promoted in the overall transportation and train operation fields. In the field of signal control for directly controlling signals and point switches, approaches were taken toward implementation of computerized interlocking, and then, as seen in ATOS used in the Tokyo metropolitan area, a general-purpose electronic interlocking device was developed. There was however an unexpected and serious failure wherein outdated wiring was used between the equipment room and on-site devices. The delay in Chuo line construction work that occurred in the fall of 2003 was one of the most significant examples of this failure.

The problem here was that electricity was fed into individual wires to directly control on-site signal equipment (point switches and signals). Since a large number of wires were required to control a single device, there was a lot of wiring work, and also a lot of time and effort was required to test these wires. This work was done manually and would have been almost a miracle if no mistakes were made. The performance was maintained by double-checking and testing. The amount of work, however, seemed to be too great for a large-scale engineering project (figure 6).

Fig. 6: Wiring and Cables in the Existing Signal Equipment Room

Problems here can be summarized as follows:

(1) There was a vast amount of wayside equipment such as cables.

(2) The large amount of wiring work increased the total amount of work.

(3) A lot of time and effort was required to test the wiring.

(4) On-site equipment had low reliability due to its monoplex configuration.

6 Toward innovation of signal control

To solve the problems described in the previous chapter, it is proposed to send control data in batches via optical cables and install an on-site computer terminal for reading such data in each piece of the signal equipment for signal control. This is called network signal control (Figure 7). The packet communication technologies used widely in information communications are used. Since the on-site terminal will operate when data arrives, there is the advantage that the only on-site check required is that the optical cable is connected properly. Furthermore, the large volume of on-site testing that had to be carried out before can now be carried out in the factory, thus improving testing efficiency. Each on-site terminal has a self-diagnosis function and signal equipment diagnosis function; therefore, centralized monitoring and control of the on-site terminals will contribute to improvement of maintainability.

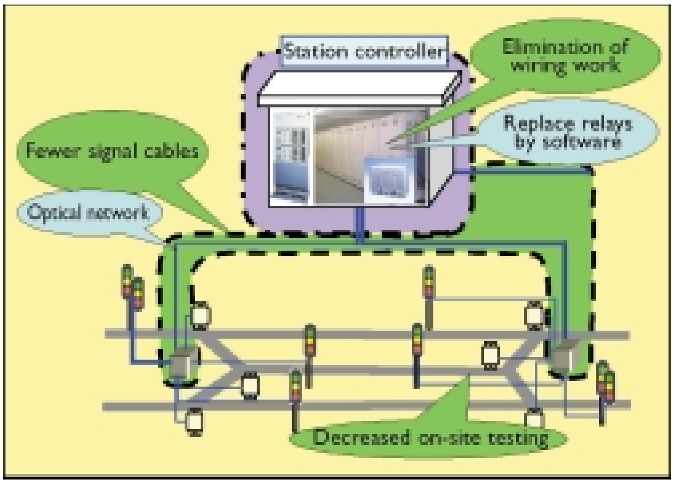

Fig. 7: Network Signal Control System

Although it is possible to use a loop system for the optical cable network configuration, connection devices called nodes must be installed at branching points of optical cables and power must be fed to these nodes, thus requiring higher cost. Now, therefore, the general-purpose network technology called EPON is used. EPON does not require power at branching points and is used for fiber to the home (FTTH). Computers must operate stably under harsh environments along tracks; therefore, the new task is to check resistance to the environment such as temperature, vibrations, electromagnetic noises, and lightning. For this reason, we plan to make the system duplex; while conducting type tests in the factory to examine whether the system could endure harsh environmental conditions, in April we started operation checks at Tsuchiura station to examine the system from various aspects such as long-term durability, software bug removal, and laying of optical cables and connection methods.

At Tsuchiura station, the focus of the test is control of point switches and signals within the station compound, but we plan to start research and development in this fiscal year in order to control signals between stations and ATS-P wayside coils in the near future after replacing old ATS-P with new ones. Furthermore, if it becomes possible to control track circuits and railroad crossings, regulation of railroad crossing alarm duration or the shortening of the circuited travel of maintenance cars will also become possible.

To realize this, it is necessary to integrate and streamline multiple computers ready for each type of signal equipment. Ideally, there will be one computer in the equipment room, and it will be connected to the on-site signal equipment via an optical cable (Table 1). Point switches and railroad crossings will still be used even when a radio-based train control system such as ATACS is employed, and therefore, the network signal control technology can be considered the base technology.

Table 1: Scope of Small Terminal Applications

Signal equipment / system	Point switch	Signal	ATS wayside coil	Track circuit	Railroad crossing
ATS	○	○	○	○	○
ATC	○	N/A	N/A	○	○
ATACS	○	N/A	N/A	N/A	○

7 New development at station

7.1 Toward a total integrated system

So far, systems for route control, train control, signal control, and vehicle control were all developed separately. Although individual systems seem to be well systemized, when we take an overall look at them as one operation control system, it isn't necessarily considered an optimal system.

Each system has the same data, and each system carries out similar processing. The previous systems consisted of individual systems accumulated based on the latest technology at the time of development and the demands of that time. Therefore, they were not designed to be a total integrated system. In future systemization, a brand new system establishment that will be a technological breakthrough is necessary, instead of simple partial system improvements. This approach is shown in Figure 8.

There is also another problem in that a newly replaced device must be compatible with the specifications of the existing systems since wayside equipment and onboard equipment have different replacement schedules. Matching the replacement schedules will be one solution. Installation on a new vehicle of an onboard safety device that is compatible with both ATS and ATC (and ATACS in the future) will be another solution. In this case, either ATS or ATC must be supported by switching software on a computer, instead of simply installing two devices. This will increase inter-operability, and trains can thus use any lines with no restrictions. Therefore, technological development in this direction must also be promoted.

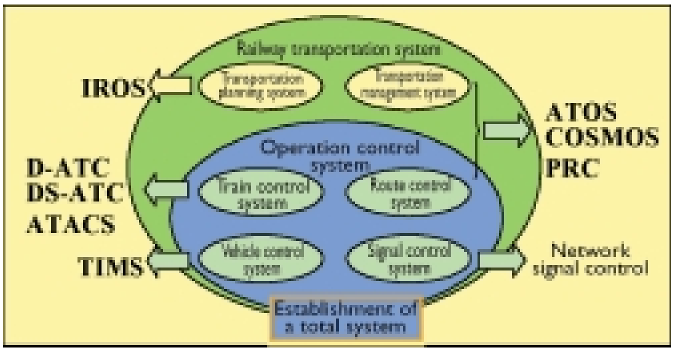

Fig. 8: Total Operation Control System

7.2 Establishment of a simple system

Previously developed vehicle control devices and electronic interlocking devices outputted electricity, but from now on, data transmission will suffice. Therefore, computers to control such output can be configured in simpler ways. As you can tell from the advancement of computer software that you use on a daily basis, in the world of computers, various technologies such as object-oriented technology, general-purpose databases, hierarchical programming, and shared platforms have been developed.

These technologies should be further incorporated into the field of signal systems, and signal systems should become easier to develop, upgrade, maintain, and replace. By incorporating the latest knowledge of software technologies, it will be possible to construct a basic system that can be easily customized for each station instead of a single basic system. This not only greatly contributes to shortening the construction schedule and cost reduction but also decreases the number of bugs in system creation, thus contributing to stable system operations. These aspects will be highly important in future research and development.

7.3 Compliance with international standards

In the field of quality assurance, ISO9000 has been the international standard, and it has been adopted in Japan, too. The concept of the international standard also applies to the field of railways, and the following standards are the ones related to signal systems that recently became the international standards or that will become the international standards in the near future:

- The Reliability, Availability, Maintainability, and Safety standard (RAMS)
- The software safety standard
- The railway signal failsafe transmission standard
- The signal system safety requirements and document control standard

In addition to the above, the Urban Guided Transport Management and Command Control standard (UGTMS) and the Automated Urban Guideway Transit (AUGT) standard have been discussed, and these international standards can no longer be ignored when trying to implement future railway signal systems. Needless to say, research and development must be carried out while also taking these standards into consideration.

8 Conclusion

This paper has discussed why signal system innovations are necessary from the point of view of the history of signal system development, and it has also explained related issues and solutions. I hope the readers have come to understand that the establishment of a network signal control system using an optical cable is not our ultimate goal, but only a part of the solution. As engineers involved in system creation, I believe our ultimate goal is to redevelop previously established systems into total integrated systems, remove what is not necessary, integrate overlapping features, and to create optimal systems.

References:

1) History of Railway Signal System Development: Signal Safety Institute, 1980.

2) The Latest Japan National Railway Signal Technologies: Signal Safety Institute, 1987.

3) Masayuki MATSUMOTO: Electric Railway, Morikita Shuppan Co., Ltd, 1999.

4) Akira EZAKI: Railroad History from the View of Transportation Safety, Grand Prix Press, 1998.