Hitachi's Initiatives in Addressing the Challenges of 21st Century Railway Systems

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Overview: Railway systems of the 21st century must address environmental issues while providing a high quality of service in terms of comfort and convenience. At the same time, railways must also hold down fixed charges and lower their costs to reinforce the structure of railway operations. The balance achieved in Japan by trains that are highly punctual yet operate at high speed in the dense railway zones has won the widespread approval and support of the overwhelming majority of the user public. Meanwhile, renewed attention is being focused on monorail and linear metro transportation systems offering medium-capacity transport in urban areas at relatively low construction costs, and manufacturers are aggressively moving to meet these needs. In another development, maglevs (superconducting magnetic levitation system) are undergoing test runs, and are making progress toward actual deployment. Further efforts are also being focused on the operations management system, that supports safe and punctual rail operations in corridors and districts of Japan where rail lines are densely concentrated. Hitachi has extensive expertise in the fields of rolling stock, signaling, communications, information systems, and power, not to mention the advantage of a railway operating company within the Hitachi Group. Hitachi is thus particularly well positioned as a comprehensive railway system integrator to meet the requirements of railway companies and to offer creative solutions at the right time.

INTRODUCTION

SURVEYING the railway environment in the 21st century, there is a general expectation that, while reducing CO_2 emissions and addressing other environmental issues, railways must offer a very high level of service in terms of comfort and convenience. At the same time, railway companies must also move aggressively to rollback their fixed and other operating costs to reinforce the basic structural soundness of railway operations.

Many are now showing renewed interest in monorail and linear metro system as viable means of medium-capacity transportation that can be deployed at a relatively modest outlay of construction costs in urban areas. At the same time, the maglev—superconducting magnetic levitation system that are envisioned for the 21st century—are undergoing demonstration trials, and are moving toward practical deployment.

The train operations management system is another critically important technology for supporting safe, punctual railway operations, and will see continued development and refinement in the years ahead.

Based on its accumulated wisdom and experience across a wide range of relevant areas—rolling stock, signaling, communications, information systems, power, energy transformation, and equipment manufacturing—Hitachi is pushing ahead with its R&D initiatives to meet the needs of railway companies as a railway comprehensive systems integrator. In this article we will survey some of the key issues confronting the rail industry, and highlight Hitachi's proactive efforts to address those issues. Fig. 1 illustrates the diverse range of research undertaken by Hitachi in its role as a systems integrator.

CHALLENGES OF A RAILWAY SYSTEM FOR THE 21st CENTURY

Fig. 2 shows an overview of some key issues relating to railway systems. In order to reinforce the basic structural soundness of their operations, first and foremost railway companies must provide safe and punctual transportation, yet at the same time they must hold down and even reduce their fixed and other operating costs. In the near future, we can anticipate large-scale reductions in personnel of railway companies as the workforce continues to age, and inevitably this will require labor-saving and cost saving modernization across the rail industry. Yet at the same

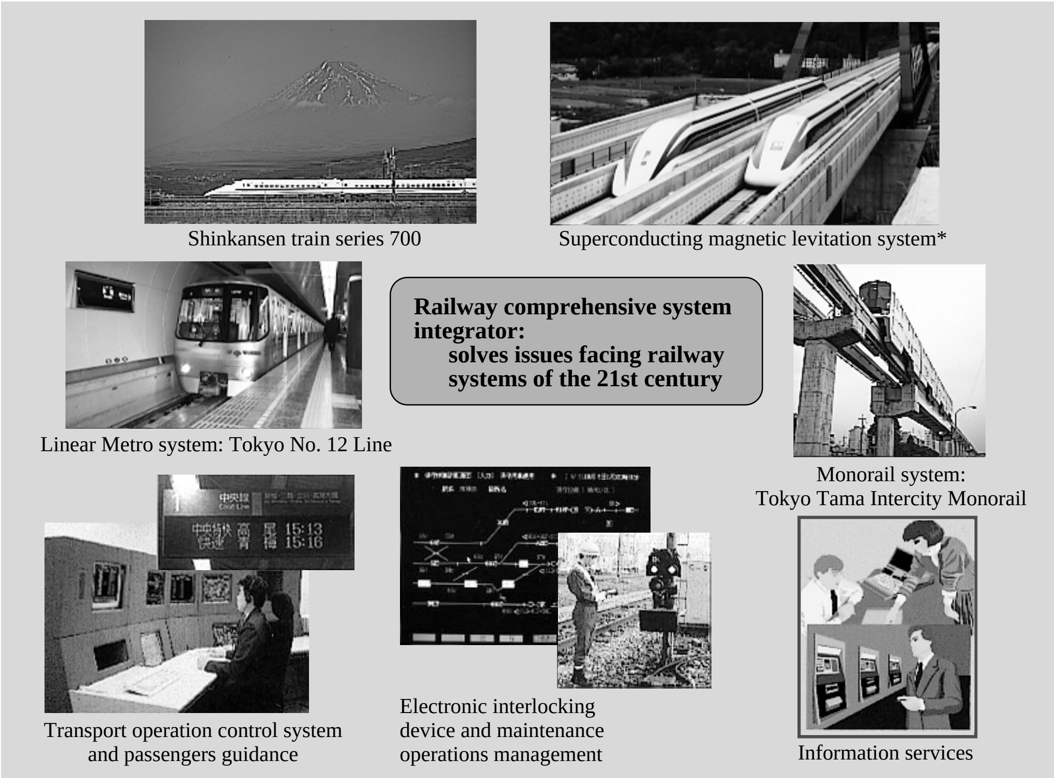

Fig. 1—Projection of the Railway System of the 21st Century.

**Photo courtesy of Central Japan Railway Company.*

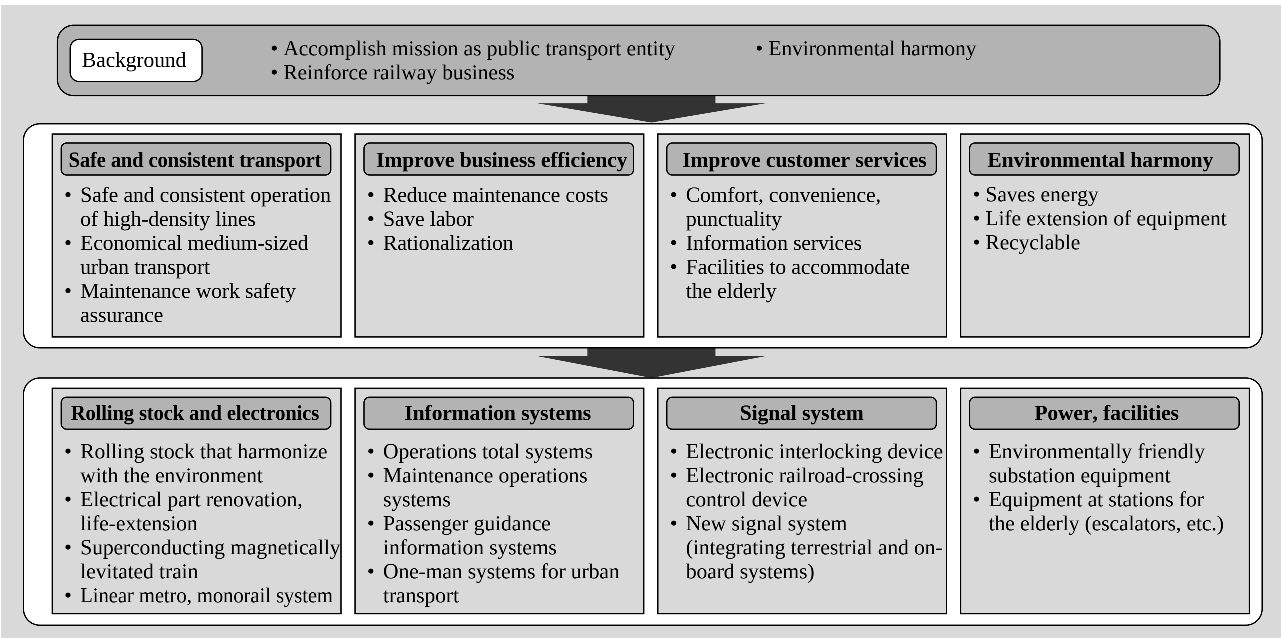

Fig. 2—Key Issues for Railway Systems of the 21st Century.
In its capacity as a comprehensive system integrator, Hitachi is responding to the needs of railway companies across a broad range of issues: railcar, electrical, information systems, signaling systems, power, facilities, and more.

time, it is also necessary to conceive enticing new services sustaining and even increasing rider demand, while addressing the problems of urban transport in a way that harmonizes with the environment.

Hitachi is pushing the state of the technology across a broad range of relevant areas to meet these needs, including ground-breaking work on rolling stock, information systems, signaling systems, power equipment, and many other types of facilities and equipment.

ROLLING STOCK TECHNOLOGY

In this section we will review Hitachi's current initiatives in the area of rolling stock systems.

Enhancing the Speed, Environmental Impact, and Comfort of Trains

Hitachi has developed a substantial number of high-speed trains for long-distance inter-city transport. The work being carried out will provide the technological underpinnings to support higher speeds, while at the same time wrestling noise and vibration issues to minimize the environmental impact. Environmental compatibility will become increasingly important as time goes on, and renewed R&D emphasis is being placed on environmental concerns. Fig. 3 highlights the main technological issues relating to the train systems that are currently being wrestled.

Shinkansen trains (High speed trains)

Hitachi's R&D efforts to reconcile lower noise and vibration to satisfy environmental concerns with higher speed led to the development of the efficient, lightweight 500 series and state-of-the-art 700 series Shinkansen trains that reach a world-class running speed of 300 km/h in revenue service. In terms of carrying capacity, the double decker E4 series Shinkansen trains are capable of transporting most passengers than any other comparable train. Our success in reducing vibration and noise can be attributed to a number of R&D initiatives: aerodynamic analysis of the front shape, development of a low-noise pantograph, smoothing the outside sheet of car body, lightweight aluminum-alloy car body structure (e.g., honeycomb and double-skin aluminum-alloy structures), modualization of inner packages, and implementation of more compact, lighter equipment.

Trains for existing lines

Hitachi developed an active tilt system that permits trains to pass each other at higher speed on curved sections. This enabled limited express trains to run faster while maintaining enhanced ride center of gravity. We are now trying to integrate this technology with a tilt system and vibration control system that promises to enhance the speed performance and comfort of trains even more. In another development, an aluminum double skinned body shell structure and modularization of inner packages were incorporated

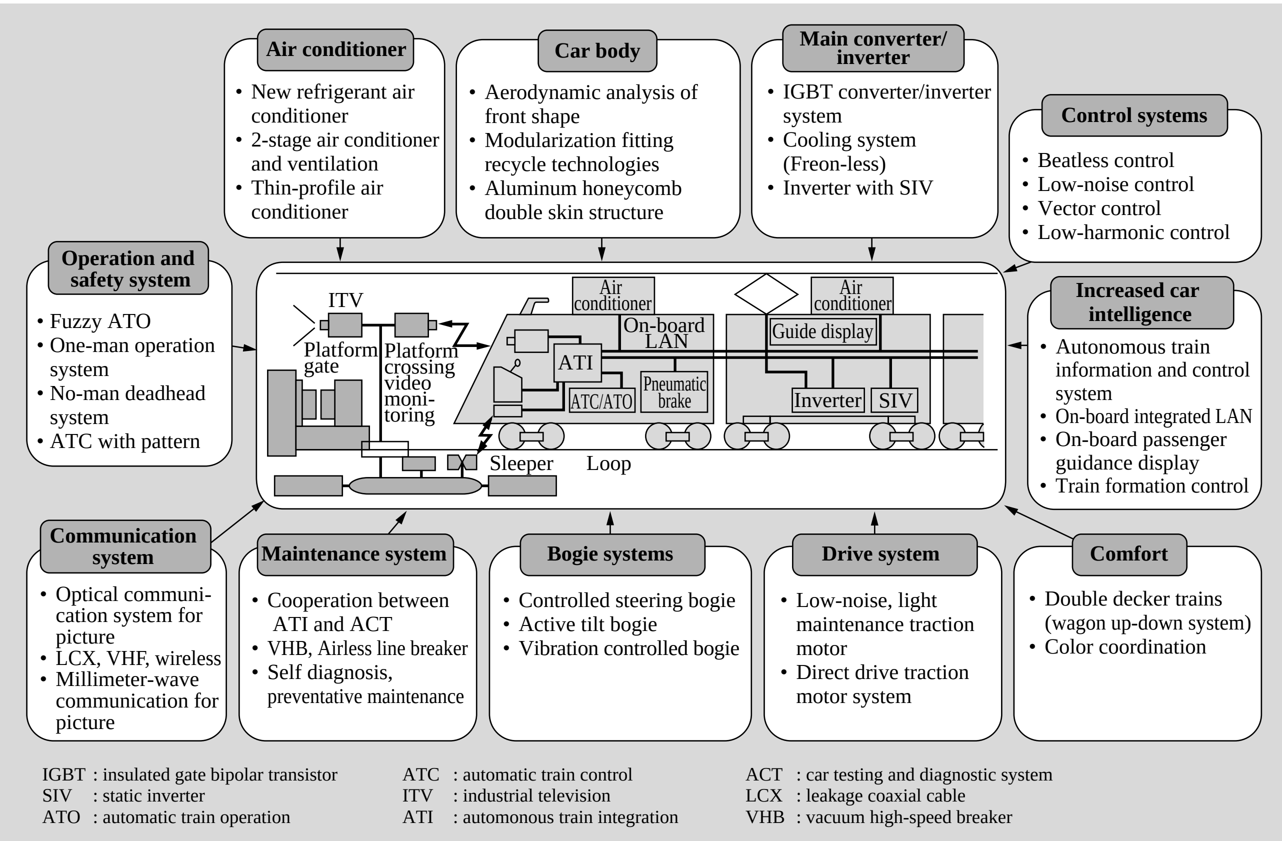

Fig. 3—Train System-oriented Technologies.
The latest technologies are incorporated in train and electrical systems to promote consistent transport, improved business efficiency, better service, and minimal environmental impact.

in the FRESH HITACHI E653 series limited express trains. This type of environmentally friendly train has been deployed not only on limited expresses but on commuter service trains as well, and we anticipate further refinements as time goes on.

Superconducting magnetic levitations system (Maglev)

The practical feasibility of a magnetic levitation system, which is widely anticipated as the high-speed railways of the 21st century, is being evaluated at the Yamanashi Maglev Test Line. Speeds of up to 550 km/h have been reached, and trials are now underway to evaluate the viability of two trains passing with a mutual speed of over 1,000 km/h. Hitachi is closely involved in maglev project integrating R&D on aluminum honeycomb carbody, controls on board of the train, sidewall traction and levitation coils, the operating control system, the power converter, and other elements as a total system.

Enhanced Functionality and Performance of the Propulsion and Control System

Basic research objectives are to enhance functionality and performance by reducing size, weight, energy, and maintenance to increase the speed of inter-city trains like the Shinkansen while increasing the density, the commercial speed by high acceleration and deceleration train of existing trains and subways in urban areas. At the same time, another important research objective is to minimize the environmental impact of railway systems.

IGBT-implemented propulsion system

In one ground-breaking project, Hitachi developed a new insulated gate bipolar transistor (IGBT) technology for application to rolling stock, and incorporated the part in a traction inverter. After developing a practical working version 3.3-kV, 1,200-A IGBT, we implemented a robust large-capacity IGBT-based series. The controllability and environmental impact of the part was carefully evaluated, and the device has now been widely incorporated in urban transportation systems, Shinkansen trains, and locomotives.

Propulsion system for ac line

IGBT-based inverters were first incorporated in dc line train, followed more recently by the development of IGBT-based converters and inverters for ac line train. By implementing low-harmonic control in ac line trains that holds the power factor to 1 and suppresses harmonic noise, excessive clean current can be returned to the power company using an ac regenerative brake control system. This system has already been implemented on 731 series commuter and E653 series limited express trains, and efforts are now underway to adapt the system for use on the latest 700 series Shinkansen trains.

Propulsion system support control technology

A high-speed and high-capacity microcomputer was implemented to save energy, reduce noise, and achieve low harmonics to enhance the performance and functional capabilities of the inverter traction system. Practical versions of a number of key control systems for ac trains have been developed including a power factor controller that holds the phase angle between current and voltage constant, harmonic reduction control, and beatless control. In addition, the availability of a practical vector control technology for dc as well as ac trains has increased the regenerative brake efficiency and realized more advanced adhesion (slip/slide) control. Finally, a low-noise control capability was realized using a spectrum diffusion technique.

Train information and control systems

Train information and control systems are implemented as a way to achieve more intelligent, information-oriented trains. A wide range of systems and functions have been developed and deployed to support drivers and maintenance personal including an autonomous distributed double loop integrated LAN mounted on board of trains, equipment status monitoring, fault and failure recording, emergency instructions are displayed when problems occur, remote operating capability, control command transmission, a capability to check on board of trains, traveler guidance display, and capabilities to convey commands to service equipment.

Development efforts will continue over the near term in an effort to organically integrate the separate subsystems of the train, to coordinate and synchronize data with landline systems, and to expand functions for operation and safety functions, including the signal systems and train formation control as well as the one-man and the driverless operation systems.

Air conditioning and ventilation systems

Another cornerstone of Hitachi's R&D effort is to develop air conditioning and ventilation systems that meet the needs of improved passenger comfort while remaining friendly to the environment. A practical two-stage air conditioner/ventilating system was developed that features an approved environmentally friendly substitute refrigerant for Freon R22, a more compact implementation, and substantial energy savings along with better refrigeration capability by implementing a two-stage heat exchanger.

URBAN TRANSPORTATION SYSTEMS

Hitachi has developed and deployed monorail and linear metro systems as viable means of medium-capacity transportation that can be deployed at a relatively modest outlay of construction costs in urban areas. Fig. 4 illustrates the tradeoff between construction costs and carrying capacity for a number of different transportation systems.

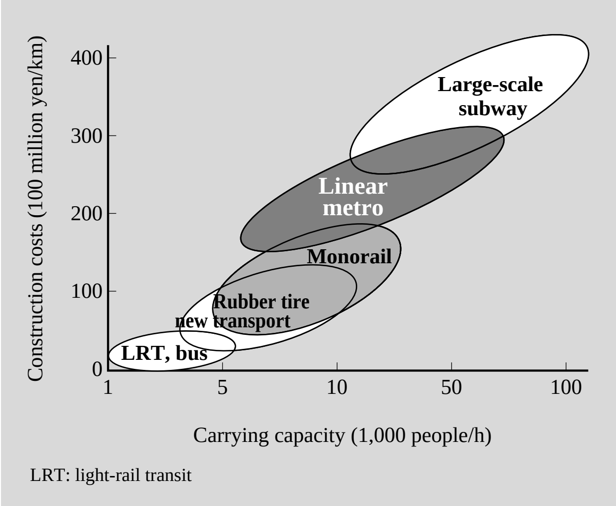

Fig. 4—Carrying Capacity Versus Construction Cost for Urban Transport Systems.
Construction costs of linear metro lines are less than those of conventional subway lines to the extent the cross sections of tunnels are less. Monorail has greater carrying capacity than new rubber-tired transport, but the construction costs are comparable.

Monorail System

Hitachi deployed a fully operable straddled-type monorail system as early as 1964 in Tokyo. That line was so successful that it was followed by four monorail lines. Currently, four lines including extension lines are under construction. Straddled-type monorails offer a cost-effective urban transport system. They have low adverse impact on the cityscape because they are deployed over existing roadways, they interfere very little with the road surface below, and they are very user friendly in terms of the vibration and noise that they produce. In line with recent urban planning for core regional cities, Hitachi is currently studying the feasibility of monorail systems with relatively small carrying capacities that can be constructed at modest cost.

Hitachi is also expanding aggressively in offshore markets with the ability to handle a total project from the initial planning stage to design, fabrication, and even maintenance and operation of rail systems.

Linear Metro

The Linear Metro is driven by a non-adhesion steel wheel/steel track system that does not rely on friction between the wheels and the rails to haul the train. Two advantages of this approach are that it enables great freedom in route planning since trains are able to negotiate steep gradients and sharp curves safely and smoothly, and it reduces tunnel construction costs by reducing tunnel cross sections.

Hitachi conceived the basic system configuration of the Linear Metro in 1978, and spearheaded the development since then as the primary manufacturer. The Linear Metro has been adopted in Japan by two transport authorities: the Osaka Municipal Transportation Bureau and the Transportation Bureau of the Tokyo Metropolitan Government. Currently, Hitachi is constructing a fleet of Linear Metro trains to fill a blanket commission from Transportation Bureau that will run on the loop portion of Tokyo Subway Line No. 12 when it is partly opened. In addition, three other cities in Japan are planning to deploy Linear Metro lines.

It is anticipated that the Linear Metro will not be confined to subway routes but will be adapted for use on elevated railways as well.

One-Man and Automatic Operation Systems in Urban Area

To enhance efficiency and save labor, Hitachi has developed a suite of robust systems that support automatic operation and/or operation by a single traincrew. These key systems include Automatic Train Operation (ATO), Automatic Train Control (ATC), an operating management system, an automatic broadcast guidance system, Autonomous Train Integration (ATI), station platform door control system, and wayside to train image and data transmission system for monitoring station platforms. We will certainly see further R&D focused on this area in the years ahead.

OPERATION CONTROL SYSTEMS

In another recent development, sophisticated new operation control systems were introduced with the aim of boosting overall efficiency of the Operations Division and improving passenger services.

Autonomous Decentralized Transport Operation Control System

The prime example of a system that substantially upgrades the efficiency of overall operations in areas of high rail density is the Autonomous Decentralized Transport Operation Control System (ATOS). Fig. 5 shows a schematic diagram of the system as it is deployed in the Tokyo metropolitan area.

The reach of the preexisting operation control system was vastly extended and the efficiency of on-site operations markedly improved by implementing an autonomous decentralized system using a large number of general-purpose computers. When trains get off schedule, the system greatly relieves the burden on the controller by working in concert with the train movement adjustment function that is manipulated by the controller, by regulating the spacing between trains, and by providing all automatic routing control at each station. The system demonstrates the full range of its capabilities and power in this situation when trains get either ahead or behind schedule.

The maintenance work management system was developed to better ensure the safety of maintenance crews and to improve the efficiency of track maintenance work. The system not only ensures safety by interlocking zones where work is being done to prevent trains from entering, it also lets the maintenance personnel directly set and release track closures, and route setting of maintenance cars using a wireless handy terminal. This arrangement not only allows maintenance crews to work without having to rely on a signal controller back at the station, it also promotes far better system-wide safety and efficiency by enabling individual maintenance personnel to control their own work schedules when many jobs are involved even when there are many trains running in the area.

Shinkansen Operation Control Systems

The first operation control system that was deployed to assist in running Japan's railroad pride—the high-speed, frequent Shinkansen trains—was the Computer-Aided Traffic Control (COMTRAC) system on the Tokaido and the Sanyo Shinkansen routes, which has now been contributing safe, punctual Shinkansen travel

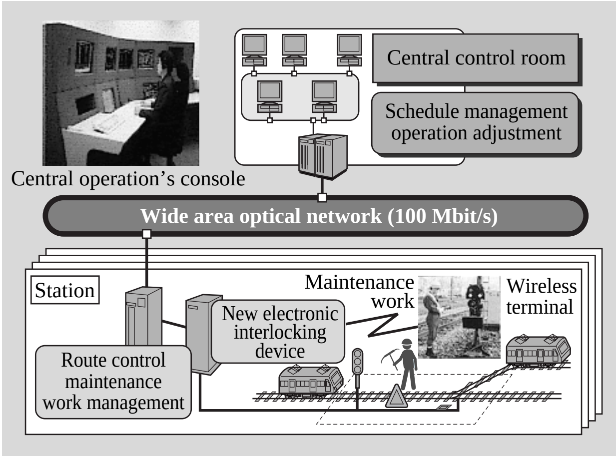

Fig. 5—Overview of the Autonomous Decentralized Transport Operation Control System.
System contributes to rationalization and safety assurance of station operation work.

for more than a quarter of a century. Today a second command center for the Tokaido and Sanyo COMTRAC system has been erected as a backup in case the first one is knocked out by an earthquake or other natural disaster.

To streamline overall operations and improve Shinkansen service for the 21st century, COSMOS (Computerized Safety, Maintenance and Operation Systems of Shinkansen) was constructed on the Tohoku and Joetsu-Nagano line in 1995, and has been running stably for the past four years.

NEW SIGNAL SYSTEM

Past Signal System Efforts

Hitachi has been involved in the research and development of signal systems since 1990. In order to improve the rail operations, the traditional signal system of past must be totally changed. The problem with the preexisting system is that to assure safety it employs numerous proprietary components and lacks flexibly. This means that it is very difficult to incorporate new features or capabilities in the old system. This led us to develop an all new signal system that, while implemented using general-purpose computers, nevertheless provides equivalent or better safety than the conventional system. One of chief advantages of the new system is its flexibility which allows new functions to be added at will.

Fig. 6 shows an overview of Hitachi's signal system development efforts. One can see that beginning with an electronic interlocking device we have developed a wide range of signal equipment over the years including an electronic railroad-crossing control device, a network for linked stations with a central system, a next-generation signal system, and a variety of different switches. Our objective is to make railroad signal system even more robust and reliable by broadening their range of applications and by taking fuller advantage of advanced information technologies.

New Electronic Interlocking Device

We succeeded in developing a fail-safe electronic interlocking device by exploiting the latest information technologies and using general-purpose computers. This has enabled us to go beyond conventional interlocking capabilities to streamline station operations by implementing shunting work control, line closure interlocks for maintenance work, and other capabilities using a wireless terminal.

The logic in the new electronic interlocking system has been implemented in software, so the reliability of the software becomes an issue. We were able to overcome this problem by representing interlocking tables as diagrams that can be interpreted and processed as is. We also developed an automatic testing system that automates the tedious and time-consuming interlock testing process, and this substantially improved the efficiency of the testing process. These measures greatly increased the flexibility of the system, thus yielding information-based electronic interlocking system that is excellent in terms of maintainability and scalability. Currently, some 94 of these robust electronic interlocking systems are in use, and they perform very stably.

Next-generation Signaling System

Traditional signal systems use on-site ground-based train location detection and control logic, and are controlled by commands coming from ground-based equipment. These systems thus involve a great deal of ground-based equipment and a huge effort to keep it maintained.

The next-generation signal system is being completely revamped by applying a consistent concept to the conventional ground/car ATC (Automatic Train Control), interlocking, and route control. With this approach, the control is implemented for all the railcars by endowing the cars with enhanced intelligence. Wireless transmission is used for communication between ground-based facilities and trains, and this enables ground-based equipment and maintenance to be substantially reduced. It also permits movement blocking schemes to be applied in high-density rail traffic areas.

As a key element in the development of this next-generation signaling system, Hitachi completed the phase-one trials of the ATACS system on the Senseki Line, and we are continuing to further develop and refine the system. Fig. 7 shows an overview of the next-generation signaling system.

NEW INFORMATION SYSTEM

System for Upgrading Customer Services

Going into the 21st century, it will be increasingly important to bolster customer services systems in order

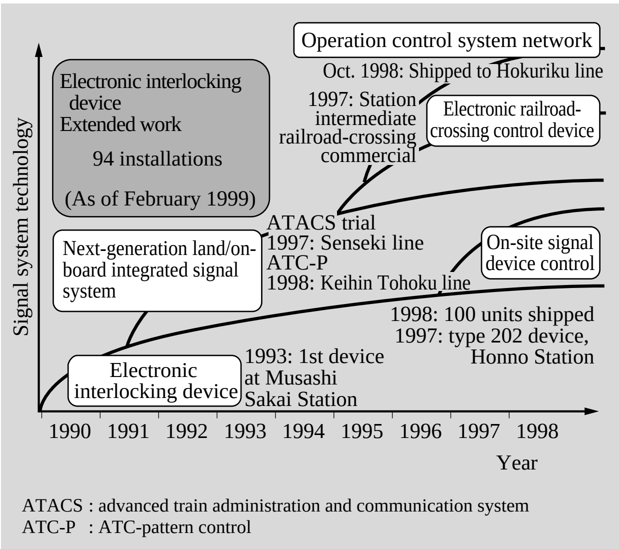

Fig. 6—History of Hitachi's Efforts on New Signal Systems.
Hitachi has developed a wide range of signal equipment over the years including an electronic interlocking device, an electronic railroad-crossing control device, and a next-generation land/on-board integrated signal system.

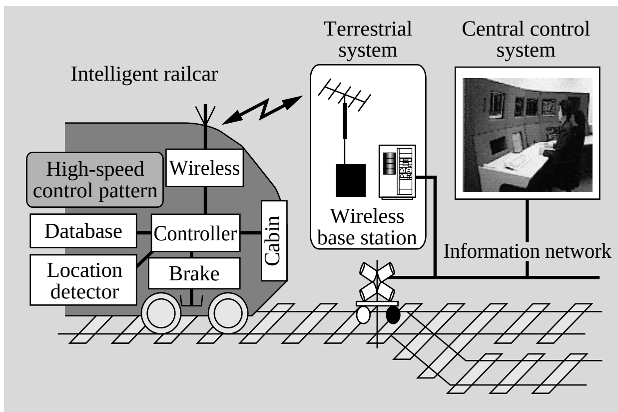

Fig. 7—Schematic of Land/on-board Integrated Next-generation Signal System.
The next-generation signal system is a new intelligent on-board signal system that communicates between ground-based and on-board equipment using wireless communications.

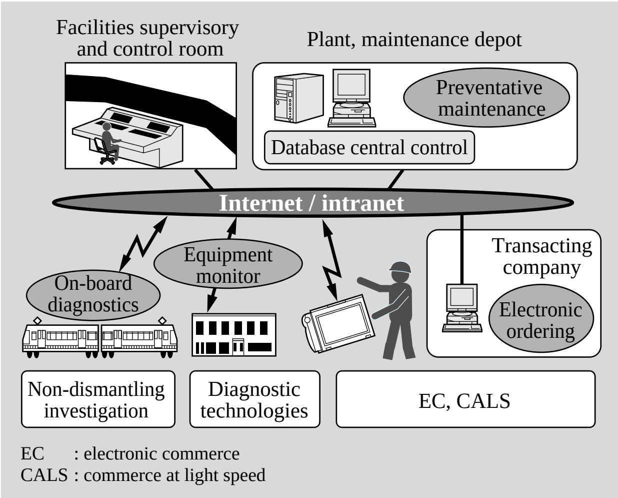

Fig. 8—Overview of New Maintenance System.
The system adopts a network-centered approach to reduce maintenance costs using CALS, equipment monitors, on-board diagnostics, and so on.

to build rail travel appeal and increase the number of passengers. There are many issues pertaining to customer service that must be addressed; these include information services such as the capability for passengers to make hotel and car rental reservations from on board the train, and providing more extensive guidance information for travelers at train stations. In order to address these needs, Hitachi is implementing a mobile communications network linking railcars with the landline network, and seriously contending with other issues involved in deploying a more robust information service system.

Maintenance CALS

Railways have an huge amount of equipment and facilities that must be maintained on a regular basis, and figuring out how to manage this maintenance operations is a major issue. There has been a growing tendency in recent years to convert data, documents, and software relating to equipment and facilities into electronic format. The ability to systematically manage these data resources—not only within individual railway companies but also for exchanging data with associated manufacturers and construction companies over a linked network—would save a tremendous amount of labor and improve efficiency. Implementation of a maintenance-oriented CALS (Commerce at Light Speed) system will be highly effective for achieving these goals. Fig. 8 shows a schematic overview of a new CALS-based maintenance system.

CONCLUSIONS

In this article we have surveyed some of the key issues confronting the rail industry, and highlighted Hitachi's proactive efforts to address those issues. As an environmentally friendly form of public transportation and communication industry affecting a large proportion of the population, the railways have excellent prospects for continued growth and development in the years ahead. In this era of globalization, Hitachi is pushing ahead with its R&D initiatives on everything from rolling stock to systems in order to meet the needs of railway companies and to offer creative solutions as a comprehensive systems integrator.

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