Overview

Railway Systems Designed for Greater Comfort and Environmental Performance

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CHALLENGES FACING RAILWAYS SYSTEMS AND HOW TO RESPOND

THE circumstances in which railway systems operate have been changing in recent years due to factors such as global environmental problems, a falling birth rate, and an aging society. Although railways are a very energy-efficient form of transportation compared to cars and aircraft, they still need to achieve greater energy savings in order to respond to global environmental problems. Meanwhile, as the birthrate falls and the population ages, there are demands from the elderly and others to provide greater support for mobility. For their part, railway operators are losing experienced staff and have fewer people able to take their place, and this too is creating a greater need for supporting technologies such as information and communication technology (ICT). Meanwhile, there is ongoing demand from transportation agencies to improve comfort in order to enhance the advantages of railways.

Ongoing technology development aimed at ensuring safe and reliable operation is also important.

OVERVIEW OF TECHNOLOGY DEVELOPMENT AND KEY SECTORS

Hitachi is a total system integrator for the railway industry, with a product range that includes rolling stock and drive control systems as well as traffic

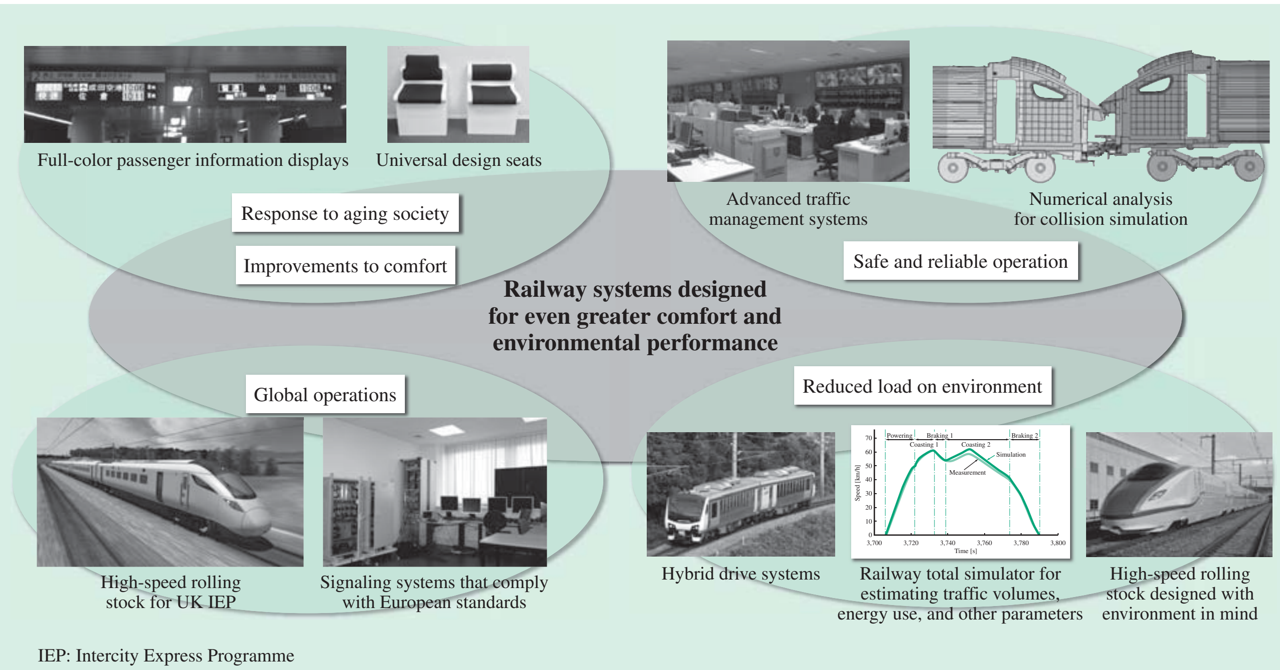

Fig. 1—Railway Systems Designed for Greater Environmental Performance and Comfort.
As a total railway system integrator, Hitachi is developing technologies for railway systems that combine environmental performance with comfort.

management systems[a], power management systems, and information services. It develops advanced technologies for faster trains, higher traffic densities, more punctual service, and more reliable operation, so that it can contribute to advances in these fields. As a global company, Hitachi supplies products throughout the world. This makes it able to contribute to the development of railways not only in Japan but also in other countries such as the UK and China, with products including medium- and high-speed rolling stock and signaling systems that comply with European standards (see Fig. 1).

Table 1 lists the challenges that railways need to overcome and the main research and development being undertaken to achieve this.

The first challenge is energy efficiency, a field in which developments by Hitachi include reducing the weight of rolling stock to reduce energy use and energy-saving technologies based on the use of batteries. The second challenge is to improve comfort. Work in this area includes providing passengers with information services using on-board displays, and making its products barrier-free (accessible to the disabled). The third challenge is to improve operational safety and reliability. Examples of this work include further development of traffic management systems, the development of techniques for providing emergency traction power using regenerative energy storage systems, and improvements to the productivity of maintenance and inspection work. Through these technical developments, Hitachi aims to contribute to the ongoing future progress of railway systems.

(a) Traffic management system
A computer system for centralized management and realtime control, with functions that extend from producing train schedules to the automatic realtime control of train operation, signals, points, and other equipment; the use of train schedule predictions to support rescheduling; and the monitoring, control, and maintenance of equipment. It also includes other systems such as those for passenger information.

Table 1. Challenges, and Research and Development Aimed at Overcoming Them

Hitachi is responding to challenges with a variety of approaches to research and development.

Challenge	Research and development response
Energy efficiency	• Energy saving technologies for rolling stock (lighter weight, LED lighting, etc.) • Energy saving technologies for traction systems (SiC-based technologies, etc.) • Energy saving technologies utilizing batteries • Technologies for energy management systems that coordinate on and off-train systems
Improve comfort Aging society	• Comprehensive information services for passengers (on-board displays, platform displays, etc.) • Rolling stock designs in harmony with location • Application of experience design • Barrier-free accessibility, universal design
Safe and reliable operation	• Technologies for using regenerative power storage systems to supply emergency traction power • Development of crashworthy structures for rolling stock • Productivity improvement for maintenance and inspection work

LED: light-emitting diode SiC: silicon carbide

DEVELOPMENT OF TECHNOLOGY FOR ROLLING STOCK SYSTEMS

Hitachi supplies rolling stock for Shinkansen and commuter trains, designed to reduce the load on the environment by being built from aluminum alloy for light weight. To meet demands over recent years for improved comfort, Hitachi has adopted active suspension[b] on its latest high-speed Shinkansen rolling stock to minimize the transmission of vibrations through the floor when traveling at high speed.

To provide barrier-free accessibility, braille signage is provided on the deck to indicate the passenger compartment layout, and braille seat numbers are provided at the top of all seats in the Series E7 and W7 high-speed Shinkansen rolling stock built for the East Japan Railway Company and West Japan Railway Company, respectively. Hitachi is also progressively adopting other products that provide barrier-free accessibility, including multi-function toilets that are designed for use with electric wheelchairs (see Fig. 2).

Energy efficiency improvements are also being developed for commuter trains. Reducing lighting power consumption in rolling stock has become an important issue in recent years, with ongoing adoption

(b) Active suspension
A suspension system comprising control equipment, electric actuators, and sensors for detecting carbody perturbations that provides a comfortable ride at high speed by operating the actuators in response to movement of the carbody to minimize lateral vibration.

Fig. 2—Braille Signage and Multi-function Toilets for Latest High-speed Shinkansen Rolling Stock.
The latest high-speed Shinkansen rolling stock use internal fittings selected with barrier-free accessibility in mind.

Fig. 3—Mockup of UD Seat.
Hitachi is developing UD seats for use in trains.

Fig. 4—TMK10000 Series Monorail.
The exterior design was chosen to harmonize with the surrounding area.

of light-emitting diodes (LEDs) for headlights. Hitachi has demonstrated that LED headlights can provide better visibility and illumination than the sealed beam or high-intensity discharge (HID) lamps used in the past. The power consumption of LED headlights is only about one-sixth that of HID headlights.

Universal design (UD) seats are increasingly being adopted at public and medical institutions to provide priority seating that is less physically demanding to use for those such as the elderly or people with reduced mobility who need a long time to sit down or stand up. Hitachi is working on development aimed at adapting these UD seats for use on trains. Based on market research and other studies, Hitachi has identified "having the seat higher off the ground but shorter in the depth direction to make sitting down and standing up easier" as a key requirement, and is aiming to develop seats that provide the following benefits: (1) reduced physical effort for sitting down by avoiding the need for major bending of the knee, and (2) a larger available area in the train interior by raising seat height and making seats less deep. To prepare for commercial use, Hitachi evaluated and tested these UD seats under actual conditions (see Fig. 3).

Hitachi has also developed the 10000 Series monorail rolling stock for Tokyo Monorail. This series is based on Hitachi's A-train technology and optimized for use on monorails. The carbodies are built from lightweight and easily recyclable aluminum alloy, and use friction stir welding (FSW), a proven technology for carbody welding, to minimize welding-induced distortion. The exterior design represents the sky, sea, and parkland character of the surrounding area (see Fig. 4).

DEVELOPMENT OF NEXT GENERATION OF TRACTION DRIVE SYSTEMS

Along with reducing the losses from individual items of equipment such as the inverter and traction motors, Hitachi is also seeking to improve the energy efficiency of traction drive systems by working on developments that use system control to reduce power consumption. Fig. 5 lists work being undertaken on the next generation of traction drive systems.

For inverters, Hitachi has been improving the efficiency of individual components by, for example, developing silicon carbide (SiC) hybrid modules. These modules succeed in reducing inverter size and weight by 40% and power loss by 35%, compared with the silicon (Si) components typically used in past inverters.

To improve energy efficiency further, Hitachi has developed a technique that uses PWM[(c)] control to reduce motor losses.

(c) PWM
Abbreviation of "pulse width modulation." A technique for controlling output voltage (and current) by varying the on-time (width) of pulses (electric signals that alternate between on and off). The technique has excellent controllability and efficiency, and is widely used in inverters.

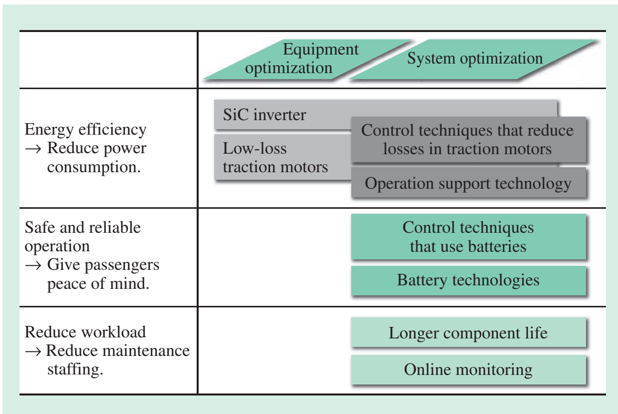

Fig. 5—Work on Next Generation of Traction Drive Systems.
Development work extends from the optimization of individual items of equipment up to system optimization.

Hitachi is also improving the efficiency of traction motors by developing techniques that reduce the losses that occur in these motors, including iron losses, copper losses, mechanical losses, and harmonic losses(d). To reduce iron and copper losses, Hitachi is increasingly utilizing the low-loss materials used in traction motors for the Shinkansen in commuter trains also. Hitachi has succeeded in reducing total losses by approximately 11% compared with previous models by using detailed analysis of magnetic fields to determine the harmonic flux distribution in traction motors and then developing inverter control to reduce harmonic losses, and also by developing traction motors that use low-loss materials.

GLOBAL OPERATIONS

To serve the global market, Hitachi has developed the Class 800/801 rolling stock for the Intercity Express Programme (IEP) that will run between London and other major cities in the UK. The IEP is intended to replace all of the rolling stock on the UK's East Coast Main Line and Great Western Main Line, which have been in service for more than 30 years (see Fig. 6).

The Class 800/801 rolling stock needs to comply with the latest European and UK railway standards and have the flexibly to run on a number of different lines with different infrastructures (some of which are not electrified), and to adapt to future plans for electrification and variable passenger demand. Trains have a unit configuration of up to 12 cars, including the ability to add or remove standardized intermediate cars and generator units (GUs) consisting of a diesel engine and generator, which is needed to operate commercial services on non-electrified lines.

Europe has standards for collision safety performance. To develop crashworthy structures that comply with these standards, Hitachi first conducted dynamic crash tests on a full-size leading car to demonstrate the structures' basic characteristics. This also included confirming that numerical analysis simulations could reproduce the test results. This numerical analysis technique was also used to verify collision safety performance by simulating a crash for a multi-car train, something that is difficult to test by experiment.

To enable its signaling systems to be marketed globally, Hitachi has successfully developed products that comply with the European Train Control System (ETCS)(e), a European common standard for signaling systems. The newly developed ETCS-compliant signaling system complies with European standards. It has been certified by a certification agency, having undergone an audit by a notified body (NoBo)(f) and third-party independent safety assessor (ISA) to verify that it has been designed and tested in accordance with the standard and achieves the stipulated reliability (utilization) and safety (critical failure rate) targets.

(d) Iron losses, copper losses, mechanical losses, and harmonic losses
Iron losses occur due to the time-variation of magnetic flux in the core of a transformer or motor, copper losses occur due to the resistance in the coils of a transformer or motor, and mechanical losses result from friction between the motor bearings and brushes and from the air resistance of the rotating parts. These are the main losses that occur in motors and similar devices. Harmonic losses are the result of harmonics (current distortion) generated by one electrical machine affecting another.

(e) ETCS
Abbreviation of "European Train Control System." ETCS is a train control system for intercity services that was established to allow trains to operate across borders within Europe. Use of ETCS is obligatory in Europe in particular under a European Union (EU) directive.

(f) NoBo
Abbreviation of "notified body" (third-party certification agency). An organization that reports to the European Commission and is made up of government-appointed members. The members are selected according to whether they satisfy the requirements, including knowledge and independence, needed to assess compliance with common and other standards.

Fig. 6—Class 800/801 High-speed Rolling Stock for UK IEP.
The rolling stock was developed by applying technologies developed in Japan for lighter weight and higher speed to UK railway systems.

The ETCS-compliant signaling system is the first such safety equipment developed by a non-European supplier to be certified as complying with European standards and with safety integrity level 4 (SIL4)[g]. Hitachi is actively marketing the system in the UK and other markets around the world.

ADVANCES IN TRAFFIC MANAGEMENT SYSTEMS AND SERVICES FOR PRESENTING PASSENGERS WITH EASY-TO-UNDERSTAND INFORMATION

The Autonomous Decentralized Transport Operation Control System (ATOS) is the main control system for railway services in the Tokyo region and is operated by the East Japan Railway Company. In addition to traffic management, it also supports better services for passengers and helps improve the safety of the engineering workers responsible for the maintenance and inspection of railway infrastructure. Having been in service for 18 years, ATOS is currently undergoing a major system-wide upgrade. This includes a major update to the portable terminals used by engineering workers (the "portable terminal for engineering works") based on an experience design approach.

Experience design is about imbuing products and services with the potential for users to obtain rich experiences. This is achieved by identifying users' explicit and implicit requirements and then presenting them in real terms. Specifically, one of the main approaches adopted is based on a human-centered design process and aims to work through an iterative process that involves (1) understanding the users, (2) identifying what they want, (3) building a prototype, and (4) evaluating how well the users are satisfied.

In developing the new portable terminal, Hitachi accompanied engineering workers engaged in overnight maintenance work to observe their use of these devices and to hold consultations. Next, Hitachi determined the design concepts and produced rough sketches and real-size mock-ups to consider the graphic design. Through a process of repeatedly obtaining feedback (comments and suggestions) regarding things like changes to coloration and button layout, they succeeded in developing a new device that is easy for users to operate.

Coinciding with the establishment of a new integrated control center by the Bureau of Transportation, Tokyo Metropolitan Government, the agency responsible for Tokyo's subways, the traffic management systems for the Toei subway lines (Mita Line, Asakusa Line, Shinjuku Line, and Oedo Line) were progressively upgraded beginning in February 2013, with the last line being completed in February 2014.

The upgrade shifted all of the central systems to an integrated control center. Traffic management work has also been made more efficient by having a common user interface, including the traffic display panels for each line that are installed side-by-side in the control room, and also the supervisory control desk screens and inputs (see Fig. 7).

In a measure aimed at ensuring safe and reliable operation, the project included the installation of new

(g) SIL4
An abbreviation of "safety integrity level," SIL is a measure of safety level specified in the IEC 61508 international standard for functional safety based on the magnitude of risks posed by plants and other systems. The four safety levels are from SIL1 to SIL4, with SIL4 representing the highest level.

Fig. 7—Control Room at Integrated Control Center.
Traffic monitoring and automatic control of all trains on four lines is handled from supervisory control desks and the traffic display panels for each line that are installed side-by-side in the control room.

notification displays and the establishment of a new method for delivering operational instructions to train and station staff, integrating these with the automatic rescheduling function to ensure the timely provision of operational instructions to train and station staff and to prevent delays from being exacerbated.

Additionally, the passenger information displays on the Asakusa Line were upgraded to full-color LED displays. These displays provide passengers with easy-to-understand information on train services by using a color-coded display for the various services along the Asakusa Line, including a through-train linking Haneda Airport (Tokyo International Airport) and Narita International Airport.

EASY-TO-UNDERSTAND ON-BOARD PASSENGER INFORMATION DISPLAYS

On-board passenger information displays have increasingly been installed on commuter trains in recent years to provide better passenger information. Hitachi commenced serious development in 2006, by performing information design (visibility and intelligibility) to suit the diverse variety of people who ride on commuter trains. This involved taking account of UD when designing the information to display on passenger information screens. For example, in terms of viewing angle and text size, easy-to-understand designs were achieved by dividing the distance between the passenger and liquid crystal display (LCD) panel into three ranges and stipulating the priority of the information to be conveyed and the text sizes (see Fig. 8).

The on-board passenger information system uses an autonomous-decentralized architecture like those already used for traffic management and other systems. This enables both a high level of equipment utilization and the high-speed distribution of display content, and is particularly valuable when updating content that requires realtime performance, such as news and weather reports.

TECHNOLOGIES FOR IMPROVING ENERGY EFFICIENCY

Further improvement in the energy efficiency of railway systems is needed in response to global environmental problems. Hitachi commercialized a regenerative energy storage system incorporating lithium-ion batteries [stationary energy storage system (SESS)] in 2007 that currently operates at

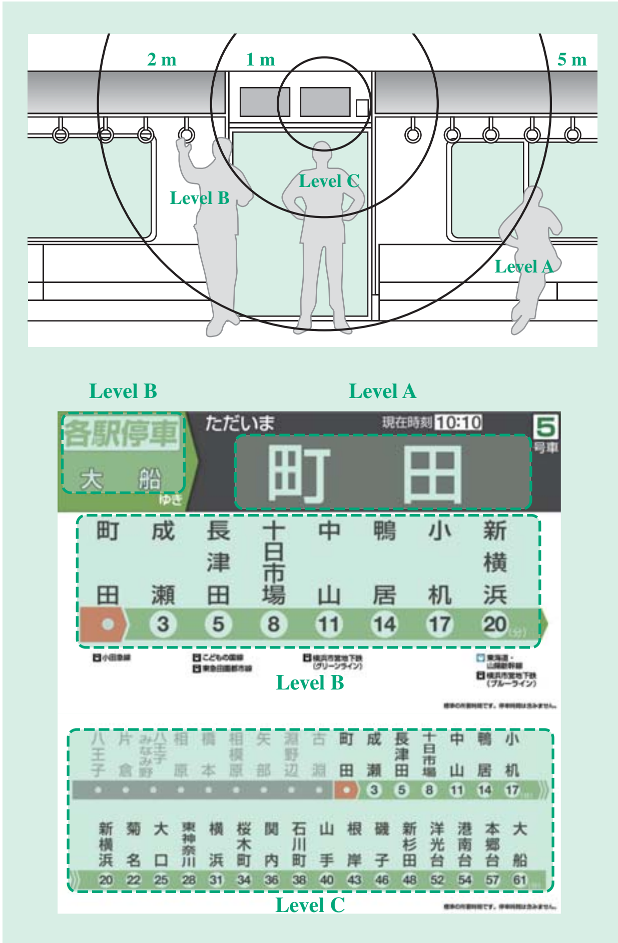

Fig. 8—Viewing Angle and Text Size.
The design divides the distance between the passenger and display panel into three ranges and uses a text size based on the priority of the information.

seven sites. To save power, the regenerative electric power produced during braking is supplied via the overhead lines to other trains that require traction power. However, this regenerative braking becomes unavailable when the number of trains able to use the power falls, such as at off-peak times. The SESS solves this problem by installing wayside batteries to store this regenerative electric power.

Since the Great East Japan Earthquake, there have been heightened concerns about power outages caused by major disasters and other emergencies, and about how to deal with tsunamis. This has led to growing demand from railway operators throughout Japan for the ability to use stored electric power to provide emergency traction power during such an outage. Hitachi and Tokyo Metro Co., Ltd. undertook a demonstration project for such an emergency power system using the technology developed for SESS. This included planning, designing equipment, installing equipment, and performing inductive disturbance testing (to check the effect on the signaling system). On January 26, 2014, it succeeded in powering a 10-car train along a 2.7-km section of the Tokyo Metro Tozai Line from Nishi-kasai to Minami-sunamachi Station.

Growing use is also being made of lithium-ion batteries on the rolling stock itself. To reduce fuel consumption and the toxic emissions released by diesel railcars, Hitachi and the East Japan Railway Company jointly developed a series-hybrid system that combines a diesel engine with lithium-ion batteries. The system reduces fuel consumption and noise by using electric power for both traction and auxiliary equipment, with high-output lithium-ion batteries designed for hybrid cars inserted into the traction drive circuit to implement regenerative braking, idle-stop, and constant-speed operation, functions not possible on conventional diesel hydraulic railcars(h). A Kiha E200 train fitted with the system became the first hybrid train to enter commercial operation in July 2007, with the Series HB-E300 resort train (see Fig. 9) also commencing commercial operation in October 2010.

Lithium-ion batteries have applications in electric trains also. To counter the loss of regenerative energy on rolling stock, Hitachi is seeking to save energy by incorporating battery systems into existing traction systems so that they can use this regenerative energy.

In addition to specific energy-saving technologies for wayside and on-board systems, it is anticipated that advances in the technology for integrating and coordinating these technologies will be made in the future by utilizing ICT. Hitachi is developing an energy management system that is intended to save power by coordinating on-board systems with wayside systems for substations, power system supervisory control and data acquisition (SCADA), and traffic management. Fig. 10 shows an overview of the energy management system. The aim of the system is to reduce the amount of energy used to power the trains by collating information from the rolling stock, substations, SCADA, and traffic management systems, and by issuing "suspension of automatic departure route setting," "coast operation," and other instructions based on the current system status.

Precise simulations are essential to the study of energy efficiency. Hitachi is developing a "railway total simulator" that simulates a railway system to estimate traffic volumes, energy use, and other parameters. The system consists of models of the train operation subsystems running on a common framework (rolling stock, signaling, traffic management, substations, and the electrification system(i), which includes SCADA).

(h) Diesel hydraulic railcar
A railcar that uses a torque converter to transmit motive power from an internal combustion engine to the wheels. A torque converter is a gearing mechanism that uses the mechanical properties of a fluid (oil) to multiply torque through the difference in input and output rotational speeds. They are widely used in applications such as automatic transmissions in cars.

Fig. 9—Series HB-E300 Resort Train.
15.2 kWh of lithium-ion batteries are installed on top of each car.

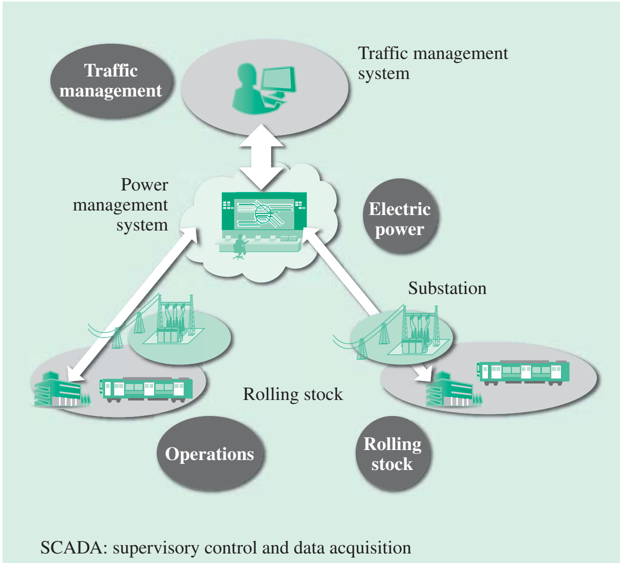

Fig. 10—Hitachi's Concept for Energy Management Systems that Coordinate On and Off-train Systems.
The system reduces energy use by collating information from rolling stock, substations, SCADA systems, and traffic management systems, and by issuing "suspension of automatic departure route setting," "coast operation," and other instructions based on the current system status.

(i) Electrification system
A system for supplying electric power from a substation, via overhead lines (catenaries), to an electric railcar or locomotive. The electric power carried by the overhead lines is used to drive the motors, with the circuit being completed via a return wire (rails, etc.) to the substation. A variety of systems are in use, including both direct and alternating current configurations.

Proposals for saving energy on a particular line can be developed by combining these models and optimizing control.

Understanding how energy is used in a railway system is also essential to the study of energy efficiency. Accordingly, Hitachi has undertaken a joint study of energy use with Okinawa Urban Monorail Inc. An analysis of the effect on energy consumption of using or not using cruise operation (in the latter case, the speed was operated manually by engaging and disengaging the notch setting) found that manual operation used 5% less energy. In operational trials in which trains were or were not allowed to draw traction power simultaneously, a comparison of the energy supplied by the substations found a difference of 10% or more between modes. It was concluded from these results that there is still scope for further improving energy efficiency by adjusting train speed patterns. It was also concluded that energy could be saved by preventing trains from drawing traction power simultaneously. Meanwhile the accuracy of the railway total simulator was assessed based on measurements from the operational trials, indicating that it is able to predict rolling stock energy to within 4% of the measured value. In the future, Hitachi plans to use the railway total simulator to offer a variety of energy saving measures.

DEVELOPMENT OF TECHNOLOGIES TO SATISFY EXPECTATIONS PLACED ON RAILWAYS

Factors such as the growing severity of global environmental problems are driving higher expectations for railway systems throughout the world. While transportation operators are developing a variety of technologies to help create a sustainable society, there is a need for ongoing technical development to further enhance the inherent advantage that railways have of imposing a low load on the environment. In addition to safe and reliable operation, it is also important to develop technologies that will make railways more attractive to passengers, such as through the use of ICT.

As a total system integrator of railway systems, Hitachi seeks to satisfy these expectations. Its aim is to combine technologies from across the companies of the Hitachi Group to create railway systems that deliver even greater comfort and environmental performance.

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