Evaluation Technology for Energy Consumption and Traffic Volume on Railway Traffic Systems and Hitachi's Energy-saving Efforts

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OVERVIEW: Having produced a wide range of different subsystems for railways, Hitachi is able to combine these to offer total railway system solutions. Hitachi also recognizes that reducing energy consumption and ensuring sufficient capacity to satisfy user requirements are important considerations when offering these total solutions. To this end, Hitachi has developed (1) a railway total simulator, the main objectives of which are to predict energy consumption and traffic volumes, and (2) energy-efficient operational technologies that reduce energy consumption. The railway total simulator is made up of building block models for each subsystem, including the rolling stock, signalling system, traffic control system, and power supply system, so that these models can be combined as required to predict energy consumption and traffic volumes under a wide range of different conditions. Hitachi is also working to save energy, having developed energy-efficient operational technologies that use eco-brakes to obtain the maximum benefit from electric braking, driver support technologies, and operational control methods that take account of other trains on the line. This article describes these two technologies.

INTRODUCTION

AS a means of transportation that is conscious of the environment, demand for railways has grown in recent years, with countries around the world planning the construction of railway systems. In the past, Hitachi has used a wide range of different evaluation techniques in the engineering of subsystems such as signals, rolling stock, and propulsion systems. Meanwhile, there has been an ongoing demand in recent years for the supply of total systems made up

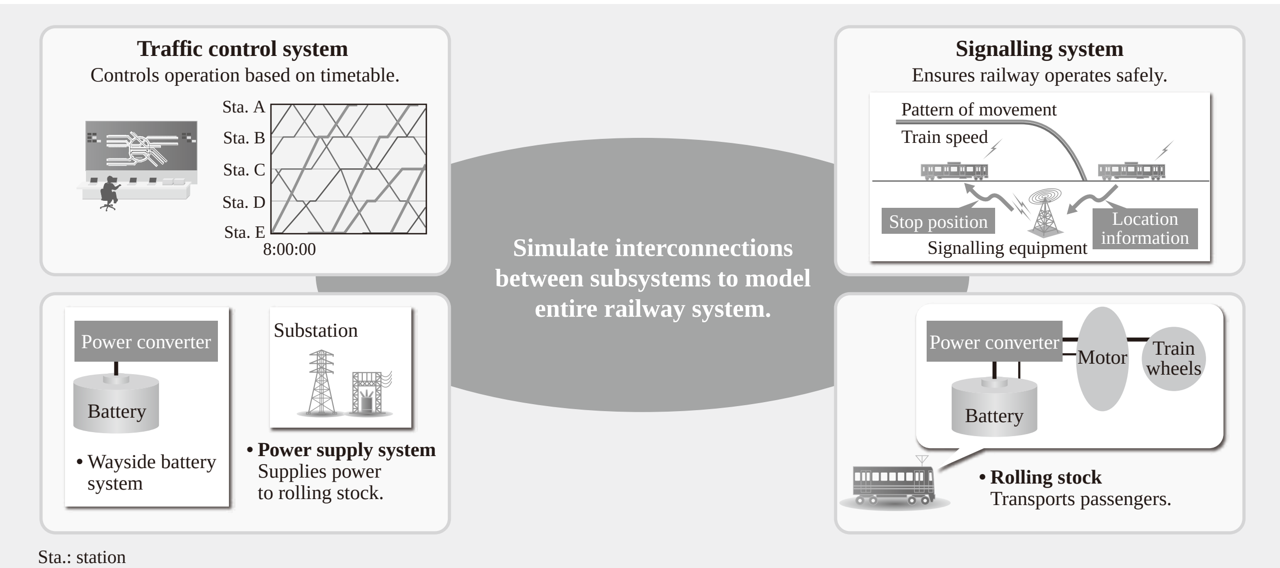

Fig. 1—Overview of Railway Total Simulator.
It is possible to calculate quantitative estimates of the energy costs and traffic volumes for a complete railway system by simulating the standalone operation of the rolling stock, signals, traffic control, electric power, and other subsystems that make up the system, and also the interlock control and other interoperation between subsystems.

of a combination of these subsystems. In Japan, this demand has been for energy efficiency. Elsewhere, particularly in emerging economies, the demand for energy efficiency has also been accompanied by a requirement to deliver sufficient capacity to satisfy customers.

In response to these needs, Hitachi is developing specific energy-saving systems along with a simulator able to perform integrated simulations of entire railway systems so that it can offer solutions based on energy efficiency and railway capacity.

RAILWAY TOTAL SIMULATOR[1]

Features of Railway Total Simulator

A wide range of different simulations can be performed by dividing the railway system into subsystems, including the rolling stock, signalling system, traffic control system, and power supply system; developing models for each of these subsystems and functions; and then running various combinations of these models on a common framework (see Fig. 1). For example, it is possible to simulate the operational performance of rolling stock using models of individual vehicles. Similarly, the energy consumption that will result from a particular timetable can be estimated by combining the rolling stock, traffic control system, and power supply system, as shown in Fig. 2.

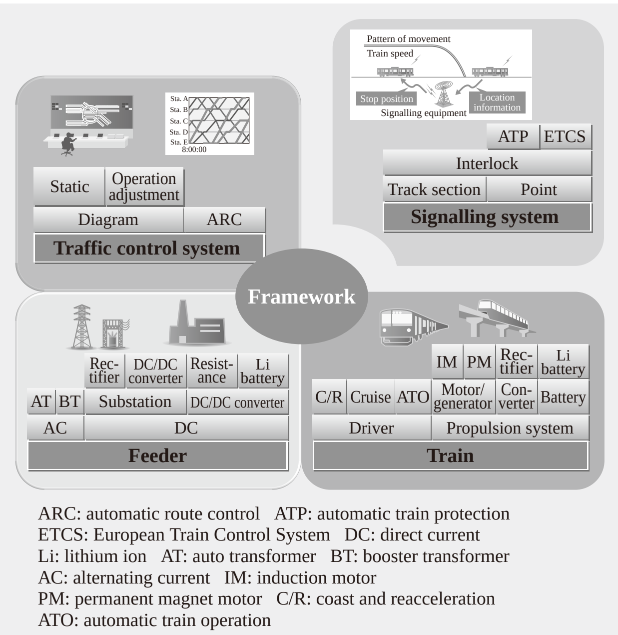

Fig. 2—Features of Railway Total Simulator (Building Block Configuration).
By allowing the user to select the subsystems and other equipment required for a particular simulation, evaluations can extend from individual equipment to the entire system.

It is also possible for the user to select which model to use for each subsystem based on the purpose of the analysis. Examples of rolling stock models include diesel cars and variable-voltage variable-frequency (VVVF) cars. Examples of signals models include automatic train protection (ATP) and the European Train Control System (ETCS).

Example Simulations Using Railway Total Simulator

This section describes three examples of actual simulations run using the railway total simulator. Unless otherwise stated, the simulations are based on the power supply system layout and operating conditions (determined by the timetable) specified in Table 1 and Fig. 3. The simulation also assumes

TABLE 1. Simulation Conditions for Railway Total Simulator
The table lists the equipment conditions used in the simulation.

Equipment conditions	Substations	Rated voltage	DC 1,500 V
		Rated output	3,000 kW
		Regulation	6.7%
	Rolling stock	Operation method	Coasting and repeat traction
		Max. motor output	224 kW
		Configuration	4M2T
	Traffic control	Headway	10 min

M: motor T: trailer

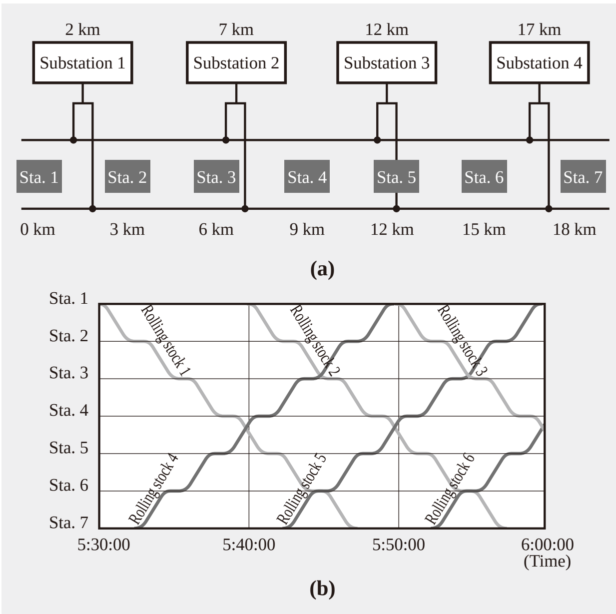

Fig. 3—Specific Simulation Conditions for Railway Total Simulator.
Electric power results for power supply system (a) and operating conditions (b) are shown.

use of VVVF rolling stock and the ability to transfer power generated by regenerative braking to other rolling stock.

(1) Prediction of energy consumption using proposed timetable

Fig. 4 shows the simulation results. Fig. 4 (a) shows the pattern of operation, the catenary voltage, and current for rolling stock 1 when it travels from station 1 to station 2 as specified in Fig. 3 (b), and the catenary voltage and current at the substation for each timing. As this involves a single train only, as indicated in the schedule in Fig. 3 (b), the supply of electric power from the substation is determined by the operation of rolling stock 1. Although a heavy current is supplied from the nearest substation (substation 1) when the train is under traction, substations 2 and 3 also supply a certain amount of current, and the results demonstrate that the simulation has modeled the drop in catenary voltage due to the current flow.

Fig. 4 (b) shows the voltages and currents at each substation for an extended simulation time scale, running from 5:30:00 to 6:00:00. The results show that the output current from each substation varies depending on factors such as the location of the rolling stock and the number of configurations, which change over time. The results also show an overload at 5:45:00, with a sudden drop in catenary voltage occurring at substations 2 and 3. The cause of the overload can be seen to be the simultaneous departure of two trains at 5:45:00, as shown in the Fig. 3 (b) timetable, which means that both trains are under traction at the same time. In this way, the capabilities of the simulation include being able to calculate factors such as the peak electric power demand for a given timetable and when

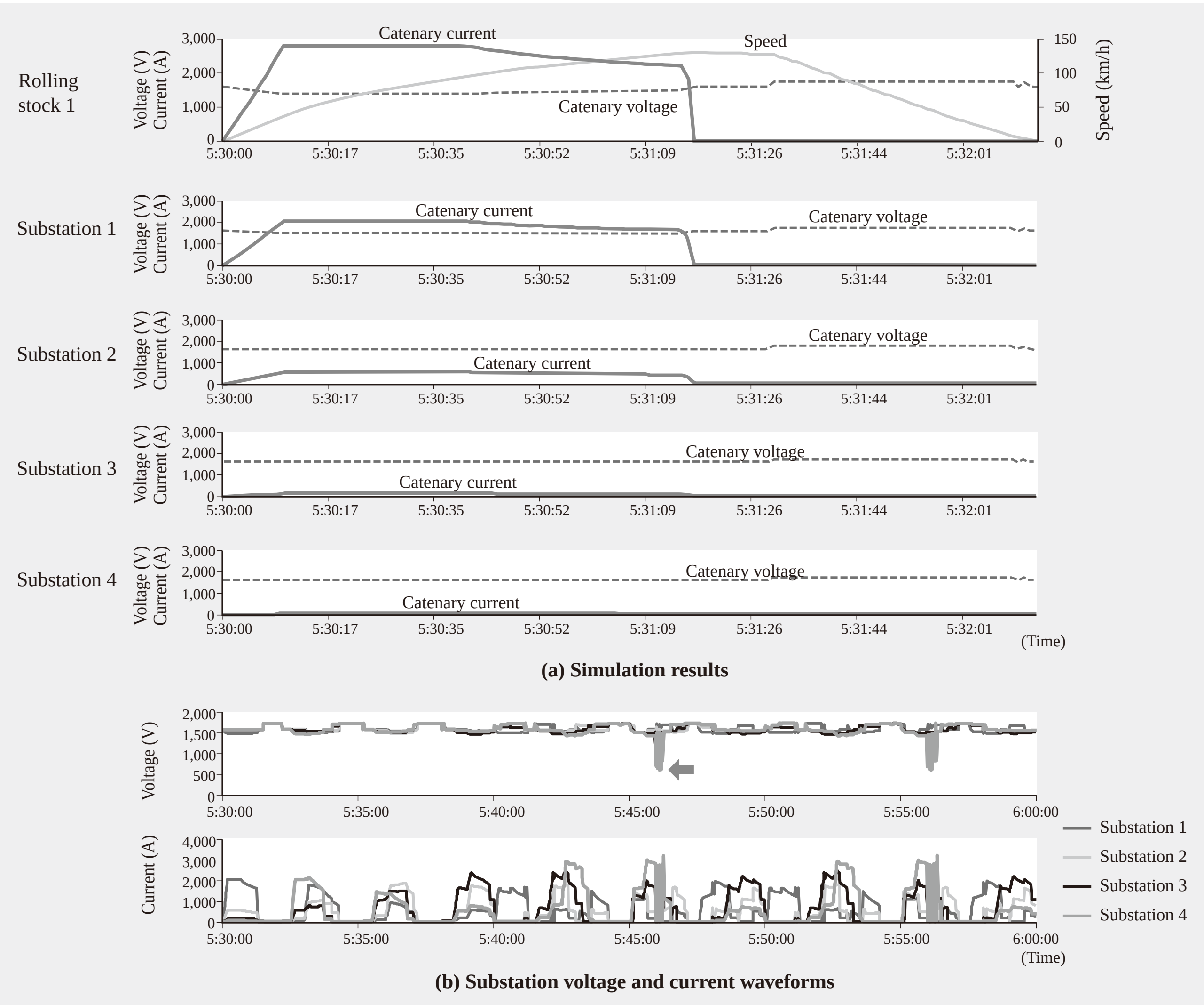

Fig. 4—Example Simulation Using Railway Total Simulator (1).

These results show the rolling stock and substation energy consumption for a proposed timetable.

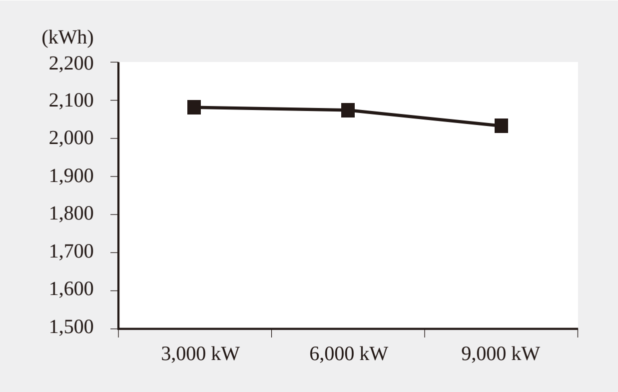

Fig. 5—Example Simulation Using Railway Total Simulator (2).
This shows the relationship between substation capacity and energy consumption.

this demand will occur. This indicates that one use for the simulator is to assist the design of timetables that take account of peak electric power demand.

(2) Relationship between substation capacity and energy consumption

It is also possible to simulate how the energy consumption varies when the substation capacity is changed. Fig. 5 shows the total energy consumption across all substations when the simulation conditions for (1) above were repeated three times with substation capacities of 3,000 kW, 6,000 kW, and 9,000 kW respectively. The results indicate that increasing the rated substation output decreases total substation energy consumption. This occurs because increasing the rated substation output raises the voltage output by each substation, and this in turn holds up the catenary voltage at the rolling stock. The higher the catenary voltage at the rolling stock, the lower the current drawn under load, and this reduces substation energy consumption by cutting the losses that occur during transmission.

(3) Relationship between headway and energy consumption

The effect of headway on energy consumption can also be simulated. Fig. 6 shows the total energy consumption across all substations when operation over a one-and-a-half-hour period was simulated for three different conditions: a four-car configuration with a headway of four minutes, an eight-car configuration with a headway of eight minutes, and a ten-car configuration with a headway of ten minutes. Each of these provides the same hourly capacity. The results show that increasing the frequency of service reduces total substation power output. This is because increasing the number of configurations increases the number of rolling stock under traction or regenerative braking, and this increases the opportunities for utilizing the regenerative electric power.

These simulations of the relationship that substation energy consumption has with substation capacity and headway provide examples of how the railway total simulator can be used. By setting a wider range of conditions, it is also possible to study numerous other situations. Examples include calculating headway, which is the critical number when designing timetables, or studying the energy savings that could be achieved by installing storage batteries in the rolling stock or on the wayside.

EVALUATION OF TECHNOLOGIES FOR ENERGY-EFFICIENT OPERATION

Hitachi has been using the railway total simulator described above to evaluate technologies for achieving energy-efficient operation while maintaining traffic volume (timetables). This section describes three aspects of this use of the simulator to perform energy efficiency assessments.

(1) Identification of optimum runcurves
(2) Operational support evaluation based on runcurves
(3) Assessment of effect on other trains

Identification of Optimum Runcurves

Energy efficiency is not necessarily taken into account when making runcurves, which typically consider factors such as traffic volumes and journey time requirements. However, growing awareness of the environment and the need to save electric power have created a demand for more energy-efficient runcurves, and one example of this is how to make the best use

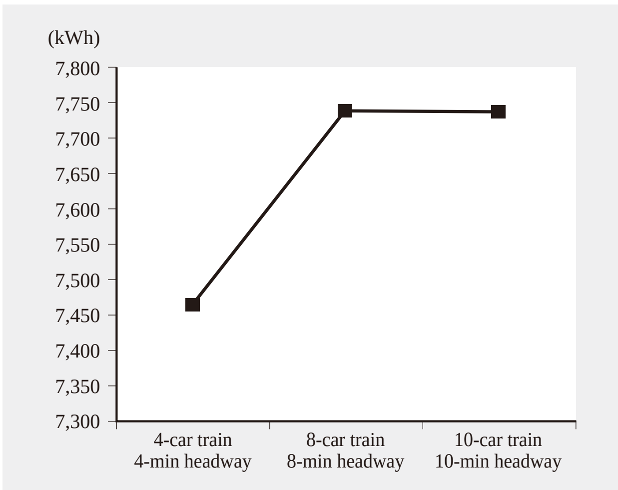

Fig. 6—Example Simulation Using Railway Total Simulator (3).
This shows the relationship between headway and energy consumption.

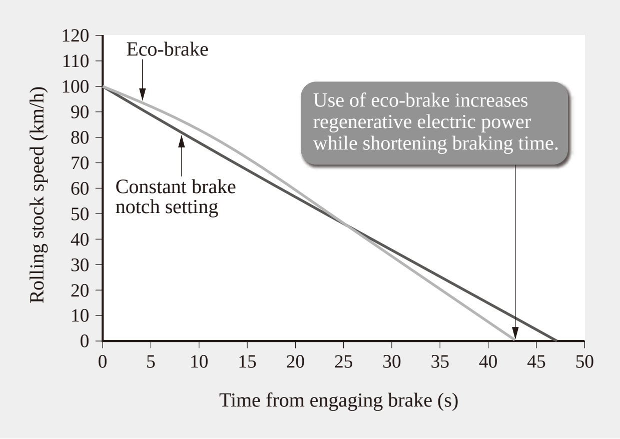

Fig. 7—Example Runcurve Optimization.
Even for the same braking distance and speed when brake is initially applied, the braking time and amount of regenerative electric power are different depending on the brake notch settings.

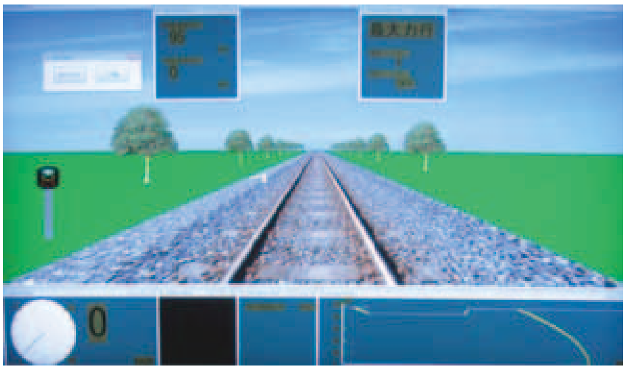

Fig. 8—Example Operational Support and Method for Evaluating Operational Support Technologies.
Operational support technologies are evaluated by providing operational support based on the optimum runcurves calculated using the simulator, and comparing energy consumption values from the modeling results and simulator.

of regenerative energy. The braking components of most current runcurves assume use of a constant brake notch from the time the brake is applied until the train stops. This requires use of the pneumatic brake at high speeds where the electric brake is unable to provide the full braking force needed, and this means that the available regenerative energy is not fully utilized. In response, Hitachi has developed an energy-efficient eco-brake that optimizes the brake notch setting to decelerate the train using the electric brake only. When evaluated on a simulator, using the eco-brake for deceleration not only reduced energy consumption, it was also able to shorten the braking time (see Fig. 7). It can be assumed that the benefits of the eco-brake will depend on the load conditions. As the simulator allows the weight of the rolling stock to be varied, it can be used to obtain quantitative estimates of the benefits of using the eco-brake under different load conditions.

Another energy-efficient technology is the optimization of runcurves between stations. The simulator described above, which allows line conditions, rolling stock characteristics, and notch settings to be changed as required, is used to determine the optimum runcurve from among the different options, which might include runcurves that involve frequent cruising, frequent coasting, or downhill gradients.

Operational Support Evaluation Based on Runcurves

It is comparatively easy to implement the optimum runcurves obtained using the simulator on sections of line with auto train control (ATO). Implementing optimum runcurves on lines that do not have ATO, on the other hand, requires some form of driver support (see Fig. 8). Hitachi believes that it is possible to develop more effective methods for supporting drivers by comparing the optimum runcurves obtained from the simulator with the actual runcurves used by the driver when operational support is provided.

Assessment of Effect on Other Trains

As a train that halts at a non-scheduled stop between stations needs to operate under traction again to restart, this increases the amount of power it consumes. It is possible to save energy by sending information about a delayed train to the trains behind it so as to prevent these oncoming trains from getting too close to the delayed train, and to avoid unnecessary acceleration and deceleration (see Fig. 9).

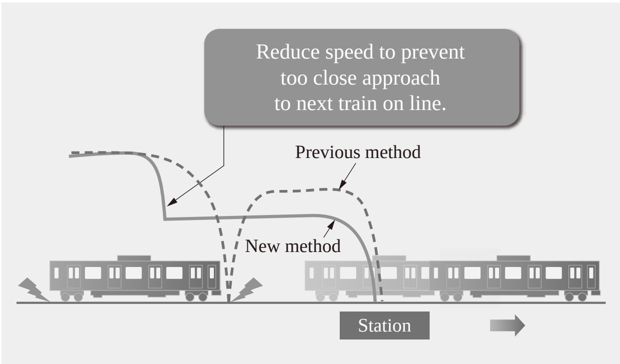

Fig. 9—Example Assessment of Effect on Other Trains.
In practice, train operation is affected by the trains ahead. The railway total simulator can be used to evaluate energy-saving technologies that control the train based on the movement of other trains.

As the simulator models functions like signals and traffic control as well as the rolling stock, it can also be used, for example, to assess the impact that the movements of a train will have on the trains behind it. Hitachi is using the simulator to work out how best to modify the runcurves of trains in response to the movements of the train ahead of it so as to save energy while also minimizing the disruption to the timetable.

CONCLUSIONS

Numerous opportunities for achieving energy-efficient operation are possible using wayside-to-train communication. One possibility is to save energy by reducing the dwell time at stations used by few passengers and allocating the time saved to travel time. In the future, Hitachi intends to contribute to further improvements in the energy efficiency of railway systems by analyzing actual data and other information to identify problems, and by using total-system simulators to study increasingly complex railway systems.

REFERENCE

(1) M. Suzuki et al., "Development of Railway Integration Evaluation System," Proceedings of 48th Symposium of the Congress of Japan Railway Cybernetics, No. 103, Congress of Japan Railway Cybernetics (Nov. 2011) in Japanese.

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