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ADVANCE

Innovative Transport System Solutions toward New Social Issues on Railway Business

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Changes for the Better

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Innovative Transport System Solutions toward New Social Issues on Railway Business

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CONTENTS

Precis

The Mitsubishi Electric Transportation Business has a long history of contributions to the advancement of social infrastructure through the delivery from on-board equipment to ground facilities of railway systems. Going forward, we will contribute to sustainability throughout the entire transportation industry through railway maintenance, autonomous driving, and energy savings. This edition presents solutions to drive energy savings, improve management efficiency and reduce the impact on the environment based on ever-changing social issues.

Overview

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Sustainable Development of Transport Technology in 2025 -with the Rapid Spread of Artificial Intelligence-

In 2022, the 150th anniversary of Japan's railway system, I had the opportunity to listen to the technological perspectives of many experts, as well as express my views. What I found was a common awareness related to reliable public transport, responding to the digital society and how to improve transport technology in the information society. This was underpinned by a discussion on how mobility should contribute to a sustainable society in the midst of an ageing and rapidly shrinking population as well as a sense of urgency about pandemic preparedness and the dramatic changes in the way we live and work as a result of such experiences.

This special issue on transport technology, planned just after the 150th anniversary, is also a collection of articles that specifically describe Mitsubishi Electric Corporation's technical research on transport systems in response to important development issues, such as sustainable management, energy-saving technology that consider carbon neutrality, automation and efficiency of operation and maintenance, application of wireless technology, and automatic train operation in the post-Corona era. These are up-to-date summaries of current technologies.

In a series of discussions during the 150th anniversary, I introduced the idea of "SF prototypes" and made a rather bizarre suggestion that it would be worthwhile to focus on how the technology that will wipe out the rail system in the next 30 years is portrayed in science fiction in order to discuss sustainable development issues for rail. Less obvious at the time, but generative AI is currently attracting even more attention due to the impact of the pandemic.

How it will change the future is being discussed as an actual problem, not science fiction. As seen in dystopian science fiction films such as Terminator and Ex Machina, Western societies seem to be very concerned and wary of AI and the proliferation of robots in our living spaces. In fact, representatives of the artificial intelligence community, such as Sam Altman, CEO of OpenAI, and Dr. Demis Hassabis, CEO of Google DeepMind, as well as other scientists, have expressed strong concerns about the general public's use of the advanced AI they are promoting, and have surprisingly suggested that certain limits be placed on the pace of development.

In contrast, few engineers in Japan seem to share the serious concerns expressed above, as they focus on the positive aspects of using this technology to improve productivity and meet individual customer needs, and see the importance of pushing ahead with its progress without hesitation. A commentator on the radio said that this may be because our image of advanced technology is based on Astro Boy and Doraemon, the most famous Japanese cartoons that have depicted the bright future of a technological society. Although this is not an argument based on solid evidence, I feel that it is an intuitively correct view.

While we are cautious about looking beyond advanced technology to utopia, I think many of us have "Yamato-Damashii", the Japanese spirit of taking advantage of new technological achievements based on good intentions and having orderly and ethical behaviour, rather than misusing or deliberate interfering with the system. In fact, the application of machine learning to railway operations management is already making progress in some Japanese railways.

In the field of high-speed railways, China is increasing its presence in the international market with the "One Belt, One Road" initiative, based on the experience it has rapidly accumulated with its vast network. On the other hand, in the field of urban transport, although Japan pioneered fully automatic train operation in the 1980s with its "new transport system", i.e., urban elevated railways, it lags far behind other countries in the practical application of GOA-3/4 driverless automatic train operation in heavy rails, and there is a strong sense of urgency in Japan.

However, Japan is growing with technologies that have uniquely Japanese strengths, such as highly reliable and high-frequency operation of the Shinkansen; the Chuo Shinkansen, a long-distance intercity high-speed maglev train; GOA-2.5 driverless automatic operation based on advanced ATP with intermittent train localisation (with frontal crew); high-frequency operation combining wireless train control and automatic operation; train energy-saving operation technology with high accuracy and repeatability using automatic operation; and so on.

I hope that the articles in this special issue will give you a glimmer of hope for the future of our mobility.

"Railway LMS on INFOPRISM" Contributing to the Sustainability of Transportation Business

Authors: *Kenji Hiroshige*, Shunsuke Shiraishi**

**Transportation Systems Div.*

1. Introduction

Railway operators have shown a greater need for digital technologies illustrated by its use to enhance inspections and improve the efficiency of maintenance work. In fact, in Asian region, Japan, Hong Kong and Singapore are struggling to secure a labor force with the decline of the working age population. The adoption of digital technologies is an effort that hopes to not only save labor and enhance railway functionality but also improve the on-site work environment and make the railway industry more attractive to prospective employees.

The Railway Lifecycle Management Solution (LMS) on INFOPRISM developed by Mitsubishi Electric has built a consistent track record of helping railway operators increase efficiency throughout the entire life cycle from train services through maintenance via Internet of Things (IoT) and Artificial Intelligence (AI) technologies since the service launched in 2019. This platform enables wayside equipment to collect data from trains in service to monitor and analyze the rolling stock and equipment in real time. This reduces suspended operations caused by equipment issues, increase the efficiency of maintenance work, and supports train services. LMS on INFORPISM also helps improve railway operations using data from railway operators as well as equipment and system manufacturers. In addition, these solutions can store and use the diverse data that has been collected to increases railway management efficiency and optimize asset management, which in turn contributes to the sustainability of transportation businesses.

This paper provides an overview of the work and success done in the development and provision of the Railway LMS on INFOPRISM services and describes initiatives to innovate solutions that use the wide range of data that has been aggregated to further drive railway management efficiency and optimize asset management.

2. Railway LMS on INFOPRISM

Railway LMS on INFOPRISM is built on the unique Mitsubishi Electric INFORPISM IoT cloud platform as a value-added solution that helps increase the efficiency of train maintenance and ensures reliable and safe railway operations by rapidly troubleshooting onboard equipment failures and other such issues (Fig. 1).

Railway Maintenance Solution, one of the applications of the Railway LMS on INFOPRISM, stores and utilizes the operational data from onboard equipment collected via the TCMS, which provides broad functionality. Wayside equipment can verify the operational status of onboard train equipment, view information displayed on driver's cab, detect or monitor signs of potential trouble with rolling stock, and remotely conduct exterior inspections at railway depots. Our driver assistance solution offers features that range from the visualization of the rolling stock in service between railway lines run by different railway operators to the optimization of train schedules based on passenger occupancy and support of energy-saving operations. Beyond the Railway LMS on INFOPRISM platform, our collaborative work solution enables multiple operators to use data and closely coordinate with one another. This supports greater on-site operational efficiency, especially when responding to various types of mechanical trouble using maintenance data provided by railway operators as well as equipment and system manufacturers.

The use of the diverse data aggregated by Railway LMS on INFOPRISM will expand the features and solutions available in the platform in the future. These will contribute to higher railway management efficiency, whether optimizing asset management throughout the entire life cycle of railway transportation services or analyzing the energy consumption throughout all trains in service.

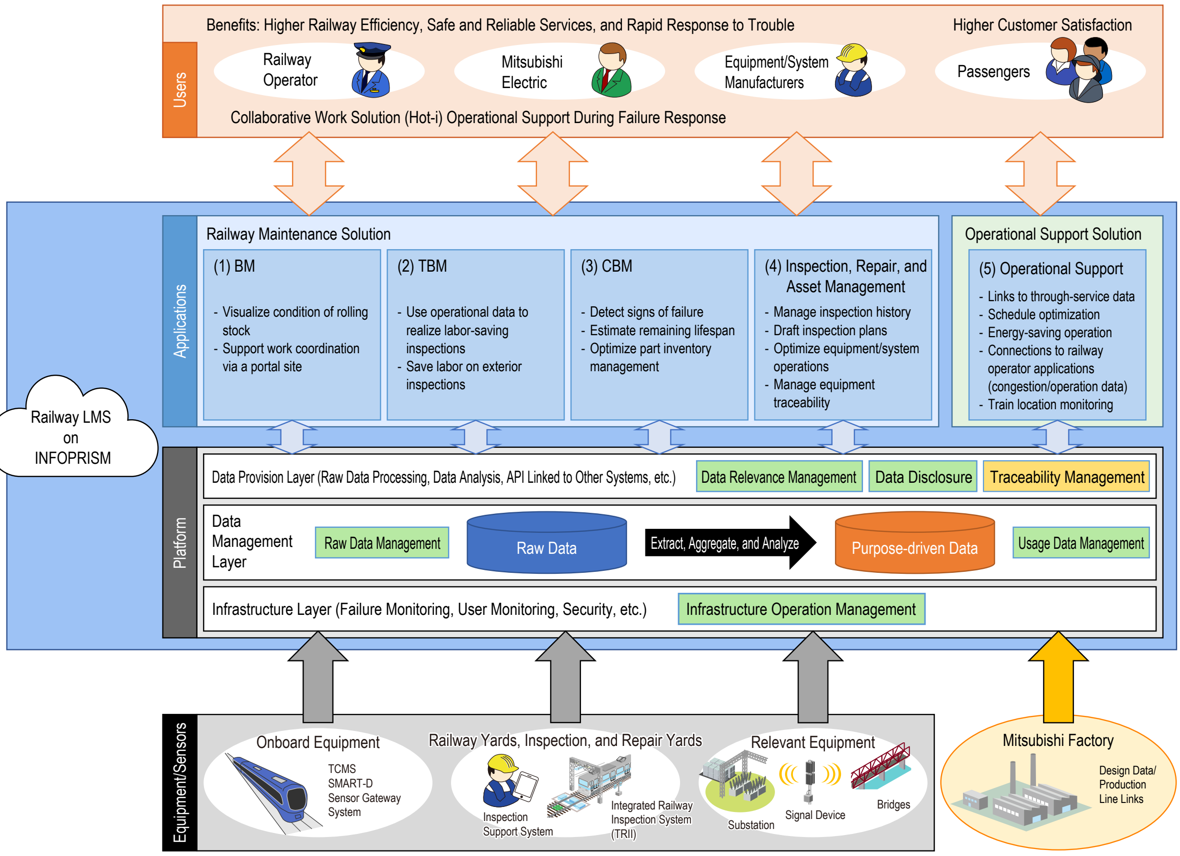


Fig. 1 Overall structure of Railway LMS on INFOPRISM(1)

3. Past Initiatives and Development Results

3.1 Railway maintenance solution using operational equipment data

The railway maintenance solution encompasses monthly and routine inspections as well as general and critical part inspections done primarily by railway operators in accordance with mandates stipulated by the Japanese government to prevent service disruptions caused by equipment failures or degradation. However, the scope of maintenance work has grown with the greater functional complexity of equipment as well as the new systems built into rolling stock. Railway operators are struggling with a shortage of inspectors due to the dwindling labor force caused by an aging population with a declining birthrate, which presents a challenge in efforts to guarantee safe and reliable services while reducing the manpower required to carry out this maintenance work. Information and Communication Technologies (ICT) and the digital technologies are two strategies that could potentially overcome the challenges brought by this labor shortage. Mitsubishi Electric has been promoting its railway maintenance solution as a means to save labor in maintenance work through the use of operational equipment data.

3.1.1 Visualization of the conditions on rolling stock for higher efficiency during repairs

Train crew has been identifying conditions on each train based on failure detection data exported to display units in driver's cab when an issue arise on a train that is in service, while verbally coordinating with officers in the Operational Control Center (OCC) to conduct repairs. Accurate information exchange is essential to carry out these repairs quickly. However, a lack of information or any misunderstanding between train crew can extend the time it may take to recover standard service operations. Railway LMS on INFOPRISM constantly receives and stores the operational data generated by the equipment on rolling stock to address these issues as an application configured to visualize the location of each train, any malfunctions, and other conditions of the rolling stock in service as much as possible in real time (Fig. 2). OCC can use this data to quickly and accurately assess failures and other conditions on rolling stock, which drives the efficiency of any repairs and more quickly recover regular train services.

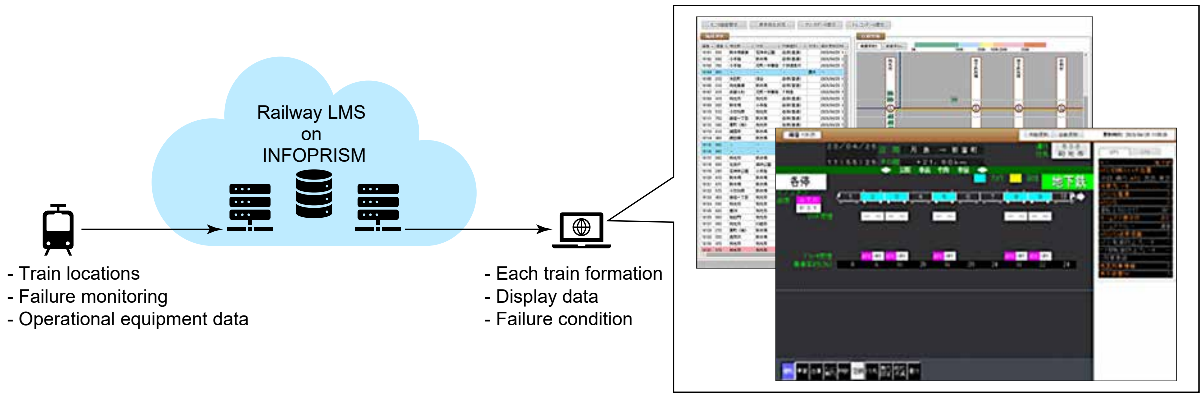


Fig. 2 Visualizing application and examples of vehicle status display

3.1.2 Labor-saving inspections during time-based maintenance

The railway industry conducts routine inspections of rolling stock according to Time Based Maintenance (TBM) practices that guarantee safe and reliable railway transportation. These routine inspections replace brake shoes and other wear-out parts, clean out clogged filters and conduct any other necessary repairs, run operational checks on train doors and other equipment, and measure the brake cylinder pressure in activating and after releasing the brakes. The inspection of doors and some of the other equipment could use the operational data aggregated from rolling stock in place of these operational checks because train crew operate the equipment during commercial train services. As one railway maintenance solution, Mitsubishi Electric developed a labor-saving inspection application that reviews operational logs for information equivalent to inspections in the operational data aggregated from onboard equipment in order to submit those findings as inspection results (Fig. 3).

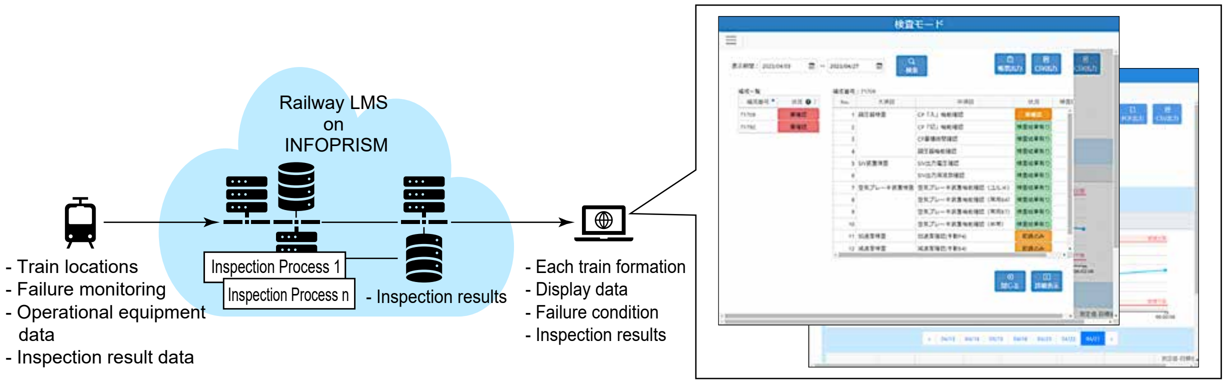


Fig. 3 Labor-saving application of railway inspection on TBM

These types of analysis applications come with concerns of higher management costs because operators have to handled more and more equipment operations as the number of train formations for inspection as well as equipment operations for analyses (inspection logic) grow. As a measure to mitigate the rising costs, our application narrows any analysis to only train formations coming up on routine inspection to optimizes the amount of data stored by the Railway LMS on INFOPRISM. To do this, the solution limits data to only the inspection results deemed valid by an inspection validation process running on equipment when collecting operational data.

3.1.3 Failure detection and monitoring to achieve condition based maintenance

Typical railway maintenance today consists of mainly Breakdown Maintenance (BM) and Preventive Maintenance (PM), which are two main aspects of TBM. Sections 3.1.1 and 3.1.2 have described solutions to enhance the efficiency and speed of maintenance work.

Railway maintenance going forward though will strive to reduced costs by emphasizing Condition Based Maintenance (CBM) that approaches repairs based on the degradation of equipment with the hope of reducing costs. CBM not only requires the aggregation of the operational data described in Section 3.1.2 but also constant monitoring of the equipment in operation. To respond to these needs, Mitsubishi

Electric has configured an analysis system to monitor operational data aggregated by the Railway LMS on INFOPRISM from each piece of equipment to identify degradation trends of aging equipment. This analysis system triggers alerts based on “warning” and “abnormal” values surpassing a certain threshold determined in advanced to enable crew to check the severity of equipment degradation according to the number of each of these alerts.

3.1.4 Small monitor analyze record terminal-depot/Onboard sensor gateway systems

Railway condition monitoring and control communication functions play a central role in the conventional Train Control and Monitoring System (TCMS) built into most rolling stock worldwide. The TCMS expands functionality and enhances stability, which contributes to safe and reliable transportation as well as reduces Life Cycle Costs (LCC). However, conventional TCMS does not have the recording functions to obtain all the different types of condition and monitoring data necessary to take full advantage of Railway LMS on INFOPRISM. Therefore, the system requires a means to select, record, and transmit all of the required data to wayside equipment. To satisfy these requirements, Mitsubishi Electric developed the SMART-D small monitor analyze record terminal-depot system to enable TCMS data collection without making any drastic modifications to rolling stock.

3.2 Development of solutions to support safe and reliable operations

Wayside equipment can monitor railways that can visualize the condition of rolling stock. However, Japan has numerous railway lines operated by different companies that offer through-services to one another, especially in the Tokyo metropolitan area. If a failure occurs while a train is operating on a railway run by another company, OCC can only communicate these issues verbally because the systems are not currently linked to one another. We developed a system to link and share through-service data from onboard equipment by visualizing rolling stock operating on every through-service railway line so that OCC of each railway operator can grasp the condition of through-service trains on any line via Railway LMS on INFORPISM.

In addition to the operational equipment data that it collects, Railway LMS on INFOPRISM emphasizes the use of passenger occupancy, car temperature, power consumption and other such data. For instance, the use of passenger occupancy data enables various analyses to revise train schedules and alleviate congestion, while the visualization of power consumption can help optimize service patterns for the purpose of saving energy.

3.3 Functions making the railway LMS on INFORPISM platform possible

The Railway LMS on INFOPRISM platform enables five different functions—infrastructure operation and management, raw data management, usage data management, data relevance management, and data disclosure management—configured through the data provisioning, data management, and infrastructure layers indicated in Fig. 1. These functions make the solutions described above possible.

In addition to these five functions, Mitsubishi Electric is currently developing a traceability management feature in the data provision layer to connect the rolling stock and onboard equipment data. This kind of link is a necessary component to advance asset management in the future. This section outlines this traceability feature.

Each solution provided by Railway LMS on INFOPRISM associates and facilitates use of a wide range of data, such as engineering design, production, operational history, operational data, inspection, and maintenance data throughout the life cycle from the design and manufacture through operation and disposal of rolling stock and onboard equipment. A traceability management function links, manages and uses this plethora of information. First, the system converts and aggregates this diverse data across the entire operational history as a digital thread consisting of a database model that is able to create historically traceable links between multiple companies and manufacturers. These links drive operational efficiency and sophisticated asset management by supporting plans for total overall of onboard equipment and expediting the horizontal exchange of information about any mechanical issues (Fig. 4).

Data relevant to rolling stock includes data to manage each train formation, such as management, inspection and operational data as well as data to manage the equipment and systems, such as design, manufacturing, part replacement, and repair. Reviews that use thses data to assess the health of rolling stock and onboard equipment must include information on the train formations (location of onboard equipment)

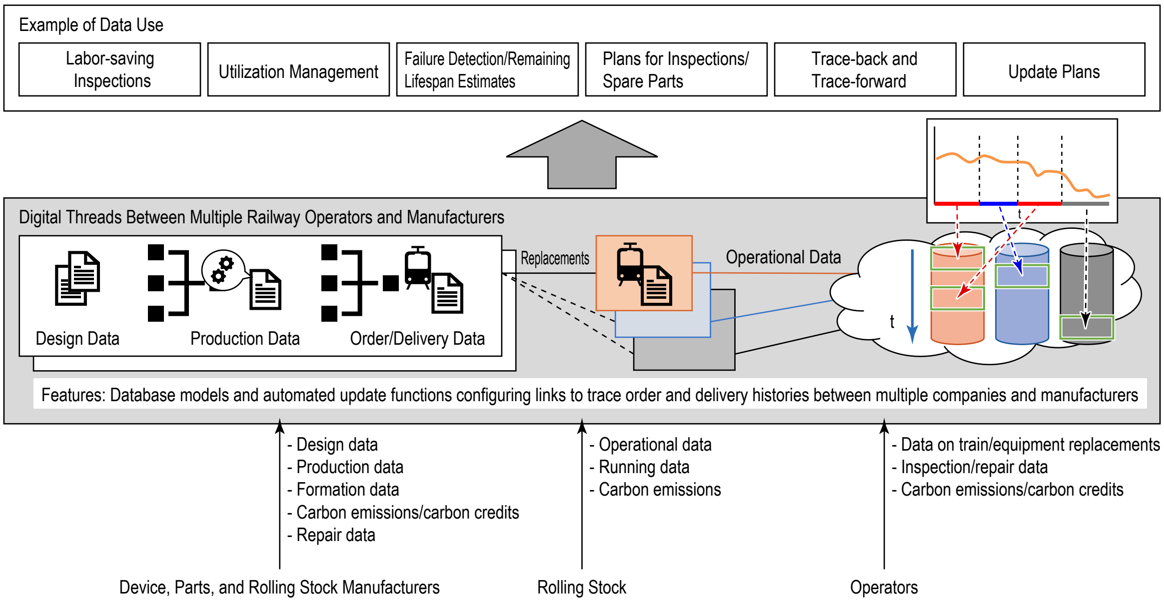


Fig. 4 Digital thread data among multiple railway operators and multiple manufactures with traceability management functions

and accurate data on the operational history of each piece of equipment. The traceability management function guarantees validity of operational histories and ensures access control through digital threads that use blockchain technologies. Currently, Mitsubishi Electric is in the process of evaluating and expanding the development of a prototype that primarily aggregates and uses operational history (onboard equipment data).

As outlined earlier, Railway LMS on INFOPRISM is provided as a solution to support the entire life cycle of rolling stock and onboard equipment in order to help continually build and forge partnerships between transport service users, railway operators, and companies involved in the industry in addition to contributing to sustainable railways. To achieve this goal, the platform must support initiatives to create and provide value from a broad range of data in cooperation of numerous companies and manufacturers.

4. Future Initiatives

4.1 Expansion of the railway maintenance solution

The future of railway maintenance will reform maintenance standards using operational equipment data, which should further drive TBM inspection efficiency through the labor-saving inspections described in Section 3.1.2 as well as other solutions. Moreover, the aggregation of operational data from equipment utilizing failure detection and monitoring as well as AI analyses will make CBM a reality.

4.2 Management optimization of all railway assets

The development of solutions to support the cooperative maintenance work to address equipment trouble takes advantage of data collected by condition monitoring systems that monitor failures as well as data about past equipment trouble in order to more rapidly determine the initial response. The traceability management function saves labor by acquiring data through automated data recognition and collection technology (automation), realizes the traceability of circuit boards, and advances links between equipment design and production data from manufacturers to help drive the efficiency of broad yet meticulous maintenance work. To solidify a foundation from this success, Mitsubishi Electric is collaborating with railway operators to innovate asset management solutions that help optimize management of all railway assets.

4.3 Innovations to bring about next-generation railway transport systems through the use of data

Next-generation systems will take a stance on data use that aims to integrate not only the railway and rail yard maintenance data currently available in the Railway LMS on INFOPRISM, but also operational monitoring; electrical and signal transmission; station monitoring; track, civil engineering and construction monitoring; sales; and a wide range of other data across railway operators. The objective of these innovations is to develop a platform of next-generation railway transportation systems that offer energy savings, autonomous driving, and travel services plus higher efficiency throughout all railway operations. (Fig. 5)

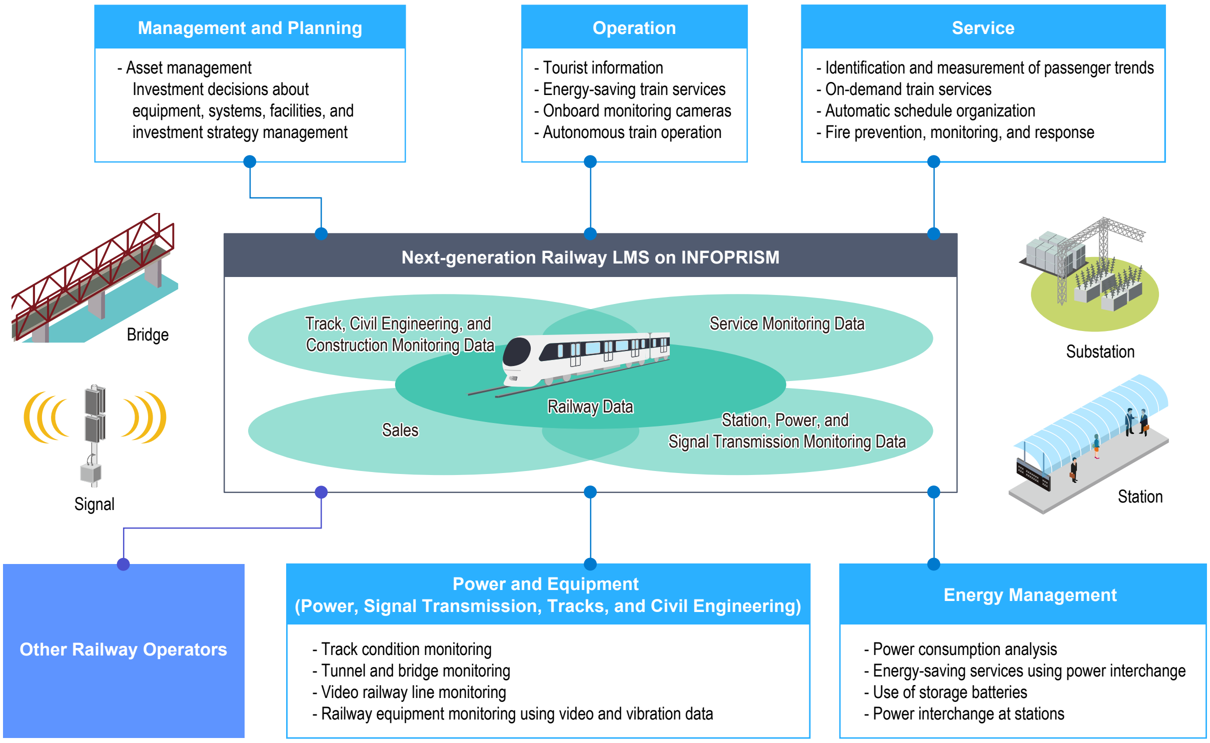


Fig. 5 Concept of structure of the next generation railway system with data utilization[1]

5. Conclusion

This paper has described the past development efforts, results, and future initiatives of the Railway LMS on INFOPRISM. Mitsubishi Electric leverages its expertise amassed in railway equipment and inspections thus far to further the development of railway maintenance solutions that visualize the condition of rolling stock, save labor on TBM and utilize operational equipment data in other ways as well as solutions coordinating maintenance work by utilizing maintenance data. Going forward, development of open platforms will work to add a lineup of equipment and inspection processes compatible with railway maintenance solutions and expand asset management solutions that help drive operational efficiency of all railway assets with the aim to expand and make possible the next generation of railway systems that can further capitalize on data. Through these developments, we will provide solutions to drive railway management efficiency and optimize and contribute to the sustainability of transportation businesses.

Reference

(1) Yokoshima, K., et al.: “LMS on INFOPRISM” Contributing to Efficient Train Maintenance Work and Stable Operation, Mitsubishi Denki Giho, 94, No. 12, 669-673 (2020)

Autonomous Driving Initiatives for Sustainable Public Transportation

Authors: *Masahito Chihira*, Motonori Sugaya**

** Transportation Systems Div.*

1. Introduction

Japan, Hong Kong and Singapore in Asian region are struggling to secure a labor force in the railway industry due to an aging society with a declining birthrate and a dwindling working age population. Train drivers in particular require high-level skills and experience, which is heightening needs for autonomous trains that do not require drivers due to the need for significant time for training to master those skills. Railway operators also saw profit drop during the COVID-19 pandemic. With future reforms to work and life styles, the demand for travel via railway may not return to the same levels as before the pandemic, which is further increasing the hope for autonomous driving from a management efficiency perspective.

Many urban railway systems have been adopting Communications-Based Train Control (CBTC) and self-driving trains overseas when constructing new lines as dedicated tracks with platform doors. Autonomous trains have found a foothold primarily in major Asian cities. Japan built the first automated driverless railway in the world on a commercial line of a new transport systems in the 1980s, which became the standard of autonomous trains. However, these self-driving trains did not immediately find traction due to the need for measures to prevent entry onto the tracks of existing railway systems with train crossings and no platform doors. Ongoing technical development and reviews of modifications to legislation are raising the potential for more widespread use in the future.

Since the first automated driverless train in the world began service on Japan's new transport systems, Mitsubishi Electric has been building a track record as the pioneer of driverless and autonomous technologies, promoting technical development that aims to realize as efficient and comfortable autonomous driving systems as possible.

This paper describes the framework for our autonomous driving, passenger service, and train service support solutions, which utilize the latest Mitsubishi Electric data processing and transmission as well as AI and sensor technologies, as a next-generation autonomous driving solution.

2. Three Solutions to Realize Sustainable Public Transportation

Urban railways must handle a high volume of passengers at each station in addition to staffing train drivers, conductors and other crew to ensure safe and reliable transportation, even when someone or something interferes with train crossings or the railway tracks. Mitsubishi Electric has analyzed the work done by crew in detail to realize automation that aims to reach a level higher than the new Grade of Automation Level 2.5 (GoA2.5: automatic-operation with a person for emergency stop operation. Japanese original definition) as a new standard of autonomous driving suitable to train services in Japan on standard railway lines with train crossings. These analyses have enabled us to advance the development of three automated driving solutions to systematize crew operations from driving tasks and decision-making to passenger services and troubleshooting.

(1) Autonomous driving solution

This solution mainly aims to automate controls used to drive the train. Drivers have to control the train, speed and continually make decisions taking into account various conditions that change moment to moment from passenger congestion and the status of the train to rain, snow, and other environmental conditions. We aim to realize a solution that provides ideal train services by autonomously determining each assigned role based on data collected from the network of onboard and wayside equipment.

(2) Passenger service solution

This solution mainly aims to automate passenger service systems. Train divers and conductors have an extremely important role and duty to keep passengers safe. For instance, the crew needs to respond to various foreseeable passenger scenarios that include passengers deboarding the train even after the departure time has passed or the high potential of door pinching of passengers as they rush onto the train. The use of Internet of Things (IoT), Artificial Intelligence (AI) and other cutting-edge technologies strives to not only maintain but improve on the passenger services currently provided by train crew.

(3) Service support solution

This solution mainly aims to automate tasks to troubleshoot problems on the train due to equipment failure or other abnormal situations. An autonomous train without any crew aboard that runs into trouble may suffer long delays until standard services resume while waiting for personnel to arrive to address the problem. Therefore, this type of solution must monitor the health of the train in real time based on data to deal with any problem that arises as quickly as possible before it disrupts train services.

The sections below describe case studies for these three solutions.

3. Autonomous Driving Solution

Autonomous driving systems have to replicate the necessary controls and tasks typically performed by train drivers and crew to realize truly autonomous train services. To optimize the control of a train, the solution has to collect data on a constantly changing railway environment in order to drive and control the speed of trains as well as make decisions based on various conditions that change from moment to moment, whether passenger congestion and the condition of the train or rain, snow and other weather conditions.

Mitsubishi Electric has amassed knowledge and expertise on train operation control system, train control and the wireless technologies that connect rolling stock with wayside equipment. We are also furthering the application of self-driving technology for automobiles propelling autonomous driving forward in applications for the railway industry. A solution would autonomously drive a train through sophisticated system links. Mitsubishi Electric is ramping up its efforts to realize that autonomous driving solution in order to successfully optimize train services through these links.

The following describes the mechanisms that configure the autonomous driving solution.

3.1 Control of trains through system links to wayside equipment

The major key to an ideal autonomous driving system that can automate the tasks typically done by drivers and crew is determining which system should handle each task.

Wayside Automatic Train Operation (ATO) equipment can not only simply notify each train of schedule data managed by train operation control system but can also broadly oversee the control operations and entire railway as fleets of trains. These capabilities can finely adjust arrival times to regulate the train headway or delay recovery operation. It is difficult for operators to make such adjustments manually.

Drivers perform delay recovery operation as necessary under their own discretion when any small departure delays occur due to opening and closing boarding doors multiple times. However, autonomous driven trains try to adhere to arrival times provided by wayside ATO systems by autonomously switching driving patterns between stations after the onboard ATO systems closes the passenger doors.

Figure 1 shows the division of these tasks. By assigning these tasks to respective systems, the solution can control services and save running energy of trains while considering all trains on the entire railway line.

Without a driver, railway operators do have concerns that autonomous driving will place a larger operation burden on operation control centers. However, the solution autonomously handles a majority of the operations done by drivers. This limits operation control center intervention to emergencies as is the case with current train services.

For instance, previously, the operation control center gathers information from the driver and passengers and give instructions to drivers when a disruption in service occurs. On a train using an autonomous drive system, the operation control center can give instructions to each train via a control console, control recovery of the train, and decide whether to continue autonomous operations based on the state of recovery. The control console even offers an ergonomic Graphical User Interface (GUI) that contributes to greater efficiency by enabling smoother operations.

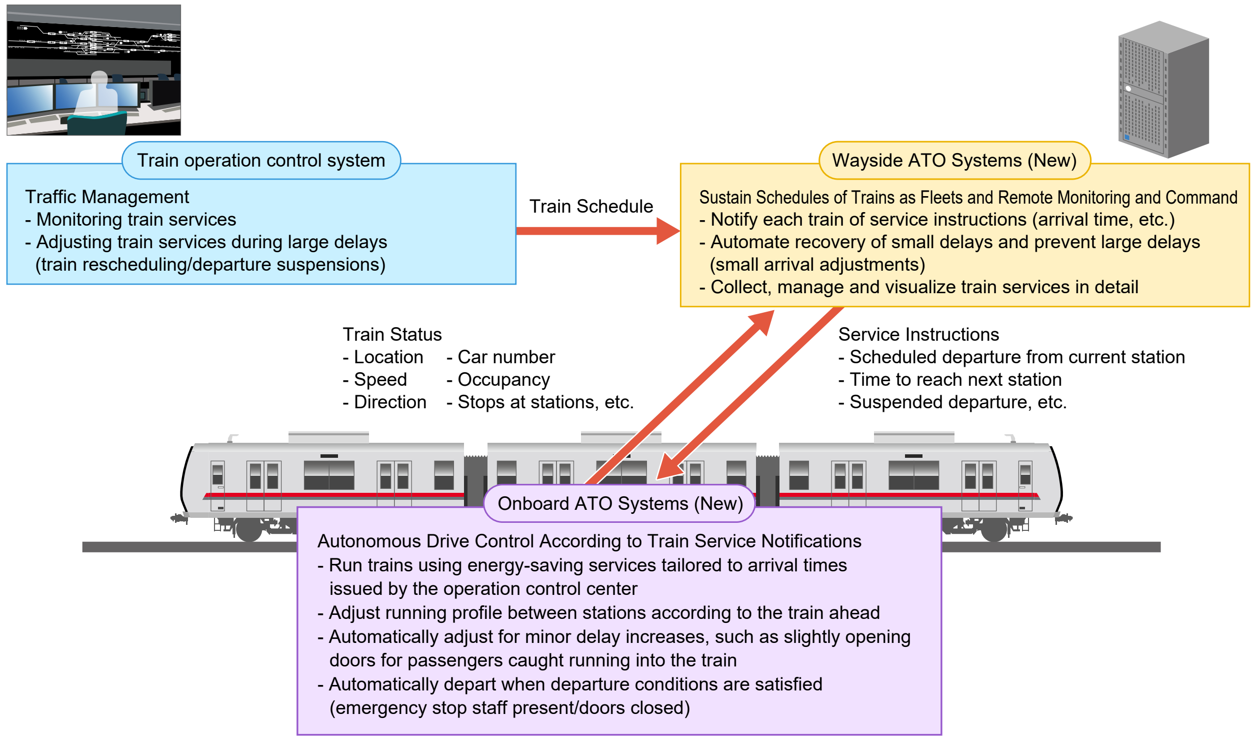


Fig. 1 Division of roles in the wayside-train interconnection system

3.2 Control as fleets of trains

A delay in one train due to a disruption in the schedule causes congestion as passengers wait for the train on the platform, which results in even further delays due to the extra time required for people to get on and off the train. To avoid such delays, the typical operation control center adjusts the train headway through wireless instructions. However, it is difficult for operation control center staff to adjust the large number of trains running on the entire railway line. The time required to recover schedule relies on the experience and expertise of the staff. Mitsubishi Electric is developing a train fleet control feature to overcome these challenges. This system wirelessly coordinates wayside and onboard ATO systems while optimizing and controlling the entire railway line to avoid station congestion and quickly get trains running on time again after delays.

Figure 2 and 3 present examples that quickly restore on-time train services by averaging the train headway. In both Figure 2 and 3, the top indicates verbal instructions for each train made by the operation control center while the bottom shows the new control system that handles trains as a fleet.

Figure 2 illustrates what happens right after departure delays due to higher passenger congestion when the station on the far left requires more time for passengers to get on and off the train. The typical and new control systems both have an equal train headway ahead at this point.

As shown in the top half of Fig. 3, typical instructions issued by the operation control center to adjust the train headway ahead after departure delays boards the increasing number of passengers at the station on the train ahead to mitigate congestion on the train that has been delayed. However, train headway expands when the train ahead does not receive the instructions that have to be issued to each train individually, which increases the amount of time it takes to average the train headway.

As illustrated in the bottom half of Fig. 3 though, the new control system can link the wayside and onboard systems to handle all of the trains as a fleet and adjust the departure times of all of the trains leaving stations. This process can quickly average train headway. We can expect this new system to more rapidly recover standard train services than typical instructions from the operation control center, which results in ongoing congestion. The new control system must issue commands according to the characteristics of each railway line. Train services that have trains overtaking one another need a well-balanced control that averages the train headway.

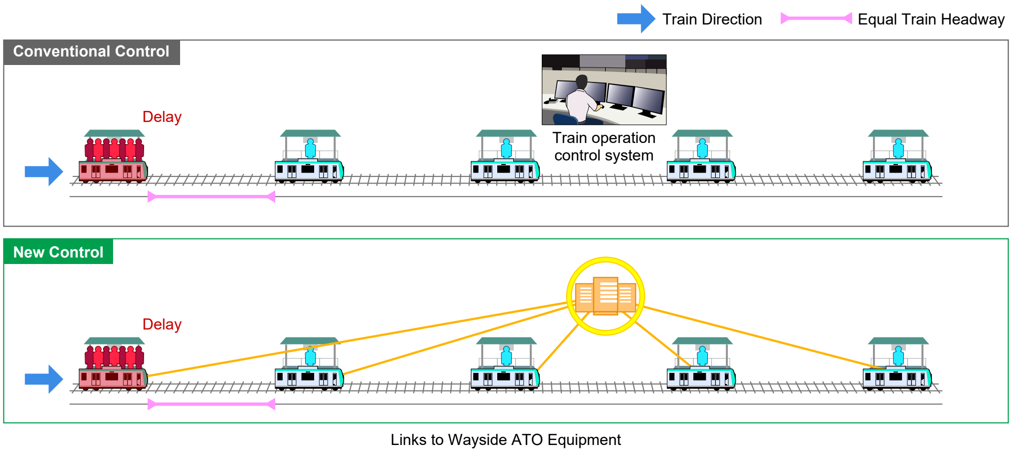


Fig. 2 Train position immediately after occurrence of delay

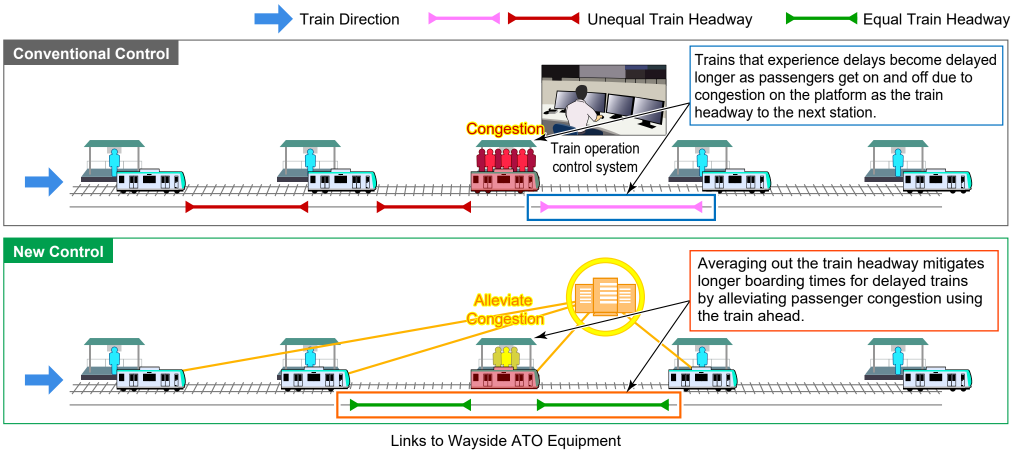


Fig. 3 Difference in congestion relief timing between conventional control and new control

3.3 Train crew monitoring

Self-driving vehicles in the automotive industry have led the development of control technologies that use various sensors, which has made drive control possible under specific conditions. Mitsubishi Electric is advancing a wide range of technological development, which includes its driver monitoring system.

We are pioneering new development for applications in the railway industry while capitalizing on our expertise in the automotive field. The following describes the driver monitoring system, which is one of these technologies. We are furthering development of this automotive driver monitoring system for railway applications as a crew monitoring system. This solution is intended for applications in autonomous trains equivalent to GoA2.5 that have conductor intervention, but it is also effective in automation at or below GoA2: semi-automatic operation.

The driver monitoring system developed for automotive use notifies drivers when a potential danger is detected from speed, steering and other vehicle data in addition to facial expressions, eye closure, head direction and eyeline.

The broader use of autonomous driving and one-person operations in the railway industry is increasing needs for railway operators in Japan to monitor driver health. A system installed in the train cab utilizes our expertise in the automotive field to monitor the health of drivers based on the unique railway environment and operational conditions as well as video data recorded by the onboard system. To prevent drivers from nodding off, the system measures eye closure as shown in Fig. 4 and uses time series processing to measure sleepiness. The system verbally communicates the measurements to the driver, issues driving instructions and notifies the driver's supervisor. Numerical values and video indicating the sleepiness of drivers helps the supervisors who oversee the driver and train services decide whether to switch drivers. The crew monitoring system also prevents excessive detection of sleepiness by linking the speed, location, direction, and other data about the status of trains received from the Train Control and Management System (TCMS).

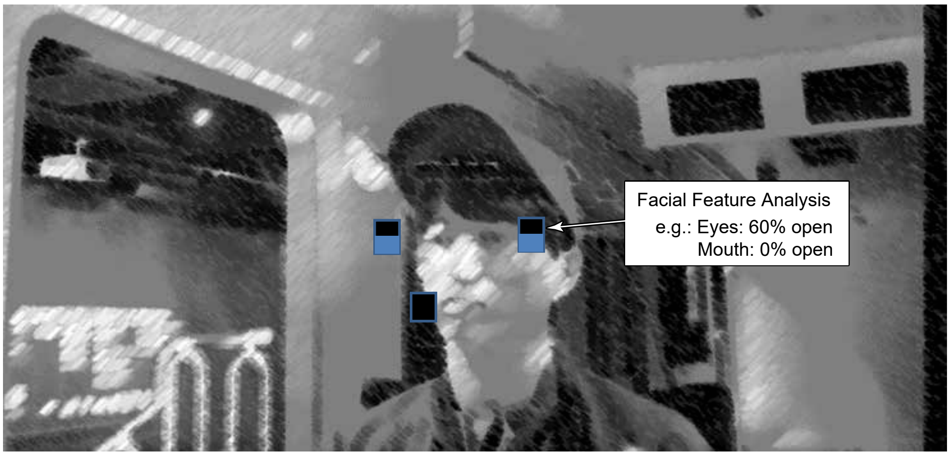


Fig. 4 Operating image of the crew condition monitoring system

4. Passenger Service Solution

Crew have primarily dealt with passenger services on trains up until now. The shift to autonomous trains requires the operation control center and systems to take over the services currently rendered by the train crew. However, this places a larger burden on the operation control center and makes it difficult to keep track of passengers and provide meticulous services with a limited crew.

Mitsubishi Electric automates these services by integrating leading-edge sensors, video analysis using AI, and wireless technologies with its train operation control system and control technologies. Services rendered collaboratively through the person in charge at the operation control center and system does not greatly increase work at operation control centers while sustaining safer and more compressive passenger services, even after the adoption of autonomous trains.

As one example of these wide-ranging initiatives, this section describes door-closing control AI.

Train crew are instrumental to train operations. Crew currently needs to have a high level of skill to open and close doors at the right time according to departure times and various other train service requirements in addition to controlling power and braking while considering passenger comfort to maintain regular train services.

Urban railway lines have a large number of people getting on and off trains. The crew needs to respond to various foreseeable passenger scenarios that include passengers getting on and off the train even after the departure time has passed or the high potential of door pinching of passengers as they rush onto the train. Train drivers must work to recover delayed train operations after a train departs late due to delays caused when having to open and close the doors. The proper automation of door opening and closing is an important initiative as departure delays lead to increased energy consumption.

Mitsubishi Electric is driving forward initiatives to automate door operations alongside the criteria to determine whether to close the doors considering the people getting on and off the trains, platform congestion, and other complex circumstances as well as link this to the train control system. Automation of tasks to determine whether to close the train doors involves AI analyses of video taken by ITV camera monitoring the platform typically used by conductors and drivers to decide whether to close train doors based on the location and circumstances around passengers.

As illustrated in Fig. 5, AI analyzes video from the ITV camera to integrate and assess the analysis results for each train to determine whether the train doors can close. This system automatically closes the doors by notifying the train of the analysis results wirelessly so that the onboard system can determine whether to close the doors while evaluating departure conditions from the departure time to data from the signal system. The unique Maisart AI technology provided by Mitsubishi Electric drives the efficiency of the AI analyses in this system to increase the speed of processes to determine whether to close train doors while responding to passengers running to rush onto the train and other sudden situations that arise. Through this approach, the system was able to make accurate decisions on when to close the train doors roughly 90% of the time in offline testing using ITV camera at several real stations.

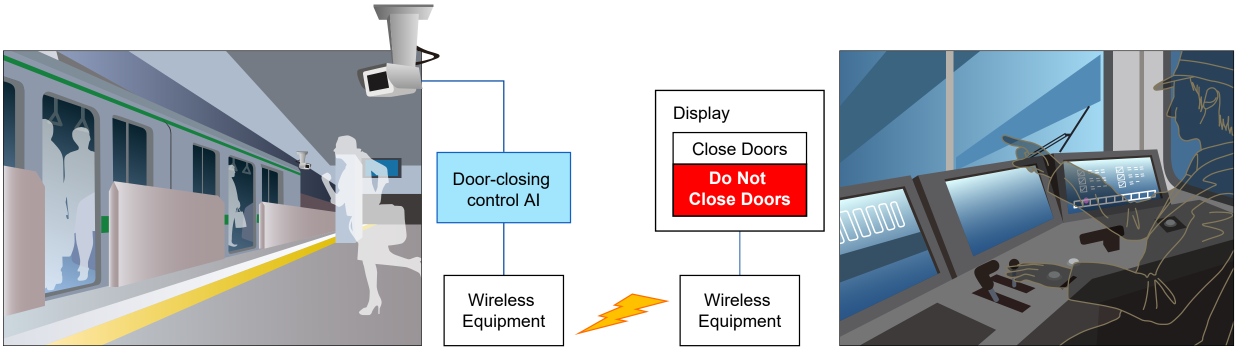
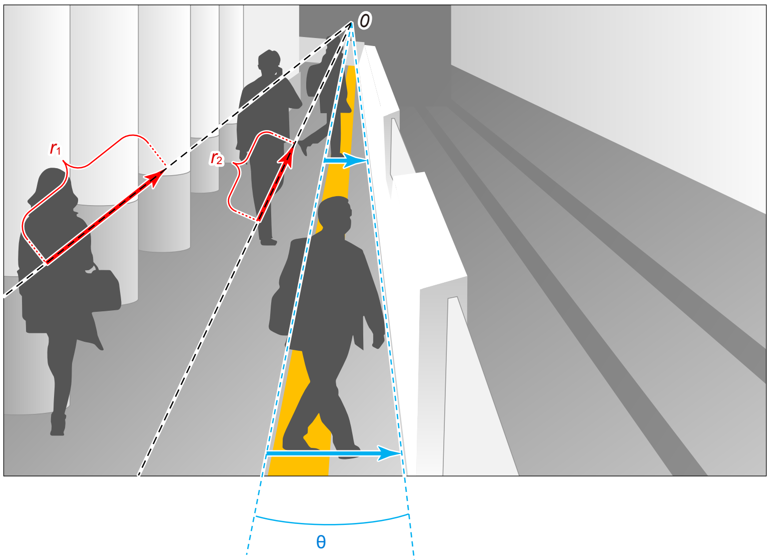


Fig. 5 Overview of the door-closing control AI

AI analyses has also struggled more to assess small figures far from ITV camera than those nearby. As shown in Fig. 6, development is advancing measures to implement motion extraction methods via coordinate transformations in order to overcome this challenge.

In the future, Mitsubishi Electric will further the efficient development of AI and evaluations in real train operations so that this system can easily accommodate multiple railways.



The system converts the platform into a coordinate system with the origin at the farthest end of the platform to determine the direction of movement using the theta component (length in the direction around the origin).

Fig. 6 Movement distance extraction method using coordinate transformation

5. Train Service Support Solution

Crew currently check the state of any trouble or other abnormalities on the train due to equipment failure while communicating with operation control center staff before the operation control center makes a final decision, and then issues instructions to reset equipment or shift to low-speed manual operations based on train service rules. On autonomous trains without any crew onboard though, remote operations limit tasks to recover standard train services, which is challenging because it requires a considerable amount of time to deploy capable crew to the site who can respond to the problem or drive the train in order to get the train up and running again.

Mitsubishi Electric is already building an analysis system that can track equipment degradation by collecting and monitoring operational data from each piece of onboard equipment via its unique INFOPRISM IoT platform to realize Condition Based Maintenance (CBM) that improves maintenance work. To further enhance functionality and establish a solution that can achieve stable train services, this analysis system has to assess the health of the train in real time based on data to more quickly vehicles exchange before failure or address any other potential problems. The solution would avoid vehicles exchange in operation that experience failures and lower the occurrence of service disruptions.

6. Conclusion

This paper has described the solutions that Mitsubishi Electric views as necessary for its autonomous driving system and some of the functions provided by those solutions. We are already working with railway operators to prove the concepts of these technologies while ramping up efforts toward practical use from data aggregation and problem detection to response analyses in the event of any abnormalities. In particular, safety evaluations are necessary and require proof-of-concept testing and third-party assessments. We recognize these efforts as priority initiatives.

Mitsubishi Electric is continuing to validate, review and collect data on the various solutions currently in development. We are doing everything in our power to provide solutions that both railway operators and passengers can feel secure in using sooner rather than later.

Railway operators made these proof-of-concept tests possible by providing a venue to validate each solution.

Mitsubishi Electric will continue to help maintain and expand sustainable urban and rural railway systems as well as other public transportation by strengthening relationships with railway operators and train manufacturers as well as representatives of various organizations and associations.

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Carbon Neutrality Initiatives by Reduction of Operating Power of Railway Vehicles

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1. Introduction

Developed nations have committed to realizing carbon neutrality by 2050 in an effort to combat climate change as people become more vested interest in decarbonization throughout the world. Japan is already engaged in active efforts to reach the ambitious goal it set to reduce greenhouse gas emissions 46% by 2030 compared to 2013 levels.

Railways give hope to these initiatives as a highly efficient transport system with a low environmental impact. Development is already advancing technologies toward a greater modal shift from automotive and air travel to railway transport as well as greater railway energy-savings and decarbonization(1). Mitsubishi Electric has pioneered efforts to realize carbon neutrality through the sophisticated technologies it has amassed in its transportation systems business with the hope to bring about a sustainable society offering safety, comfort, and prosperity.

Trains make up roughly 70% of the CO_2 emissions produced by railway operators. The reduction of these emissions is essential to realize carbon neutrality in the railway industry. As a few measures to save energy during the operation of train systems, Mitsubishi Electric introduced silicon carbide (SiC) applied drive control equipment and highly efficient totally enclosed electric motors to the main circuit system. These innovations improve efficiency during operation and drastically increase regenerative electricity to save energy. We also developed a Station Energy Saving Inverter (S-EIV) to more effectively utilize the surplus regenerative energy produced by each train.

Both the expansion of these efforts as well as initiatives linking each subsystem configuring the railways system based on an in-depth analysis of mechanical and electrical systems is necessary to further reduce CO_2 emissions in the future. Mitsubishi Electric uses the data aggregated from the onboard electrical equipment to link data between the station and onboard systems in an effort to spearhead more effective energy savings.

This paper describes adjustments to substation transmission voltages to improve utilization of the regenerative energy as well as other initiatives to realize carbon neutrality in the railway industry. These initiatives employ technologies to save energy in onboard systems, to realize high efficiency through the adoption of innovative circuit systems as well as improve the efficiency of devices throughout the Train Control and Management System (TCMS) configuration, and those to save energy by linking stations and trains.

2. Energy-saving Technologies for Onboard Systems

Onboard systems include energy-saving technologies from the main circuit systems directly tied to the drive control of trains and Auxiliary Power Supply System to methods that reduce the equipment in operation under light-load conditions in order to drive trains in the high efficiency regions as well as analyses of vast run curve data from actual trains. These technologies give hope to realize approaches that create optimal energy-saving services according to each section of railway line.

2.1 Greater energy savings through technological innovations of main circuit systems

Mitsubishi Electric pioneered, commercialized and integrated a high-efficiency, totally enclosed Induction Motor and an Insulated Gate Bipolar Transistor (IGBT) hybrid SiC power module with an inverter system that adopts a Sic-Diode as the flywheel diode—a first in the world*1—into an energy-saving main circuit system for use on commercial lines in February 2012. This system contributes to greater energy savings throughout the entire circuit system by expanding the effective region of Power Regenerative Brake and reducing motor loss through high-frequency switching.

In addition, Mitsubishi Electric developed the first high-efficiency Synchronous Reluctance Motor (SynRM; Fig. 1) in the world*2 for railways and a Synchronous reluctance motor and inverter Traction drive System (SynTRACS). Railways use SynRM as drive motors due to the lower losses and higher efficiency characteristics than Induction Motors (IM). Permanent Magnet Synchronous Motors (PMSM) offer one option for a high-efficiency train motor, but the magnets embedded into the rotor of PMSM are powerful rare-earth magnets. However, rare earth elements will become harder to acquire in the future. Each motor requires an open magnetic contact in case of problems because the motors produce electromotive force when coasting, which makes the circuit configuration more complex and comes with other such challenges.

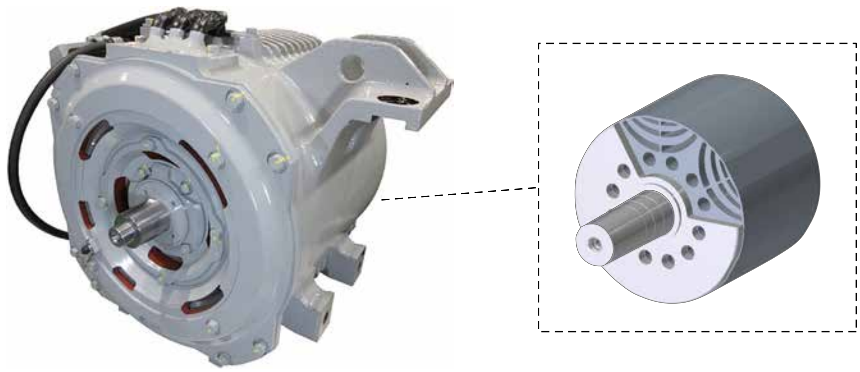


Fig. 1 Image of SynRM for rolling stock and the rotor inside the motor

SynTRACS consists of a SynRM and SiC inverter to realize the highest efficiency in the world without using rare-earth elements. The maximum motor output is 450 kW and reduces the losses generated in each motor by 50% compared to conventional high-efficiency IM. As described in Section 2.1.2, SynTRACS can even reduce power consumption by 18.1% throughout the entire propulsion control system compared to standard IM systems based on evaluations of the effective energy savings on commercial railways(2). As illustrated above, the SynTRACS system will contribute to even greater energy savings on railways in the future.

*1 Based on our research as of September 27, 2012.

*2 Based on our research as of November 10, 2022.

2.1.1 SynTRACS technical characteristics

PMSM have rare-earth magnets embedded in the rotor and produce electromotive force as described before. On the other hand, SynRM do not produce electromotive force while coasting and do not require the same measures be taken while coasting as IM systems because the rotor consists of an iron core just like IM. Most trains coast after accelerating to a certain speed after departing a station until braking to stop the train at the next station because rolling stock have a large amount of inertia and minimal running resistance. IM systems are seen as advantageous from the perspective of inducted voltage measures while coasting as well as mitigation of the losses produced due to changing magnetic flux in the motor under drive. However, IM systems require the flow of current in the rotor conductors, which produces cooper losses due to the winding resistance when current is flowing in the rotor. Therefore, in principle, synchronous motor systems is more advantageous from an efficiency standpoint. SynRM combines the benefits of IM with the high-efficiency characteristics of synchronous motors.

Generally, PMSM produce rotational force using the torque produced through the rare-earth magnets and reluctance torque produced by the rotor geometry. SynRM do come with many challenges in realizing larger capacity and high-torque variable speed control as a drive motor for railway applications because only reluctance torque produces the rotational force. Mitsubishi resolved these challenges in two ways: (1) optimization of the iron core geometry of the rotor and (2) utilization of the SiC inverter characteristics. Figure 2 presents the rotational principles of SynRM.

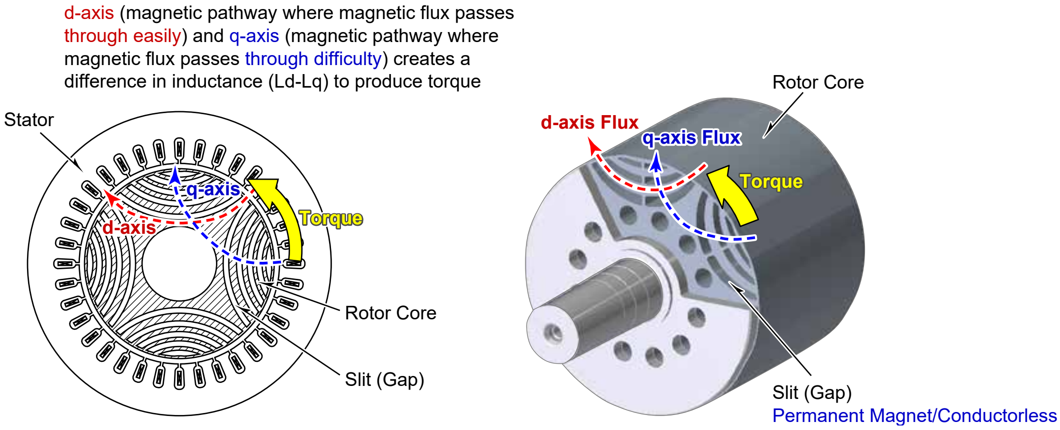


Fig. 2 Rotation principle of SynRM and image of rotor

2.1.2 Validation of the effectiveness in saving energy through SynTRACS

The SynTRACS was installed on a 13000 series train running on the Tokyo Metro Hibiya Line to conduct a running test and evaluate the energy savings during commercial operation in December 2021. Over a month and a half of commercial operations, Tokyo Metro measured the power consumption of its trains equipped with SynTRACS. The trains traveled a cumulative distance of 11,157 km with a power consumption intensity of 0.88 kWh/(train per kilometer). To verify the energy-saving benefits of SynTRACS, these results were compared to the power consumption intensity of typical IM systems. Table 1 shows this comparison after converting the different weights of the trains equipped with each system. The validation results comparing the SynTRACS system against the typical IM system indicate 18.1% better power consumption.

Table 1 Comparison of SynTRACS and conventional IM systems for consumption rate

	Train weight (t) (per train)	Intensity consumption (train per kilometer)		
		Motor	Regenerative	Actual consumption
SynTRACS 13000 series test-loaded trains (after train weight conversion)	33.31	1.58	0.81	0.77
Conventional IM System 9000 series large scale renewal construction trains	29.25	1.87	0.93	0.94

18.1% better

In addition, a simplified cooling structure that utilizes the high-efficiency characteristics of the SynRM not only reduced weight (-7.1%) but also increase capacity (+11%) compared to typical IM systems. Moreover, SynRM does not require the open contact necessary in PMSM systems in case of failures between the built-in inverter and motor in the event of any abnormalities, which simplifies the system.

2.2 Greater energy savings through formation control using TCMS

The load factor impacts the efficiency of the auxiliary power system (SIV system), decreasing equipment efficiency compared to the standard efficiency at a light load. To overcome this problem, each train formation that includes multiple SIV for parallel synchronous operations (control aligning the amplitude and phase of the three-phase output voltage) can take advantage of the ability to start and stop using an uninterruptible power supply. This system adjusts the SIV drive units in operation according to the load factor for the entire formation to realize a high-efficiency drive region during light loads.

More specifically, this control method reduces the number of SIV drive systems at a light load to increase the load factor of the SIV systems while the train is in service in order to enhance SIV system efficiency as a train formation (Fig. 3/Fig. 4). The SIV systems that have been shut down only take roughly one second to recover synchronous operations and adapt to rapid load fluctuations. The use of operational data from other SIV systems and loading equipment in TCMS (HVAC heating and cooling load/operational status of air compressors) enables the precision of in-operation/shutdown control.

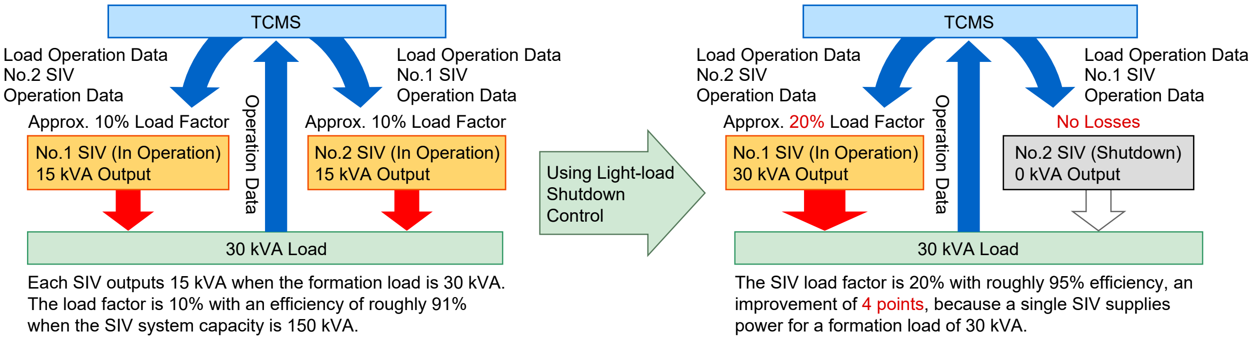


Fig. 3 Improved equipment efficiency through light-load deactivation control of SIV measures in the train

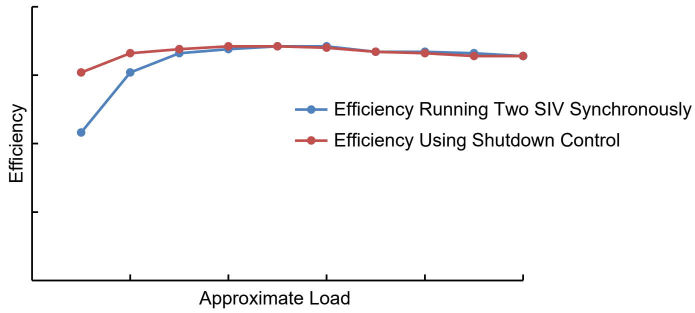


Fig. 4 Comparison of efficiency when two SIV units are operated in parallel and in idle control

2.3 Speed profile optimization for energy saving

The optimization of train speed profile to effectively use coasting and other drive conditions is known to greatly reduce power consumption, even with the same travel time between stations. Mitsubishi Electric has optimized ATO speed profile as well and demonstrated the tremendous energy-savings on real train lines(3). Train operators do require results tied to data to make decisions on whether to invest in revising train speed profile in order to save energy, but the collection and analysis of this data involves a significant undertaking. However, the aggregation and analysis of a huge volume of data has become much easier now that onboard data collection is possible using cloud computing. Mitsubishi Electric gained the following two insights as a result of visualizing and analyzing onboard data for numerous trains operating during actual train services.

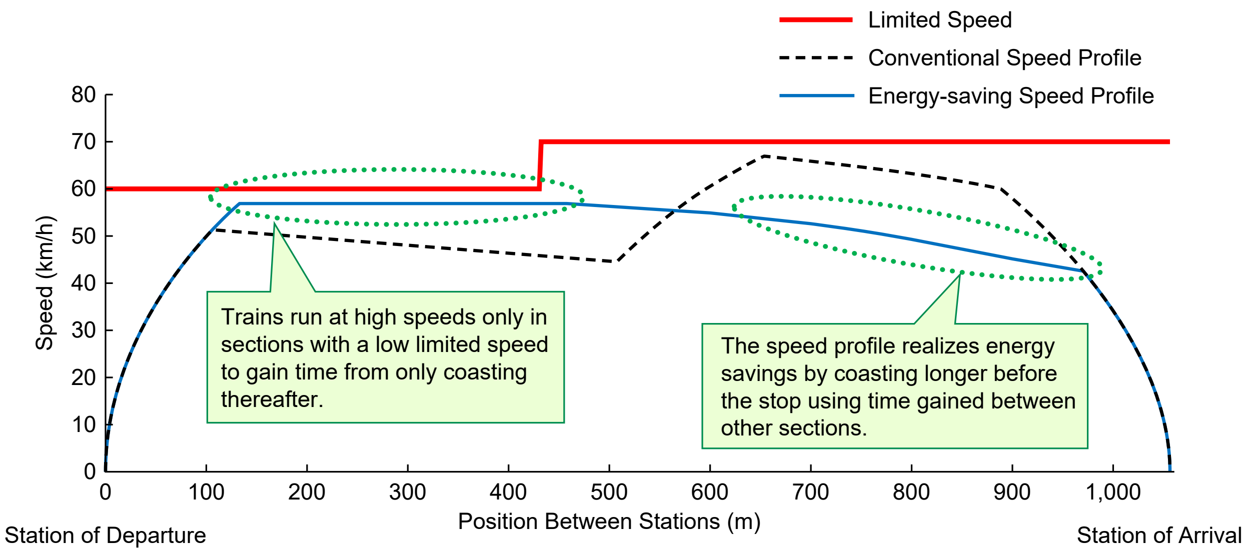
(1) Some cases selected the ATO recovery mode (mode to reduce the travel time as much as possible within speed limits) even without delayed services.

(2) There was some room to improve these train speed profile, especially as there were excessive acceleration between some stations.

To reduce the travel time by two seconds in the recovery mode outlined in (1), power consumption increases at least 10% between some stations. A revision of standard service and recovery speed profile should resolve this problem. As illustrated by Fig. 5, the speed profile optimizations intended to save energy during operation does demonstrate a 15% improvement to the power consumption between stations. The visualization of onboard data in this way can properly select effective measures using minimal effort.

3. Energy-saving Technologies Using Links Between Wayside and Onboard Equipment

Section 2 has described the energy-saving technologies of the onboard systems. A better usage rate of regenerative energy produced during braking in addition to the higher onboard equipment efficiency have been measures to reduce power consumption. It is essential to understand and adapt to the level of regenerative energy, which is influenced by factors that include the train load and voltage fluctuations in the overhead lines. Under minimal load, trains cannot always sufficiently use all of the regenerative energy produced during service operations either. That is why we are considering ways for station systems to effectively use surplus regenerative energy.



	Time to Reach Next Station (s)	Power Consumption (kWh)
Conventional Speed Profile	88.0	12.5
Energy-saving Speed Profile		10.6 (15% Reduction)

Fig. 5. Example of energy conservation promotion through optimization of speed profile

3.1 Higher usage rate of regenerative energy by modifying substation transmission voltage and narrowing regenerative train voltage

The effective use of regenerative energy requires awareness about the state of mechanical and electrical systems and substations. If multiple trains are running in the same feeder section, it is difficult to grasp the power exchange between trains using only measurements done at substations. The use of overhead line voltage and other measurable train data (onboard data) identifies the power conditions and enables optimization throughout all mechanical and electrical systems. This section describes the transmission voltage substations and effective use of regenerative energy based on onboard data analysis.

Figure 6 presents a schematic diagram of the power exchange between the overhead line voltage, motor trains and regenerative trains. When the transmission voltage from substations is high, the overhead line voltage raises above the constant voltage during regeneration. To avoid any excessive rise in voltage in the regenerative trains, the system narrows the regenerative current to reduce the regenerative energy. At the same time, the power supplied to the motor trains from the regenerative trains decreases, which proportionately increases the power supplied by the substation. In other words, the narrowing characteristics of the overhead line voltage and regenerative trains vary the regenerative energy. The analysis of the overhead line voltage, regenerative energy, and other data collected from the trains makes evaluations of measures to reduce the drive power and the effectiveness of those measures throughout all mechanical and electrical systems possible.

One measure to reduce drive power decreases the transmission voltage of the substation and increases the regenerative narrowing voltage to expand the range of the regenerative energy supply from the regenerative trains, which should improve the regenerative power usage rate. However, a drop in the transmission voltage from the substation decrease the overhead line voltage, which can lower train performance and increase motoring time. As an onboard function, such a measure limits the input current to mitigate the formation output if the overhead line voltage falls below a designated value during drive. When the overhead line voltage falls, the overhead line current increases to sustain the drive performance of the train, which could also increase power loss in the overhead lines. This measure must avoid any unnecessary drop in the overhead line voltage and adapt to the current conditions of the train by closely monitoring onboard data about the amount of transmission voltage drop of the substation.

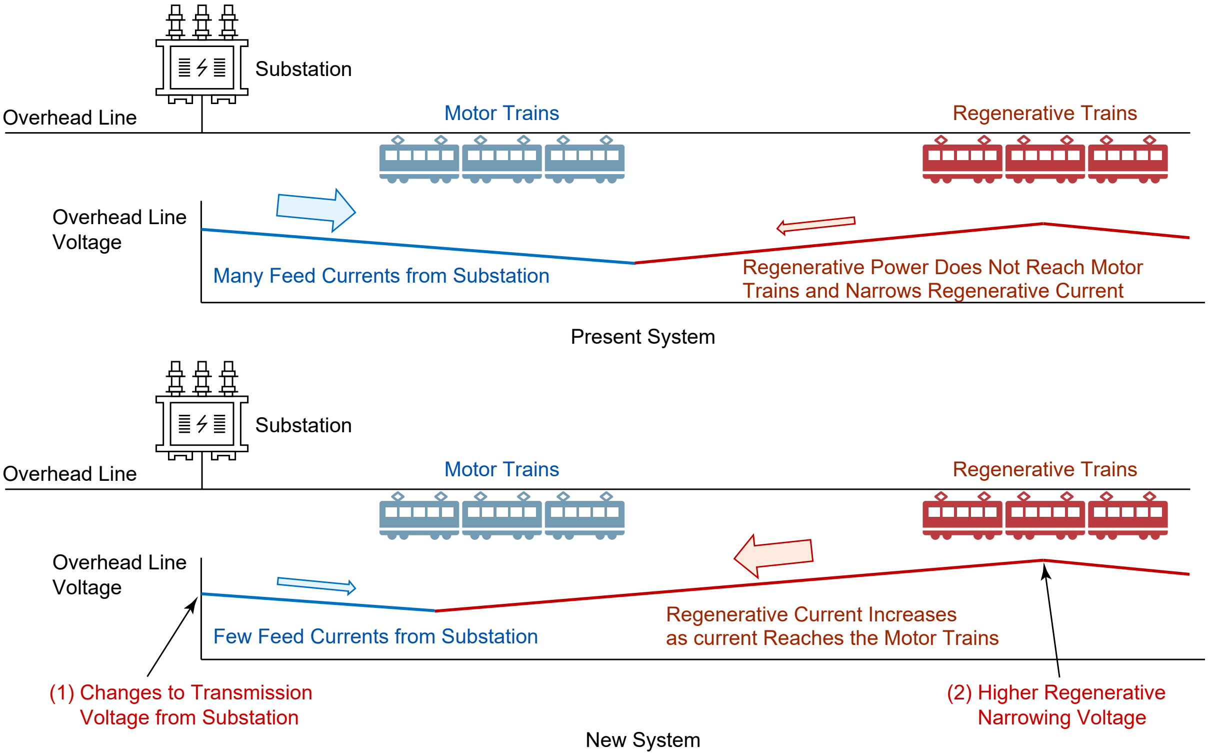


Fig. 6. Schematic diagram of overhead line voltage and power transfer between power and regenerative vehicles

3.2 Effective use of surplus regenerative energy using S-EIV

We are also working to use onboard data to assess S-EIV sites, which save energy through the use of surplus regenerative energy. This technology analyzes the drive power and pantograph voltage of the train from onboard data to visualize any surplus regenerative energy to evaluate sections between stations that have a large amount of regenerative narrowing power for selection as candidates for S-EIV stations.

An ideal system would collect and analyze onboard data from every train running on these section of track, but current evaluations only make considerations after analyzing data acquired from a certain percentage of every train because the data for every train cannot be. The results indicate that this measure can identify surplus power trends on each section between stations, even with only about 25% of the data. In the future, we hope to improve the accuracy of assessments by gradually increasing the number of trains included for data collection.

These reviews select potential installation sites, and then quantitatively identify the effective energy savings. The actual measurement equipment consists of a Direct Current Potential Transformer (DCPT) and effective nest measurement units that can be installed outdoors. The DCPT, S-EIV calculation and monitoring control units use the same equipment as the actual system to provide real measurements in a configuration equivalent to the actual S-EIV system. We estimate the annual amount of regenerative energy by taking actual measurements for at least nine days to calculate the average on weekdays and holidays as well as the monthly average, which is multiplied by a seasonal coefficient. The smooth adoption of S-EIV systems more quickly realizes carbon neutrality because actual measurements can evaluate the effective energy savings before implementing the actual system.

4. Conclusion

This paper has described various technologies to reduce the power used in train services that make up 70% of CO_2 emissions by railway operators as an initiative to realize carbon neutrality. As onboard systems for rolling stock, the SynTRACS development to realize the highest efficiency in the world in addition to SiC applied drive control has shown 18.1% lower power consumption than traditional IM systems in commercial operations. Moreover, auxiliary power systems can realize high-efficient train services by adjusting the number of SIV drive units in operation according to the load factor for all of the formations during parallel synchronous operations.

To optimize not only the onboard systems but also the wayside mechanical and electrical systems, this paper has looked at the use of onboard data to optimize the transmission voltage of substations and effective use of regenerative energy via an ideal placement of station energy-saving inverters.

In the future, comprehensive identification and analysis of current mechanical and electrical systems is essential to efforts that are working to establish links between systems in order to further reduce CO_2 emissions. Mitsubishi Electric will continue to contribute to the realization of carbon neutrality in the railway industry by expanding measures to further heighten effective energy savings using data collected from electronics onboard trains.

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