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Our 100-Year History and the Sustainable Future of Transportation Systems

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Changes for the Better

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Mitsubishi Electric **ADVANCE**

Our 100-Year History and the Sustainable Future of Transportation Systems

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CONTENTS

Precis

For 100 years since foundation, Mitsubishi Electric Corporation's transportation business has developed in line with the history of advancement of electric railway technologies. Railway transportation is so environmentally friendly that can contribute to solving the global environmental problems and social issues that have been intensifying against the backdrop of the COVID-19 pandemic. In this edition, we look over the technological trends of the last 100 years toward the sustainable future and aim to highlight the following: the promotion of energy-saving through power electronics technologies; the expansion of our overseas transportation business and the SDGs (Sustainable Development Goals) initiatives; and the consideration being given to societal change in the face of the COVID-19 pandemic.

Foreword

Author: *Carsten Thomas**

Transportation Systems - Approaches to SDGs

Megatrends are fundamental changes over an extended period that affect the whole of society. Some of the key megatrends are in direct contradiction to each other, such as population growth, urbanization and megacities on the one hand, and climate change and resource scarcity on the other. Such conflicting megatrends are a huge challenge for society. The global demand for transport is expected to more than double by 2050, while transportation accounts for a very large share of greenhouse gas emissions (e.g., 22.3% in the EU). Examples like this illustrate that sustainable growth can only be achieved if megatrends are holistically understood and if the associated challenges are mastered.

In 2012, the United Nations Conference on Sustainable Development in Rio de Janeiro adopted the Sustainable Development Goals (SDGs). This set of universal goals describes the objectives that must be met in order to master the urgent environmental, political and economic challenges facing the world. They serve as a universal framework to enable countries to better target and monitor progress across all three dimensions — social, environmental and economic — of sustainable development in a coordinated and holistic way. In the years since 2012, the SDGs have been steadily growing in importance, with 193 nations in the world having now endorsed this policy framework.

The transport domain contributes directly to several SDG targets, including road safety (target 3.6), energy efficiency (target 7.3), sustainable infrastructure (target 9.1), urban access (target 11.2) and fossil fuel subsidies (target 12.c). All organizational stakeholders in the transport domain, including railway sector governments and municipalities, infrastructure providers, operators, rolling stock manufacturers and subsystem suppliers, are urged to improve the domain such that the SDGs can be progressively implemented.

The railway sector plays a key role in this context. Railway transport for both passengers and freight is considerably safer and more energy-efficient than road transport with its much higher traffic densities, and is already largely independent of fossil fuels. Clearly, a strong shift from road-bound transport towards railway transport would serve the SDG objectives very well. However, although such a shift has been discussed for many years, it has not yet happened. In the EU in 2017, road transport was used for 80% of all passenger kilometers and 51.7% of all (freight) ton kilometers, compared with only 8.3% and 11.6%, respectively, for railway transport[1]. What is required to change this picture?

To date, road-bound transport is considered more flexible and individualized than railway transport. On roads, freight can be delivered directly door-to-door, and passengers have many choices to individualize their journey, such as starting time, route, breaks and detours. Sometimes this flexibility may be only a perceived advantage, rather than a real one. Nevertheless, in many cases, individualization and flexibility make road transport more attractive and economical than railway transport. Therefore, the railway sector must find ways to provide the same flexibility and individualization to its customers to be able to attract transport demand. This likely requires major changes to today's railway transport system. Railway transport needs to connect seamlessly with other transport modes, train scheduling densities should be improved by orders of magnitude, and freight transport must be made attractive for small volumes through routing flexibility and coverage of the last mile to the sender or receiver. In addition to such conceptual and systemic changes, further improvements are required in terms of energy efficiency, automation, maintenance optimization and other areas, to decrease the life-cycle cost and make railway transport more attractive.

Under its corporate mission, Mitsubishi Electric is continually striving to improve its technologies and services, thereby helping to achieve the objectives of the SDGs. This special issue focuses on specific challenges that Mitsubishi Electric faces as a major global subsystem manufacturer in the railway sector, and concrete examples of contributions that Mitsubishi Electric is making in its mission to support implementation of the SDGs.

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[1] https://www.eea.europa.eu/data-and-maps/indicators/passenger-and-freight-transport- demand/assessment-1

**Professor, HTW Berlin, University of Applied Sciences*

The 100-Year History and Future Perspective of Mitsubishi Transportation Systems

Authors: *Yoshiyasu Hagiwara** and *Masaki Sugaya***

1. Introduction

Mitsubishi Electric Corporation started transportation business in 1921 when the company was founded, and thus has a history of 100 years. Currently, the company provides a wide range of products for whole railway systems, from equipment for railway vehicles (equipment of the train system for running, stopping, and control) to ground equipment with power electronics, control, radio, and video technologies as the core (Fig. 1).(1) In the 1960s, the company expanded its railway business to overseas, and has now supplied products for more than 60,000 railway vehicles in 36 countries around the world.

Railway transportation is an eco-friendly high-speed mass transit system; it is a social infrastructure that supports economic growth. It is also regarded as an important means of mitigating various social issues such as overcrowded cities and environmental problems, thus helping to achieve the SDGs[*1] to create a sustainable society.

This paper looks at changes in the railway business and our core technologies cultivated in the last 100 years. It also introduces our technologies and product development that will pave the way for future activities to create new values towards achieving the SDGs.

2. Social Issues in the Railway Business in Japan and Overseas

Railway transportation is a safe and highly-reliable social infrastructure that is essential for societies today, such as for metropolitan railways, inter-city railways, and freight transportation.

In some industrial countries such as Japan and Germany, the population has started to fall. In Japan, in particular, the birthrate and labor force have been rapidly decreasing and the population has been dramatically aging. The Japanese railway business has been growing based mainly on passenger transportation as well as freight transportation. However, the population has been decreasing as society matures, and the industrial structure has been changing as it shifts toward the

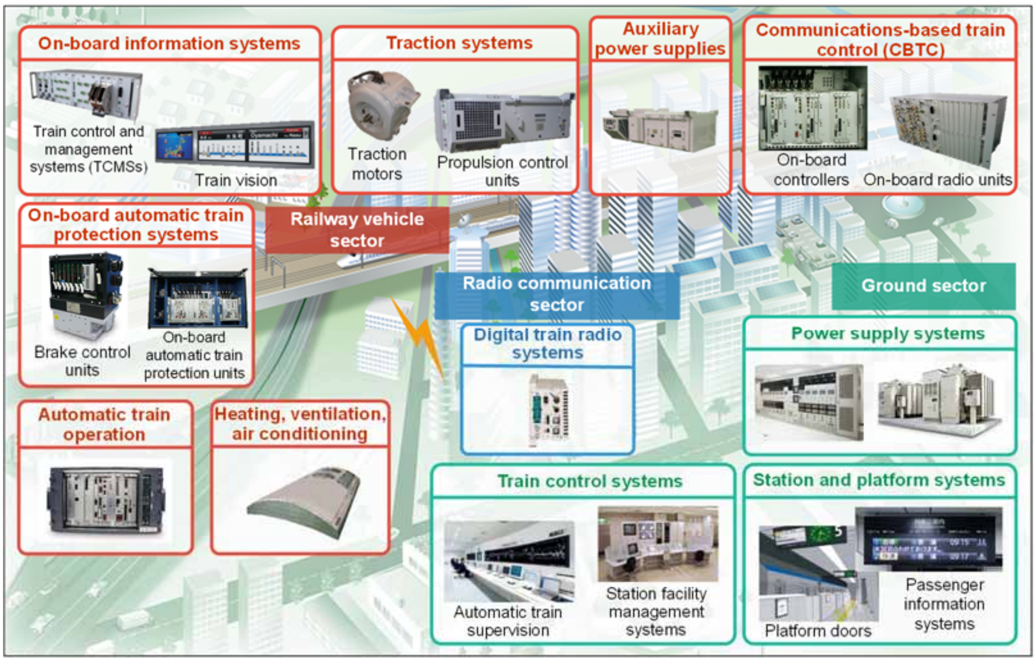

Fig. 1 Mitsubishi Electric's products and systems in the transportation business

*1 SDGs: Sustainable Development Goals

*Engineering Planning Dept. **Overseas Marketing Div.

tertiary industry; this may cause a structural decrease in railway transportation volume. In addition, demand for transportation may decrease due to changes in working style, such as the expansion of digitization and teleworking and a sharp decrease in passenger demand due to the recent COVID-19 pandemic, driven by the growth of the Internet community and infection prevention measures.

In response to such changes in the social environment, there is a pressing need in the railway business to improve business efficiency by promoting digitization and reducing operating costs. In addition to measures against the aforementioned energy and environmental problems, social issues related to railway transportation are becoming greater in scale and complexity. Examples of such issues are antiterrorism measures for the security of society, infrastructure maintenance and management, and preparation for large-scale disasters caused by global warming and global-scale climate change.

Overseas, in Europe, which is the center of railway technologies, regulations and systems, EU directives have been issued indicating a policy of separating railway operation (upper side) from infrastructure (lower side), and business efficiency has been improved based on the principle of competition since the 1990s. Policies for the railway sector are in line with economic policies such as the European Green Deal and Green Recovery. In addition, in emerging countries mainly in Asia where the focus has been on developing urban areas, metropolitan railways have been rapidly constructed and developed since the 2000s to solve urban problems, such as population concentration, traffic congestion, and atmospheric pollution. As new lines have been constructed, technologies such as CBTC[*2] and autonomous driving have been adopted and new maintenance systems and concepts such as CBM[*3] and asset management have been introduced.

In view of the changing railway business environment in Japan and overseas, social issues may be solved by applying new technologies in order to help achieve the SDGs, too.

3. Technology Bases in the 100 Years Since the Foundation of Mitsubishi Electric Corporation

It is considered that railway services started with railway transportation by Stephenson's steam locomotive between Stockton and Darlington in the U.K. in 1825. Electric railway services started with passenger transportation by Siemens & Halske AG in a suburb of Berlin, Germany in 1881.(2)

In Japan, railway services began between Shimbashi and Yokohama in 1872, while electric railway services began in Kyoto City in 1895—approximately ten years after that in Berlin—and thus have a history of more than 120 years.

Mitsubishi Electric entered the transportation business in 1921 when the company was established. It engaged in the electric railway business in Japan as a leading maker of technologies that revolutionized the field, such as AC electrification, technologies for Shinkansen, and induction motor drive, and the company has grown in line with the history of electric railways in Japan. This section looks at the history of railway technologies and Mitsubishi Electric's transportation business in each era.

3.1 From the foundation of Mitsubishi Electric (1921) to before the war: Technical cooperation with overseas companies

The 1920s, when Mitsubishi Electric was established, saw rapid industrialization in Japan. The company delivered electric components for railway applications from its founding year, such as transformers to the Ofuna Substation of the Japanese Ministry of Railways (1921), standard type traction motors for electric trains of the Japanese Ministry of Railways (1936), and Abt-system electric locomotives, and built up a strong track record. In addition, Mitsubishi Electric formed a technical tie-up with Westinghouse Corporation in the U.S. in 1923 and Westinghouse Air Brake Technologies Corporation in 1924; it learned new designs, drawing methods, engineering technologies, and factory management methods, which helped it modernize the company and enhance the technical level of its railway products.(3)

3.2 From after the war to the 1950s: Start of AC electrification and improvement in equipment performance

During Japan was recovering from the war, Japan National Railways (JNR) decided to promote AC electrification to increase the transportation capacity. Mitsubishi Electric delivered transformer units for AC electrification to JNR (1956) and developed and delivered prototype electric components with mercury rectifiers for AC electric locomotives (1956). AC electrification technologies led to technologies for locomotives for overseas markets and the Tokaido Shinkansen in the 1960s. During this period, performance was improved by development of the WN drive, reducing the weight of the traction motors and improving the acceleration and deceleration performance. We developed and delivered the first HVAC[*4] system for JNR sleeping cars (1950) and the

*2 CBTC: Communications-Based Train Control
*3 CBM: Condition Based Maintenance
*4 HVAC: Heating, Ventilation, and Air Conditioning

first electric components for DD50 diesel locomotives (1953).

3.3 1960s: Revenue Service of the Tokaido Shinkansen, pioneering radio and train control, and the start of overseas business

Japan rebuilt itself after the war during the period of high economic growth, and hosted the Tokyo Olympics. In the event of the Tokaido Shinkansen project, we were in charge of designing the main electric components for railway vehicles, and delivered them in 1963. In addition, the use of information and control systems, such as train radio (1960) and ATC*5 systems (1961), began. As our first business overseas, we exported ignition-rectifier AC electric locomotives for Indian Railways (1960) and then electric components for DC electric locomotives for Spanish National Railways (1966) (Fig. 2, Fig. 3).

3.4 1970s: Energy saving, computer control, power electronics, and choppers

In this era, computer control, power electronics, and energy-saving technologies advanced. We developed chopper systems for chopper-controlled railway vehicles (1970) and for the world's first chopper-controlled railway vehicles with regenerative brakes with thyristors, which were put into service from 1971.(4) Various technologies, such as reverse conductive thyristors, automatic variable field choppers, ebullient cooling, and four-quadrant choppers, were developed and chopper systems were adopted mainly for subways in cities in Japan. Mitsubishi Electric made its mark in this era as a manufacturer of chopper-controlled systems for urban traffic and exported chopper systems to overseas markets such as Mexico (we have received many orders, totaling 1,521 vehicles since 1979).

As ground equipment, Mitsubishi Electric developed thyristor inverter systems for electric power regeneration for the first time (1976). In 1981, Japan's first new transportation system with unattended operation using ATO*6 entered operation.

3.5 1980s to 2000s: Advancement of power devices, development of inverter-induction motor drive systems, and further expansion overseas

The Japanese economy recovered from the oil shocks and exports from Japan increased. In 1980, we held the Mitsubishi Transportation System Exhibition to promote our new inverter technologies to customers in Japan and overseas and accelerated development. In 1982, we supplied the first traction inverter systems for trams. Then, we worked for the high-voltage GTO thyristors (rated voltage of 4,500 V) and developed 1,500-V VVVF inverters for the first time (1984). Today, railway vehicles with inverters are standard for subway trains, electric trains for urban and inter-city lines, electric locomotives, and Shinkansen high-speed trains.

As various other countries developed their urban traffic transportation systems, we set up manufacturing bases for local production in Mexico, Australia, the U.S., and China and supplied products. We also rapidly increased exports to Spain, Singapore, Hong Kong, South Korea, Taiwan, Turkey, and India.

3.6 2010s to present: Promotion of SiC*7 inverters, ground-vehicle cooperation, railway LMS*8, and localization, and increase in the number of overseas customers

As power electronics technologies advanced, we commercialized SiC inverters for railway vehicles ahead of other companies (2012) and introduced the world's first SiC auxiliary power supplies (2013), realizing energy saving and smaller and lighter equipment. We also developed and commercialized CBTC systems that used information transmission technologies. In addition, we developed and introduced technologies to monitor the operation status of equipment through ground-vehicle cooperation and autonomous driving. Furthermore, as services to reduce maintenance work using IoT platforms, CBM, and asset management, we started providing LMS for railways (2019). Moreover, we have

Fig. 2 AC electric locomotive in India (in 1960)

Fig. 3 DC electric locomotive in Spain (in 1966)

*5 ATC: Automatic Train Control
*6 ATO: Automatic Train Operation

*7 SiC: Silicon Carbide
*8 LMS: Lifecycle Management Solution

developed a measuring vehicle MMSD[*9] that measures devices along railway lines and tunnels in detail. We have been continuing to develop technologies that help make the railway business more efficient.

Overseas, we established new production sites in Italy and India and promoted localization in Poland and Finland in cooperation with local companies. We increased customers in South America, such as Brazil, Chile, and Argentina as well as in Western Europe, such as the U.K., Germany, Italy, and the Netherlands.

This section looked at the trend of railway-related technologies for the 100 years since Mitsubishi Electric was founded in 1921. In all the eras, we promoted the railway business through strong cooperation with customers and applied the latest technologies in each era, such as power electronics, radio communications, and power transmission and distribution technologies, to railway infrastructure. We will keep advancing in the next 100 years by applying the latest technologies, such as AI[*10], sensors, and quasi-zenith satellites.

4. The Future of Mitsubishi Electric's Transportation System Technologies

Mitsubishi Electric handles all the functions of "running, stopping, and control" as a single company and proposes various types of products and technologies to satisfy diverse customer needs as a general electric machinery manufacturer. Our development and proposal activities are geared toward achieving the SDGs, which the entire staff have been actively working toward. The four solutions that will form the next-generation railway transportation system (Fig. 4) are: Eco-friendly and Environment; Maintenance and Asset Management; Safety, Security, Reliability, and Stability; and Autonomous Driving.

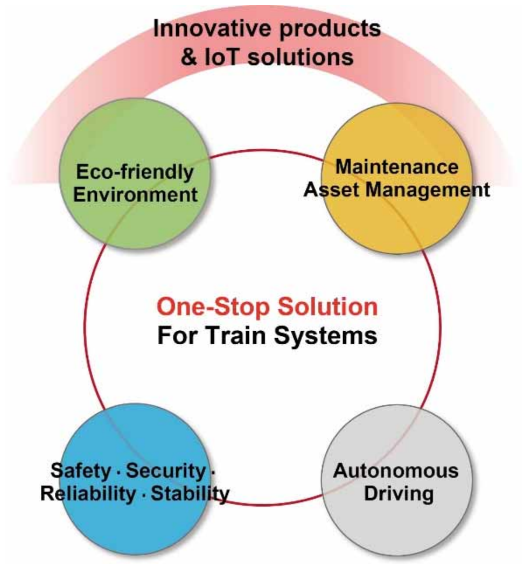

Fig. 4 Concept of the next-generation transportation system

4.1 Eco-friendly and Environment

A key target of our transportation business is to create a sustainable society and so we have focused on developing environmental and energy-saving technologies.

(1) The use of self-cooling (cooling method using traveling air and air convection) in propulsion control systems for railway vehicles reduces noise and enhances reliability, thus increasing maintenance efficiency and saving energy. Self-cooled converters, inverters, traction transformers, and traction motors are efficient, smaller, and lighter.

(2) One of our strengths is that we can propose optimum solutions for replacement projects and functional improvement and satisfy customer needs appropriately. We supplied traction transformers for French railways (SNCF) in a replacement project and IGBT inverter systems as replacements for chopper systems, achieving energy saving, lower noise, and reduced life cycle costs.

(3) For HVAC for railway vehicles in Europe, we have been developing low-GWP[*11] HVAC systems using a low-GWP refrigerant or a natural refrigerant (CO_2) to satisfy GWP regulations and help mitigate global warming.

(4) Our power semiconductor research/development and production sections cooperate on product development. We have developed SiC power modules ahead of other companies in the world, achieving higher efficiency, smaller size and weight, and energy savings of equipment for railway and electric sectors.

4.2 Maintenance and Asset Management

We have been promoting the LMS Platform, a total life cycle management solution for railway vehicles. The core of the LMS Platform is a TCMS[*12] that monitors the states of on-board equipment and manages them. In the LMS Platform, in addition to the TCMS, a WMDS[*13] for ground-vehicle cooperation, propulsion control unit, and other sub-systems are integrated. We will improve the efficiency of life cycle management in the railway business by providing various applications, and will propose optimum systems that realize customers' ideas, while also considering compatibility with existing systems.

In addition, in Japan, we provide railway vehicle maintenance solutions that help improve the business efficiency of railway operators and ensure safe and

[*9] MMSD: Mitsubishi Mobile Monitoring System for Diagnosis
[*10] AI: Artificial Intelligence
[*11] GWP: Global Warming Potential
[*12] TCMS: Train Control and Management System
[*13] WMDS: Wayside Monitoring and Diagnostic System

stable train operation by using our proprietary IoT platform, which features Maisart*14, Mitsubishi Electric Corporation's AI technology.

4.3 Safety, Security, Reliability and Stability

We have been proposing flexible solutions that include cooperation between units on board and units on the ground to satisfy customers' diverse needs, providing safe, secure, stable, and reliable services. Video analysis that detects passenger attributes (e.g., a wheelchair) and suspicious substances enables prompt response. The PIS*15 with high-resolution screens notifies passengers of information accurately through universal design. In addition, we provide safe, prompt and stable services, such as estimation of load factors through cooperation between train operation management and PIS and information provision to contribute to the security of passengers and train crews.

4.4 Autonomous Driving

In the railway sector, research and development of autonomous driving has accelerated, and autonomous driving has been spreading in Europe in particular. We have been developing autonomous driving systems for the next-generation railway transportation system by leveraging our knowledge on the design and production of train protection and control units such as CBTC and ATO. We will also contribute to enhancing the performance of train control, for example, for more comfortable rides, higher stopping accuracy, and energy-saving operation, in addition to safe train operation.

5. Conclusion

This paper looked at the technical progress of transportation systems in the 100 years since Mitsubishi Electric was founded, and at future plans for its transportation systems. These activities allow us to adapt to recent social and environmental changes in the transportation business, while helping to attain the SDGs including recent countermeasures against infectious diseases.

In order to create the next-generation railway transportation system for a sustainable society, it is crucial to use Mitsubishi Electric's technical synergies and to apply new technologies through research and development. It is also important to cooperate with stakeholders and customers. We will establish a new eco-system together with railway operators, the railway industry, government and municipal offices, universities, and research institutions in Japan and overseas by using IoT platforms. We will work hard toward the next 100 years based on our achievements in the past 100 years.

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*14 Maisart: Mitsubishi Electric's AI creates state-of-the-art technology

*15 PIS: Passenger Information System

Traction Inverter Systems with SiC Power Modules for Railway Vehicles

Authors: *Tetsuo Sugahara** and *Takahito Ishida**

1. Introduction (1) (2) (3)

After the adoption of the Kyoto Protocol in 1997, various measures against the global warming have been promoted. In 2018, the UN adopted the Sustainable Development Goals (SDGs) to mitigate social issues from a broader perspective. Under such circumstances, Mitsubishi Electric Corporation (MELCO) has been working to help build a sustainable, safe, secure, comfortable, and affluent society by using technologies that we have cultivated in the railway sector. Regarding the effective use of energy, in February 2012, we carried out a test to evaluate the performance of traction inverter systems using the hybrid SiC power module on Tokyo Metro's line No. 1, for the first time in the world. For such power modules, silicon (Si) is used for the insulated gate bipolar transistors (IGBTs), and SiC is used for the diodes. Since then, we have applied many SiC technologies to traction inverter systems for the Japanese and overseas markets. The application of SiC power modules has helped reduce the energy consumption of entire main circuit systems, for example, by expanding the range of power regenerative brakes and reducing the loss in motors through high-frequency switching. In February 2016, our propulsion control units, the world's first to use full-SiC power modules, received the Excellent Energy-Saving Device Award from the Japanese Minister of Economy, Trade and Industry. In such power modules, SiCs are used for both metal-oxide-semiconductor field-effect transistors (MOSFETs) and diodes.

To continuously contribute to the energy-saving goals of the SDGs in the future, we have developed smaller and lighter traction inverter systems by applying the latest SiC power modules that can act flexibly for the customer requirements as to the main circuit system.

Recently, the world-standard type of power module is the LV100 package, which is suitable for a parallel drive. Although various manufacturers have been commercializing LV100 Si power modules, MELCO commercialized LV100 full-SiC power modules for the first time in the world.[1] The full-SiC power module reduces about 80% of the switching loss in comparison to the Si power module, which helps reduce the energy consumed by the main circuit system. Yet, the application of the world-standard package also enables the size and weight of the traction inverter system to reduce. Thus, the optimum design can be chosen depending on the configuration and capacity of various types of traction inverter systems for railway vehicles.

This paper describes the advantages of the traction inverter systems with the latest SiC power modules for railway vehicles and its energy-saving effects in real operation.

2. Traction Inverter Systems with LV100 full-SiC Power Modules

2.1 Traction inverter systems

Table 1 describes the main specifications of a traction inverter system with LV100 full-SiC power modules, and Figure 1 shows its appearance. Assuming systems for conventional lines in Japan, one traction inverter system drives four induction motors of up to 220 kW connected in parallel as the specifications.

A traction inverter system consists of a line breaker circuit, power unit, and gate control unit. The LV100 SiC power module enables the cooler to be compact and the

Table 1 Main specifications of a traction inverter system with LV100 full-SiC power modules

Item	Specification
Input (overhead line) voltage	1,500 VDC
Main circuit method	2-level voltage source PWM inverter
Motor drive capacity	Maximum rating of 220 kW × 4 units
Cooling method	Self-cooling by moving air

Fig. 1 Traction inverter system with LV100 full-SiC power modules

[1] As of May 11, 2017, researched by Mitsubishi Electric Corporation

*Itami Works

power units to be high-density packaging, such as a filter capacitor and laminated busbar configurated with the SiC power module. This achievement reduces about 60% of the volume and 50% of the mass in comparison to the conventional Si power module application.

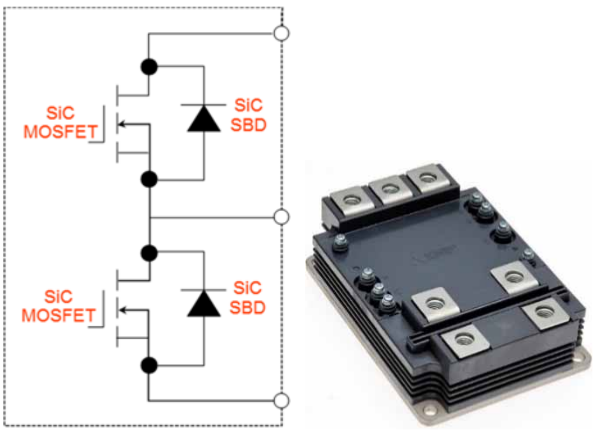
2.2 Advantages of LV100 full-SiC power modules[4]

Figure 2 shows the circuit diagram of the LV100 full-SiC power module and its appearance. The power module in the LV100 type consists of the circuit for the one arm of the two-level inverter. In general, Si power modules, the Si-IGBTs, and flywheels consist of silicon diode (Si-Di) devices while, for full-SiC power modules, they consist of SiC-MOSFETs and SiC Schottky Barrier Diodes (SiC-SBDs).

MELCO has commercialized Si and hybrid SiC power modules that are compatible with full-SiC power modules as our LV100 power modules, adding to full-SiC power modules, and they allow the optimum devices to be selected based on the required specifications of railway vehicles.

The LV100 power module also has the terminal arrangement to make the parallel drive easier, which is the advantage to achieve optimization by altering the parallel numbers corresponding to the vehicle specification.

Table 2 describes the main specifications of an LV100 Si power module and LV100 full-SiC power module. In comparison to the Si power module, the full-SiC power module increases 25% of the current-carrying capacity and about 16% of tolerable junction temperature, as well as reduces 80% of the switching loss. The achievements enable the equivalent motor to the Si power one to drive in the smaller number of the terminal arrangement than the Si power.



SBD: Schottky Barrier Diode

(a) Circuit diagram (b) Appearance

Fig. 2 LV100 full-SiC power module

Table 2 Main specifications of LV100 power modules

Module type	Si module	SiC module
Drain-source voltage	3300 V	3300 V
Drain current	600 A	750 A
Maximum junction temperature	150°C	175°C
Switching section	Si-IGBT	SiC-MOSFET
Diode section	Si-Di	SiC-SBD
Outside dimensions	100×140 mm	100×140 mm

3. Application to the Odakyu 5000 Series

Odakyu Electric Railway ("Odakyu") started operating the remodeled 1000 series in 2014. Mitsubishi Electric delivered traction inverter systems with 3.3-kV full-SiC power modules for the remodeled series for the first time in the world and demonstrated the energy-saving effects. In February 2016, we received the Excellent Energy-Saving Device Award from the Japanese Minister of Economy, Trade and Industry jointly with Odakyu.

In 2019, we delivered traction inverter systems with LV100 full-SiC power modules, as described in section 2, for the Odakyu 5000 series. This section mainly describes the case where traction inverter systems with LV100 full-SiC power modules for the 5000 series were used.

3.1 Specifications of the inverter system

Table 3 lists the specifications of vehicles of the 5000 series and remodeled 1000 series. The train set of the 5000 series is ten vehicles (5M5T), the same as the remodeled 1000 series. The newly manufactured series are to replace 8000 series vehicles and other types. As shown in Fig. 3, as the main circuit system, one variable voltage variable frequency (VVVF) traction inverter system controls four main motors.

Figure 4 shows the appearance of a VVVF traction inverter system. Traction inverter systems for the 5000 series are smaller and lighter: the volume was reduced by about 30% and the mass by about 20% compared to the traction inverter systems for the remodeled 1000 series.

Table 3 Specifications of Odakyu railway vehicles

Item	5000 series	Remodeled 1000 series
Electrical mode	1,500 VDC (overhead line method)	
Train set (MT ratio)	Ten vehicles (5 Motor cars 5 Trailer cars)	
Gauge	1067 mm	
Maximum speed	120 km/h	110 km/h
Acceleration	3.3 km/h/s (to a load factor of 250%)	
Deceleration	4.0 km/h/s	
Gear ratio	6.31	
Train set mass	308.7 tons/ train set	351.8 tons/ train set
Main-circuit control method	SiC voltage source VVVF inverter	

3.2 Results of running tests on a main line

MELCO conducted the performance confirmation test of the traction inverter systems for the 5000 series on an Odakyu main line. Figure 5 shows the power running test chart, and Fig. 6 shows the regeneration test chart. MELCO used the test result to evaluate the performance, such as the acceleration and deceleration of the various types of vehicles at powering and braking, as well as verify the noise of the traction inverter systems with the LV100 full-SiC power module. The modulation method based on our knowledge gained through developing the conventional traction inverter system with SiC power modules achieved the reduction of noises and to provide further comfortability for passengers onboarding.

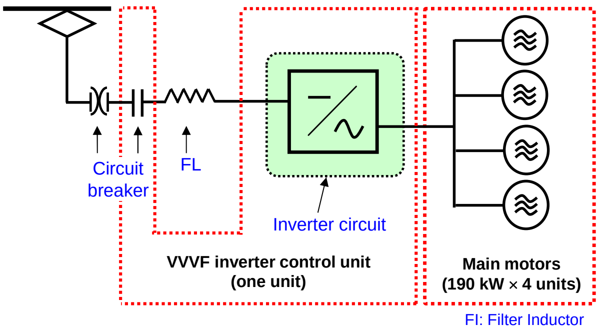


Fig. 3 5000 series main circuit system configuration

Fig. 4 VVVF traction inverter system for the 5000 series

Table 4 shows the results of analyzing the intensity of vehicles of the 5000 series and remodeled 1000 series in operation on lines in use. Although the running conditions vary, the intensity of the 5000 series is 0.0241 kWh/(km·ton), and that of the remodeled 1000 series is 0.0232 kWh/(km·ton), both the values being of a similar level. These values confirm that the main circuit system for the 5000 series saves roughly the same energy as that for the remodeled 1000 series, which reduces energy usage by about 40% compared with vehicles with the existing gate turn-off thyristors (GTOs).

4. Conclusion

This paper described the advantages of traction inverter systems with LV100 full-SiC power modules for railway vehicles and their application to the Odakyu 5000 series.

As manufacturers around the world must contribute to the SDGs, railway systems that have less environmental impact and that help save energy will play an important role. In the semiconductor device and

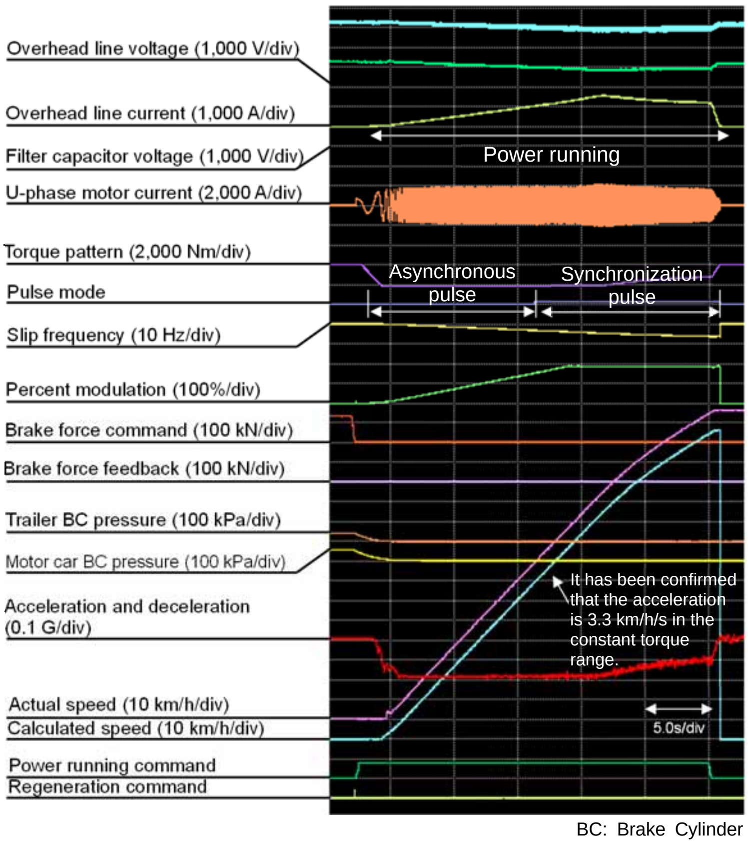


Fig. 5 Power running test chart

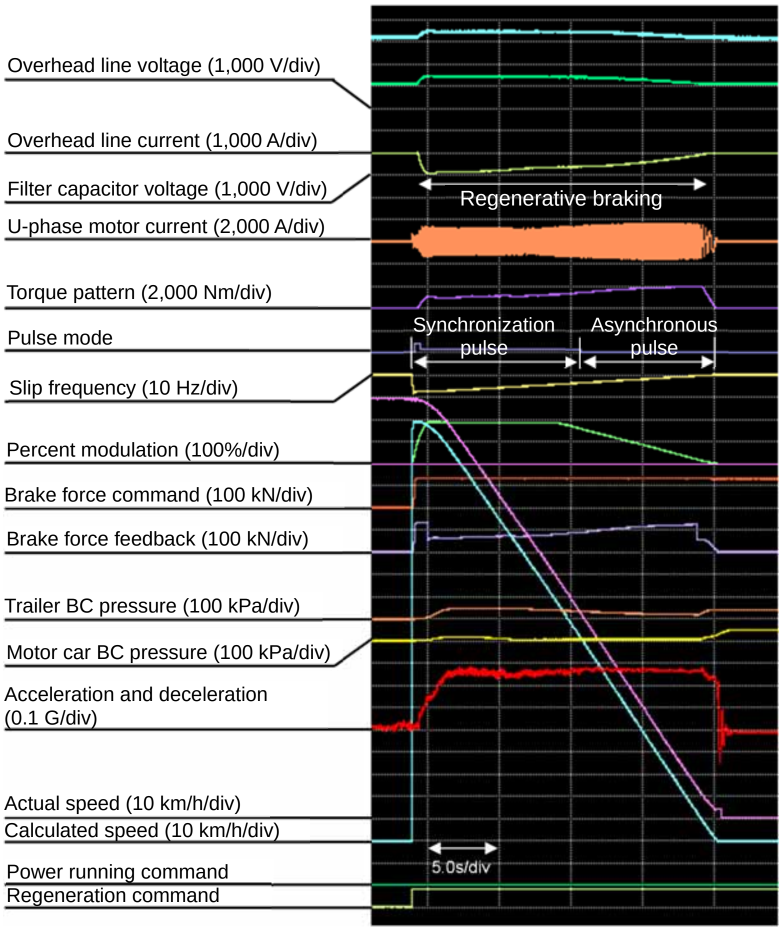


Fig. 6 Regeneration test chart

Table 4 Power analysis results of vehicles of the 5000 and remodeled 1000 series

5000 series

Train set with vehicle code 5051 (5M5T)

	Power running intensity (kWh/(km・vehicle))	Regenerative intensity (kWh/(km・vehicle))	Intensity (kwh/(km・vehicle))	Intensity (kwh/(km・ton))
Total of the train set	1.3330	0.5880	0.7450	**0.0241**

Remodeled 1000 series

Train set with vehicle code 1093 (5M5T)

	Power running intensity (kWh/(km・vehicle))	Regenerative intensity (kWh/(km・vehicle))	Intensity (kwh/(km・vehicle))	Intensity (kwh/(km・ton))
Total of the train set	1.5500	0.7340	0.8160	**0.0232**

power electronics sectors, which are likely to keep advancing, more energy saving systems will continue to get developed.

As the world's first manufacturer of SiC power modules for railway vehicles, Mitsubishi Electric will continue to develop and commercialize energy-saving equipment to help reduce environmental impact.

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Activities in Overseas Transportation Business to Achieve the SDGs

Authors: *Tetsuo Komura** and *Yoshinori Yamashita**

1. Introduction

Mitsubishi Electric Corporation has been expanding its overseas transportation business during the last 60 years with the mission of providing safe, secure, and stable transportation and comfort by constructing infrastructure in the global market. Through technological development, Mitsubishi Electric has satisfied various needs such as for compliance with local regulations, smaller and lighter equipment, energy-saving, and easier maintenance.

Today, global warming and other environmental issues are growing to be paid attention. In Europe, which is the center of railway systems and technologies, there are rising expectations for environmentally beneficial railways, which are also related to economic policies such as green recovery triggered by the COVID-19 pandemic. In addition, to enhance the competitiveness of the European railway industry, various technological development schemes such as Shift2Rail have been promoted with funds from the European Union (EU). There has been systematic technological development linked to the EU's railway policies, certification system, and development of standards, and these schemes and regulations have been expanded around the world. Since the UN adopted the SDGs at the UN General Assembly in 2015, aiming to build a sustainable society, various actions to create a decarbonized society and other actions have been taken.

Under those circumstances, Mitsubishi Electric established local production bases in Mexico, Australia, USA, China and India. In recent years, we invested Mitsubishi Electric Klimat Transportation Systems S.p.A. (MEKT) in Italy manufacturing air conditioning systems for railway vehicles, MEDCOM Sp. z o.o.(MEDCOM) in Poland providing solutions supporting public transport systems and power supply systems for industrial applications and EKE-Electronics Ltd. (EKE) in Finland which excels at train control and management systems and maintenance technologies. (Fig. 1)

This paper describes our contribution to sustainable development mainly through our technologies and cooperation with overseas manufacturers, along with the roles that Mitsubishi Electric will play in the global market in the future, while also examining the trend of the changing external environment.

2. Overseas Transportation Business of Mitsubishi Electric

The overseas transportation business of Mitsubishi Electric started with AC electric locomotives for the

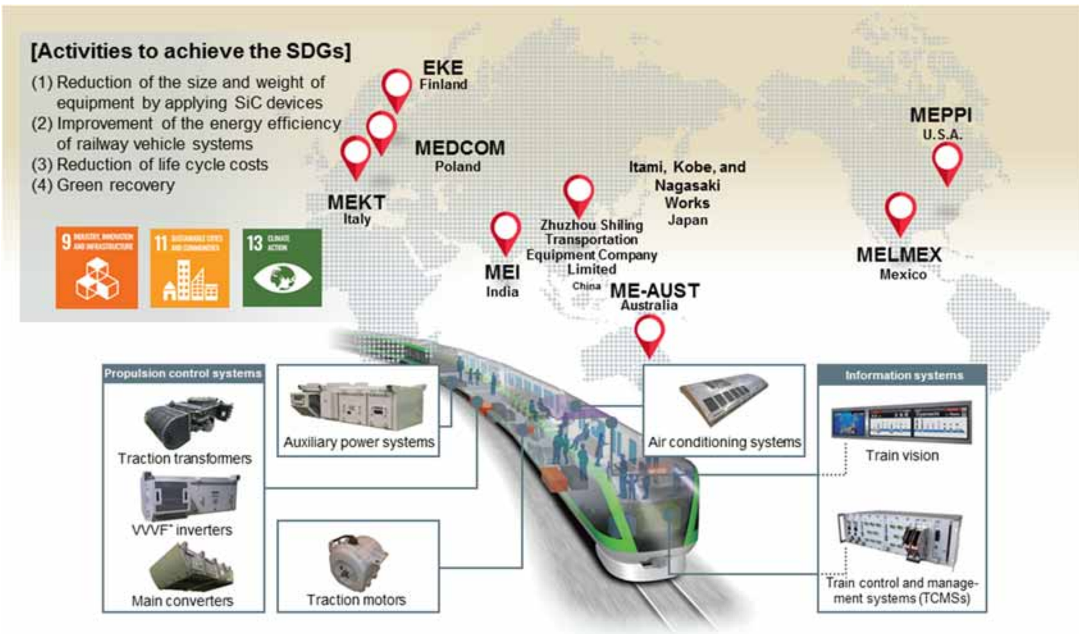


Fig. 1 Our global system that realizes synergy effects of technologies as a general electric machinery manufacturer

*Itami Works

Indian national railways in 1960, and expanded thereafter. We received orders for electric locomotives for the Spanish national railways in cooperation with a Spanish railway vehicle manufacturer. In the 1970s, we received orders for electrical equipment in Australia and Mexico and set up ME-AUST (1974) and MELMEX (1976) as local production sites. Later, we received orders for air conditioning systems for railway vehicles for the New York Metropolitan Transportation Authority in 1997 and orders for railway vehicle electrical equipment in 1999, which means that we fully entered the U.S. market by starting production there. In China, meanwhile, as the Chinese government rapidly expanded its urban transportation systems, we received orders for railway vehicle electrical equipment orders for Tianjin Line 1. Taking this opportunity, we participated in many projects in China and set up Zhuzhou Shiling Transportation Equipment Co., Ltd. in 2005 as a local production site. We re-entered the Indian market in 2001 by winning orders for Delhi's Metro and started local production in 2015 in response to growing demand for domestic production with an increasing number of self-financing projects. In Europe, in 2006, we received air conditioning system orders for railway vehicles for London underground for the first time. We acquired an Italian manufacturer of air conditioning systems for railway vehicles a fully-owned subsidiary in 2014 to start local production and made the products more attractive by combining their technologies with our air conditioning technologies. In the same year, we expanded our sales offices in Europe with the aim of boosting sales by combining railway vehicle electrical equipment with air conditioning systems. In 2015, we invested in MEDCOM, a Polish electrical equipment manufacturer, which has been providing solutions supporting public transport systems and power supply systems for industrial applications. MEDCOM has the state-of-the-art power electronics technologies as well as technologies for reducing size and weight, and has increased the competitiveness of its products by combining their technologies with our advanced technologies including power semiconductors. Most recently, in June 2020 we invested in EKE in Finland, which excels at train control and management systems and maintenance technologies, and we intend to rationalize the railway vehicle maintenance business in the future.

While expanding its global business, Mitsubishi Electric has been developing production sites for local production. Furthermore, to understand the latest trends in markets and quickly respond to customer requests, we have been forging alliances with overseas manufacturers. Under such initiatives, we will contribute to realizing the SDGs through supplying railway vehicle electrical equipment.

3. Technological Development Activities

This section describes cooperation with MEDCOM, EKE, and MEKT regarding technological development to achieve the SDGs.

3.1 Reduction of the size and weight of equipment by applying SiC devices

Mitsubishi Electric delivered propulsion control systems with hybrid SiC devices for metro vehicles in service operations in February 2012,(1) becoming the first in the world[1] to apply SiC devices to railway vehicles, and have since reduced the size and weight of equipment. We have also applied full-SiC devices to commuter train vehicles(2) and traction systems for Shinkansen vehicles. We have been working to reduce the size and weight of auxiliary power systems (APSs) in cooperation with MEDCOM by utilizing the low loss characteristics of SiC devices. For conventional APSs, transformers that are used to isolate the input circuits from output circuits account for a large proportion of the volume and mass of the entire system. Therefore, we focused on reducing the size and weight of transformers and developed high-frequency link type APSs with SiC devices. The high-frequency link type isolates the input circuit from the output circuit by combining a high frequency drive inverter, transformer, and rectifier as shown in Fig. 2. As an example, for the APS of 95-kVA

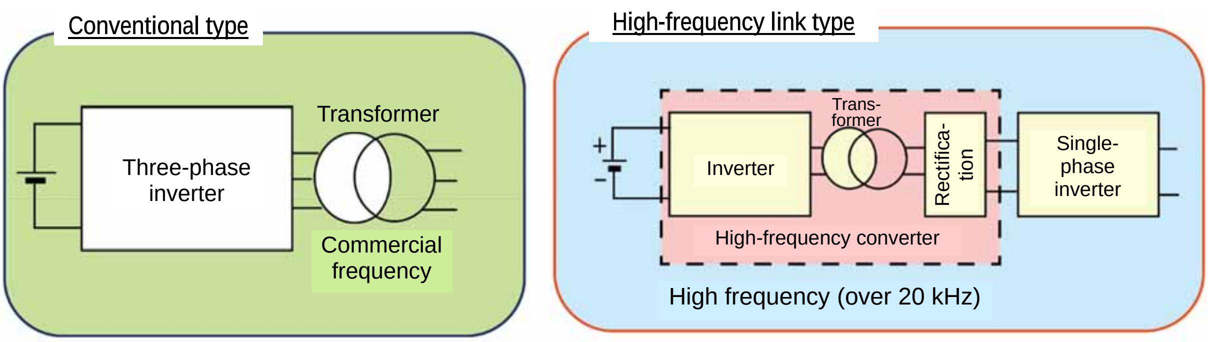


Fig. 2 Comparison of APS types

[1] As of September 27, 2012, researched by Mitsubishi Electric

Fig. 3 High-frequency link type APS with SiC devices

Fig. 4 APS/propulsion/charger combined system with SiC devices for E-BUS

with SiC devices shown in Fig. 3, the volume was reduced by approximately 30% and the mass by approximately 60% compared to the conventional type with the same output capacity.

In addition to APSs, MEDCOM has developed propulsion control systems in which auxiliary power systems and battery chargers get combined as systems with SiC devices for E-BUS (electric bus). Figure 4 shows its appearance; such systems get installed on rooftops. SiC devices can reduce the loss by up to 30% compared to conventional types, allowing to extend the traveling distance on storage batteries and to reduce both the volume and mass by 40%. The on-ground battery chargers for E-BUS have gotten developed adding to on-board systems, which satisfy various needs with charging capacities ranging from 30 kW to 650 kW for boost charge.

3.2 Improvement of the energy efficiency of railway vehicle systems

According to the analysis of the loss that gets generated in the main circuit system for the conventional vehicle, the loss of the running resistance accounts for a large percentage, and the one from the inverter.(3) Which infers the low-loss SiC device application fails to decrease the loss of an entire system well enough. Thus, Mitsubishi Electric focuses on the performance curve of vehicles for the SiC device application. We combine SiC devices with low-impedance motors, which allow us to improve the amount of regenerated power with necessary brake forces ensured through the regenerated brake from the high-speed range. The combination improves the energy-saving effect of the entire vehicle systems. Besides, we have been implementing various measures for long train sets to reduce the energy use of the entire sets and optimize the configuration, such as controlling which units in a train set are used depending on the magnitude of the required tractive force for the train set, and another configuration in which the braking force is changed depending on the unit located in a train set to prevent the regenerative braking force from decreasing due to sliding. MEDCOM has been developing high-efficiency drive systems using supercapacitors for short train sets (e.g., light rail vehicles (LRVs)). For propulsion control systems for LRVs that repeatedly accelerate and decelerate frequently, supercapacitors that have lower internal resistance than storage batteries can get rapidly charged and discharged, which allows for the high-efficiency systems to contribute to energy-saving as well.

3.3 Reduction of life cycle costs

Mitsubishi Electric and EKE supply train control and management systems (TCMSs) and remote train maintenance support systems to railway companies.

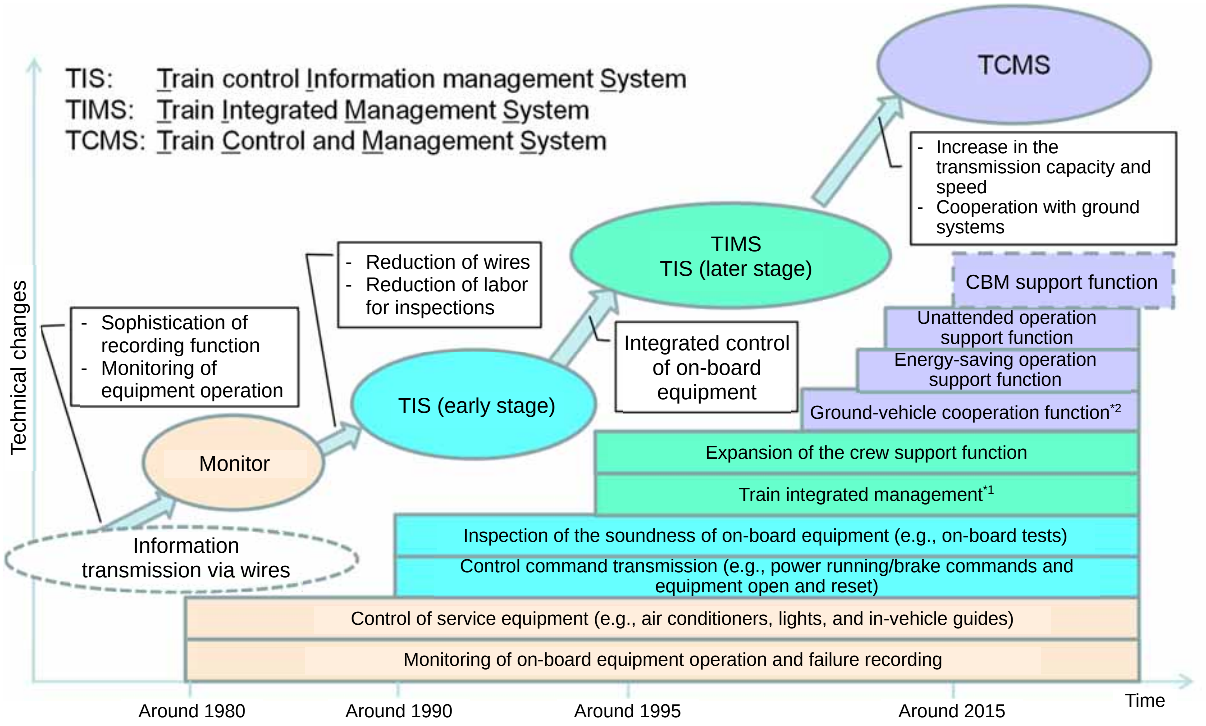
As shown in Fig. 5, TCMS serves as a brain of a train, providing various functions such as energy-saving driving support, maintenance support through communications with ground facilities (ground-train communication functions) and automatic train operation support, in addition to monitoring and control of on-board equipment. TCMS has a wide variety of applications in railway vehicles for safety and stable transportation.(4)

In recent years, there has been increasing demand for remote monitoring and condition based maintenance (CBM) of railway vehicles using digital technologies such as the Internet of Things (IoT) and big data, for achieving more labor-saving and efficient maintenance activities for railway vehicles. Mitsubishi Electric and EKE have been actively using technologies of both companies to reduce life cycle costs of railway vehicles, aiming to implement the TCMS-based CBM support functions shown in Fig. 5 and the remote train maintenance and CBM support system shown in Fig. 6.

The first stage is remote monitoring of on-board status, and this has already been commercialized as the remote train maintenance support system. This function sends on-board equipment status data collected by TCMS to ground systems through wireless communications, achieving real-time monitoring of on-board status. In the event of an on-board failure, this function allows ground operators and maintenance staff to check details of the failures and expedites the recovery operation.

In addition, this function also allows maintenance staff to remotely collect logs from on-board equipment and change parameters of on-board equipment, achieving labor-saving maintenance activities.

The second stage is visualization of on-board status. The operation data of on-board equipment collected by



*1: Train integrated management: Function to control electrical equipment in an integrated way so as to optimize the operation of the entire train set
*2: Ground-vehicle cooperation function: Railway vehicle maintenance support and train operation support functions by cooperation between ground systems and TCMSs

Fig. 5 Changes in functions of train control and management systems (TCMSs) of Mitsubishi Electric

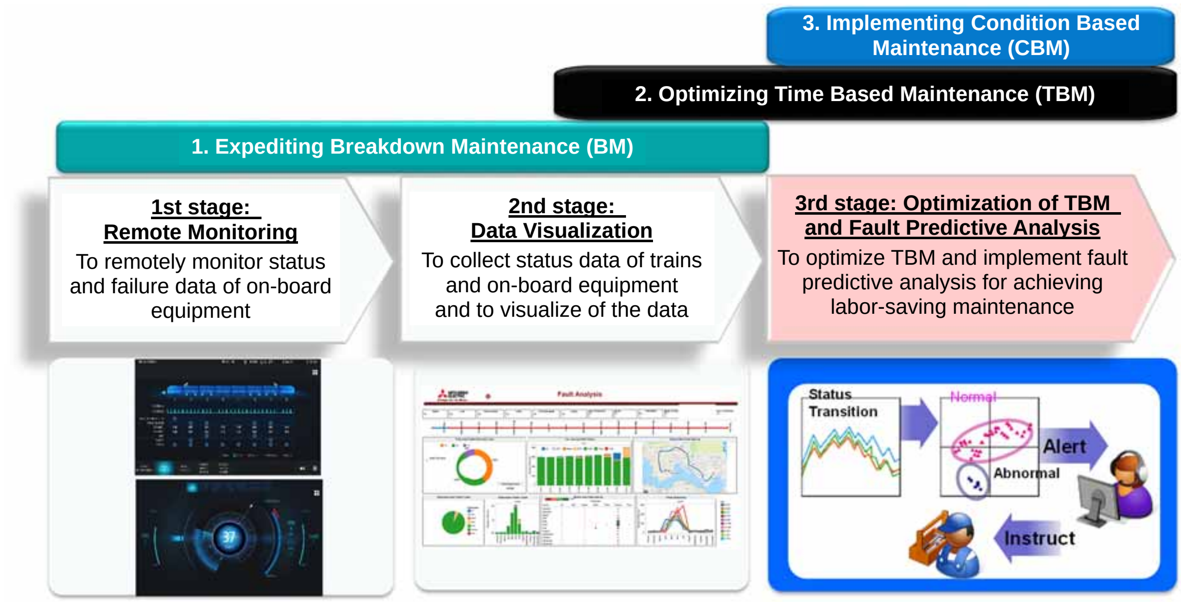


Fig. 6 Mitsubishi Electric's concept for Remote Train Maintenance & CBM Support System

TCMS is accumulated in a database, supplemented with information such as date and time, traveling location, train speed, and environmental conditions. This function statistically compiles the accumulated data from various aspects and visualizes their results, allowing ground operators and maintenance staff to analyze characteristics in operating conditions of on-board equipment and signs of failure occurrences.

The third stage is optimization of TBM and fault predictive analysis. This activity is to establish a mechanism for identifying trends of equipment degradation and irregular data among operation data of on-board equipment. This promotes reduction of downtime and optimization of maintenance cycles as equipment can be replaced prior to failure occurrences.

3.4 Green recovery

For air conditioning systems for railway vehicles, hydrofluorocarbon (HFC) which is an alternative of hydrochlorofluorocarbon (HCFC) or chlorofluorocarbon (CFC) refrigerants, such as R407C and R134a, are used and their global warming potential (GWP) is around 1,500. GWP regulations to combat global warming have been tightened, making it essential to switch to lower GWP refrigerants. Currently, targeting projects in Europe, we have been carrying out fundamental development of air conditioning systems with natural refrigerant CO_2 of GWP1 and considering reducing energy consumption by controlling the compressor inverters in addition to changing the refrigerant. We intend to release such air conditioning systems into the European market after commercialization development at MEKT and field tests in the market. In addition, the ventilation function provided by air conditioning systems of railway vehicles has attracted attention during the COVID-19 pandemic. As a temporary measure, the volume of air taken in from outside has been changed to increase the amount of ventilation. However, this increases the heat load too and impacts the performance of cooling and heating the air in the vehicles. To solve these problems, we are working on improving the ventilation function and energy efficiency as medium- to long-term tasks.

4. Conclusion

Amid the COVID-19 pandemic, needs in the railway sector are changing in various ways. At the Rail Summit held in Berlin in June 2020 under the sponsorship of the German government, various goals were cited: Double the number of railway passengers by 2030 and increase the frequency of railway services between all main cities to shorten the interval to 30 minutes in the future in order to make railways more convenient for users.[5] “Flight shaming”, which started in Europe in 2018, may have affected this trend. Mitsubishi Electric has obtained a supplier certification for communications-based train control (CBTC) for the New York Metropolitan Transportation Authority in the North American market. Therefore, we can help improve the transportation capacity and stabilize transportation by utilizing moving blocks. In addition, regarding Shift2Rail, various approaches using new technologies are essential to establish integrated platforms that offer sustainable transportation services. Digitalization, automation, telecommunications, and satellite services will be key for this purpose.[6] As a general electric machinery manufacturer, Mitsubishi Electric will work hard to contribute to the international community through its railway business by gaining the synergy effects of technologies across multiple businesses that specialized manufacturers cannot offer.

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The Impact and Future of the Railways on a New Society Brought by COVID-19

Author: *Kazufumi Yoshida**

1. Introduction

In 2020, as the COVID-19 pandemic spread, people in cities and regions around the world were asked or ordered to stay at home under lockdowns. As a result, people's attitudes have changed and they now voluntarily refrain from going out when it is not essential, causing a great change in the situation for Japan's railway business. Japanese companies have been promoting teleworking and so the revenues of railway companies may fall dramatically. Development around stations, the operation of station shops, leisure, and sightseeing are based on the premise that passengers go places, and so these functions have also been severely affected. Various measures to solve these issues have been considered, such as leveling of transportation, dynamic pricing to encourage people to avoid crowding, and unattended stations.

In addition, efforts to achieve the UN's sustainable development goals (SDGs) are also important for the railway business in the future.

Mitsubishi Electric Corporation's Integrated Design Center has long been thinking about foresight and the future. Changes wrought by the COVID-19 pandemic are overturning what had been taken for granted. Therefore, we considered the future of Japan and how railway transportation should be in a new society brought about by the COVID-19 disaster, and perspectives to be taken into account.

2. Perspectives on Changes in Society

2.1 Approach to the future

Mitsubishi Electric Corporation's Integrated Design Center has been thinking about the future and the target for various stakeholders related to the business. One specific measure is foresight, which refers to creating a time line for possible actions in the future to bring new perspectives to research and development. It aims to stimulate discussion and make it constructive by sharing organized and analyzed information on the external environment in and outside companies. In this study, because common practice has been changing, a single future that was envisioned based on hypotheses from the existing perspective (inside out) is used, and was not created based on hypotheses from unexpected social changes (outside in) (Fig. 1).

2.2 Micro and macro perspectives

Changes in society are considered from both the micro and macro perspectives (Fig. 2).

From the micro perspective, changes in people's awareness and sense of values are viewed; from the macro perspective, infrastructure and other social systems are viewed. Understanding changes in society from both the micro and macro perspectives may facilitate discussion considering individuals and society.

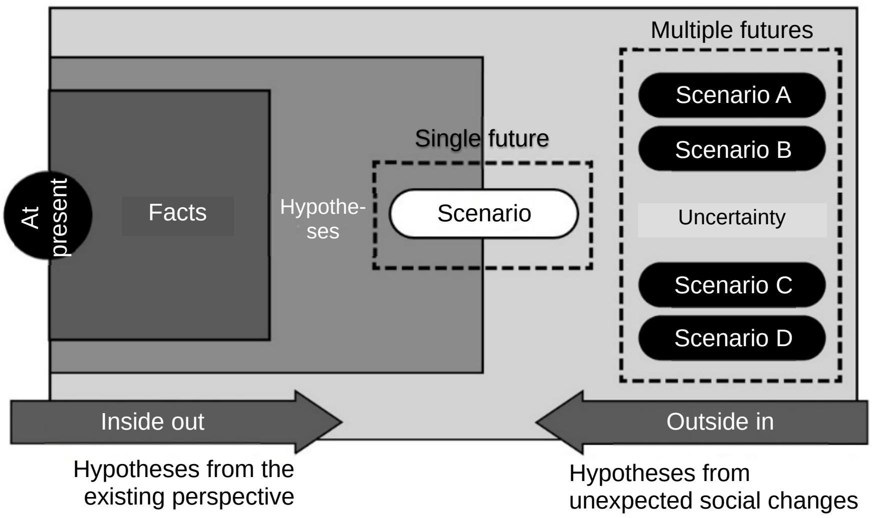

Fig. 1 Foresight and future scenarios

*Integrated Design Center

3. Influence on Railways in a New Society and Perspectives to Be Considered

3.1 Recognition from foresight of mobility

Even before the COVID-19 disaster, the Integrated Design Center had been making foresight scenarios for the four sectors of life, industry, infrastructure, and mobility in Japan. The subject of the scenarios is society, and not our company. The micro and macro perspectives are plotted on the vertical axis and time on the horizontal axis.

Railways are included in the foresight scenario for mobility, which is one of the four sectors (Fig. 3). Therefore, based on recognition on the future obtained from this foresight scenario, the influence on railways in a new society and perspectives to be considered were studied.

3.1.1 Recognition when viewed from humans

Based on the foresight of mobility, we focused and considered the values of people brought about by the COVID-19 pandemic. Figure 4 summarizes what people used to take for granted before the pandemic and what people may take for granted from now on. Currently, the situation is extreme: it has suddenly become difficult for people to do what they used to take for granted (before the pandemic) (Fig. 4 (1)). In the future, people may recognize and select what they truly need and what is not so important, and they may review their values (Fig. 4 (2)). In addition, people may try and fail to build a new lifestyle, which may lead to various new alternatives. As a result, people may naturally select various matters as they like (e.g., where they work) (Fig. 4 (3)). In such a society, conventional routine travel such as commuting and going to school may decrease, and the main purpose of travel may change to doing activities that can be experienced only at certain places.

3.1.2 Recognition when viewed from society

One factor that may have a serious influence when viewed from society is the acceleration of digital society. It may become the norm to use the Internet to do things wherever possible because people's awareness has been changing due to the pandemic. If people need to travel in the real world, it may be necessary to do so in private spaces considering the risk of infection.

3.2 Influence on railways in a new society

Figure 5 shows influences on the railways in the future based on the recognition from foresight.

In Japan, there was concern that services in cities may become unsustainable due to the decrease and aging of the population. Railway companies and

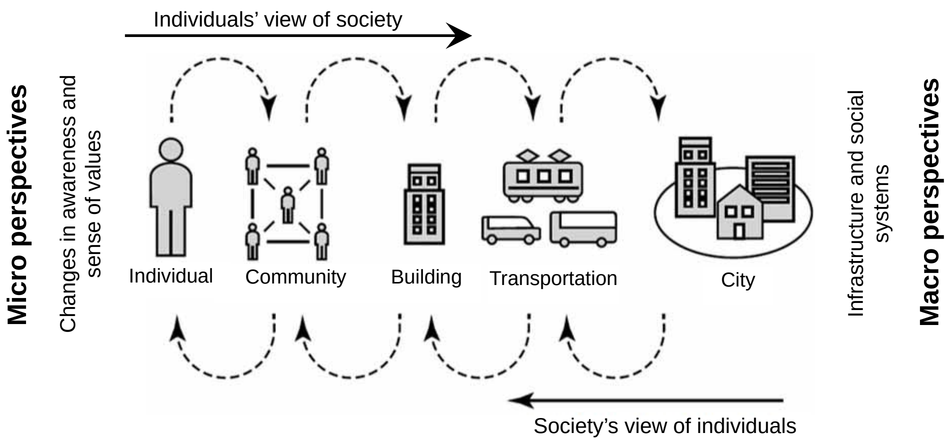

Fig. 2 Micro and macro perspectives

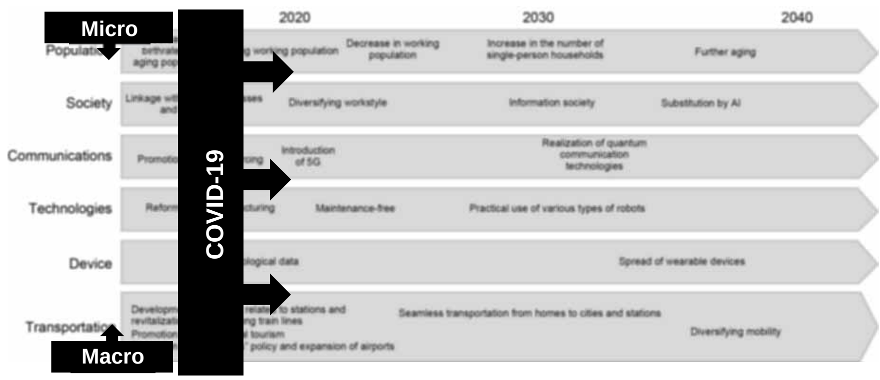

Fig. 3 Mobility Foresights

governments have therefore been working to create "cities along train lines" that bring together near stations as transportation hubs the functions needed for living, such as welfare, parenting support, and shopping. In view of such projects, Mitsubishi Electric has been considering stations and smart cities. Taking the various changes brought by the pandemic as an opportunity, the company focused on two perspectives: changes to the relationship with railways (Fig. 5 (1)) and reconsideration of roles in an area (Fig. 5 (2)). The term "roles in an area" refers to the roles of railways in an area as a transportation means for residents in daily life; "roles outside the area" refers to the roles of railways for exchanges with neighboring areas.

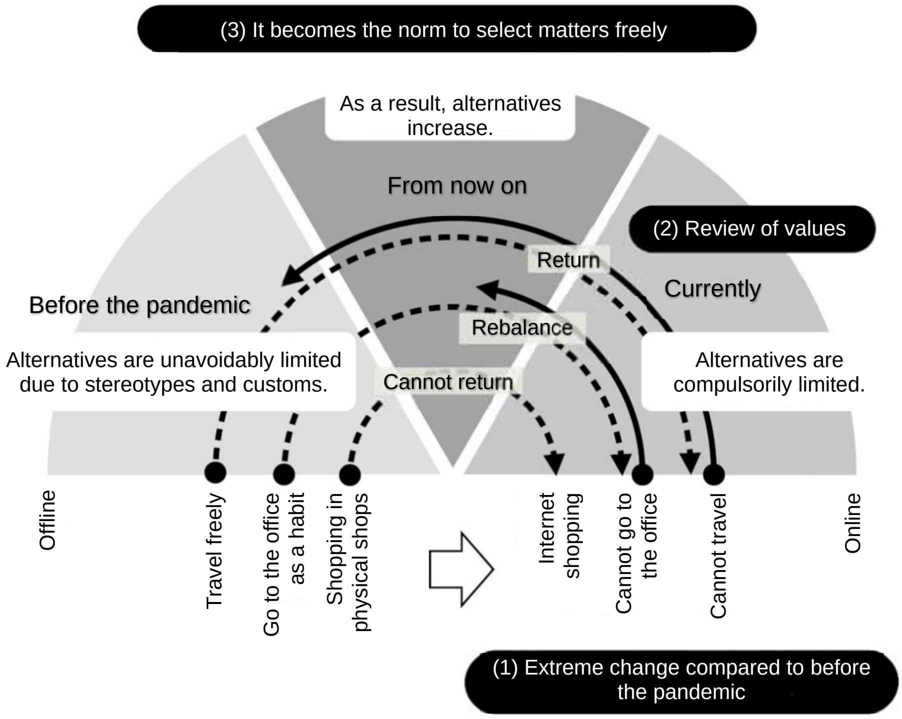

Fig. 4 The effects of COVID-19 on human lifestyles

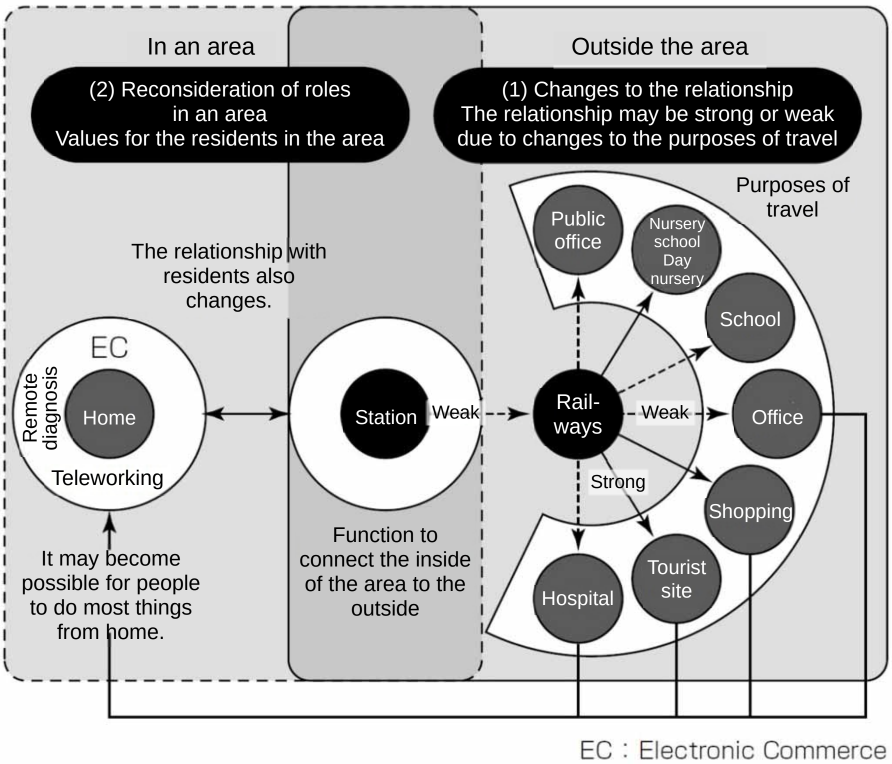

Fig. 5 The future of railways

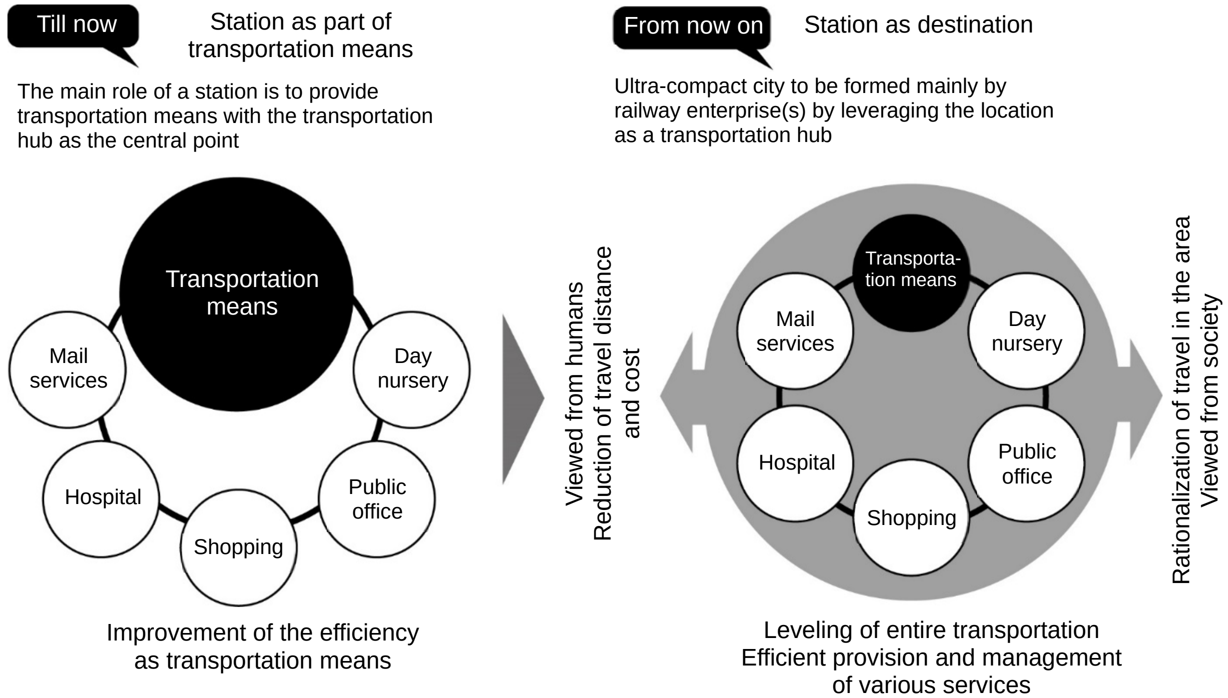

Fig. 6 The past and future of stations

Regarding the “changes to the relationship” (as a perspective), although railways in the past had strong relationships with various places (destinations), the relationship may be stronger or weaker due to a decrease in routine travel. For example, the relationship with offices may weaken due to an increase in teleworking; on the contrary, the relationship with tourist sites where people can experience the unusual may become stronger. Regarding “reconsideration of roles in an area” (as a perspective), people living along train lines and in the neighborhood may need to reconsider their values due to decreases in the purposes of travel and travel opportunities. Improving services in the area based on these perspectives and overlooking it again including the outside may reveal what the sustainable public transportation that has taken hold in the area should be.

3.2.1 Railways for a new society

As noted, strengthened or weakened relationships may accelerate various changes, such as making small stations unattended, medium-scale stations specific for sightseeing, and stations that have civic functions in an integrated way including public services, as already discussed. With advanced stations like these examples, ultra-compact cities may be formed mainly by railway enterprises by leveraging the locations as transportation hubs (Fig. 6). If stations have these roles, it turns them into places where people can access public services and various other services while serving as transportation hubs; and stations also become destinations in themselves. As a result, in addition to passengers for the purpose of travel, people with other purposes may come to stations and the roles of station staff may also change.

3.2.2 Perspectives to focus on

Based on perspectives that railway enterprises should focus on after the pandemic, they may need to change their services from providing conventional, uniform services by regarding all passengers as groups, to providing services in consideration of the preferences, feelings, and locations of individuals. Briefly, the center of such perspectives is humans. However, it may be difficult for railway enterprises, which have focused on mass transportation, to adopt such perspectives. In a new society, unconventional demands become strong. For example, routine travel, such as commuting and going to school, may decrease, whereas demand for travel in comfortable private spaces may grow. This new society should be viewed as a chance, not as a crisis.

4. Conclusion

This study reviewed potential future scenarios, and how the COVID-19 pandemic may affect society, and what may or may not change. It also identified the course of action to aim for and the perspectives to focus on. Although they may not be exactly new perspectives, their importance may increase due to the issues facing sustainable railways in the future and the acceleration of a digital society, driven by the pandemic and new lifestyles.

Mitsubishi Electric will continue considering the future of railways that have developed in line with cities, while focusing on the SDGs.

MITSUBISHI ELECTRIC CORPORATION