Railway Technology in Japan —Challenges and Strategies

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Introduction

Attempts to improve railway technology have generally focused on safety and speed, two important characteristics of rail transport. Improving safety and speed is not enough, of course, but the focus of railway development will probably remain there. However, the social environment in which railways operate is evolving, meaning that it will become necessary for the development of railway technology to orient itself in slightly different directions.

This article examines the past development of railway-related technologies in Japan, and proposes areas of research that should be tackled in light of changes in the social environment. I will also suggest slightly different directions that should perhaps be taken, and look at new areas of research for futuristic train systems.

History and Special Features of Japanese Railways

Rail transport began in Japan in 1872, on track measuring about 29 km in length from Shimbashi (in Tokyo) to Yokohama. At first, both the government and the private sector constructed their own railways, but the majority of private railways were nationalized in 1906. It was around this time that the government established the Railway Investigation Office under the auspices of the government railways, in order to promote the development of rail technology for the government railways.

Today, Japan has about 27,000 km of line in operation, owned either by the JR group of companies or by other private railways. Figures 1 and 2 show the years in which important technological advances in rail transport occurred in Japan—years during which speed and carrying capacity increased. The maximum operations speed remained at about 95 km/h until around 1955, but in 1958 the *Kodama* EMU limited express boosted this to 110 km/h. Then, the Tokaido Shinkansen began operations in 1964, achieving speeds above 200 km/h. The shinkansen track was constructed between Tokyo and Osaka—where the Tokaido main line had long played the leading role in Japan's most important transport corridor—in order to boost capacity. The latest shinkansen train sets have since boosted commercial speeds to 300 km/h and the Maglev guided transport system now under development has already achieved a world speed record of 552 km/h.

One important difference between Japanese railways and those in Europe and North America is that most Japanese rail services are passenger oriented, with freight operations playing only a very minor role. Another difference is that about 70% of Japan's land mass is mountainous, creating an extremely varied topography that necessitates steep grades, sharp curves, long tunnels and bridges. The complex track configurations and structural challenges cause problems that Japanese engineers have solved with new technological developments, such as innovative tunnelling techniques, tilting carriages that permit higher speeds through curves, etc.

Technological Developments 1906–87

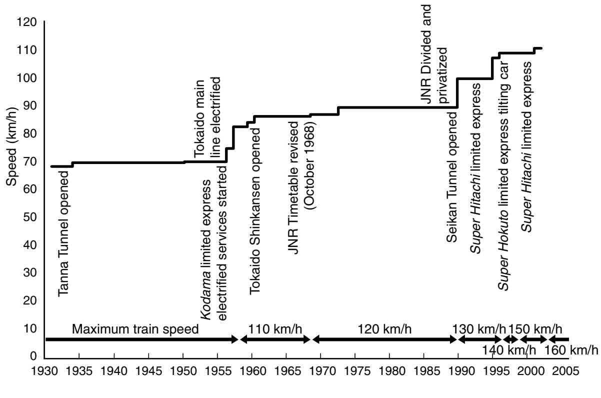
When the Railway Investigation Office was established, its main functions were to conduct studies, apply the results of research, and test materials. In 1913, the

Figure 1 Chronology of Major Railway Events

1825: World's first passenger railway opened in Great Britain
1850: Commodore Matthew Perry demonstrated working model steam locomotive in Japan
1872: Japan's first railway opened
1893: First steam locomotive built in Japan (Class 860)
1895: Japan's first electric tramway opened
1906: Railway Nationalization Law passed
1927: Japan's first subway opened
1949: Japanese National Railways (JNR) established
1954: Centralized Train Control (CTC) system first adopted in Japan (Keihin Electric Express Railway)
1957: Hokuriku main line electrified (AC)
1958: *Kodama* limited express started EMU services between Tokyo and Osaka
1960: Computerized seat reservation system started
1964: Tokaido Shinkansen opened
1972: San'yo Shinkansen opened
1982: Tohoku and Joetsu Shinkansen opened
1987: JNR divided and privatized
1988: Seikan Tunnel opened under Seikan Strait between Honshu and Hokkaido; Seto Ohashi road and railway bridges opened between Honshu and Shikoku
1992: Yamagata Shinkansen opened
1997: Akita Shinkansen opened; 300 km/h shinkansen services started; Nagano Shinkansen opened
1999: Maglev test train recorded 552 km/h speed

Source: *Railway Statistics*

Figure 2 Improvement of Fastest Train's Scheduled Speed, 1930–2003



Source: *Railway Statistics*
Note: Average speed from origin to destination including intermediate stops

name was changed to the Research Institute, which was restructured as Railway Technical Research Institute (RTRI) in 1942.

After WWII, it was clear that Japan's railways were in a shambles and had fallen far behind world standards, so many recent technologies were introduced from abroad. The executives of the recently created Japanese National Railways (JNR) realized that RTRI needed the skill of top technicians and engineers and many were successfully recruited from former army and navy laboratories and from private companies. Some aviation engineers joined JNR and their input help with development of the Tokaido Shinkansen. It is now widely recognized that the shinkansen lead advances in railway technology worldwide, especially in Europe, where the French TGV and German ICE soon appeared on the scene.

In 1968, just 4 years after the Tokaido Shinkansen opened, the government announced a plan to construct a shinkansen network measuring 7000 km throughout the nation. The plan was embodied in the Nationwide Shinkansen Development Law, which was promulgated in 1970.

In 1972, shinkansen trials on unopened new tracks achieved a record speed of 286 km/h based on various major innovations, including development of an auto-transformer (AT) feeder system. In 1979, a shinkansen train achieved a world record speed of 319 km/h.

The opening of the Tohoku and Joetsu shinkansen through Japan's snow country saw a great deal of R&D into snow countermeasures too.

JNR also worked hard to improve safety and services on conventional narrow-gauge lines. Notable examples include studies on multiple-factor derailments using freight cars on a test line, and experiments on tunnel train fires. In the area of speed, developments in the early 1980s saw improved bogies and car-tilting control mechanisms. A narrow-gauge test train attained 169 km/h.

In an attempt to cut labour costs and reduce its massive debts, automatic ticket wickets were developed by JNR. Although automatic wickets are everywhere today, they were a great novelty at the time.

Japan's development of Maglev technology (see *JRTR* 25) began in 1963 with research into a next generation, ultra-high-speed rail system. The first linear-motor test vehicle—the ML100—was shown to the public in 1972 to mark the centennial of railways in Japan. A test track was constructed in 1977 in Miyazaki Prefecture and the ML500 achieved a world record speed of 517 km/h in 1979. It would require almost 20 more years before the old record was broken during test runs on the Yamanashi Test Line in Yamanashi Prefecture in 1997.

Railway R&D in Japan Today

The JR group

Before JNR was divided into six passenger railway companies and one freight rail carrier in 1987, there was much debate on what form technical support for the new JRs would take. The result was the formation of today's independent RTRI.

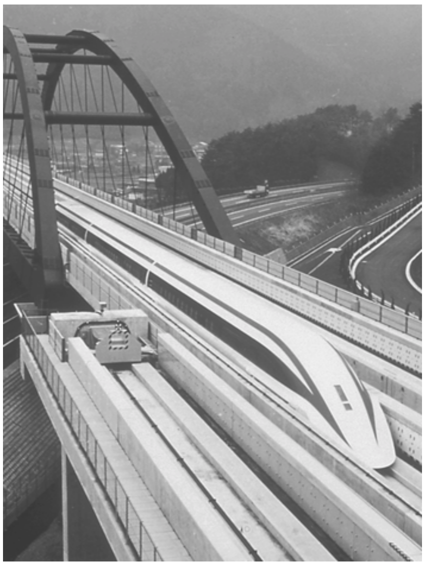
Moreover, since 1987, each JR company is conducting its own R&D into problems that are unique to its business. For example, JR Hokkaido and JR East operate many diesel railcars (DMUs), and JR East is researching hybrid 'new energy' (NE) trains using driven by rechargeable battery at lower speeds, and both by battery and diesel-driven generator at higher speeds. Likewise, in response to the government's call for a modal shift from road to rail transportation, JR Freight has developed a Super Rail Cargo system that uses electric rolling stock to haul freight (see Photostories in this issue). JR East and JR Central established their own research centers in 2001 and 2002, respectively. The main R&D activities of JR East's Research and Development Center are described in five other articles in this issue of *JRTR*.

JR Central's main R&D focus is on upgrading railway technology and opening up new fields. It takes a unified, comprehensive approach with emphasis on shinkansen, but is also working with RTRI and Japan Railway Construction Public Corporation (JRCC) on Maglev development at the Yamanashi Test Line.

Other private railways

In many cases, other private railways in Japan conduct joint research with rolling-stock manufacturers with the primary objective of developing technologies they need. Here I will mention the Technical Research & Development Institute of Kinki Nippon Railway Co., Ltd., which is the only such institute operated by a private railway in Japan.

Kinki Nippon Railway (Kintetsu) serves areas in and around Nagoya, Kyoto and Osaka with lines totalling 573.7 km, making it the largest operator in Japan excluding the JRs. Its Institute was established in 1962 as a joint venture with



Superconductive magnetically levitated linear motor car running on Yamanashi Test Line (RTRI) its rolling-stock manufacturer, Kinki Sharyo. Both companies were motivated by JNR's 1958 decision to build the Tokaido Shinkansen through Nagoya, Kyoto and Osaka, the heart of Kintetsu's operations base. Kintetsu realized that it had faced the future competition by upgrading its lines and introducing faster services. For its part, Kinki Sharyo hoped to receive orders from JNR to build shinkansen carriages and knew it would have to improve its overall technical capabilities first.

The Institute is famed for its 1966 tests that led to the development of Japan's first automatic wicket capable of handling commuter passes. The Institute's name was changed to Technical Development Center in 2001 and it continues to promote technical developments in the railway industry.

RTRI also works on joint research with other private railways and railway businesses and established the Railway Technology Promotion Center for this purpose. The Center's activities focus on:

- Proposing technical standards for the railway industry
- Holding examinations for railway designers
- Providing information on railway-related technologies
- Offering technical support
- Managing a public database on railway accidents

Government and public bodies

This section describes the government's support for the technological development of railways as well as efforts by the National Traffic Safety and Environment Laboratory (NTSEL—an independent administrative body) and JRCC.

The Ministry of Land, Infrastructure and Transport (MLIT) has jurisdiction over railways and is supporting development of future high-speed rail systems and the Maglev. It also supports developments promoting environmental conservation and transportation safety.

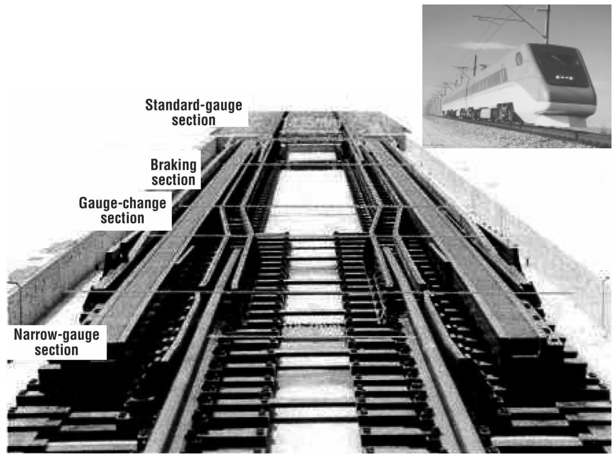
The government also supports development of an automatic gauge change (free-gauge train) to permit through services on tracks of different gauge. The early development was handled as joint R&D between JRCC and RTRI and Technological Research Association of Gauge Changing Train (composed of major rolling-stock manufacturers) established in 2002 to promote the work. Japan's increasingly aging society faces the need for barrier-free transport systems such as low-floor cars (Fig. 3). However, the narrow gauge of Japan's conventional lines precludes simple design modifications to achieve this aim, so the government is supporting the Technological Research Association of Low Floor Light Rail Vehicle Bogie.

The NTSEL is a public body established by the government in 1950 under the jurisdiction of the then Ministry of Transport. It became an independent administrative institution in 2001 and its main R&D areas are development of next-generation urban railway systems based on LRT, and the study, design and testing of special rail systems, such as guided transit systems and ropeways.

The JRCC was established in 1964 to promote railway construction projects that will improve rail networks with a view to strengthening the nation's economy and reducing regional economic disparities. It also implements projects that will contribute to the maintenance and enhancement of urban functions, especially in large cities.

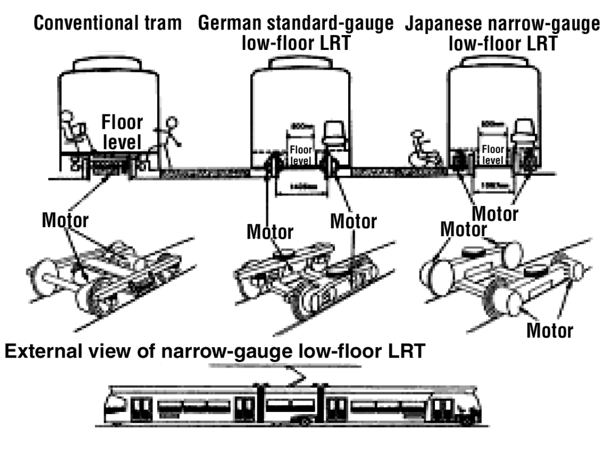
Its three main areas of activity are construction and improvement of

Free-gauge Train and Gauge-Changing Track



(RTRI)

Figure 3 Conventional and Low-floor LRT



Source: MLIT website

shinkansen, main, and urban railway lines; development of new tunneling and bridging technologies; and development of new track cost-effective technologies promoting ride comfort and environmental protection.

Railway Technical Research Institute profile

As previously explained, RTRI was established when JNR was broken up and privatized.

When established, its aims were set out as follows:

- Develop advanced technologies that can be transferred to the JR companies
- Conduct basic research with little immediate commercial application
- Conduct R&D in a wide range of applied technology fields
- Continue Maglev development

RTRI's projects have included the development of high-speed systems that respect the trackside environment along shinkansen and narrow-gauge lines; refinement of low-maintenance methods; and the enhancement of urban transit systems. RTRI has also promoted development of technologies that can be applied to the superconductive Maglev system on the Yamanashi Test Line.

The JRs contact RTRI with a wide range of requests for assistance in transportation-related issues affecting their base of operations or management policy. RTRI is presently promoting technical developments in accordance with a basic 5-year plan called *Research 21*, which was initiated in 2000.

The basic plan promotes four objectives for rail-related R&D: greater reliability; lower costs; systems that passengers will find more attractive; and environmentally friendly rail transport. The intention is to pursue these four objectives in order to achieve the following (Fig. 4) :

- R&D for possible future application
  RTRI promotes multi-disciplinary research in areas where railway-related developments could conceivably be applied within a time frame of several years to a dozen years or more, promoting innovative technical developments that could solve existing problems one day.
- Technical developments for commercial applications
  RTRI develops technologies that can improve railway operations within the short term. Examples include developments requested by railway operators to raise safety levels, improve maintenance techniques, protect the environment, and enhance inspections and diagnoses. RTRI also receives requests from public organizations to develop gauge-change electric rolling stock and establish rail-related technical standards.
- Basic railway-related research
  RTRI's research lays the groundwork for the development of new railway-related technologies. Its basic research is expected to resolve numerous problems that currently hinder railway operations.
- Maglev development
  At its high-speed test track in

Figure 4 RTRI R&D Objectives and Activities

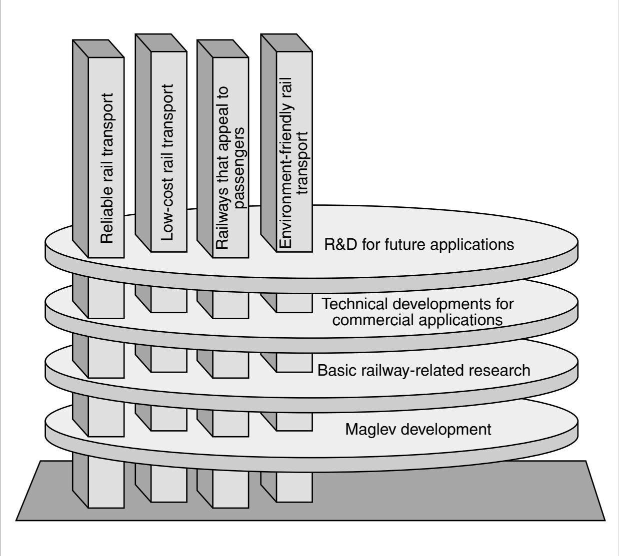
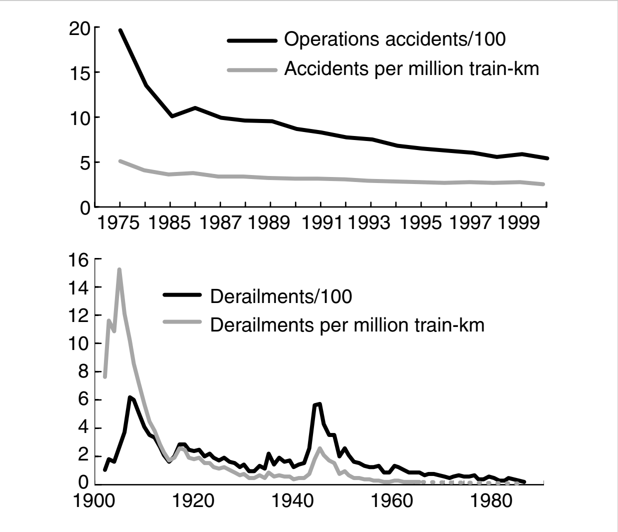


Figure 5 Decline in Number of Operations Accidents and Derailments



Source: Railway Bureau of Ministry of Land, Infrastructure and Transport

Wheel-climb derailment (RTRI)

Yamanashi, RTRI is verifying the long-term reliability and durability of the Maglev system, conducting research into making the system more cost-effective, and improving the aerodynamic performance of Maglev rolling stock.

RTRI's international activities include participation in the World Congress on Railway Research (WCRR). The 4th Congress was held in Japan in 1999 and the WCRR Secretariat was located in Japan for the occasion. RTRI also promotes joint research projects with the French National Railways (SNCF) and actively participates in joint projects with China and South Korea.

Major research areas

Safety

As far as safety is concerned, Japanese railways have achieved a fairly sophisticated level, having largely developed ways to prevent accidents such as collisions involving two or more trains, and derailments.

The number of train accidents has decreased steadily and the number of derailments is in decline (Fig. 5) Both declines are due to research into accident prevention. However, fatal accidents still occur sometimes; a recent accident in 2000 on the Hibiya subway line in Tokyo involved a wheel-climb derailment on curved track suitable only for low-speed operations. As a result, RTRI conducted extensive studies to learn more about wheel-climb derailments. The results indicate that they are usually caused by a combination of circumstances, including a high reduction in wheel load, a high derailment coefficient, and a high degree of lateral track distortion.

Future areas of safety research include prevention of accidents due to natural disasters and external factors, such as automobiles on level crossings, and developing mechanisms to prevent human errors.

In an earthquake-prone country like Japan, railway operators must remain vigilant. RTRI is presently working with the Japan Meteorological Agency to develop new systems that can prevent train mishaps during an earthquake (Fig. 6). Examples include mechanisms to stop trains quickly during an earthquake, and to restart operations as soon as possible after one.

In the case of human error, it is generally agreed that an important research area is evaluating aptitude.

At a time when equipment is so advanced, attention must turn to the human factor—the psychological aptitude of train engineers. Another related area will most likely include enhanced sensors to better monitor conditions ahead of the train (Fig. 7).

Higher speeds

German engineers succeeded in running a test train at 200 km/h very early last century, indicating that railway technology in Europe has long been forward-looking and explaining its advanced state today. More recent developments show that Europe's desire

Figure 6 New System to Detect Seismic Activity and Prevent Earthquake-related Accidents

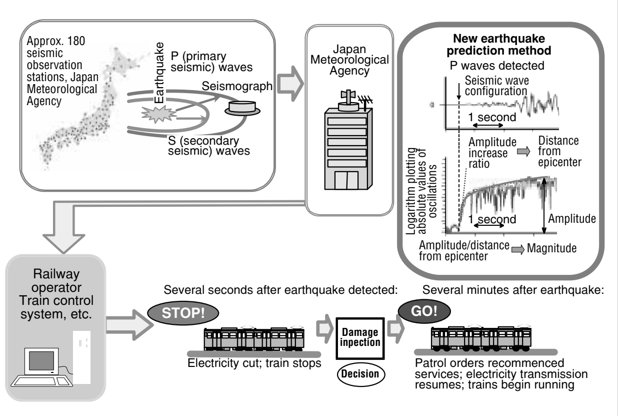


Figure 7 Support System for Safe Transport

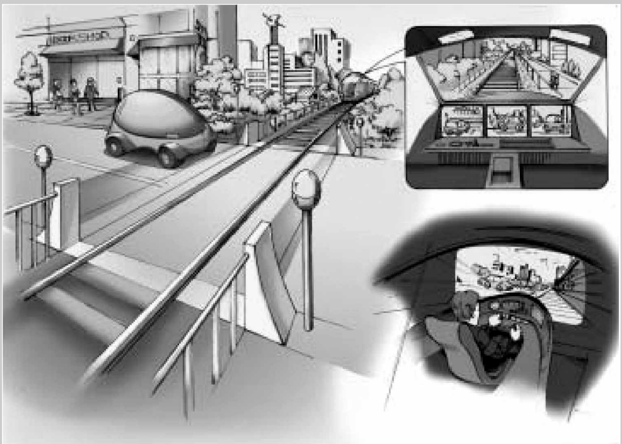
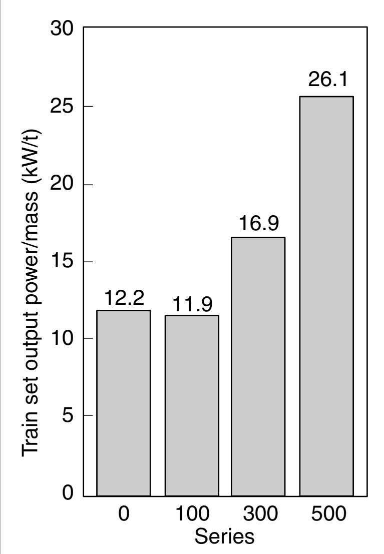
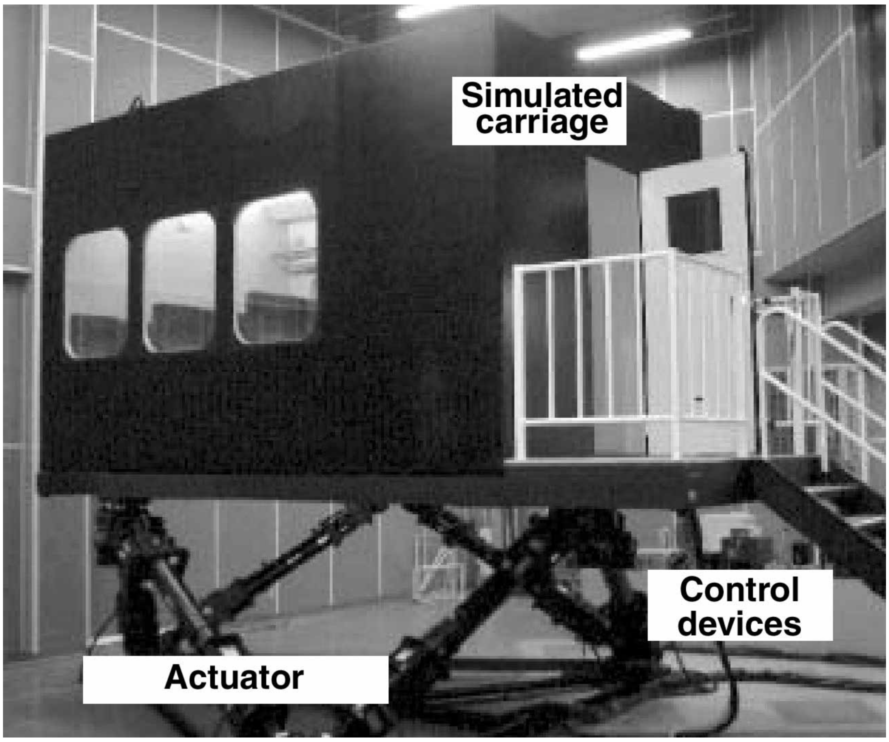


Figure 8 Improvements in Shinkansen Output Power





Simulating carriage comfort levels (RTRI)

for higher speeds is not restricted to France but extends to the other European countries as well. During tests, the French TGV has achieved a world record of 515.3 km/h, while the highest speed in Japan to date for wheel-on-rail technology is 443 km/h and the highest commercial speed is 300 km/h.

Speed is influenced by many factors, such as running efficiency, adhesion, power-weight ratio, running resistance, noise and vibration limits, maintenance, and cost-performance. At least two of these factors—maintenance and cost-performance—should not be allowed to negatively impact track conditions.

The Ministry of Environment has stipulated that shinkansen trackside noise must not exceed 75 dB, demonstrating how Japan's dense population sometimes creates unique railways problems.

Engineers have developed new approaches to overcoming these technical factors and making higher speeds possible. Over the years, rolling stock has become lighter at the same time drive mechanisms have become more powerful. For example, the first Series 0 Tokaido Shinkansen had a power output ratio of 11.6. In contrast, the modern Series 500 has a power ratio of 26.1 and runs at 300 km/h (Fig. 8). This has been achieved by advances in power electronics boosting power and advances in materials reducing the weight of carriages and bogies. Big improvements in adhesion control have also contributed to higher speeds.

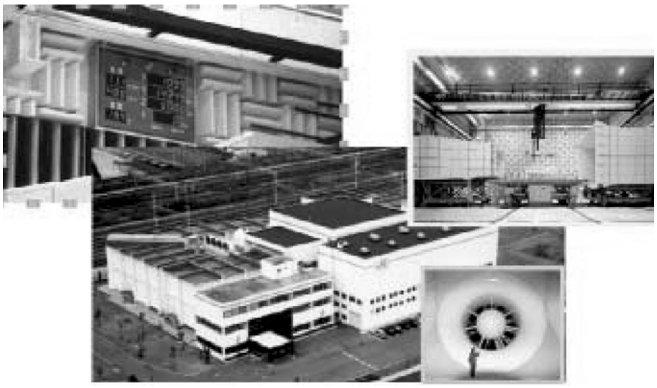
In Japan, noise is said to be the greatest impediment to raising maximum commercial speeds but advances in aerodynamics have reduced running noise, and development of sound barriers has also created a better trackside environment. Such advances are an excellent example of how technology can eliminate limits to higher speeds. Today, trains on the Tokaido Shinkansen run 60 km/h faster than in 1964 but noise levels have decreased steadily over the years and the Series 700 now registers only 74.5 dB(A).

Passenger comfort and convenience

Of course, passenger comfort and convenience involves comfort while sitting, but it also depends on a whole gamut of factors, including the comfort level of the car interior and stations, connections with other modes of transport, ambiance, etc.

RTRI's current development objective is based on the concept of a 'Universal Design of Railway Space and Evaluation of Ride Comfort.' It serves as a guide when determining the extent to which psychological and physical barriers impede access to railway services for all passengers—mobile or disabled. RTRI is developing tools to support a universal design for stations and rolling stock and to assess their comfort levels.

To further improve on-board comfort levels, RTRI has developed a simulator that replicates felt vibration caused by complex line configurations (passing switches), interior car design, actual



Facilities of large-scale and low-noise wind tunnel (RTRI)

Ladder track (RTRI)

seating comfort levels, and even passing scenery. The simulator results supplement the data collected through evaluations of actual comfort levels.

Environmental considerations

As I mentioned above, noise and vibration are two areas of particular attention in Japan because reducing them ensures a better environment for trackside residents. In general, aero-acoustic noise is reduced by using smooth exterior surfaces and the reduced air resistance is a bonus. RTRI has constructed a large low-noise wind tunnel to study the aero-acoustic noise and aerodynamic factors of high-speed rail transport. The tunnel has less background noise than any other such facility in the world (75.6 dB when simulating 300 km/h runs) and high-precision measurements of aero-acoustic noise are possible in the large anechoic chamber. Wind tunnel tests to determine the sources of aero-acoustic noise from rolling stock have led to its successful reduction.

To reduce train-induced vibrations and noise on elevated track sections, RTRI developed ladder sleepers supported on vibration-reduction pads. The ladder sleepers reduce vibration acceleration to levels far lower than those on track with conventional prestressed concrete sleepers. Recently, RTRI has also conducted research into electromagnetic compatibility (EMC) to prevent interference between various types of electric and electronic devices. In addition, studies are being conducted on quantifying the total global environmental load of all railway components and the system as a whole. These methods will incorporate Life Cycle Assessments (LCA).

Impact of social environment on rail operations

The social environment surrounding railways is changing both in Japan and internationally. Six recent trends are:

- Environmental conservation
  Against this social background, railways must develop new ways to protect the global and trackside environment, reduce energy consumption, and promote recycling. These efforts must include reduced CO_2 emissions.
- Demographic changes
  Japan's low total fertility rate and aging population will probably result in lower passenger levels, creating even more demand for value-added services. Station space and on-board environments should be made more appealing and comfortable. In this regard, more consideration should be given to RTRI's universal design concept for railway spaces.
- Global, borderless, and universal factors
  Railways are generally regarded as a domestic transport mode, but as new technologies are developed, they will take on a greater international presence. Exchanges between people of different nationalities will become more important, and international collaboration will be required when dealing with such issues as global trade and standardization.
- Seamless travel patterns
  Passenger transport should be seen in totality, including other modes too. The various modal operators need to work together to remove barriers to movement and ensure that different services complement each other.
- Deregulation
  Railways in Japan are subject to technical standards defined by legislation, although under a new law introduced in 2002, technical standards are based on performance. This means that railways will have to develop their own frameworks for responsible operations.
- Joint effort by industry, government and academic institutions
  The question is always, which sector should perform R&D? There will always be a need for the involvement of each sector, but it will become more important for them to collaborate on certain projects.

New development directions

It is increasingly important to ensure that R&D efforts are aligned with the above trends. This section discusses some research that responds to these trends.

Environment protection and energy conservation

So far, environmental R&D in Japan has been aimed at resolving problems of trackside noise and vibrations. In the future, greater attention will have to be paid to examining noise sources, analyzing sound transmission paths, and developing better ways to evaluate low-frequency vibration. But the impact of railways on the global environment also needs examining from the perspectives of energy conservation, global warming, waste disposal and recycling.

Railways are correctly seen as offering excellent energy conservation potential. The data (Fig. 9) show that in terms of passenger-km, trains consume about 75% less energy than aeroplanes and about 85% less than automobiles. Conversely, they emit only 16% of the CO_2 emissions of aeroplanes and only about 10% of those of automobiles.

Another advantage of electric trains is their ability to regenerate power. Until recently, trains were the only transport mode that could do this, but hybrid motors and fuel cells are being developed for motor vehicles, so this advantage of trains has been lost to some small extent. Railway operators must tackle this through more development.

Storage of electrical energy is another area being pursued. Track-side power sub-stations could have energy-storage systems to store surplus power for later use (Fig. 10). RTRI has constructed a prototype using double-layer capacitors and is presently examining its performance. Electrical energy can also be stored on-board and RTRI is promoting development of rolling stock with power recycling to store regeneration energy (Fig. 11). It is also promoting research into fuel cells to provide motive power. Such a train would produce no hazardous emissions at all. In pursuit of an energy-efficient linear motor car, research into superconducting transformers for rolling stock is also well underway (Fig. 12). The new transformer is much more efficient than current models and far lighter too.

New materials

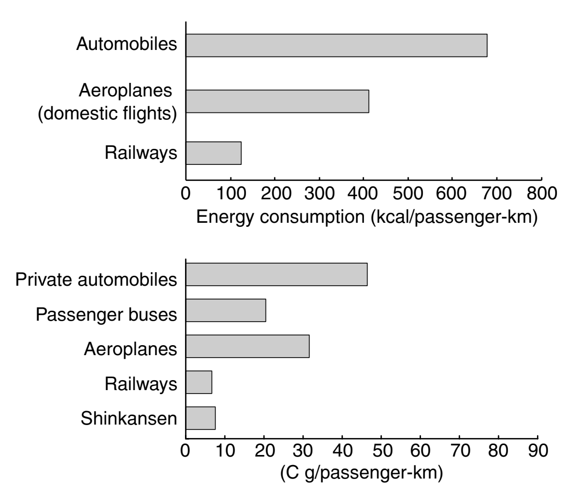
New materials receiving attention so far are lighter, stronger and more cost effective than the older materials. In the future, attention will focus on other advantages, such as functionality, resource conservation, recycling, and life cycle costs.

Traction oil is one example of a new material (Fig. 13). Oil is used to prevent squeal as the wheel flanges shift on curves. However, it can also reduce the adhesion excessively to cause wheel slip and sliding. Ordinarily, when the slip ratio increases, the adhesion coefficient decreases and more slipping occurs. However, if we can develop a new oil producing a progressively higher friction coefficient as slipping increases, we can prevent slipping. Thus, one type of oil could both prevent squeal and reduce slippage. This is the objective behind today's research into traction oil.

Human factor

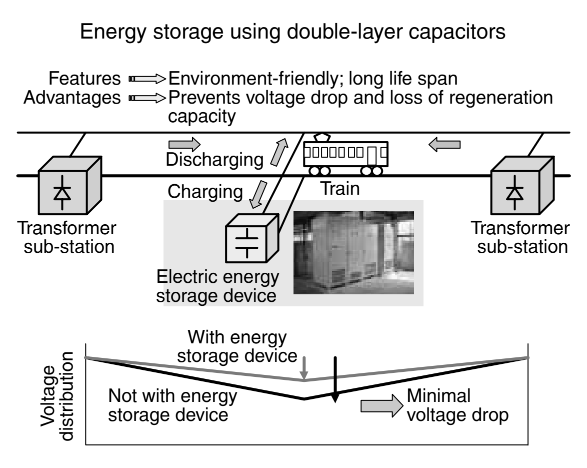
The human factor is an important area for future research in the railway sector. Actually, it has become a focal point for research in many fields.

Figure 9 Energy Consumption of Various Transport Mode



Source: *Energy Consumption Survey, Transportation Sector (1999)*

Figure 10 Electric Energy Storage at Sub-station



Railways will always be closely connected to the human element. In the past, railway employees were considered solely as workers controlling machinery, but future research will regard them as capable of preventing human error, as an interface between people and machines, as participants in failsafe procedures, and as service providers. In the final analysis, accidents and services are closely intertwined with workers, so it is natural that future research will examine the human factor closely.

Cost reduction

Efforts to cut costs need to consider lifecycle costing (LCC), which means establishing an integrated maintenance management system for the full life of equipment and infrastructure, from construction to disposal.

Although more expensive to manufacture, bainitic steel rails are a good example of the advantage of considering total lifetime cost. Bainitic steel rails have the same tensile strength as ordinary rails, but resist shelling because of their ability to self-remove the rolling contact fatigue layer at the rail head (Fig. 14). Use of such rails on straight and slight curves where shelling damage occurs extends the rail life span and reduces total maintenance costs.

Information technologies

Information technologies (IT) can be use for many purposes, from new train control systems and better safety mechanisms to more efficient operations and more profitable business activities.

Operators have already begun introducing IT information services for passengers, and

Figure 11 Rolling Stock with Electric Power Recycling Devices: Current System and System Under Development

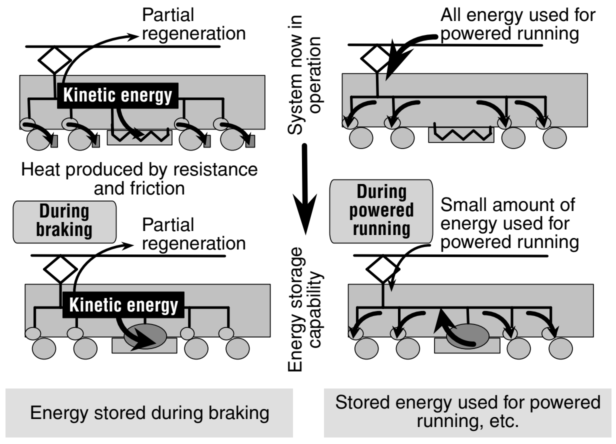


Figure 12 Main Superconducting Transformer

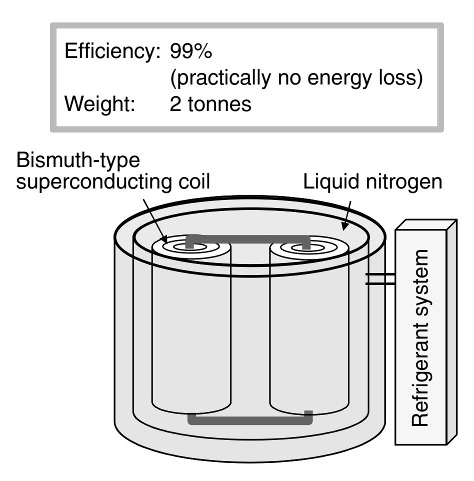


Figure 13 Development Concept for Traction Lubricant

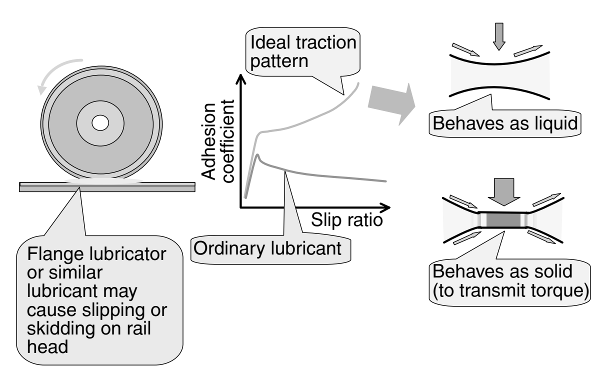


Figure 14 Extended Rail Life by using Bainitic Steel

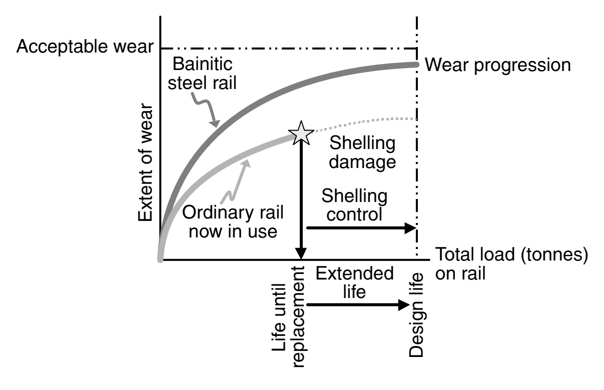


Figure 15 CyberRail Concept

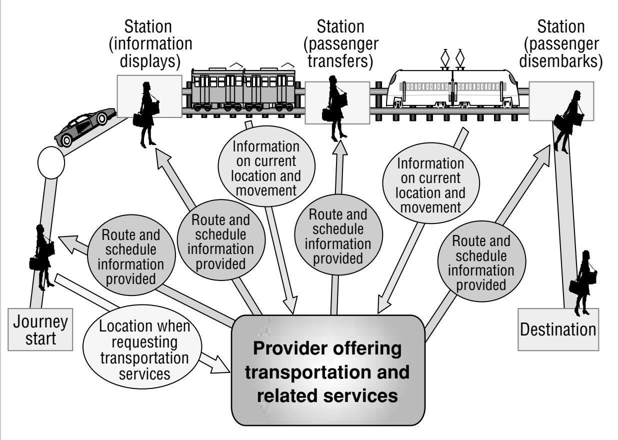
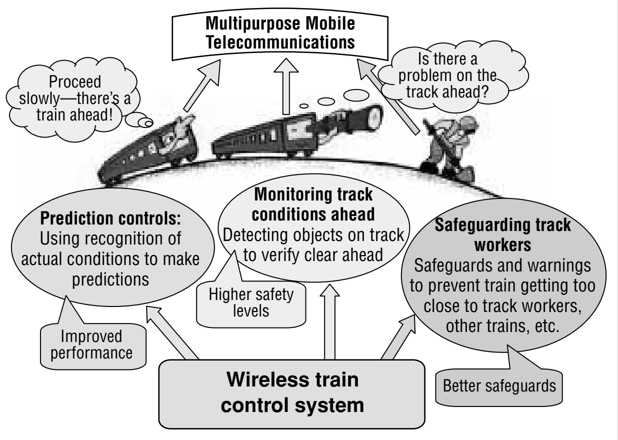


Figure 16 Intelligent Train Control System



trends point to a higher level of such services in the future.

One possible innovation might be a two-way communications system linking individual passengers and the operator. Another would be a system permitting information sharing between different modal operators to permit smoother transfers. RTRI's CyberRail concept (see *JRTR* 32, pp. 28–34) envisions these types of innovations (Fig. 15).

Of course, train controls and safety will always remain areas where IT offers important advantages. IT can be used to determine when a train should decelerate to keep its distance from an ahead train, and to verify whether something is obstructing the track. There is a need for research to develop train controls with fail-safe functions capable of monitoring ahead conditions (Fig. 16).

The Future

So far, I have discussed the various directions taken by railway-related R&D. But we must also ask how railways will develop over the distant future. What is needed to ensure that they continue to serve vital social needs?

One apparent trend is the liberalization of electric power, which will result in widespread installation of local energy-generating devices. If the trend toward energy saving becomes stronger, will superconduction technologies be needed? New transportation systems in development now include Maglev and free-gauge trains. Possible future systems include vacuum-tube railways, and door-to-door transportation systems that respond to passenger demand. Unfortunately, these futuristic systems are only at the concept stage. But whatever the research, it will only be seen as worthwhile if the resulting system is environmentally friendly and offer, excellent origin to destination (OD) advantages.

Development has one objective—the discovery and application of new technology—but the objective can be reached in various ways: through intuitive experience, careful R&D, leaps of inspiration, etc. Personally, I believe that technical problems occur not so much in systems using advanced technology, but occur all too often when technologies are developed in traditional ways based on experience when the basic research is insufficient. The same is true of railways. To achieve its objectives, I believe the Japanese railway industry should emphasize development of technologies with near-term applicability, development of basic technologies entailing risk with no uses in the near future, and development of futuristic technologies.

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