Change to Domestic Production of Railway Rolling Stock in Japan

Ichiro Tsutsumi

Railway as Force for Japanese Modernization

This article explains the history of domestic production of railway rolling stock in Japan; it covers steam and internal combustion locomotives, as well as carriages and wagons, including internal combustion railcars. Electric trains forming the heart of today's railways in Japan are explained in another article.

The first railway line in Japan opened in October 1872 between Tokyo and Yokohama under direct control of the Meiji government. It was a public passenger and freight railway modelled on the Liverpool and Manchester Railway (L&MR) opened in Great Britain in September 1830, and brought unseen western technology to a modernizing Japan just emerging from the feudal shogunate system.

In November 1871, a year before the first railway opened in Japan, the Meiji government sent a mission of 48 people, led by the Minister of the Right Tomomi Iwakura (1825-83) to Europe and America. They returned 22 months later after crossing the Atlantic from America to Great Britain. The officials, who had seen the fruits of the Industrial Revolution, drew up a framework for Japan's modernization based on the slogan of 'Enrich the country, strengthen the military, and encourage new industry'.

'Enrich the country, strengthen the military...' aimed to construct an affluent state with mining and manufacturing as its industrial base; '... encourage new industry' aimed at the evolution in Japan of the Industrial Revolution that had begun in Great Britain. This meant a shift from the existing system based on agriculture to one based on mining, manufacturing and trade. The goal for Japanese industry was to assure domestic manufacture.

At the time, there was an urgent need to introduce the scientific knowledge and new technology required for the railway, which was essential for industry as well as for mining and metallurgy, shipbuilding, machinery, telegraphy, electrical supply, construction (architecture) and printing. The quickest way was to invite engineers from the West to give on-the-job training to Japanese who would go on to take the lead in each industry. After the early training, using the advice of British engineers for the government-run railways on Honshu (Imperial Government Railways or IGR), and of American engineers for railways for the Hokkaido Development Commissioners used to spearhead the opening up of Hokkaido, everything, from surveying and construction to management, was done by Japanese. Private railways were built in Kyushu and Shikoku under the guidance of a German railway engineer who also supervised the construction of an industrial line at Besshi copper mine in Shikoku.

Both the IGR and the private railways were constructed to the narrow-gauge specification of 3 feet 6 inches (1067 mm). When railway construction first started, the Engineer-in-Chief E. Morell (1840–71) asked the government to select a gauge but they knew nothing about such matters and adopted the gauge in Morell's proposal. This narrow gauge still continues to cause technical problems for Japanese railways today. However, Japanese railway engineers successfully achieved high speeds and good safety on narrow-gauge tracks over weak alluvial ground and on grades. They also continued to make great efforts to develop technology aimed at switching to 'broad' gauge (standard gauge) and to manufacture rolling stock domestically.

Most of the 'officially hired foreigners' were British because the Meiji government had sought financial assistance from Great Britain as a consultant, and the Industrial Revolution in Britain had created a surplus of skilled railway engineers with both specialized technical skills and leadership skills after leading railway construction in the British colonies of South Africa, Australia, Ceylon (now Sri Lanka), and India. However, these advisers gradually returned home as Japanese trainees took over the core of the practical work, such as civil engineering, operations, management, and manufacturing. It was part of the terms of their employment, as was the high remuneration they received. Given these circumstances, there were high expectations for Japan's railways as a major force in the country's modernization.

Introduction of Technology for Manufacturing Rolling Stock

This section discusses the introduction of technologies supporting domestic production of rolling stock. 'Domestic production' here means the manufacture of products in Japan (by Japanese) even using imported items and materials. In general, introduction of new technology is a phased process of digestion and establishment. For rolling stock, it consists of the following five phases.

Phase 1: In this phase, the new technology is introduced as a complete system; locomotives, carriages, and wagons are imported as semi-finished products from the catalogue of an overseas rolling-stock manufacturer and are assembled and used under the tutelage of foreign mentors. In this stage, the Japanese trainees mastered practical skills and technical expertise by assembling and operating products. Use of rolling stock causes wear and tear, so spare parts for maintenance and repair are imported too.

From this point on, the technical level for domestic production is indicated by the degree of responsibility borne by Japanese engineers in (a) production planning, (b) design of mechanisms and parts, (c) parts manufacturing, and (d) assembly and adjustment.

Phase 2: In this phase, some machine parts are manufactured under the tutelage of skilled mentors; carriages and wagons are remodelled and manufactured because these processes require only low skill levels. Locomotives are not handled because they require advanced technological competence acquired through both technical training and on-the-job training in inspection and repair.

Phase 3: This phase builds on the experience from phase 2. Although foreign-made products are used for major rolling-stock components, other parts are manufactured domestically and the rolling stock is assembled and completed. Manufacture of rolling stock during the mid-Meiji era by IGR and private railways comes in this category.

Phase 4: In this phase, everything from materials to parts as well as essential machine tools is manufactured domestically. Japan started mass-production of steel from government steelworks in 1904 and it was supplied to domestic manufacturers of rolling-stock main frames and running gear.

Phase 5: In this last phase, the mastered technologies and expertise are exported and technical assistance is provided to other countries.

Based on this background, we will discuss examples of the manufacturing of coaches and wagons first, and then locomotives.

Domestic Production of Carriages and Wagons

With the exception of internal combustion railcars discussed later, carriages and wagons have no motive power and are hauled by locomotives. Their role is to carry passengers and freight, so railways always have large fleets of both. When the first line between Tokyo and Yokohama opened, it used 58 carriages and 75 wagons imported from Great Britain. These arrived as semi-finished products. The wooden bodies and main-frame components, and the steel parts, such as bogies and wheel sets, were assembled by Japanese trainees working under foreign instruction, work which provided them with very beneficial practical experience. The imported items were then used as patterns with only steel parts being imported subsequently. Four-wheeled carriages were manufactured at the IGR Kobe Works in 1875, and at the Shimbashi Works in 1879, continuing to about 1900. The main domestically produced parts at that time were wooden bodies. These were manufactured by experienced carpenters who drew on skills amassed up until the Edo era in building Japanese-style boats, houses, and furniture.

The standard four-wheel carriage had a length between 23 ft (7010 mm) and 25 ft (7620 mm), and a wheelbase of 12 ft (3658 mm) or 12.5 ft (3810 mm). Domestic steel for the carriage main frame had to wait until 1904, when government steelworks started producing steady supplies; the same was true for materials for rails and bridges.

Meanwhile, nine large four-wheel bogie wooden carriages were used at the opening of the IGR line between Osaka and Kobe; one third-class carriage was manufactured at the Kobe Works. It consisted of two, linked four-wheel, third-class cars with 10 seats in each divided open passenger space and a total capacity of 100 passengers. It had a prototype Adams Bogie with a composite structure of wood and iron. Four-wheel bogie carriages had better running stability and ride comfort than four-wheel carriages, making them better suited to mass transport, so demand increased yearly. Fifty-six were imported from Great Britain when the Tokaido main line opened in July 1889. In addition to the IGR Shimbashi and Kobe works, the works of private railways such as San'yo Railway, Kansai Railway and Nippon Railway built many distinctive carriages and wagons. The designers and builders were all Japanese.

The very best of these carriages belonged to the Imperial Household for private use. The first Imperial carriage (Mark 1) was a four-wheel wooden carriage built at the IGR Kobe Works under the supervision of W. M. Smith (1842–1906), the first locomotive superintendent (chief mechanical engineer or CME). It is a masterpiece combining the latest technology of the day with the elegance of beautiful Japanese ornamentation. The Meiji Emperor made the return trip in it at the opening of the IGR line between Kyoto and

Kobe in 1877. It was designated as a 'railway monument' by the former Japanese National Railways (JNR) in 1958, and as a 'national cultural property' in 2003. It is the oldest extant four-wheel Japanese wooden carriage.

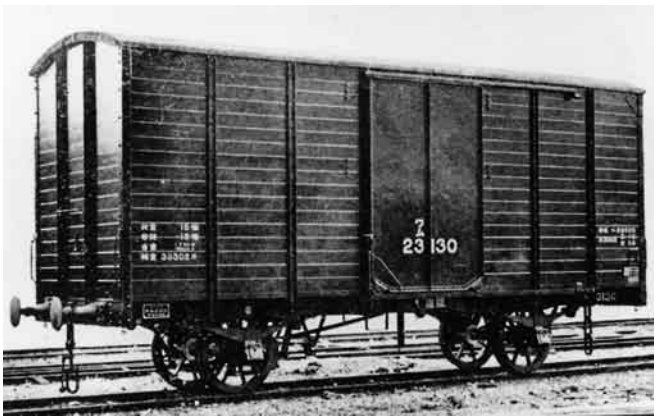
At the end of the Russo-Japanese War in 1905, the Diet promulgated the 1906 Railway Nationalization Act to create the IGR network as quickly as possible by nationalizing the lines of 17 private railway companies, including Nippon Railway, San'yo Railway, and Kyushu Railway. Nationalization had two objectives: to connect and develop the regions, and to secure rapid military transport in emergencies. A unified transport network required railways throughout Japan to adopt the same narrow gauge but the private railways had used unique designs so the use of standardized rolling stock had to wait for rolling stock standards from the Railway Agency established in 1908.

In 1910, the Railway Agency designed carriages with a length of 17 m, such as the *Hoha* 12000, which had a larger body cross-section than existing carriages. From 1919, it designed four-wheel bogie standard carriages with a length of 20 m, such as the *Naha* 22000, serving lines throughout Japan. Domestic steel was used for the main frames and running gear of the Railway Agency-designed wooden four-wheel bogie carriages, but truss rods (main-frame reinforcements) were still being fitted on both sides of the underframe. These carriages were manufactured by three Railway Agency-designated companies: Kisha Seizo (Tokyo Works, formerly Hiraoka Works), Nippon Sharyo Seizo (now Nippon Sharyo), and Kawasaki Shipyard Co.

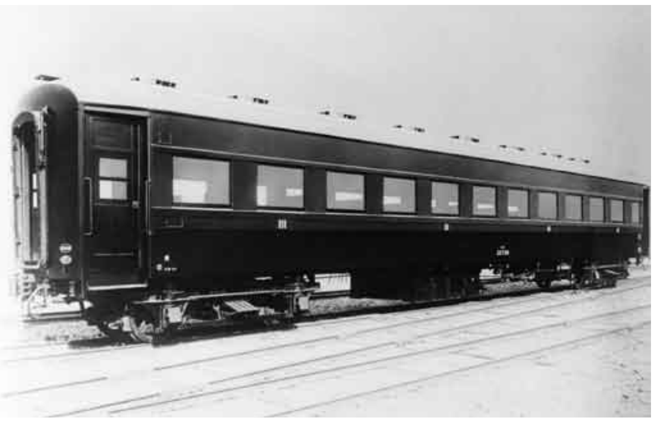
In response to freight demands, the wagon capacity was also increased from 10 to 15 tons or more, and large four-wheel bogie wagons appeared. The wagon main frames and bodies were initially wood and steel, but changed to domestic steel, and various wagons tailored to shippers' needs appeared on lines across Japan.

Carriage design changed when the Ministry of Railways was created in 1920. After some tragic accidents, plans were made to strengthen the bodies of wooden carriages; a fishbelly underframe and semi-steel body with frame and outer panels of steel and wood interior were adopted. These include the general-purpose *Oha* 30 and the wide-window express *Oha* 35. Private rolling stock works designated by the Ministry of Railways built them. When JNR was established in 1949, *Suha* 42 was designed for main-line expresses, and the next surge in demand for passenger transport led to mass-production of *Naha* 10 for express trains using a monocoque structure to lighten the body and the underframe. Pallet- and container wagons became

Hoha 12000 carriage built in 1910 (The Railway Museum)



Wamu 1 covered wagon with 15-ton capacity (The Railway Museum)



Oha 35 wide-window express carriage (The Railway Museum)

Taki 50000 tank wagon for transporting gasoline (The Railway Museum) widespread with mass-production of the large *Wamu* 80000 covered wagons, container wagons, refrigerator cars and wagons exclusively for car transport; these were used to transport freight between hubs. Tanker wagons for chemical and petroleum became increasingly bigger. A new design of light bogie was developed with a roller bearing to make transportation more efficient. This system became central to freight transport and is still in use today.

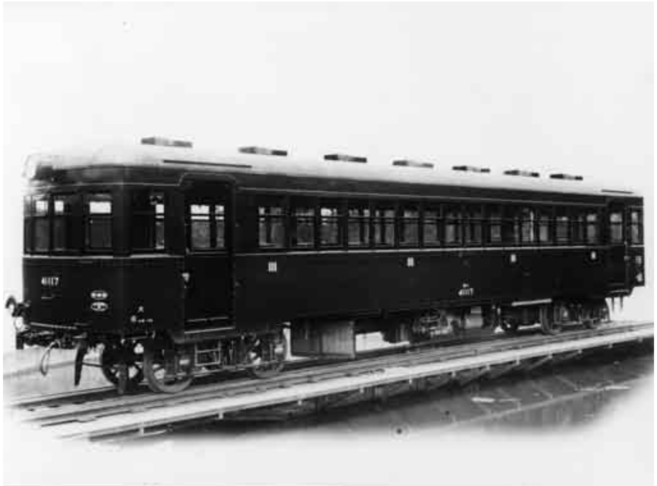
Internal Combustion Railcars

The 1923 Great Kanto Earthquake inflicted tremendous damage on Tokyo and other cities including the railways. As alternative transport to the devastated trams, the Tokyo Municipal Electric Bureau made an emergency import of 800 Ford model-T truck chassis to build buses with wooden bodies. These buses were convenient and cheap to operate compared to railways and trams, so bus operators grew throughout Japan. The impact was felt most strongly by small to medium local private railways. As a countermeasure to buses running along roads parallel to tracks, railways created new stops and started operating cheap, cost-effective, single railcars powered by internal combustion. The *kidojidosha* (automobile type railcar) developed by Nippon Sharyo is a good example.

The same phenomenon occurred on the Ministry of Railways regional lines where carriages and wagons were hauled by steam locomotives. However, the Ministry did not ask for help from private rolling-stock manufacturers, who were ahead in terms of internal combustion engine technology, design and manufacture. Instead, the Ministry of Railways designed *Kihani* 5000, a unique, small, four-wheel internal combustion railcar, which was manufactured by Nippon Sharyo in 1929. However, *Kihani* 5000 design concept differed from that of the small lightweight internal combustion railcars of private manufacturers. The body steel thickness was the same as the steel four-wheel bogie carriage stipulated by the Ministry. The engine and running gear followed Ministry policy of using domestic parts, but there was no suitable large automotive engine, so a remodelled gasoline marine engine (40 PS) by Ikegai Tekkosho was installed under the floor. The transmission was mechanical and the radiator was installed in front of the roof like German internal combustion railcars. The running gear was a four-wheel single bogie (bearing spring with sliding bearing) with improvements for comfort. However, despite its small size *Kihani* 5000 weighed 15.5 tons due to the sturdy body and main frame. This weight did not match the low output of the remodelled Ikegai Tekkosho marine engine, and performance was poor. Although there were foreign engines with large horsepower, the requirement to use domestic goods doomed *Kihani* 5000 to failure. In 1931, Nippon Sharyo and Kawasaki Sharyo each manufactured a *Kihani* 36450 large internal combustion/electrical railcar. A gasoline engine (200 PS) by Ikegai Tekkosho was installed and connected directly to a 135-kW DC generator powering two 80-kW traction motors in the bogie. This was the first domestic internal combustion (petrol)/electrical railcar but it was scrapped later because the 49.1-ton weight was too heavy for the power output.

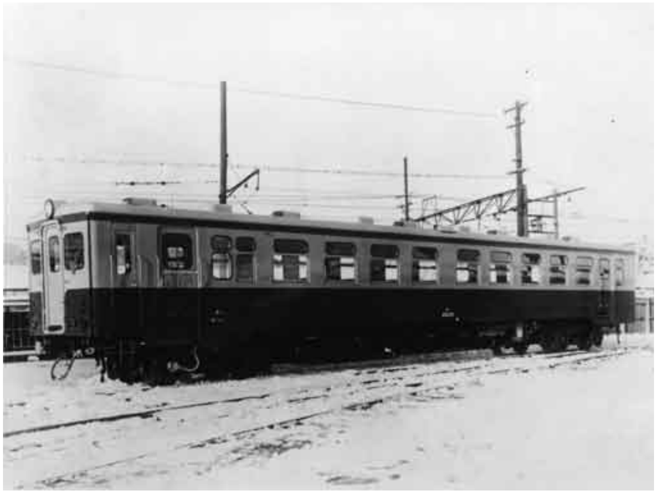
Kiha 36900 (later *Kiha* 41000) is an example of a domestic medium-size internal combustion (petrol) railcar with lighter weight matching the four-wheel bogie engine output. The Ministry's policy on internal combustion (petrol) railcar design was threefold. First, it should operate as a single-car train without considering impact at the front of the mainframe; when out of service it should be coupled to the back of a train. Second, the construction and composition of all parts should be lightened, regardless of compatibility with existing parts or standards. Third, the Ministry itself would develop a petrol underfloor engine using domestic parts. The 36 *Kiha* 41000 railcars completed in April 1933 had a body length of 15,500 mm and an unladen weight of 20.0 tons. The Ministry-designed GMF13 petrol engine (100 PS) was installed under the floor and the bogie was a TR26 bar-truck constructed of band steel with roller bearings. *Kiha* 41000 performed well and 136 units were mass-produced by private rolling stock works by 1936. They were in widespread operation throughout Japan, mainly on provincial lines. In 1935, *Kiha* 42000 appeared with a body length of 19,000 mm and higher passenger capacity. The front was streamlined, and an underfloor GMH17 (150 PS) petrol engine was fitted.

Wamu 80000 covered wagon (The Railway Museum)



Kiha 41000 medium-size gasoline railcar (The Railway Museum)

Series *Kiha* 82 DMU for limited express services (The Railway Museum)



Kiha 17 diesel railcar (The Railway Museum)

Series *Kiha* 58 DMU for ordinary express services (The Railway Museum)

End car of *Asakaze* limited express (Tokyo–Hakata) composed of Series 20 air-conditioned sleeping carriage (The Railway Museum)

The other end car of *Asakaze* with power generator for lighting and air-conditioning (The Railway Museum)

It was used widely for passenger transport, along with *Kiha* 41000, and 62 units were manufactured by 1937.

The successors to *Kihani* 36450 internal combustion (petrol)/electrical railcar were the two *Kiha* 43000 railcars completed by Kawasaki Sharyo in 1937 inspired by successful operation of the streamlined *Fliegende Hamburger* diesel/EMU express in Germany in 1933. *Kiha* 43000 was a streamlined diesel electrical railcar with a directly connected 150-kW generator and underfloor 240-PS horizontal supercharged engine designed in collaboration by the Ministry, Niigata Tekkosho, Ikegai Tekkosho, and Mitsubishi Shipyard. Three-engine models were manufactured; two 80-kWDC motors were mounted on the bogie on the coupled side and they were operated as multiple units consisting of three carriages with an intermediate trailer between.

Fuel rationing started as WWII intensified and there was a sharp drop in the operation frequency of internal combustion railcars as the war drew to an end. With the 1949 creation of JNR and improvements in fuel supply, large diesel railcars replaced models using substitute fuels, such as natural gas and coal gas during fuel rationing. This was followed by completion of *Kiha* 44000 in August 1952, an internal combustion (diesel)/electrical railcar fitted with a Ministry-designed standard DMH17 diesel engine (150 PS). In addition, an improved version of the torque-converter hydraulic transmission developed before the war was fitted to *Kiha* 42500 and *Kiha* 44500. Its good performance in multiple unit control meant that postwar Japanese internal combustion railcars were configured with hydraulic multiple unit control combining DMH17 diesel engines with hydraulic transmissions (TC-2, DF115). Series *Kiha* 10 were manufactured from 1953 as the first mass-produced hydraulic transmission internal combustion railcar. It was followed in 1956 by Series *Kiha* 55 for local expresses and *Kiha* 20 for general use; both had a larger body cross-section. The next railcars (*Kiha* 50, 51, and 52) had two built-in engines for higher power output on lines with steeper grades.

1960 marked the start of the high economic growth period. As living standards rose, line electrification and the change to internal combustion traction for top-class trains led to more frequent and faster services as well as repeatedly revised railway timetables. The ‘bonneted’ *Kiha* 81 internal combustion express railcar with two horizontal DMH17H engines (180 PS), appeared in 1960, and was modified and improved to *Kiha* 82 with gangways and high driver’s cab for the October 1961 timetable revision. *Kiha* 58 was mass-produced for express trains; diesel expresses were operated on non-electrified lines throughout Japan and the increased speeds improved rail services. Meanwhile, Series *Kiha* 30 commuter internal combustion railcar with horizontal DMH17H engine was mass-produced from 1961 to transport commuters from rapidly growing residential areas around cities. The series of internal combustion railcars was manufactured by private rolling stock works, such as Niigata Tekkosho, Hitachi Limited, Fuji Heavy Industries, Kisha Seizo, Tokyu Car Corporation, Nippon Sharyo, Kinki Sharyo, Teikoku Sharyo, and Kawasaki Sharyo.

At the same time, high-power engines were being developed to replace two-engine installations. *Kiha* 60 with 400-PS engine appeared in 1960, and a prototype internal combustion railcar with 1050-PS CT58 gas turbine was built as a Japan Association of Rolling Stock Industries project; it did not get as far as practical use. 1968 marked the start of mass-production of Series *Kiha* 181 internal combustion express railcar with a two-shaft drive and 500-PS diesel engine. It is still used today. However, the internal combustion railcars designed in the postwar years are wearing out. Some still remain or are preserved, but the railcars that underpinned Japan’s modernization are coming to the end of their days.

Steam Locomotives

The construction and mechanisms of steam locomotives are much more complex than carriages and wagons. Since domestic production is difficult without advanced mechanical engineering, practical skills and technical expertise acquired through first-hand experience, domestic production proceeded gradually, starting with remodelling of imported locomotives. The extension of the IGR line to Kyoto in 1876 led to a shortage of locomotives for passenger trains so the Kobe Works under the supervision of W. M. Smith, converted two freight 7010 0-6-0 tender locomotives to passenger 5100 4-4-0 tender locomotives. The remodelling involved dismantling the first driving wheels, removing part of the main frame, and fitting a four-wheel lead bogie. The existing 43-inch (1092 mm) driving wheels were replaced by 55-inch (1397 mm) wheels but the boiler was unchanged. That a locomotive could be remodelled only 4 years after Japan’s first railway opened is an indication of the skills of the Japanese trainee engineers. In 1884, two 4-4-0 tank locomotives manufactured in 1882 were remodelled into 4-4-0 tender locomotives at the Kobe Works under the supervision of B. F. Wright, the second CME.

A historic project to build the first domestic steam locomotive at the Kobe Works was launched in 1888 by Richard F. Trevithick (1845–1913), the third CME and grandson of the inventor of the steam locomotive, Richard Trevithick (1771–1833). The Class 860 (dubbed No. 221 and No. 137 before becoming the Class 860) used parts and steel imported from Great Britain. Its manufacture took 8 months and it was completed in 1893. It ran between Kyoto, Osaka and Kobe and achieved good results in trials comparing its performance with imported locomotives. It had the standard

2-4-2 wheel arrangement of the day but it was a compound cylinder locomotive, making maintenance difficult. After operating between Kyoto, Osaka and Kobe, it was transferred to the Sakhalin Railway where it ended its service. As the first domestically built steam locomotive, it could be called a national treasure and its loss without preservation is a gap in Japan's industrial technology history.

Trevithick eventually returned to Great Britain in 1904 but the Kobe Works manufactured as many as 34 steam locomotives under his supervision, a testament to the hard work and perseverance of his trainees, Mori Hikozo (1867–1958) and Ota Kichimatsu (18??–1927). In 1896, Mori became manager of the Kobe Works and was in charge of inspection of completed Class 230 steam locomotives, 41 of which were mass-produced by Kisha Seizo from 1902. Both men transferred to the Shimbashi Works when the Kobe Works closed in 1915. Mori then worked for the South Manchurian Railway before becoming headmaster of Nagoya Technical College in 1920. Ota transferred to Kawasaki Shipyard's Hyogo factory where he worked on the design and manufacture of the Classes 6700 and 6760 passenger train steam locomotives using the Railway Agency's standard 4-4-0 wheel arrangement, and the Classes 9550 and 9600 freight train steam locomotives with the 2-8-0 arrangement.

Design of a standard steam locomotive began in 1908 when the Railway Agency was created after the 1906–07 railway nationalization. The main reasons were because the first imported steam locomotives were wearing out, and because maintenance of the diverse types was difficult and costs were mounting. First, the Railway Agency manufactured Class 6700 saturated steam passenger train tender locomotives at Kisha Seizo and Kawasaki Shipyard. It was then decided to build a larger, high-performance steam locomotive than existing types to haul limited express trains between Shimbashi and Shimonoseki. The Railway Agency sent specifications to locomotive manufacturers in the West for a 'superheated (steam generated by boiler superheated to 350° to 400°C in superheated tubes) tender locomotive with a 4-6-0 wheel arrangement, and a wheel diameter of 1600 mm' to import samples for use as reference designs. In 1911, just 2 months after the order was placed, a Borsig Class 8850 arrived from Germany, followed by a Schwarzkopf Class 8800, and North British Class 8700 (saturated steam). However, the American ALCO Class 8900 that arrived had a different 4-6-2 wheel arrangement. Class 8850 had a main-bar underframe cut from thick steel plates and the boiler was located over the driving wheels. Class 8800 performed well and the superiority of its superheating was clear. The firebox of Class 8900 was located over the trailing wheels and the fire grate was large.

The Railway Agency adopted all the good points of these sample locomotives to design a series that suited Japanese conditions. First, a Class 6750 superheated version of the saturated passenger train tender locomotive Class 6700 was manufactured at Kawasaki Shipyard from 1913. Then, a Class 6760 improved version of the 6750 was manufactured at Kawasaki Shipyard from 1914. What is more, 687 Class 8620 passenger 2-6-0 tender locomotives were built at Kisha Seizo and Kawasaki Shipyard from 1914. To save costs, the leading bogie was connected to the first driving wheel by a linkage, a design that took operation on curves into consideration.

Class 9600 freight locomotive (2-8-0) (The Railway Museum)

Class 8620 passenger locomotive (2-6-0) (The Railway Museum)

The same process was followed for freight locomotives. A Class 9550 saturated steam tender locomotive was produced at Kawasaki Shipyard from 1912. Furthermore, 770 superheated Class 9600 tender locomotives were built at Kawasaki Shipyard and Kisha Seizo from 1913. Class 6760 and 8620 for hauling passenger trains had standardized main parts, including boiler, cylinders and 1600-mm wheels for service compatibility. Unlike the Meiji era, locomotive building


Class C51 4-6-2 express passenger locomotive (The Railway Museum)


Modified version of Class C51 with smoke deflectors
(The Railway Museum)


Class D51 locomotive (The Railway Museum)


Class D51 locomotive photographed in Mito Yard in 1942
(The Railway Museum)

was entrusted to private works chosen by the Railway Agency. The person in charge of allocating work was the Machining Section Chief of the Railway Agency, Yasujiro Shima (1870–1946), the first and second chairman of The Japan Society of Mechanical Engineers (JSME) established in 1924. This method was chosen to promote domestic manufacture by boosting technical skills in mechanical engineering, and railway works became specialized in maintenance and repair of rolling stock. As mentioned before, forty-one Class 230 2-4-2 tank engines were built from 1902 at Kisha Seizo; Class 230 was the first mass-produced tank engine manufactured by Japanese.

When the Railway Agency became the Ministry of Railways in 1920, new steam locomotives were designed to run on narrow gauge with the same performance as standard gauge. First, Kisha Seizo and Mitsubishi Shipyard built 289 units of Class C51 4-6-2 tender passenger locomotive with large driving wheels of 1750 mm from 1919, followed from 1923 by 380 units of Class D50 2-8-2 tender freight locomotive built by Kawasaki, Kisha Seizo, Hitachi and Nippon Sharyo. These locomotives had a larger boiler than previously, and the fire grate in the firebox over the following wheels was larger to generate more steam. A main-bar underframe cut from thick steel plates was used for the first time in Class D50. These were expanded upon in classes C53 (three cylinders), C55, and C57, which changed from spoked driving wheels to boxed driving wheels made of a single piece of cast steel. Class C59 passenger locomotives, and D51 freight locomotive came out in quick succession. The design of this series of Ministry locomotives proceeded through collaboration between the Ministry and private builders and was not confined to steam locomotives; the same procedure was followed for EF52 DC electric locomotives and EF53 onward.

The Ministry designers took Japan's topography with many alluvial plains and grades into account. Before installing the large boilers used in Western locomotives, it gave due thought to axle loads that would suit all stretches of lines. Efficient maintenance work was important as was standardization of driving wheel diameters and compatibility of major parts; the Walschaerts valve gear was also standard. In other words, this group of locomotives prioritized economics in the design, and it was left to the advanced technical skills of railway engineers to use them on the various lines.

The same was true of tracks. Trains were operated thanks to the tremendous efforts of skilled engineers working on each track section. The age of the steam locomotive truly was an age when technical skills were central. Of the many Ministry-designed steam locomotives, the most numerous was Class D51 2-8-2 tender freight locomotive with 1115 units built from 1926. It was a very significant locomotive in which all parts were produced domestically. Yasujiro Shima's oldest son, Hideo Shima (1901–98), who is also famous as the father of the shinkansen, was in charge of its design. Such experience and excellent results made a tremendous contribution to the postwar mass-production of rolling stock and the growth of Japanese industry. After WWII, classes C60, C61 and C62 passenger tender locomotives (all 4-6-4) and Class D62 freight tender locomotive (2-8-4) were built based on the Ministry-designed steam locomotives. However, they were soon decommissioned as more lines became electrified and internal combustion engines replaced steam. In recent years, passenger operators in the JR groups are bringing back some old steam locomotives due to demand for industrial tourism.

As a side note, a steam railcar based on a steam locomotive towing carriage with a small engine room with boiler and running gear (cylinders and driving wheels) at the front was manufactured by Kisha Seizo and adopted by some provincial private railways. The patent belonged to Kisha Seizo's Kudo Heijiro and the design was known as the Kudo Steam Railcar or *Kiha* 6400 and 6450. They were used for local transport because they carried less water and coal than larger steam locomotives. They are the predecessors of internal combustion railcars, but did not play a prominent role and were gradually decommissioned and transferred to provincial private railways.

Internal Combustion Engines

Instead of steam boiler, internal combustion locomotives get their motive power from an internal combustion engine. They are generally classified into petrol, diesel, or gas-turbine locomotives, depending on the engine, and into mechanical or hydraulic, according to the transmission. However, electric locomotives, where a generator is powered by an internal combustion engine to drive an electric motor, were also used. Foreign-built internal combustion (petrol) locomotives were used by industrial and provincial lines to replace steam locomotives earlier than on main lines. A small internal combustion locomotive fitted with a domestically produced Niigata Tekkosho diesel engine was manufactured at Amemiya Seisakusho in 1927. In 1931, a small internal combustion locomotive fitted with an Ikegai Tekkosho marine diesel engine was built at Hitachi Limited for Narita Railway, and again at Nippon Sharyo in 1937 for Kashima Sangu Railway.

The Ministry patterns were classes DC10 and DC11 imported from Germany as WWI reparations. They were ordered by the Ministry, and DC11 arrived in Japan in 1929 and DC10 in 1930. Both had a 2-6-2 rod drive wheel arrangement and were fitted with a diesel engine with the same output, but different transmission. DC10 had a Krupp mechanical system (600-PS engine and gearbox) and DC11 had an Esslingen/MAN electric system (MAN 600-PS engine and two 190-kW traction motors driven by a 380-kW generator). As soon as they arrived at Kobe Port, they were taken to Takatori Works where data was collected for design of domestically built locomotives by carefully dismantling them, drawing the parts and then reassembling them. They took a long time to reach Japan because they were war reparations and also because diesel locomotive design and manufacturing technologies were not fully established in Germany and they were difficult to manufacture. German diesel locomotive engines were either submarine (U-boat) engines or modified submarine engine designs; apparently there were no diesel engines for railway use even by 1924 because the size, mass and operational reliability of submarine engines made them ideal for railway engines, demonstrating the excellent and reliable performance of motors designed for military purposes.

These German diesel locomotives were used to shunt wagons on the Kobe Port Line and to haul freight trains between Takatori and Himeji. However, they often broke down and were taken out of service in 1935 to be scrapped in Takatori Works during the war.

Design of Japanese-built diesel locomotives began based on the dismantling and assembly of the German classes DC10 and DC11 locomotives, and on their operational performance. The background was economizing on running costs and other expenses due to the recession in the early Showa period (1930s). In 1932, eight Class DB10 diesel locomotives were built by Kawasaki Sharyo, Nippon Sharyo and Hitachi Limited as yard shunters and to haul very short trains. However, fuel rationing forced them out of service in 1938 and they were scrapped in 1943. They had a 0-4-0 wheel arrangement, weighed 10.5 tons, were fitted with a 60-PS engine made by Ikegai Tekkosho and Kobe Steel, and had a mechanical transmission.

Meanwhile, collaboration started between the Ministry, private builders and engine manufacturers to design a new domestic diesel electric locomotive for yard shunting and hauling freight trains on main lines. The participating companies were Niigata Tekkosho, Shibaura Seisakusho, Kawasaki Sharyo, Mitsubishi Electric and Hitachi Limited; the first Class DD10 locomotive with 2-2-2·2-2-2 wheel arrangement was completed at Kawasaki Sharyo in 1935. After test runs, it was put into service at the Oyama Works but was taken out of service and decommissioned due to fuel rationing. It was stored in the grounds of the Omiya Works and dismantled after WWII. It weighed 71.0 tons, had a Niigata Tekkosho engine (500 PS) and an electrical transmission with four 100-kW traction motors powered by a 300-kW generator.

Following WWII, JNR built Class DD50 diesel electric locomotive (4-4) from 1953 and Class DF50 (4-4-4) from

1956. They were used to haul both passenger and Freight trains on secondary main lines. DD50 had a driver's cab on one side and was fitted with a diesel engine (900-PS) by Shin Mitsubishi Heavy Industries (now Mitsubishi Heavy Industries) through a technical partnership with Sulzer of Switzerland. Four 130-kW traction motors were powered by a 580-kW main generator connected directly to the engine. The first production run was three units, with two operating in tandem on the Hokuriku main line. An improved model was built in the second production run of three units in 1955. DF50, meanwhile, was an improved version of DD50 with the supercharged diesel engine producing 1060-PS and fitted with a steam generator for heating the carriages. Furthermore, Hitachi and Kawasaki Heavy Industries produced 1200-PS supercharged diesel engines through a technical partnership with MAN AG of Germany. Locomotives with these engines (called DF50-500) were mass-produced from 1958.

Meanwhile, the 4-4 DD11 diesel hydraulic locomotive for shunting (two DMH17B 160-PS engines) appeared in 1954. From 1957, it was mass-produced as the larger Class DD13 (with two DM31S 3700-PS engines although later models had two DMF31SB 500-PS engines). At this time, diesel locomotive manufacturing companies in Japan built one model of locomotive each using either their own technology or through a technical partnership with companies in other countries. The purpose was to obtain technical skills in design and manufacturing, and to manufacture prototypes for export. JNR would borrow and use the locomotives for some period of time, so they were called 'borrowed locomotives.' Loan periods were broken down mainly into two periods: 1954 to 1962 and 1959 to 1965, and some borrowed locomotives formed the foundation of JNR standard locomotives. These borrowed locomotives were: DD40 (4-4 diesel hydraulic locomotive built in 1960 by Shin Mitsubishi fitted with a 665-PS Mitsubishi Sulzer engine, borrowed from 1960 to 1962, and renamed DD92); DD41 (4-4 diesel electric locomotive built in 1954 by Tokyo Shibaura Denki (now Toshiba) fitted with a 660-PS Cooper-Bessemer engine, borrowed from 1956 to 1958, purchased in 1958, and renamed DD90); DD42 (4-4 diesel hydraulic locomotive built in 1957 by Nippon Sharyo fitted with two 900-PS Kobe Steel engines, and borrowed from 1957 to 1958); DD91 (4-2-4 diesel hydraulic locomotive built in 1960 by Shin Mitsubishi fitted with a 1820-PS Maybach engine, borrowed from 1962 to 1965, and forming the foundation for DD54 manufactured from 1966); DD93 (4-4 diesel hydraulic locomotive built in 1961 by Nippon Sharyo fitted with a 1100-PS MAN Mitsubishi engine, and borrowed from 1962 to 1965); DF90 (6-6 diesel electric locomotive built in 1956 by Hitachi fitted with a 1680-PS MAN engine, borrowed from 1957 to 1961, and purchased in 1961); the initial DF91 (6-6 diesel electric

Class DF50 diesel electric locomotive (The Railway Museum)


Class DD13 diesel hydraulic Shunting locomotive (The Railway Museum)

Class DD51 diesel hydraulic locomotive (The Railway Museum)

Class DE10 2-2-2-4 diesel hydraulic locomotive (The Railway Museum) locomotive built in 1959 by Hitachi fitted with a 1560-PS MAN engine, borrowed in 1959, and manufactured for export to Taiwan); DF40 (6-6 diesel electric locomotive built in 1960 by Kawasaki Sharyo fitted with a 1200-PS MAN engine, borrowed from 1956 to 1958, purchased in 1958, and renamed DF91); DF41 (6-6 diesel electric locomotive built in 1964 by Kisha Seizo fitted with a 1320-PS Mitsui Burmeister engine, borrowed from 1959 to 1962, and renamed DF92); and DF93 (6-6 diesel hydraulic locomotive built in 1960 by Hitachi fitted with a 1100-PS MAN engine, borrowed from 1962 to 1964, forming the foundation for DF50-500).

The 4-4-4 Class DD51 diesel hydraulic locomotive (with two DML61L 1000-PS engines although later models had two DM61Z 1100-PS engines) was mass-produced from 1962 for use on main lines and played a major role throughout Japan on non-electrified lines. Also, the 4-2-4 DD54 diesel hydraulic locomotive for secondary main lines with a lower output than DD51 was manufactured from 1966 by Mitsubishi Heavy Industries based on DD91. It was a diesel hydraulic locomotive fitted with a Mitsubishi Maybach 1820-PS engine and was added by the second production run in 1967.

For shunting internal combustion locomotives, the successor to DD13 was Class DE10 with 2-2-2-4 wheel arrangement and DML61Z engine; it was mass-produced from 1966 and used on lines throughout Japan. These locomotives can still be seen today but they are wearing out and rolling stock from the 1960s and 1970s is fast disappearing.

Conclusion

This article has briefly explained the changes in domestic production of steam and diesel locomotives, carriages, wagons, and internal combustion railcars in Japan from the first days until now. Around 70% of Japan is mountainous, and the flat land is largely alluvial coastal plains created by rivers, so there are limits on use of heavy-axle trains, such as those in the West. In addition, narrow-gauge tracks posed many different technical problems from standard gauge. However, such drawbacks were brilliantly overcome, for example by adopting the large cross-sections typical of standard gauge in design of narrow-gauge locomotives, carriages and wagons, making high-speed operations possible. Manufacture of rolling stock was shared between railways' workshop and private builders and the boost this gave to Japan's industrial capabilities is an essential part of our technological history. Design and manufacture of rolling stock is the product of mechanical engineering as well as various other technologies; it enriches individual technical fields and combines with other fields as it spreads out. It has been a comprehensive industrial bottom-up led by integrated technical systems required for rolling stock manufacturing.

Today, although Japan has reached the stage where it exports high-speed rail systems to other countries, we should remember that this is founded on the successive efforts of railway engineers since the Meiji era to perfect and expand technical systems. ■

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Further Reading

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Ichiro Tsutsumi

Dr Tsutsumi is a Senior Researcher at the Institute of Vocational Training of the Polytechnic University of Japan. Prior to his current position, he was a Senior Researcher at the Japan Institute of Labour (JIL). He earned a doctorate degree in history of technology from Ashikaga Institute of Technology in 2009.