Feature

JNR's Choice of Traction System—From Loco-hauled to Multiple-unit Trains

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Introduction

In Japan, most long-distance passenger trains use the distributed traction system with powered cars carrying passengers. By contrast, in Europe, the USA and elsewhere, loco-hauled unpowered carriages are dominant, although adapted multiple units are being tested by some railways. In other words, the motive power is dispersed among the cars of the train set. Japan's high-speed trains are all EMUs while European high-speed trains are basically loco-hauled. The design concepts are very different—the shinkansen is powered by electric motors mounted in multiple locations, while the TGV and ICE use a locomotive to haul unpowered cars.

Japan's Tokaido Shinkansen was opened in October 1964 to increase passenger capacity in the Tokyo–Osaka corridor because the Tokaido main line had reached its limit. The new line had a maximum operating speed exceeding 200 km/h, the fastest in the world at that time. By dramatically increasing speed, Japanese National Railway (JNR) boosted demand for rail travel and the shinkansen became an important revenue source for JNR just as its financial situation was deteriorating. The shinkansen was so successful that it motivated countries like France and Germany to build high-speed railways. Before the shinkansen, pessimists had predicted a slump in rail travel with passengers flocking to planes and motor vehicles instead. The Tokaido Shinkansen proved them wrong and opened the way to new possibilities in railway development. The so-called 'bullet train' revolutionized the idea of high-speed rail travel.

In addition to building the Tokaido Shinkansen to boost capacity between Tokyo and Osaka, a second reason was to create a new, high-speed rail system by making innovative changes to some existing railway technologies. The innovations and improvements were reflected especially in rolling stock, track, electric power supply systems, and signalling. This article focuses on one technical development adopted for the Tokaido Shinkansen—rolling stock. As explained above, most long-distance passenger trains are electrical multiple units (EMUs). This is such an obvious fact today that one might think that the shinkansen designers would have chosen the EMU model right from the start. However, when the shinkansen was being designed in the late 1950s, most long-distance passenger trains in Japan, Europe, the USA and elsewhere were loco-hauled. Until the 1950s, the very idea of developing an EMU train was considered quite revolutionary.

So why did Japan choose the EMU as the model for the shinkansen? The most-commonly cited reasons are lighter axle load, better acceleration and deceleration, better braking, and better operating efficiency. These advantages were recognized as electric train technology improved. As a result, EMUs were soon running longer distances at high operating efficiency and JNR's decision-makers realized the good sense of using them for long-distance passenger services. This article focuses on the background against Japan chose the EMU for most of its passenger trains.

The Series 80 *Shonan Densha*

This section describes the development of the Series 80 *Shonan Densha*, which is generally regarded as the grandfather of long-distance, high-speed electric trains in Japan because it established the realization in JNR that the future of long-distance passenger rail travel lay with electric trains.

Early beginnings

In the late 1940s, a number of railway engineers began suggesting that railways should start long-distance express electric passenger services. One proponent of this idea was Hideo Shima (1901–98) who later became known as the father of the Tokaido Shinkansen. As WWII drew to a close, he began basic research in the field, hoping to play an influential role in developing high-speed, long-distance electric passenger services in Japan. Within a few years of the war's end, the newly formed JNR began an ambitious reconstruction plan and Shima's vision was to develop efficient long-distance electric passenger trains for the new network.

However, electric trains of the day suffered from uncomfortable ride characteristics caused by vibration and Shima established the High-speed Bogie Vibration Study Group in December 1946 to find a solution to the problem.

The group identified a number of factors and subsequent research focused on development of vibration-free bogies. This development made it possible to develop high-speed long-distance electric trains running on narrow-gauge track.

In 1948, Shima became Director General of the Rolling Stock & Mechanical Engineering Department in charge of rolling stock development. Soon after, the department published *Requirements for Electrification of Japan's Government Railways*, setting forth a long-term plan for high-speed electric train development. The report indicated the intention to promote electrification for medium-distance trains serving large urban centres and for long-distance trains on the Tokaido main line between Tokyo and Osaka. This plan led to the development of the Series 80 *Shonan Densha*.

Development background

Electric locomotives were being used to haul local passenger trains (known as *Shonan* Trains) between Tokyo and Numazu (126.2 km southwest of Tokyo) on the Tokaido main line. In the late 1940s, rush-hour commuters were crammed into carriages and there was a strong desire to cut the overcrowding by increasing the capacity. The government railways began looking at ways to increase capacity and Shima pushed for introducing EMUs, saying that the more-efficient operations (faster turnaround, etc.) would increase capacity. There was some opposition because EMU trains vibrated excessively and ride comfort would be far too low for a run of more than 100 km. However, increased capacity won out against comfort and the decision was made to electrify the system.

Rolling-stock development began in 1948 and was completed in 1950. The designers soon realized that the carriage interiors would need at least the same standards of comfort as conventional carriages hauled by locomotive on long-distance runs. It was hoped that the new design would be adapted for high-speed, long-distance services creating an incentive to produce advanced bodies and bogies.

The new Series 80 EMU was to be quite different in operation and technology from the existing electric trains and its development required different organizational arrangement from previous rolling stock. Responsibility for rolling-stock development within the Rolling Stock & Mechanical Engineering Department was divided between the Motive Power Unit Division and the Passenger and Freight Car Division. The former was responsible for developing locomotives and EMUs, while the latter was responsible for developing passenger carriages and freight wagons. This separation of responsibility may seem unusual because EMUs and loco-hauled carriages both carry passengers. However, officials at government railways at that time saw EMUs as quite different from loco-hauled carriages because the respective design and operations technologies were different. Assigning development of EMUs to the division that developed locomotives reflects how the government railways viewed EMUs at that time.

Although the Series 80 was to be an EMU, at the same time, it would consist of passenger carriages. The question was whether the Series 80 should be considered electric power cars. If so, the Motive Power Unit Division should develop them. Or should they be considered passenger carriages? If so, the Passenger and Freight Car Division should develop them. The solution was for the former division to develop the motive power parts, such as motors and bogies, and for the latter division to develop the body and fittings. This overlapping responsibility changed the course of EMU development and underlines the fact that the Series 80 was a unique type of train for its day.

JNR's long-distance Series 80 *Shonan Densha* (S. Kubo)

Evolution of Series 80

The first units of the Series 80 left the works in January 1950 and almost immediately began carrying passengers on local services between Tokyo and Numazu in March. Although the EMUs increased capacity as planned, passengers were subjected to frequent breakdowns. With hindsight, this is not surprising because the technology was new and trial runs had only been conducted for a few weeks before the trains entered service.

As a stopgap to relieve the problems, some commuter services were returned to loco-hauled trains. This gave the

Odakyu's Series *Deha* 3000 SE *Romance Car* (S. Kubo)

railway time to improve the rolling stock, and breakdowns were soon occurring less frequently, proving that the new EMUs could offer services on schedule. The newly established JNR was soon confident enough to begin running local-express services on weekends between Tokyo and Numazu in October 1950. This was JNR's first EMU offering superior services.

However, although ride comfort on the Series 80 local express was still inferior to that of loco-hauled trains, they were much more flexible in operations terms, leading to efficient services and greater customer satisfaction. EMU local-express services were first offered on a seasonal basis and then on a regularly scheduled basis.

By November 1956, the entire Tokaido main line between Tokyo and Osaka had been electrified, setting the stage for JNR's plan to run Series 80 EMUs between Tokyo and Nagoya (366 km), connecting with similar trains between Nagoya and Osaka (190.4 km). In October 1957, Series 80 EMU express services nicknamed *Tokai* (Tokyo–Nagoya) and *Hiei* (Nagoya–Osaka) were inaugurated.

The new EMU local expresses were soon running almost as fast as loco-hauled prestigious limited expresses on the same line. As soon as the Series 80 was running long distances, its potential was evident. The development of the Series 80 led to a change of opinion at JNR.

Series 151 *Kodama* EMU

In the previous section, we saw that the Series 80 EMU was developed to boost capacity. When the EMU was first developed, it was not intended to be fast long-distance train, but its adaptability to high speeds and long distances soon became apparent.

By contrast, this section explains the development and evolution of a train designed specifically for high speeds and long distances—the Series 151 *Kodama* (Echo).

JNR Electrified limited express services

In the mid-1950s, JNR was proceeding with electrification of the entire Tokaido main line (556.4 km) but the question remained about what type of train should be used for the fastest limited express services when the electrification was completed. Also, what should be done with the existing *Tsubame* and *Hato* loco-hauled limited expresses? Despite the advances in long-distance passenger services between Tokyo and Numazu demonstrated by the Series 80 EMU, JNR still held fast to the conservative idea that loco-hauled trains were best for long-distance and limited express services. Thus, limited expresses on the Tokaido main line were still hauled by locomotives even after the line was fully electrified in November 1956.

In 1957, JNR decided to add new limited express trains to the Tokaido main line. By then, electrification had reduced travel times between Tokyo and Osaka from 8 hours to 7 hours 30 minutes and JNR hoped to reduce it further to 6 hours 30 minutes by increasing maximum train speeds and easing speed restrictions. But which type should be used for the new limited expresses—conventional loco-hauled trains or EMUs? Shima and EMU advocates were convinced EMUs were suited for new limited expresses but some JNR officials remained unconvinced. To reach a consensus, Shima established the Electrification Study Committee. The committee concluded that EMUs were superior, offering various advantages, including lighter axle load, better acceleration, better braking, and better operating efficiency. The committee also noted

that it was possible to reduce vibration thereby ensuring a more comfortable ride. These conclusions led to the decision that the new limited express trains would be EMUs. JNR decided to introduce EMU limited express services on the Tokaido main line in autumn 1958 and the train would be named the *Kodama*. The stage was set for development of the Series 151.

High-speed tests with Odakyu Electric Railway

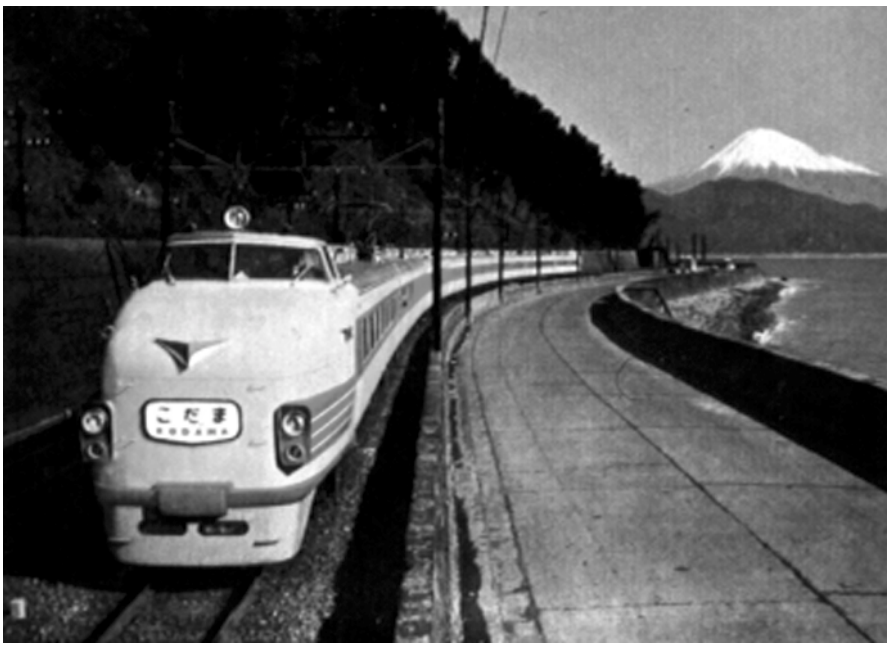
While considering what type of limited express train to develop, an opportunity arose that demonstrated the great potential of EMU trains. The private Odakyu Electric Railway was developing its Series 3000 Super Express (SE) EMU to speed up services between Shinjuku in Tokyo and Odawara (about 70 km southwest of Tokyo). The company believed that the best solution was an advanced EMU and needed to examine its performance during high-speed tests. However, Odakyu had limited technical resources, so it asked JNR's Railway Technology Research Institute (RTRI) for help with developing the high-performance EMU.

JNR agreed and a joint programme was established. The new SE train was unveiled in June 1957 with every part using the latest technologies of the day—it was lightweight; had a low centre of gravity; was articulated; was streamlined; and had a design speed of 145 km/h. However, when Odakyu ran speed tests on its own track, it could not push the train to the design speed because the track was curved throughout the entire length. Consequently, the company asked JNR to run speed tests on the Tokaido main line, which offered better test conditions. However, no private railway had ever tested rolling stock on government track and this lack of precedent caused some JNR officials to voice strong opposition. But long-distance high-speed EMU advocates led by Shima saw this as an opportunity to raise railway technology to higher levels and strongly urged JNR to agree to Odakyu's request. Their opinion was accepted and preparations began.

Speed tests were conducted in September 1957 on the Tokaido main line and the Odakyu SE achieved 145 km/h—a world record for a narrow-gauge train. The main objective of the speed test was to gather technical data on high-speed train travel, but it also demonstrated the advantages of EMUs to JNR decision-makers. The establishment of the world narrow-gauge speed record by Odakyu's Series 3000, alongside the successful start of EMU express trains using Series 80, had a considerable impact on JNR's decision to introduce EMU limited express services. JNR (RTRI) cooperated with Odakyu in developing SE technology. From one viewpoint, JNR practically asked the much smaller private Odakyu to give it the opportunity to verify the potential of fast long-distance EMUs.

Kodama development history

After JNR launched the Series 80, it continued to develop some basic technologies which later contributed to introduce high-speed long-distance EMU services. The research into the potential of EMU limited expresses was conducted in tandem with development of Series 101 EMUs, which entered commuter service in June 1957. Although the Series 101 was only built for commuter services, it embodied a number of advanced features, including a small, light motor with a Cardan driving device designed to achieve both speed and ride comfort. After the High-speed Bogie Vibration Study Group was established, car vibration was considerably reduced by mounting carriage bodies on air springs on bogies. In 1955, JNR developed the *Naha* 10, a very light passenger carriage that reduced axle load. The new technology and design were instrumental in developing lightweight EMU carriages. The new drive system, vibration-damped bogies, and lightweight



JNR's limited express Series 151 *Kodama* (A. Hoshi)

carriage bodies were all incorporated in the Series 151. When it left the works in September 1958, it was a high-speed passenger EMU well suited to long-distance runs. Comfort was also further improved to limited express levels by other new features, including fixed windows, air conditioning and upgraded lighting .

Delayed start ensures success

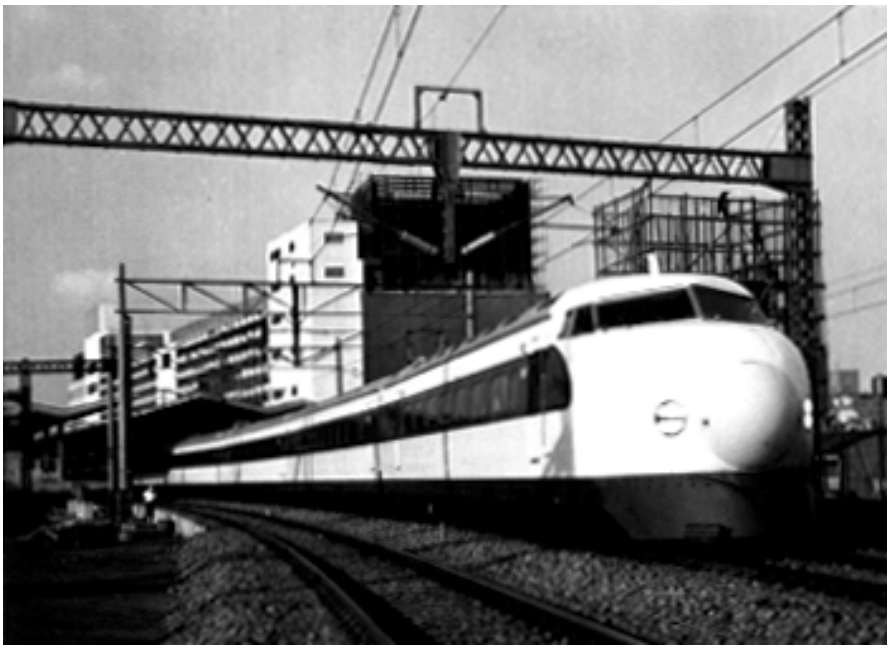
JNR decided to put the *Kodama* into service in October 1958 as the main attraction of a completely revamped national timetable. However, it actually entered service in November, about 1 month behind schedule because construction was only completed in September, leaving insufficient time for a complete set of test runs.

After its experience with the Series 80, JNR knew that if it put *Kodama* into service on schedule with insufficient testing and the new train broke down frequently, passengers might not accept EMUs as suitable for limited express services. Consequently, about 1 month was allowed before the Series 151 entered full commercial service.

Early plans called for the *Kodama* to make the run between Tokyo–Osaka in just 6 hours 30 minutes, but a provisional schedule was introduced, allowing journey times of 6 hours 50 minutes. The *Kodama* ride comfort and shorter journey times earned a good reputation and attracted high passenger levels right from the start. Interestingly, other limited express services did not suffer a drop in passenger numbers, indicating that *Kodama* was serving a new market.

The Series 151 EMUs had a maximum schedule speed of 110 km/h although the design speed was far higher at 160 km/h. To verify the train's performance, JNR conducted high-speed tests in July 1959 in which it achieved a world record for narrow gauge of 163 km/h, proving the extent of JNR's technical prowess in developing EMUs. In addition, JNR decided to cut Tokyo–Osaka journey times to 6 hours 40 minutes in September.

The avant-garde *Kodama* was very popular and highlighted the obsolescence of the much older loco-hauled *Tsubame* and *Hato* limited express trains still in operation. As a result, JNR began to consider mothballing the old trains and replacing them with new ones. But this gave rise to a difficult question—if JNR mothballed the old limited expresses, should it replace them with conventional loco-hauled trains or with EMUs? A decision was put off until the success of the *Kodama* became clear. Meanwhile, development of a new locomotive to haul limited express trains was in planning. However, this tendency towards favouring loco-hauled trains changed as *Kodama* proved its advantage and in June 1960, the old *Tsubame* and *Hato* were replaced by Series 151 EMUs with the same names. Finally, EMUs were used for all daytime limited expresses on the Tokaido main line and Tokyo–Osaka journey times reached 6 hours 30 minutes. The Tokaido main line was JNR's most important trunk line and limited expresses on this line were the most prestigious. In this sense, the Tokaido main line EMUs symbolized JNR itself and showed that the era of the EMU had truly arrived.



Trunk line electric car—Shinkansen (Transportation Museum)

Progressive Evolution towards Tokaido Shinkansen

After developing the Series 151 *Kodama*, JNR built the Tokaido Shinkansen to increase capacity on the important Tokyo–Osaka route and to create a high-speed railway system.

When constructing the shinkansen, JNR incorporated many technical innovations into the rolling stock, track, electric power supply systems,

signalling, etc. Once again, Shima played a leading role in formulating the design concepts based on his belief that an EMU system with a maximum schedule speed of 210 km/h (now 270 km/h) would be best because it offered the same advantages demonstrated by the earlier Series 80 and Series 151 EMU. The final decision was much easier to make in technical terms due to the experience with earlier EMUs and Shima even remarked to a World Bank official that the shinkansen techniques included no experimental factor but were an integration of proven advanced technologies achieved under the slogan Safety First.

The last section of this article summarizes the EMU developments and then discusses how these developments point to some strategies that a corporation can take when introducing new technologies.

Summary

Development of the Series 80 prompted the use of EMUs for longer-distance commuter services (*Shonan Densha*) and local express services (*Hiei* and *Tokai*). The success of these trains showed that EMU trains were well able to travel at high speeds over long distances.

By this time, some railway professionals were convinced that EMU local expresses could be adapted for long-distance, high-speed services and new technologies such as air-spring bogies, light carriage bodies, Cardan driving device, etc., made development technically possible. Even so, JNR continued to operate older, loco-hauled limited expresses until a joint project with the private Odakyu proved the potential of long-distance, high-speed EMUs. Still JNR was hesitant to replace existing limited express trains with EMUs until convinced by the success of it new Series 151 *Kodama*.

The whole process meant that even after long-distance EMU express services became technically feasible, it took some more time for the JNR managers to reach a consensus for the extensive use of EMUs for long-distance express services. However, the resultant change in mindset soon led to the opening of the Tokaido Shinkansen. ■

Further Reading

A. Hoshi, *Kaiso no ryokyakusha joge* (Passenger Trains in Retrospect Vol. 1 & 2), Koyu-sha, 1985.

M. Ishizawa, *Shinkansen shisakusha e no sharyo gijutsu no shuseki* (Development of Rolling Stock Technology for a Shinkansen Prototype), *JREA,* Vol. 5, No. 10, pp. 5–8, 1962.

R. Kakumoto, *Tokaido Shinkansen*, Chuo Koron-sha, 1964.

T. Matsudaira, *Kosoku tetsudo gijutsu no reimei* (The Early Beginnings of High-speed Railway Technology), *Railway Research Review,* Vol. 50, No. 3, pp. 25–29, No. 4, pp. 28–34, No.5, pp. 27–32 1993.

T. Miki, *Odakyu 3000 kei SE sha sekkei no tsuioku* (Designing the Odakyu Series 3000 SE—A Retrospect), *Railway Fan*, No. 375, pp. 91–97, 1992.

M. Saito, *Bakushin* (Ever Faster, Ever Better), Tetsudo Journal-sha, 1999.

S. Sawano, *Chokuryu densha no sekkei ni tsuite* (The Design of Electric Railcars), *Sharyo Gijutsu*, No. 83, pp.1–6, 1963.

Shinkansen 10 nenshi, (The Shinkansen—Ten Years of History), JNR Shinkansen Sokyoku, 1975.

H. Shima, *D-51 kara shinkansen made: Gijutsusha no mita kokutetsu* (From the D-51 to the Shinkansen—An Engineer's View of JNR), Nihon Keizai Shimbun-sha, 1977.

H. Shima, *Shinkansen soshite uchu kaihatsu* (After the Shinkansen, Outer Space), Railway System Research, 1987.

M. Takabayashi, *Tokaido Shinkansen sharyo no sekkei to zairyo* (Design and Materials for Tokaido Shinkansen Rolling Stock), *Kinzoku*, Vol. 33, No. 10, pp. 46–48, 1963.

R. Yamamoto, *Kosoku kansetsu densha SE sha ni tsuite* (The SE High-speed Articulated Electric Train), *Sharyo Gijutsu*, No. 40, pp. 2–8, 1958.

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