Initiative to Standardize Tokyo Commuter EMUs

Satoru Sone

Commuting in Greater Tokyo

Greater Tokyo vs. mega-cities in West and Asia

The residential population of Tokyo's 23 wards, including the central business area, is approximately 8 million but the daytime population is believed to be approximately 11 million. Since more than a few workers and students commute from central Tokyo to suburban areas, it is safe to assume that more than 3 million people commute almost every morning into Tokyo. In many cases, the one-way distance for such travel is about 60 km using conventional railway lines and more than 100 km using shinkansen lines. The average commuting time exceeds 60 minutes. Clearly, the number of daily commuters and their travel distance in the Greater Tokyo Commuting Area (GTCA) are far larger than the figures for Paris, which has a high proportion of inner city dwellers, or London and New York both with relatively high proportions of suburban dwellers.

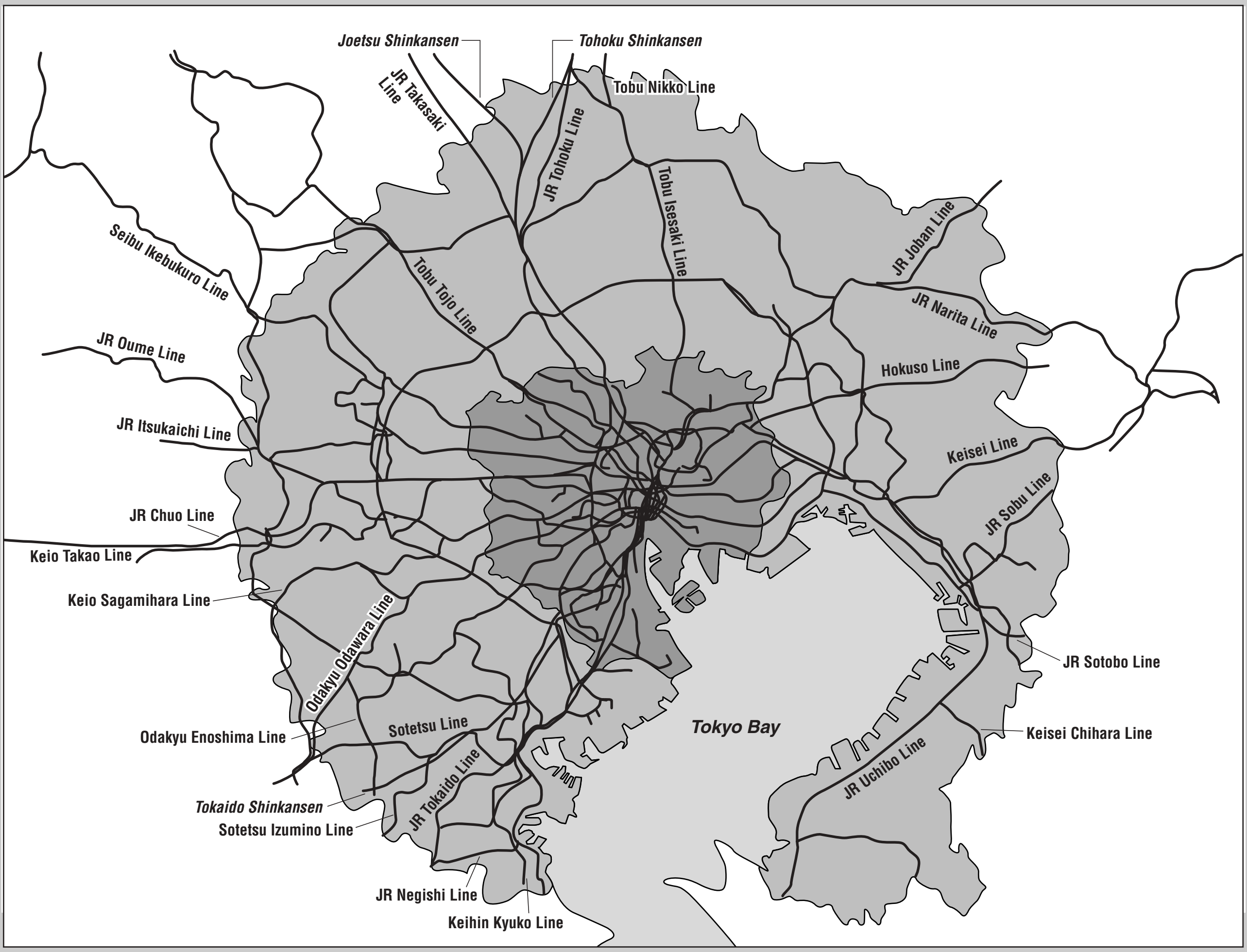
Although there are other mega-cities with a huge number of commuters, such as Shanghai and Bangkok, their share of railway transport in commuting is quite low, illustrating the importance of railway services in the GTCA.

Current situation of radial railway lines in GTCA

Some 40,000 long-distance commuters are using the Tokaido, Tohoku and Joetsu shinkansen lines. Since trains on the Joetsu Shinkansen use the tracks of the Tohoku Shinkansen for the 30-km section in and out of Tokyo, the shinkansen service in the immediate vicinity of Tokyo is provided by two double-track lines.

In addition, there are many conventional

Figure 1 Route Map of Greater Tokyo Commuting Area



lines serving the GTCA. This article only considers routes traversing Toyko's 23 wards and surrounding areas (Fig. 1).

JR East, which was formerly part of Japanese National Railways (JNR) before the 1987 division and privatization, has five quadruple-tracked routes—the Tokaido, Sobu, Joban, Tohoku and Chuo lines—and the double-tracked Keiyo and Saikyo lines.

There are a total of 16 non-JR routes operated by Keihin Express Electric Railway, Tokyo Metro (two routes), Tokyo Metropolitan Government (TMG) subway, Keisei Electric Railway, Hokuso Railway, Tobu Railway (two routes), Saitama Rapid Transit, Seibu Railway (two routes), Keio Electric Railway (two routes), Odakyu Electric Railway and Tokyu Corporation (two routes). Some of these are quadruple-tracked (the longest section is 19 km) or triple-tracked.

With exceptions, these routes operate 24 to 30 electric multiple unit (EMU) train sets in each direction during peak hours and each EMU has 10 to 15 cars. The highest cross-sectional passenger transport figure at peak times is 90,000 (150,000 for quadruple track) per hour, which is six times higher than the seating capacity!

As described, non-shinkansen lines have approximately 30 routes based on double track and many provide through services to a subway line in central Tokyo. Morning commuting stretches across about 2 hours but the evening rush lasts for some 5 hours, transporting 3 million workers and students. The overall shortage of railway transportation capacity has necessitated staggered commuting, and the evening peak hours are very long because of regular overtime working and late-night socializing with colleagues. Consequently, there is routine train congestion even after 22:00.

Cultural differences of Kansai Commuting Area

The above situation is not necessarily common to all major cities in Japan. For example, in the Kansai Commuting Area (KCA), which includes Kyoto, Osaka, Kobe and Nara, the average commuting distance, travel time and congestion levels are all markedly lower than in Tokyo because of the higher railway network density per head of population, multi-directional flows of workers and students, and more dispersed locations of cities and residential areas.

Series 101 (20-m long) introduced in 1957, combining traction system developed by private railway group and body with four 1.3-m wide doors on each side developed by JNR. This photograph shows the Series 101 on the Nambu Line, the last line on which it ran. (JR East)

Outline of EMUs in Japan

Development based on non-government railways

In comparison to other countries, a major characteristic of Japanese passenger railway transportation is that it is conducted almost entirely by EMUs. Locomotive-hauled passenger trains are limited to a small number of sleepers and tourist railways. And even some sleepers and freight trains are already EMUs. The underlying reason for this predominance of EMUs is that the EMU technologies long used on early local lines constructed by the private sector superseded the older technologies on the national railway network constructed mainly by the government.

Secondary status of JR East

As can be inferred from the number of routes in the GTCA, non-JR lines carry more passengers than JR East (although JR East 'wins' in terms of passenger-km). During the postwar period when transport demand grew dramatically, non-JNR private railway operators focussed their efforts on building lighter and higher-performance EMUs as an easier solution to increasing capacity than building new tracks. JNR also adopted technologies for high-performance EMUs developed by the private sector. A major factor favouring EMUs has been the relatively weaker load-bearing capacity of Japan's narrow-gauge railway tracks. For example, the permissible axle load for trunk lines used by freight trains is around 16.8 tonnes and is lower for many other lines, including shinkansen. This figure is much lower than the 21 tonnes for trunk lines in Europe and 26 tonnes for lines in S Africa, which use basically the same track gauge (1065 mm) as in Japan. Moreover, EMUs are better suited to shortened travel times over line sections characterized by tight curves and/or steep grades. As a result, Japan currently has about 49,000 EMUs, which is nearly half the total number of EMUs in the world.

Major impacts on world's high-speed lines

European railway operators—who have traditionally used loco-hauled passenger trains—had difficulty recognizing the advantages of EMUs, noting problems such as maintenance of many electric motors and comfort in the passenger cabin. In high-speed trains, special locomotives have been developed for the French TGV and German ICE. Similarly, in urban transport, special locomotives have been developed for the S-Bahn in Zürich, Switzerland and elsewhere. However, EMUs are being adopted gradually as shown by the development of the AGV, ICE-3 and new S-Bahn.

Past Standardization Initiatives

There have been previous initiatives to standardize commuter trains in the GTCA. At the end of WWII, wartime shortages and damaged manufacturing infrastructure forced use of austerity-design rolling stock, resulting in the Class 63 (large) for JNR lines and Ministry of Transport Standard EMUs (medium) for non-JNR lines. The Class 63 was also used on non-JNR lines when the loading gauge was appropriate. The design concepts of the Class 63, which was 20-m long with four 1-m wide doors on each side, were later combined into the Class 300 with 1.3-m wide double-leaf doors used on the Marunouchi Line from 1954. Subsequently, similar types of EMUs were used widely on both JNR and non-JNR lines in the GTCA. A typical example is the Series 101 that was mass-produced by JNR from 1958. It must be noted that such development simply means adoption of a common idea—the actual design specifications differed completely between companies. The unification of ideas and functions began in Tokyo in 1960 and helped promote through services between central and suburban lines. It is also true to say that such unification was also needed to some extent in order to make through services a reality.

This photograph was taken about 40 years ago when through operations started between the Isesaki Line of Tobu Railway and the Hibiya Line (then operated by the Teito Rapid Transit Authority—TRTA) following the opening of the Kitasenju–Ningyocho section on the Hibiya Line. The TRTA EMUs are on the left and the Tobu EMUs are on the right. (Y. Hanagami)

Recent (Voluntary) Standardization

Recent standardization attempts reflect a completely different concept. The primary motivation has been economic and there has been no strong external force driving such attempts.

JR East's Series 209 development concept and performance

The latest standardization initiative started when the newly established JR East wanted to renovate many of its old-fashioned inherited EMUs for urban and inner suburban services, consisting of the old Series 103, the Series 201 with chopper control that had been rejected by non-JNR operators, and the Series 205 that was comparable to EMUs of non-JNR operators. The Series 103 was a modified version of the Series 101 built to achieve better economic performance and was meant to be used exclusively on the Yamanote Line. The Series 103 was unique to JNR and the original plan was to manufacture only 400 carriages. However, JNR continued manufacturing Series 103 EMUs until the total exceeded 3000—even well after non-JNR operators were regularly using lightweight EMUs with regenerative braking systems and air suspension. JNR's insistence on the Series 103 is now widely considered to be a failed example of standardization. Meanwhile, the Series 201 used an armature chopper control despite the fact that such technology was regarded by private rail operators as being exclusive to subway lines. Finally, because of the relatively poor energy-saving performance of the Series 201 despite its high cost, towards the end, JNR followed the lead of private railway operators and opted for the Series 205 using rheostatic control with regenerative braking.

After inheriting JNR's old rolling stock, JR East began developing a new EMU targeted at halving the weight, cost and

First mass-produced Series 209 EMUs used on Keihin-Tohoku Line (JR East)

'life' of the old Series 103 comprising the bulk of its commuter fleet.

The first practical model after the Series 901 prototype was the Series 209, which entered mass production in 1992. The average weight of this new EMU was 24 tonnes compared to the 37-tonne Series 103, cutting operation energy by 53%. Compared to the 30-tonne Series 205, energy consumption was cut by 28%. Although cost comparison is difficult because of the different manufacturing periods and performance, it is said that manufacturing cost dropped by 24%. The JR East Nittsu Rolling Stock Manufacturing Factory (NRSMF), which began later mass production of the Series 209, made a major contribution to cost reduction. The rather confusing term 'half life' was originally intended to persuade the manufacturer to accept production of the new series because the doubled production volume would maintain an unchanged annual turnover even if price was halved. However, the current interpretation of this phrase has changed to mean that no major maintenance work is required for 13 years, or about half the life of conventional rolling stock.

Mass production by Tokyu Car Corporation and JR East NRSMF

Although the new Series 209 EMUs were operable, their reputation was not very good due to both frequent wheel slip and sliding on wet rails due to the reduced number of motor cars, causing loss of punctuality, as well as to the appearance of wrinkles in the body skin soon after manufacturing. Strenuous efforts were made to solve the problems one-by-one and to establish an in-house car manufacturing facility for mass production of a limited number of models by thorough modernization of manufacturing methods that had traditionally relied for many years on craftsmen skills. As a result, the reputation of the Series 209 improved and mass-production plans, design data, and drawings were digitized for sharing with Tokyu Car Corporation, which established a carriage works using computer-aided design and manufacturing (CAD/CAM). In addition, an essential-materials management system was introduced for the first time in railway carriage manufacturing. Other engineering features suited to mass production included wide use of interior plastic mouldings. As a result, the original manufacturing target of 400 carriages a year was largely achieved. By mass-producing the Series 209 in-house, feedback from maintenance sections to manufacturing helped with design improvements and contributed to reduction of total life-cycle costs.

Higher cost performance ratio of Series E231

The continued improvements to the Series 209 with constant feedback from the field, culminated in development of the Series E231 together with increasing maximum speeds and introduction of the high-performance train communication network (TCN) called the Train Information Management System (TIMS). The result was a considerably upgraded in-car information management system in the Series 209 Version 500 with better passenger comfort during congested peak hours due to the wider body.

Today, the Series E231 is highly reputed for providing good overall value due to its good ride performance, passenger comfort, and low maintenance, despite its relatively low cost. Since TIMS is not just an in-car information system but is also used to convey vital train control information from many parts of the train, it has substantially reduced the amount of in-car wiring and jumper cables between cars (80% in the latter case). The cost of comparable EMUs manufactured by private operators is said to be 20% to 50% higher than that of the Series E231, although there is a difference in the performance of the two as described later.

Common design for commuter and suburban services

During early development of the Series

Commuter Series E231. Although the standard formation is 4M6T with four doors on each side, this train on the Yamanote Line has a 6M5T formation with two six-door cars included during rush-hour periods. (JR East)

Suburban Series E231. Some seats are cross-compartment and the driver's compartment is reinforced to better withstand level-crossing accidents. (JR East)

209 for commuter services, a common design was partially adopted in the Series E217 EMUs for suburban service. Launched in 1994, the Series E217 differed from the Series 209 in terms of such basic components such as the body and traction system. By contrast, the Series E231 for both commuter and suburban services combined the better acceleration performance of the Series 209 and the higher maximum speed of the Series E217 (120 km/h compared to 110 km/h) and adopted a common design for basic components with only minor differences in the driver's cab and the interior of passenger areas, etc. In other words, this was the first adoption of mass-production lines for railway carriages in which individual needs were met by assembly of different options. Consequently, the expression 'general-purpose EMU' was invented to describe an EMU design for commuter and suburban services.

Adoption of Series E231 advantages by private operators

Although private railway operators led in EMU technologies and services for a long time, they occasionally adopted parts and designs used first by JNR and then by the JR passenger companies. The only time that an entire government railways design was adopted wholesale was the war-time Class 63. However, with the more recent emergence of significant disparities in cost–performance, there have been cases of technology adoption. Two are described below.

The first was the adoption of the Series 10000 by Sagami Railway. The introduction of JNR's Class 63 by another private operator gave Sagami Railway the opportunity to test the larger body size of the JNR design. The company later introduced its own commuter EMUs, with a wider body than JNR's EMUs. After the Cardan drive was introduced, Sagami Railway adopted the rectangular Cardan drive, which is now used on all its EMUs. Moreover, the company running curve was based on the then standard voltage of 1350 V, which is 10% lower than the nominal voltage (JR uses nominal voltage for the running curve).

The Series E231 was introduced to this different operations culture. Sagami Railway's Series 10000 had a modified basic system, approved by JR East via Tokyu Car Corporation, the manufacturer. The major changes for the Series 10000 were limited to the train formation and front style. JR East trains use the 4M6T formation in which 4 out of 10 cars are motorized; Sagami Railway uses the 5M5T formation to secure the faster acceleration and deceleration required by trains serving private lines with shorter distances between stations. These Series 10000 trains entered operation in February 2002.

The second case is the Series 5000 of Tokyu Corporation. Again, the train formation is 5M5T. The running performance reflects the standard specifications for private railway operators as shown in the table below and is similar to that of Sagami Railway. However, the nominal motor output is twice that of other EMUs despite having the same number of motors. Although the actual output of the motors used by Tokyu Corporation is some 30% higher, there is no rational explanation for the substantial difference of 100%. JR East attributes this difference to the different concept of short-term overloading, but it is more likely that the low motor output is a ploy by JR East to buy EMUs at a lower price.

Standardization of rolling stock for private railway operators

Work is currently in progress by the Japan Association of Rolling Stock Industries in response to a request by the Ministry of Land, Infrastructure and Transport to standardize rolling stock of private operators with a view to manufacturing low-cost, high-performance and reliable rolling stock, reflecting the technological history described above and the need to

Sagami Railway's Series 10000. This is an example of minimum design changes made to the Series E231 to suit the private operator's specifications. (Sagami Railway)

Tokyu Corporation's Series 5000. This the nearest EMU to the new standard EMU for private railway operators as of 2003. (Tokyu Corp.)

Table 1 Main Characteristics of Series E231 and Related EMUs

Company	Series	Use Purpose	Body Width (mm)	Year Commissioned	Formation	Maximum Speed (km/h)	Acceleration/ Deceleration	Nominal Motor Output (kW)
JR East	209	Commuting	2,800	1992	4M6T	110	0.69/0.97	95
JR East	E217	Suburban	2,900	1994	6M9T	120	0.59/0.97	95
JR East	E231	General	2,950	2000	4M6T	120	0.69/1.17	95
JR East	E231	Yamanote Line	2,950	2002	6M5T	120	0.83/1.2	95
Sagami	10000	Commuting	2,930	2002	5M5T	120	0.83/1.3	95
Tokyu	5000	Commuting	2,770	2003	5M5T	120	0.92/0.97	190

Note: The average carriage weight is similar for all series while the number of motors on a motorized car is four for all series.

improve the harsh business environment for private operators.

Compared to the routes operated by the JR passenger operators, routes of private railway operators are characterized by shorter distances between stations and many sections with steep grades or sharp curves. In addition, the operation modes of private operators are diverse. Furthermore, due to through operation with metro lines to improve passenger convenience, standard EMUs must offer high-speed performance in suburban sections, excellent acceleration and deceleration in underground sections, and strong traction force required for relief operation. These needs have led to unification of the basic systems, including the traction system for motor cars equipped with four 190-kW motors and a motorized to trailer car ratio of 1:1. The first standardization phase features 20-m long commuter EMUs with two types of body material—stainless steel or aluminium alloy—and four double-leaf doors 1300-mm wide on each side. The target EMUs of the next phase will be 18-m long commuter EMUs with three doors required for through operations on some metro lines. The introduction of standards is not limited just to body specifications—some electrical and mechanical components will be standardized too, which will also cut costs.

The traditional idea that EMUs should present the individual image of each private operator is accommodated by customizing the driver's compartment, signalling system and compatibility with existing rolling stock, etc. ■

Satoru Sone

Dr Sone was Professor of Electrical Engineering at the University of Tokyo until March 2000, and now teaches at Kogakuin University. He is a well-known authority on power electronics and transport, and railway systems engineering. He also served as an advisor to the Japanese government on transport, and is currently a director at West Japan Railway Company.