High-Density Transport Systems Supporting Giant Metropolis of Tokyo

Mitsuo Shinbo

Introduction

Tokyo is a giant metropolis. However, it is difficult to clearly define what area is being referred to when we say 'Tokyo'. There are the 23 wards that function as administrative districts, but if we refer to 'Tokyo' as meaning the highly populated area that is the centre of Japan's politics and culture, we are talking about a wider area. Counting the area from Tokyo Station west to Yokohama City, north to Saitama City, and east to Chiba City, we reach Greater Tokyo with a population of 30 million people, which is closer to what most people think of Tokyo as being.

Some people may say that by using this definition of Tokyo, the city spreads in a chaotic manner and its borders with surrounding cities disappear. One could point out that Tokyo is a city lacking the sense of completeness of London and Paris. However, despite having grown to enormous size, Tokyo's railways, and power and water utilities are well developed and its urban functions well maintained. Ocean and air pollution that were social problems in the 1970s were overcome by later efforts, and now Tokyo has regained clean seas and skies.

The Tokyo area has expanded greatly through its historical background of recovery from the destruction of war, the high-economic-growth period, and amplification of its mission as a world-class urban area. This article looks at how the social infrastructure of railways has evolved to support the expansion of Greater Tokyo.

Enhancement of Transport Routes

Railway Network in Greater Tokyo

The railway network in Greater Tokyo is complex, so it is described here in a general manner.

First, JR East's Yamanote Line runs in a loop around the city centre. Also, a very dense subway network runs inside or near the Yamanote Line. The JR East railway network extends radially out from terminal stations such as Tokyo, Ueno, and Shinjuku on the Yamanote Line loop. Other private railway routes also connect to Yamanote Line terminal stations in the city centre or run through-services with subways through those nodes to suburban areas.

Old JNR's Five Commuting Directions

JR East's railway lines extend radially out from the Yamanote Line in five directions. The development of these routes is outlined below.

The post-war reconstruction coupled with the high-economic-growth period saw a rapid concentration of population in the capital area. However, land-price inflation in existing urban areas made purchase of houses difficult for ordinary workers, so new house building was focussed in suburban areas. As a result, commuter trains became very congested, and 'congestion rates' (expressing actual passenger numbers as a ratio to carriage capacity) reached 300% on some sections.

To alleviate this congestion, in 1964, Japanese National Railways (JNR) planned new double-track additions to existing transport routes from suburban areas to the city centre (the Tokaido, Sobu, Joban, Tohoku, and Chuo routes). These are the capital area's so-called 'five commuting directions'. Construction started in 1965 and was finally completed after almost 20 years in 1983. The foresight of this five commuting directions campaign for the capital is probably the primary reason why transport continued to function without collapsing, despite the size to which Tokyo had grown.

Part of the campaign involved creating an additional double-track line between Tokyo and Odawara for the Tokaido route. The details are as follows:

- Construct new double-track line as underground route between Tokyo and Shinagawa
- Divert freight lines to passenger lines between Shinagawa to Shintsurumi marshalling yard
- Add double-track line on existing freight route between Shintsurumi marshalling yard and Tsurumi
- Construct new double-track line on separate route between Tsurumi and Totsuka
- Add double-track line on existing route between Totsuka and Odawara

Figure 1 shows a track chart for the Tokaido route after construction was completed. Note that lines for JR Central's Tokaido Shinkansen and the private lines of Odakyu Electric Railway and Tokyu Corporation run west from Tokyo Station. This example makes it easy to imagine the broad-ranging

Figure 1 Track Chart of Tokaido Route after Completion of Five Directions Campaign

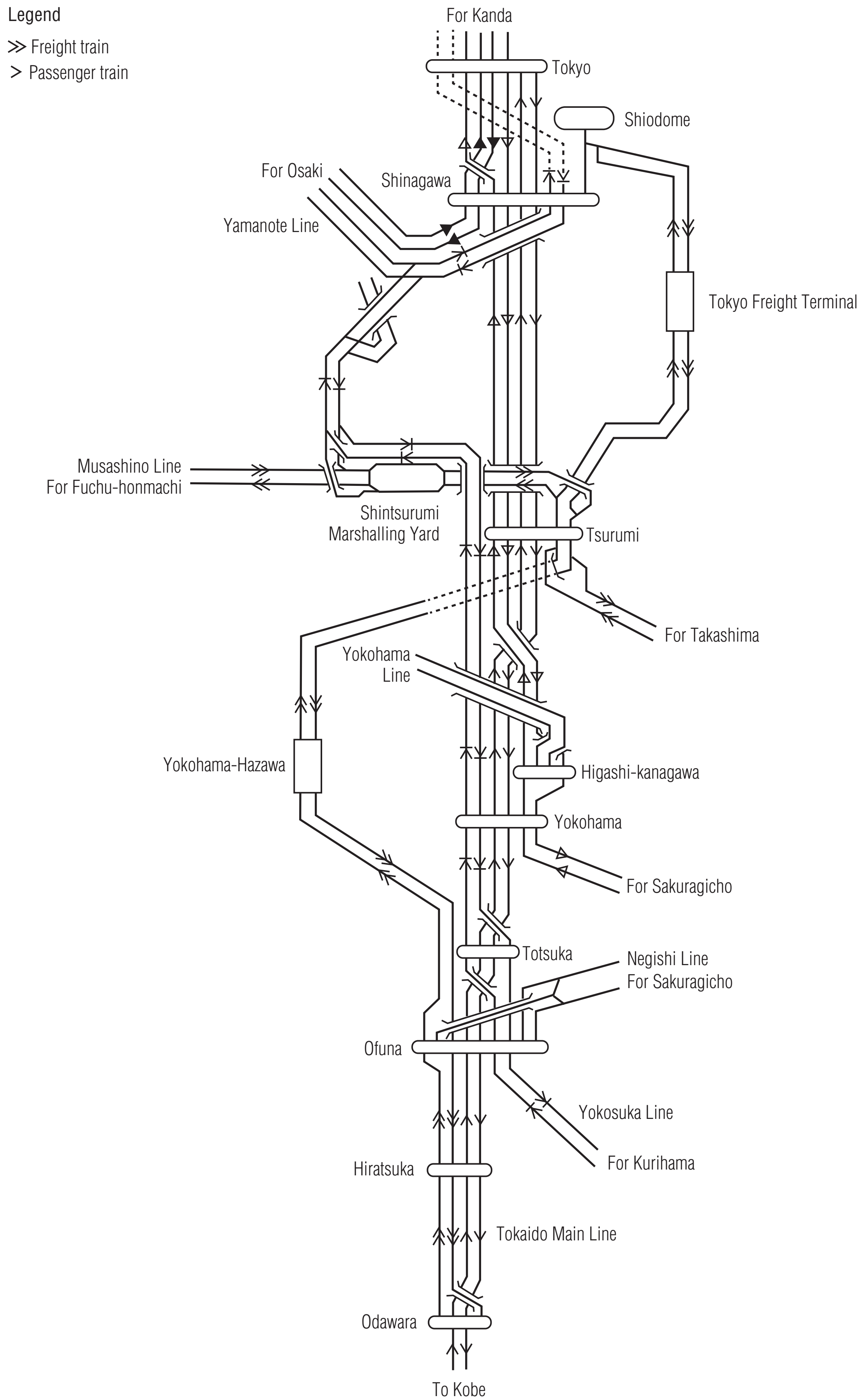
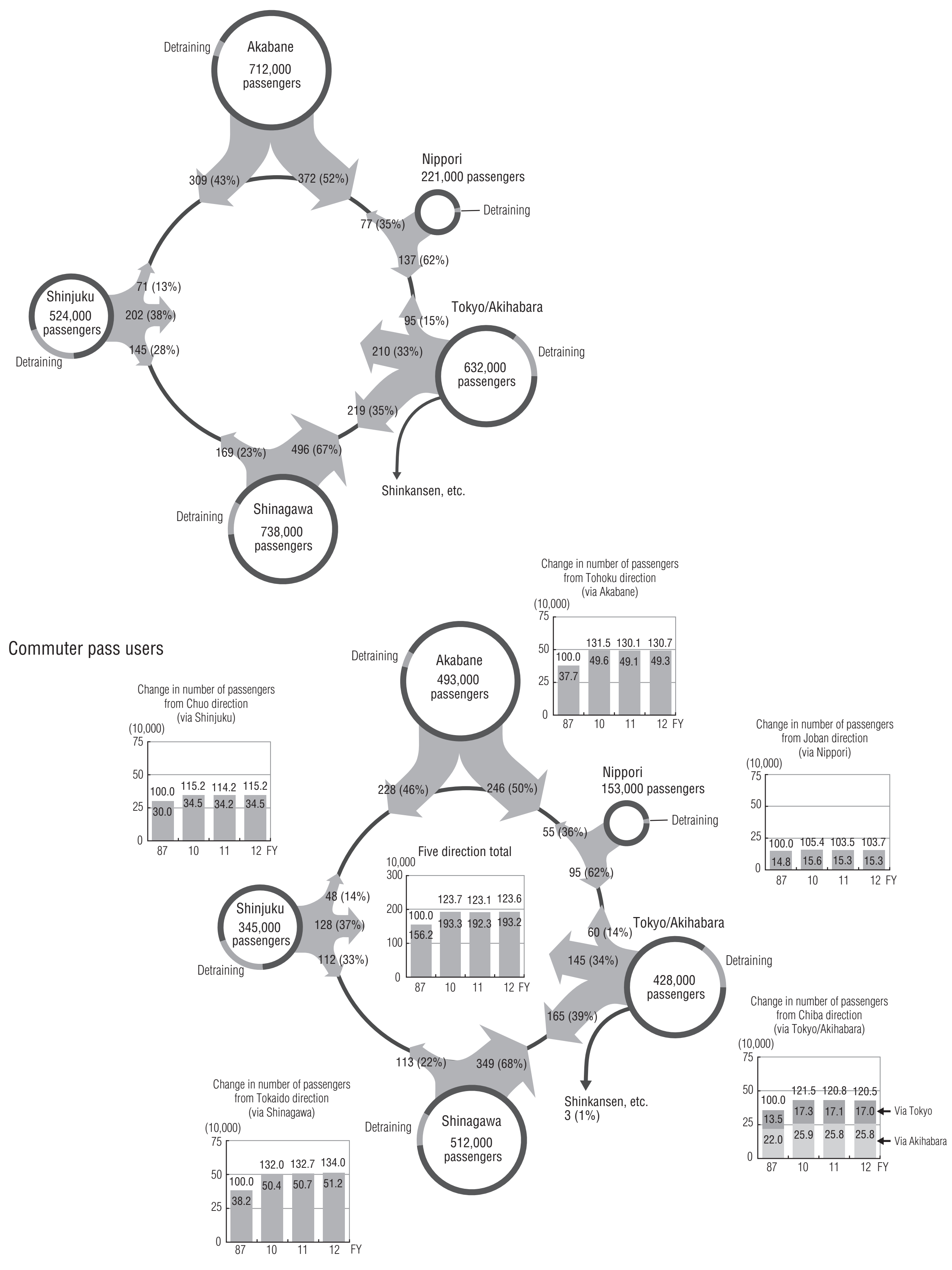


Figure 2 Passenger Flows from Five Directions to Yamanote Line

Fiscal 2012 one-day average, Units: passengers/day



Notes
1. Figures in parentheses are compared to 1987, with that year indexed as 100.
2. Figures are rounded off, so totals may not add up.
3. Prepared from tables of arriving/departing/transiting passengers.
4. Passenger flow at Shinagawa includes passengers using the Shonan Shinjuku Line.

transport routes in Greater Tokyo.

JR East took over the five-direction railway network following the JNR privatization. Figure 2 shows recent passenger flows to the Yamanote Line from the five directions.

Development of Subways

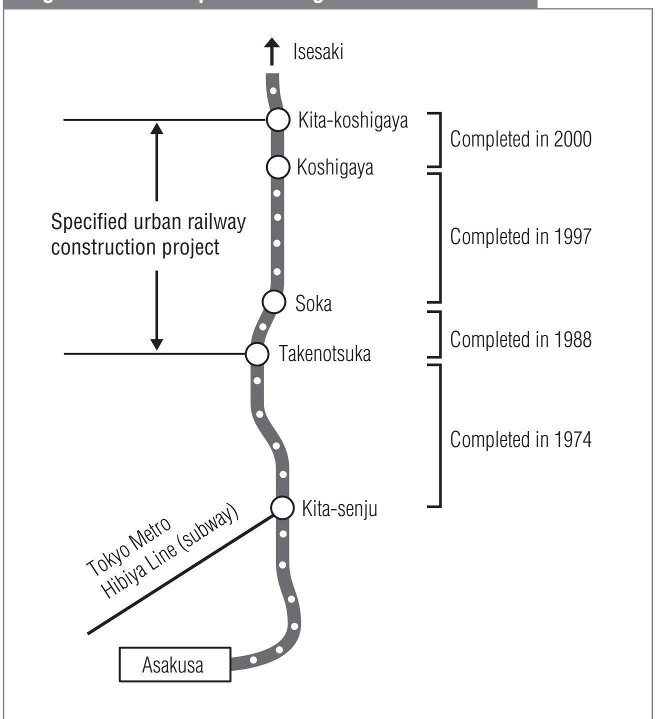
Trams took the lead in urban areas of Tokyo at the turn of the 20th century, forming a dense network of tracks shared with roads.

However, trams only have a small transport capacity that soon became inadequate in the post-war era as the number of automobiles grew in line with the concentration of functions in the city centre. Construction of subways on dedicated tracks with large transport capacity was urgently needed. Tokyo's oldest subway is the Ginza Line now operated by Tokyo Metro. It opened in 1927 with a section between Asakusa and Ueno. As subway construction progressed in the post-war era, the tram business declined, disappearing from the city centre in 1972.

Tokyo's subways are currently run by two operators. Tokyo Metro, a special-purpose company funded by the national and Tokyo Metropolitan governments, runs nine lines. The Tokyo Metropolitan Government, which started to operate subways after WWII, runs four lines. In addition to these 13 lines, Saitama Railway runs direct through-services onto Tokyo Metro's Nanboku Line and Yokohama City runs two lines as well.

The most recent addition to Tokyo's subway network was the 2008 opening of the Tokyo Metro Fukutoshin Line section between Ikebukuro and Shibuya (north of Ikebukuro opened previously).

Figure 3 Quadruple-tracking Tobu Isesaki Line



Currently, there are no subway lines under construction in the Tokyo area.

Creation of New Transport Routes by JR East

Even in 1987, there were still sections with congestion rates in excess of 200%, so alleviating congested commuter transport remained a major mission for JR East. Measures to convert freight lines from the JNR era to commuter routes were a major element of the post-privatization improvements to transport and making use of these hidden JNR assets helped alleviate congestion.

The construction of the Keiyo Line is an example of creating new transport routes. The line was partly opened in the JNR era and construction was completed in 1990 on reaching Tokyo Station, adding a third line to the Sobu route linking Tokyo and Chiba.

Quadruple-Tracking by Major Private Railways

Tokyo's other private railways urgently needed to enhance transport capacity to alleviate commuting congestion. Since the objective was more to improve services than increase revenues, some private railways had a hard time justifying the investment. To assist them, the national government passed measures in 1986 providing favourable tax treatment for costs needed to quadruple tracks and make other improvements to transport capacity. Under the scheme, operators were allowed 100% tax breaks on the part of income saved for future construction. The government approved five specified urban railway construction projects in 1987 and another two in 1995.

A good example is that of Tobu Railway, a private railway supporting commuter transport in northeast Tokyo. In 1987, quadruple-tracking on the Tobu Isesaki Line between Takenotsuka and Kita-koshigaya and renovation of Kita-senju Station was approved as a specified urban railway construction project under the scheme. Quadruple-tracking between Takenotsuka and Kita-koshigaya had started in 1976, but the new tax regime helped spur it to completion in 2000, doubling capacity and reducing travel time by a few minutes, especially during rush hour.

Figure 3 shows the project progress. Renovation of Kita-senju Station was also completed in 1997.

Role of Shinkansen

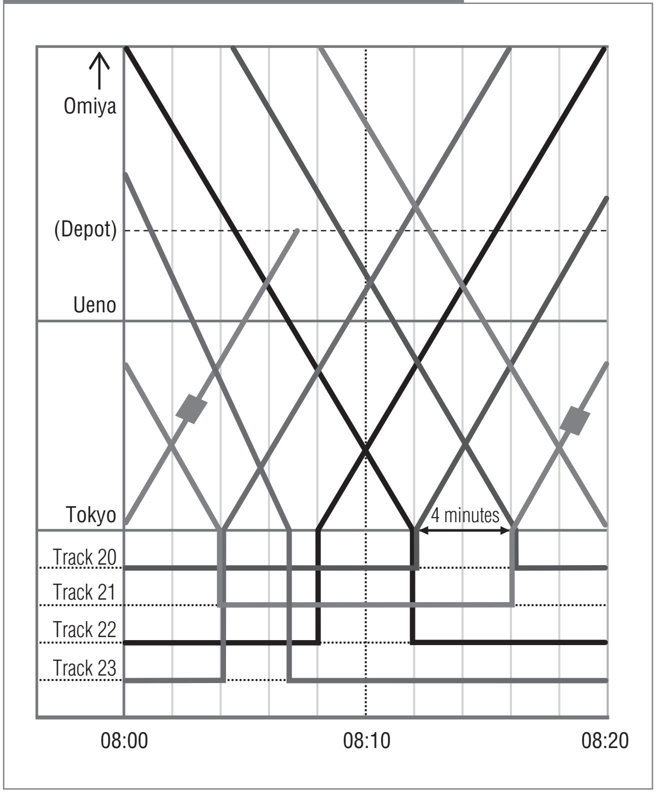
Some people may feel uncomfortable at including shinkansen as transport in the capital area but shinkansen contribute from two aspects.

First, the shinkansen relieves conventional lines from carrying long-distance passengers, removing limited express trains from the timetable for Yamanote Line terminal stations as much as possible from 08:00 to 09:00. As a result, many long commuter trains can be packed into the timetable with all trains running at the same speed and headway, achieving the maximum transport capacity supported by the system.

Second, the shinkansen itself plays a role in Greater Tokyo transport. Most passengers disembarking from shinkansen at Tokyo and Ueno from 08:00 to 09:00 boarded within 100 km of these stations and using the shinkansen reduces a 2-hour commute to just 1 hour. As a result, although shinkansen commuter passes are expensive, they are chosen commonly by long-distance commuters. Currently, there are about 17,000 people using these passes in the JR East area (Tohoku and Joetsu shinkansen) to commute to work and school.

Using JR East's shinkansen, trains from Aomori, Shinjo, and Akita merge onto the Tohoku Shinkansen, and trains from Niigata and Nagano merge onto the Joetsu Shinkansen. Finally, they all head from these five directions on the same line from Omiya Station to Tokyo Station. Figure 4 shows the JR East shinkansen timetable for trains arriving at Tokyo Station every 4 minutes from the various directions, demonstrating how the shinkansen is an indispensible part of transport in Greater Tokyo today.

Figure 4 JR East Shinkansen Timetable



Renovation of Terminal Stations

Transport and Stations

As the number of railway passengers increases, the space in stations for ticket counters, ticket gates, passages, etc., need to be expanded too. The transport functions of terminal stations, including the number of tracks and platforms, control functions for train routes, guidance for transport services, waiting rooms for limited express passengers, rest areas for drivers and conductors, etc., must be expanded as well. Sometimes, stations even require large-scale renovation.

Tokyo Station Track Layout

Tokyo Station is the terminus for many trains, so many improvements have been made over time to expand transport functions. The history of expansion viewed from the perspective of track layout is as follows:

- 1964: Tokaido Shinkansen opened with two platforms and three tracks at Tokyo Station
- 1967–79: Tokaido Shinkansen platforms at Tokyo Station increased gradually to three platforms and six tracks
- 1972: Tokyo underground platforms opened with addition of Sobu underground route of five directions campaign
- 1976: Through-services started between Sobu underground route and Tokaido underground route with addition of Tokaido underground route of five directions campaign
- 1990: Keiyo Line opened to Tokyo with two platforms and two tracks at Keiyo Line Tokyo Station
- 1991: Tohoku Shinkansen opened to Tokyo with one platform and two tracks at Tokyo Station
- 1997: Tohoku Shinkansen Tokyo Station expanded to two platforms and four tracks

Figure 5 shows the track layout at Tokyo Station, and Figure 6 shows a guide map. The station is comprised of platforms for tracks 1 to 23 aboveground, platforms for tracks 1 to 4 at Sobu underground, and platforms for tracks 1 to 4 at Keiyo underground. Comparing Figures 5 and 6 gives an image of Tokyo Station as a whole.

Advancement of Rolling Stock and Train Control

Switch to Electric Multiple Units (EMUs)

In 1945, JNR's only electrified sections were limited to urban areas near Tokyo and Osaka, and some long mountain tunnels. Along with the post-war expansion of electrified sections, trains were switched to EMUs even for rapid and limited express trains travelling long distances. The first limited express EMUs were the *Kodama* services running between Tokyo and Osaka starting in 1958, and the switch proceeded quickly from that time on. It is worth remembering that the *Kodama* name was later inherited by services on the Tokaido Shinkansen.

Figure 5 Track Layout at Tokyo Station

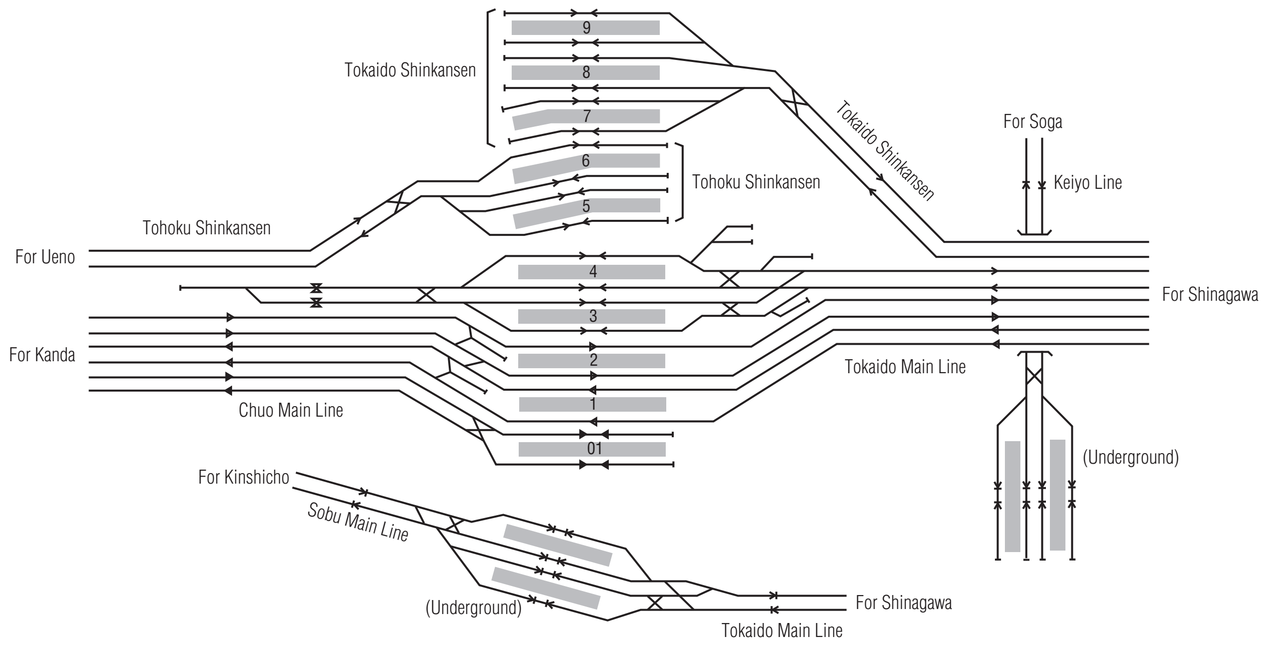


Figure 6 Guide Map of Tokyo Station

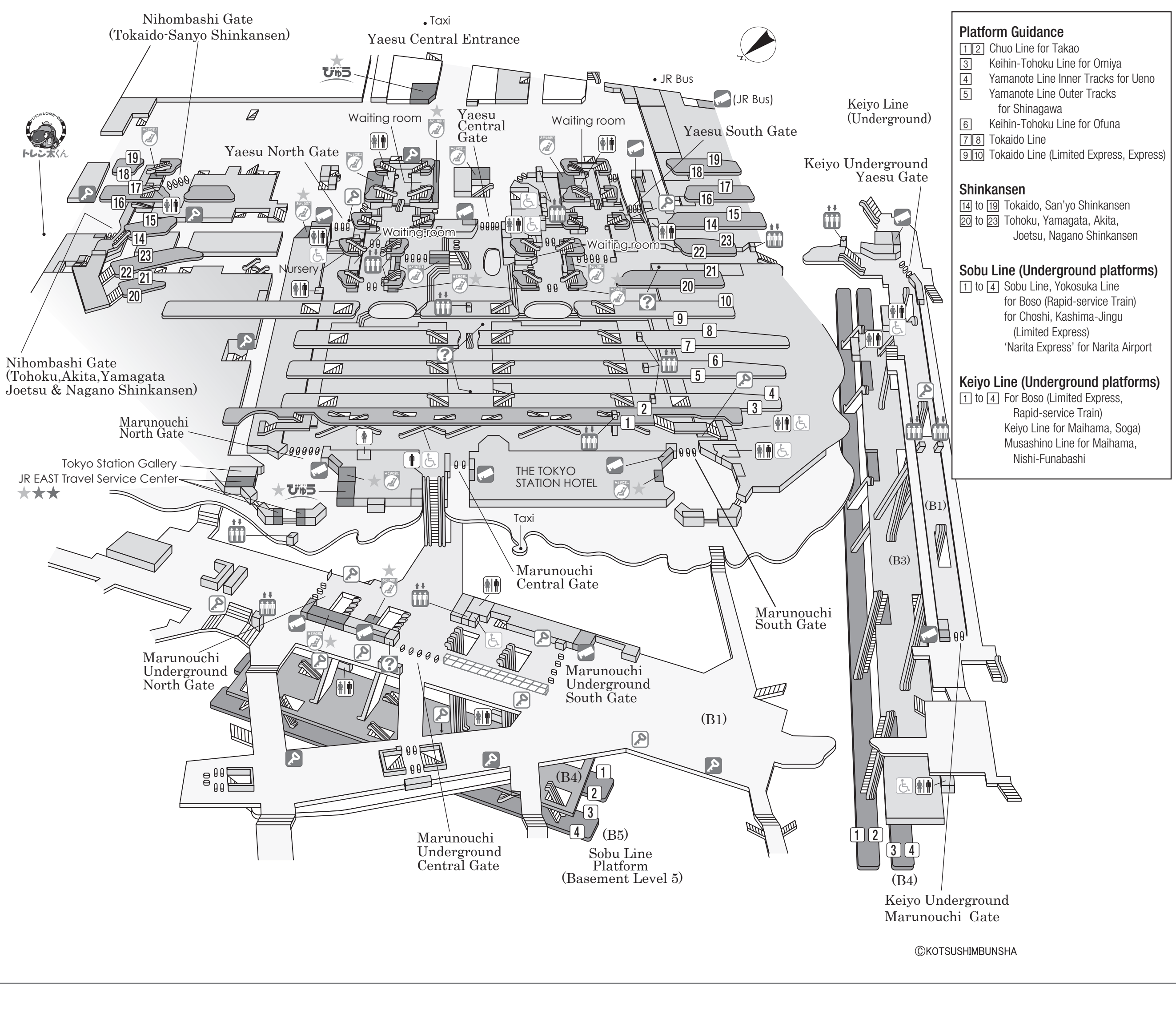


Figure 7 Generational Advance of Commuter Trains in Greater Tokyo

		Electric Power Consumption	Maximum Speed
Series 103 (1963) Dynamic braking		100	100 km/h
Series 205 (1985) Regenerative braking		66	110 km/h
Series E231 (1999) Regenerative braking		47	120 km/h

Mikawashima accident in May 1962 (100 Year History of Japanese National Railways)

Figure 8 Old and New ATC Deceleration Patterns for Yamanote Line

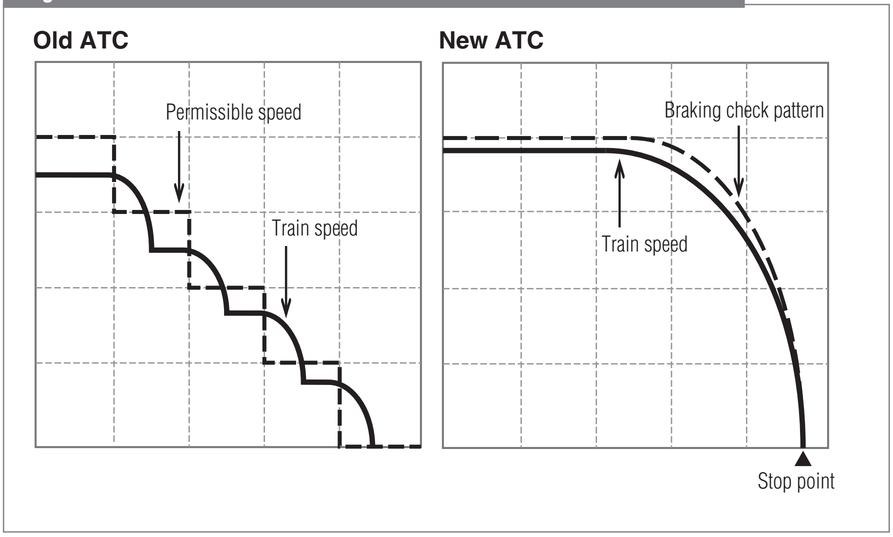
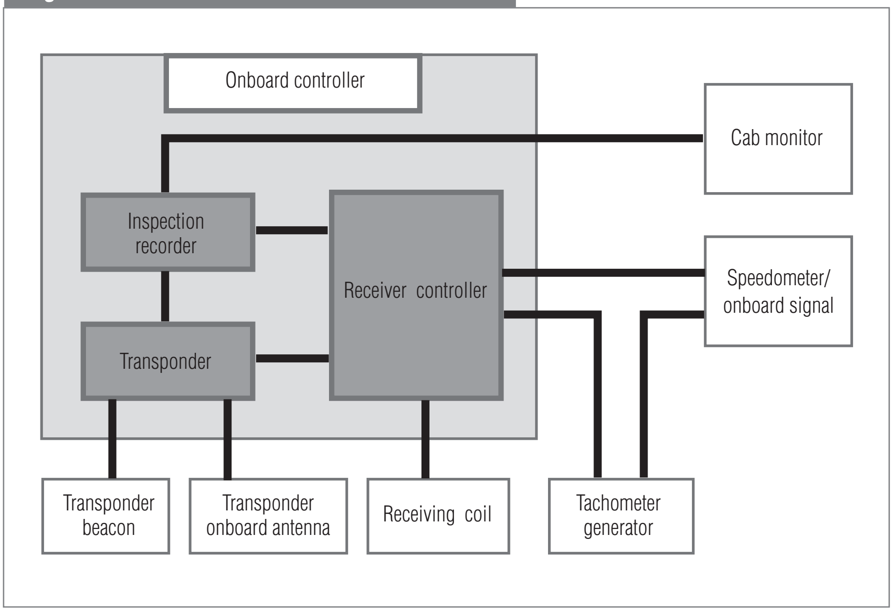


Figure 9 New ATC Device for Yamanote Line



EMUs had originally been used on both subways and private railways, but JNR switched over to EMUs for even limited express and shinkansen to support high transport capacity in the limited space available for railways in Greater Tokyo.

Figure 7 shows the generational advance of commuter trains in Greater Tokyo. The progress is summarized by key phrases, such as 'lighter rolling stock' and 'more intelligent control', and the success is quantified by increased energy-saving performance.

Progression of Train Control Systems

The increased risk of accidents must be considered when increasing transport density. With shorter headways, driver error can quickly lead to a train collision, and with many parallel tracks, a derailed train on one track can affect adjacent tracks, leading to secondary accidents.

Risk became reality with the Mikawashima accident in May 1962 when a driver missed a signal before the train derailed and was hit by subsequent trains, killing 160 people.

The lessons learned led to adoption of an automatic train stop (ATS) system in the capital area to back-up crew operations at stop signals. Subsequently, an automatic train control (ATC) protection system, which automatically decelerates trains according to the speed limit, was installed in the 1970s on the Yamanote and Keihin Tohoku lines.

Such protective devices increased safety in high-density operations but they were developed in the pre-information-technology age, so there was room for improvement in terms of increasing both safety and train operations density.

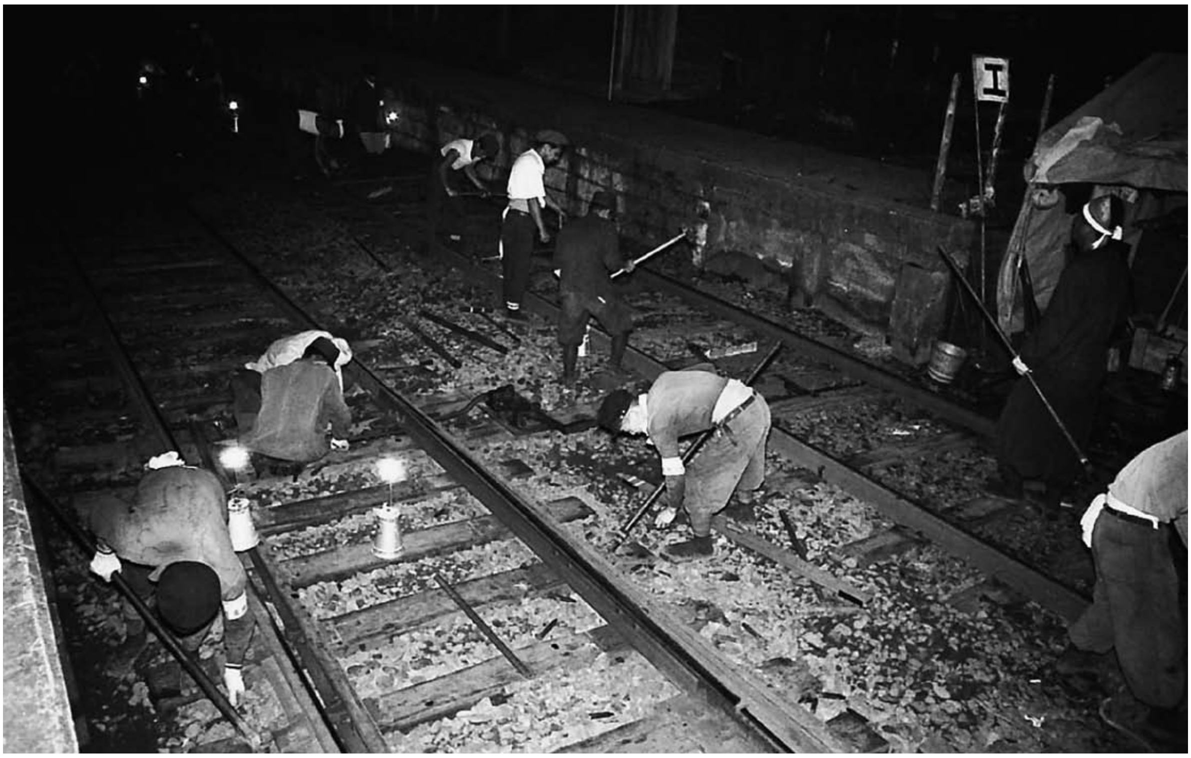
The old ATS system warned the driver at some point before a stop signal, but the risk of human error could not be eliminated if a driver decided to operate the brakes manually. Moreover, there were still limits to high-density operations, because even if a signal changed from stop to proceed, the train could not update information.

In addition, the old ATC system decelerated trains in stepped stages by receiving speed limits for individual sections from the wayside, meaning the system was unsuitable for decreasing headways.

Overcoming these issues using digital technology became an issue for JR East; it was solved using a system where the train acquires information on the location of the preceding train from wayside equipment and generates its own braking patterns based on that data. JR East calls the advanced ATS system ATS-P and the advanced ATC system digital ATC.

Workings of Digital ATC

Figure 8 compares the old and new ATC deceleration patterns for the Yamanote Line. With the new ATC, the train receives stop information and the on-board device conducts



Construction to change gauge of Keisei Electric Railway (Keisei Electric Railway)

optimal braking. Figure 9 shows the composition of the on-board system.

Subway Through-Service with JR East and Private Railways

Structure of Through-Service between Operators

There are many places where commuter passengers heading into the city from the suburbs must transfer from JR East and private suburban railway lines to subways. Through-service between operators makes such usage easier by linking lines and operating trains directly. It can be achieved without changing the existing transport and sales systems, and has been adopted widely in Japan.

Through-service between subways and JR East/private railway lines is significant for three reasons. First, passengers from suburbs are carried to the city centre seamlessly. Second, through-service increases the usage efficiency of management resources. Without through-service, terminal stations would be needed in the city centre to run turn-back operations, entailing more station space for platforms and transfer facilities and requiring extra rolling stock; avoiding turn-back eliminates wastefulness in terms of stations and rolling stock. Third, through-service demonstrates a model for division of roles in terms of investment. Public funds can be used to construct subways in the city centre, but suburban railways are built using the funds of JR operators and private railways as a rule. Through-service allows uninterrupted service while constructing railways using separate sources of funding.

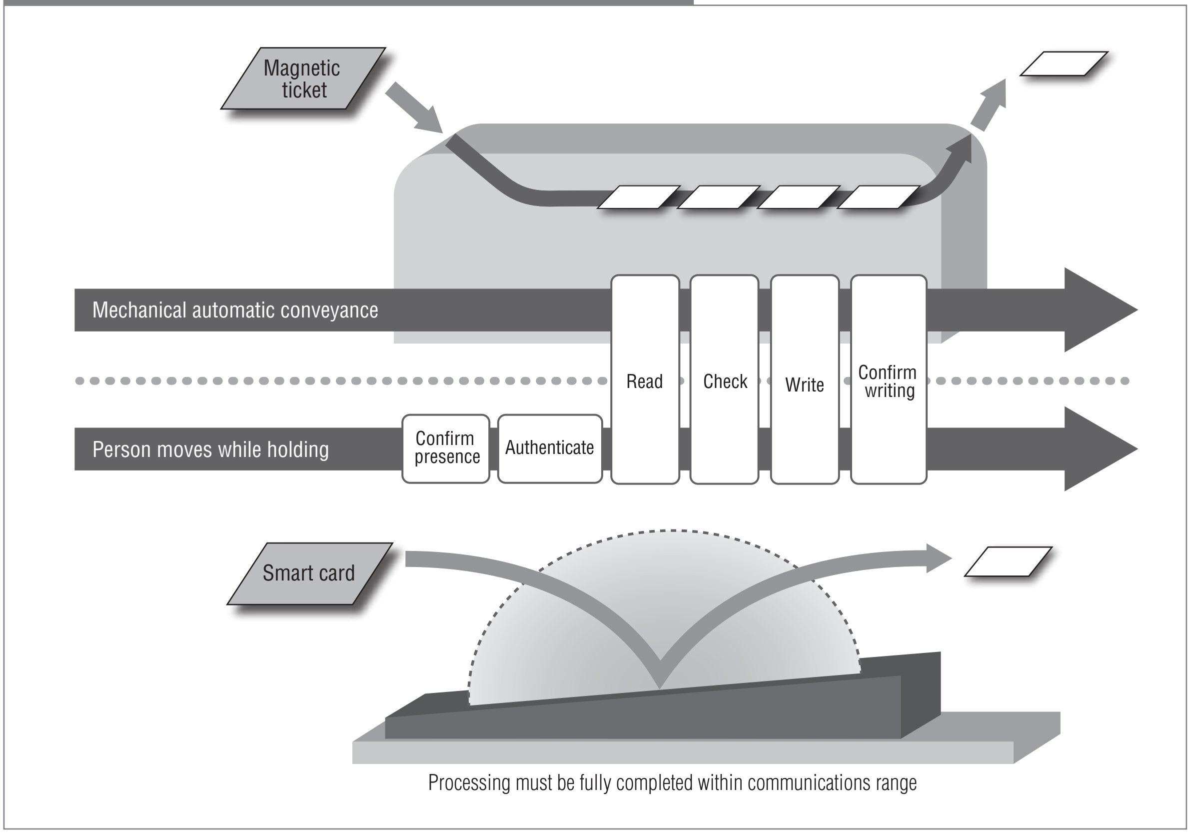
Of course, the track gauge and power collection systems (pantographs, etc.) must be compatible for through-service. However, signalling methods often differ between companies, so through-service trains have multiple protection devices that are switched over at the station where the operator changes.

Through-Service between Keisei Electric Railway and Toei Subway Line 1

The first example of through-service was Keisei Railway and Toei Subway Line 1. Toei Subway Line 1 opened partially in 1960 between Oshiage and Asakusa, and through-service started with the already-planned Keisei Electric Railway. While Toei Subway Line 1 started out as standard gauge, Keisei was already operating on a different gauge (1372 mm). To enable through-service, Keisei changed its entire line to standard gauge.

In 1968, though-service also started between Keihin Electric Express Railway and Toei Subway Line 1, connecting Keisei in Chiba, Toei Subway in the city, and Keihin in Yokohama.

Figure 10 Communications Between Tickets and Ticket Gates



Automatic Fare Collection Systems

Simplification, Standardization and High Throughput

As dense train services spread throughout Greater Tokyo, so did the number of passengers in the area. In line with this, automatic fare collection (AFC) systems were developed to make ticketing and gate operations more efficient for these short-distance travellers.

Handling of short-distance tickets was simplified, with such tickets being valid for only 1 day and not allowing stopovers. JNR introduced passenger-operated ticket vending machines that mechanized issuing of short-distance tickets, and mechanical printing was simplified from 1969 with tickets only showing the departure station and fare. In 1980, the range in which tickets displaying the fare amount could be used was expanded from 50 km to 100 km, furthering mechanization of ticketing. In this way, simplification, standardization and high throughput became the principles of AFC.

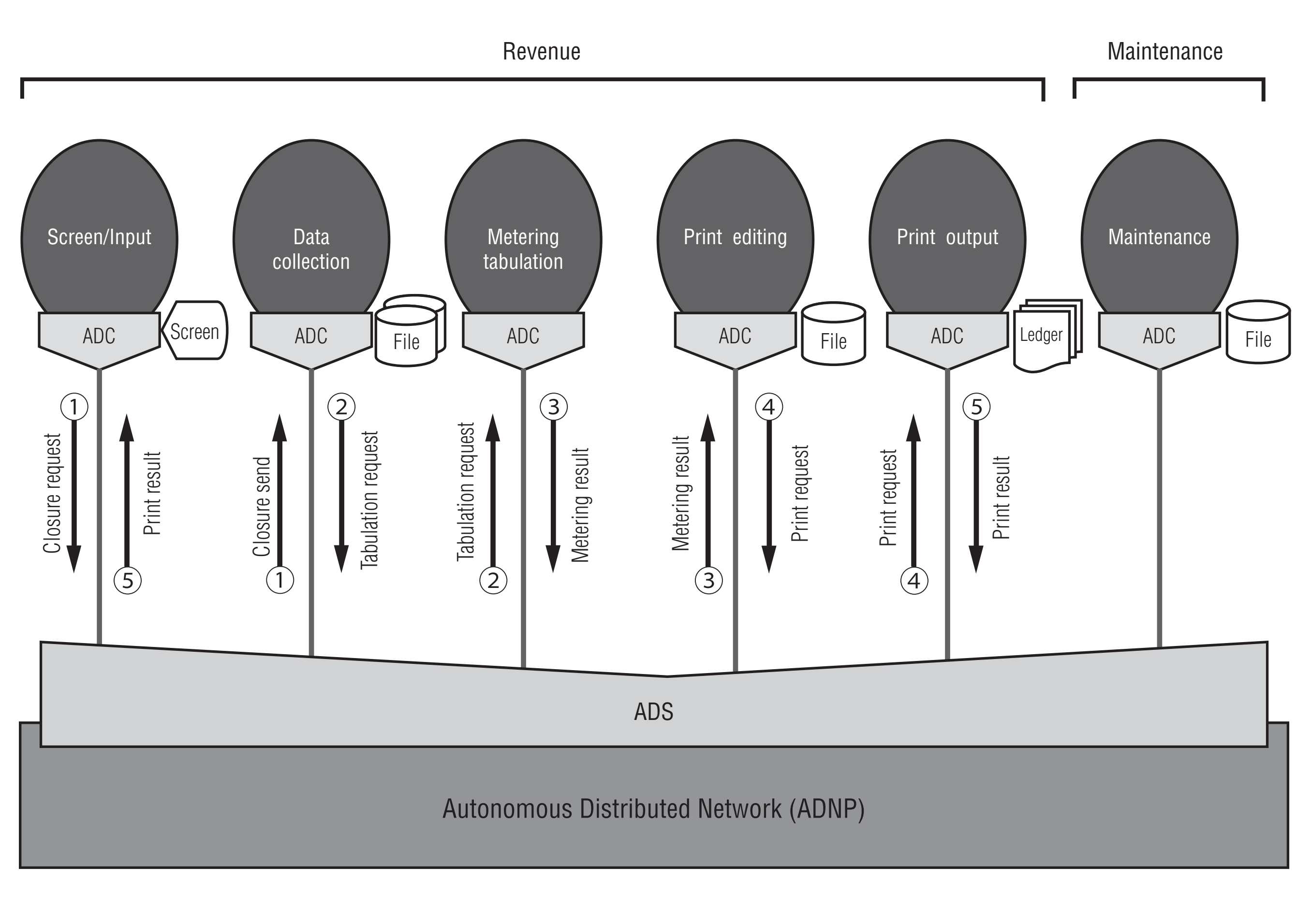
JR East started mechanizing ticket gate operations for short-distance tickets and commuter passes using automatic ticket gate systems in 1989. Automatic ticket gates had already been introduced in the greater Osaka area, but they had been slow to catch on in Tokyo. When JR East decided to introduce automatic ticket gates, subways and private railways area soon followed suit. As a result, mechanization of ticket gate operations for railway lines across Greater Tokyo made a great leap forward in just 5 years from 1989.

A system for riding on lines of multiple operators using a single ticket caught on early in Greater Tokyo. As a result, new magnetic information standards were needed to write more information to tickets with the introduction of automatic ticket gates. In-depth discussions were held at conferences that included railway operators and AFC equipment manufacturers; new standards were established and used in mechanization of ticket gates in Greater Tokyo.

Suica

JR East launched 'Suica' smart cards with short-range wireless communications in 2001 for short-distance tickets and commuter passes. These smart cards, which function over a short distance of 10 cm or less, are ideal for high throughput. Figure 10 shows a comparison of communications between tickets and ticket gates for magnetic tickets and smart cards. When using Suica as a short-distance ticket, touching the card to the ticket gate at the journey origin allows the ticket gate at the destination to

Figure 11 ED10 Software Structure



Restored Tokyo Station (JR East)

automatically collect the fare, enabling travel without using a ticket vending machine.

In 2007, Tokyo subways and private railways launched PASMO with the same functions as Suica and with interoperability. Following later introduction of smart cards by other operators and interoperability with Suica, passengers can now ride many railways and buses across Japan using a single card. The cards can also be used as e-money at locations, such as convenience stores.

The expansion of areas where cards are used and multi-functionality has increased the scope of changes needed for the AFC system software when conditions change, such as when new stations are added. One way to minimize the amount of software maintenance is to autonomize individual elements comprising software functions and arrange them in parallel. Figure 11 shows the software structure for a terminal used to manage vending machine and ticket gate revenues and operational status (ED10 for JR East). Measures have been taken with the software structure to minimize the amount of software maintenance needed for changes, and this is a model for future AFC systems.

Conclusion

Tokyo Station was built in 1914, but lost much of its beauty due to war damage and addition of functions without consideration for design. JR East completed the restoration to its original form in 2012 and the station has regained its graceful and dignified appearance. This could be a sign that 21st century Japanese society has gained the leeway to put value on classic scenery.

The next issue is to redesign urban areas so people can live in comfort while lessening the burden on the environment. First, it will be necessary to manage stations run by JR East and hotels and department stores run by group companies around stations in conjunction with the surrounding areas to achieve overall optimum service and energy consumption. Next, there are expectations for expansion of this concept to the community and for railways to contribute to development of urban spaces that are comfortable while imposing little burden on the environment.

The progress of railway systems in the greater Tokyo area is a history of quantitative expansion pursuing growth in demand. The next issue will be how to support urban sustainability. ■

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