Development of Suica Autonomous Decentralized IC Card Ticket System

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Introduction

Japan faces major changes to its social environment, such as a declining birth rate and aging population as well as globalization. Where once it was sufficient to provide safe and punctual transport, the railway business now faces changes with demands for diverse and high-quality services in areas such as safety, amenity, and convenience. One important system supporting railway management is the automatic fare collection (AFC) system. The Suica IC card ticket AFC system introduced by East Japan Railway Company (JR East) in November 2001 uses the Autonomous Decentralized Architecture to prevent possible problems spreading through the entire system. This resulted in the ability to provide continuous high-quality services thanks to the system's expandability and reliability. Many new services have been provided since the system's introduction with few major failures. This article explains the JR East Suica development background and details, technologies, and operation status since introduction.

Furthermore, it covers the management of technology (MOT) strategy for Suica, which has become deeply embedded in Japan's social infrastructure.

IC card interoperability with Suica started in the greater Tokyo area on 18 March 2007 with the PASMO IC card ticket issued jointly by 100 railway, bus, and other companies. Interoperability has made travelling around the Tokyo area dramatically more convenient as exemplified by the issue of 1 million PASMO cards in just 4 days. However, more than just transportation was stimulated by Suica PASMO interoperability and use of cards as e-money has surged.

Due to the characteristics of modern railway transport, any system of fare collection at ticket gates requires continuity of service throughout the operations area based on high-speed processing and high reliability. As a result, the Suica system uses an Autonomous Decentralized Architecture, but the technical development required a tremendous amount of labour and time.

In terms of management, creation of a medium-term management strategy was needed to deal with the changing business environment, enhance the competitiveness of railways, and deploy new businesses.

Characteristics of Railway Ticket Systems

Railway services must continue every day without a break, so stable system operation is a key requirement. In these conditions, reliable high-speed processing is the first indispensable function. A feature of Japanese urban railways is the tremendous surge of commuters in the morning and evening rush. At these times, about 24 million transactions occur at ticket gates every day, so the gate processing speed must be able to handle these passenger flows. The second indispensable function is high reliability, because a ticket has monetary value.

Suica Development Concept

Instantly replacing all magnetic tickets with IC cards as part of efforts to introduce contactless railway tickets would have been impossible. Therefore, it was important to define the most appropriate specifications, assuming current magnetic tickets would continue in use for some time.

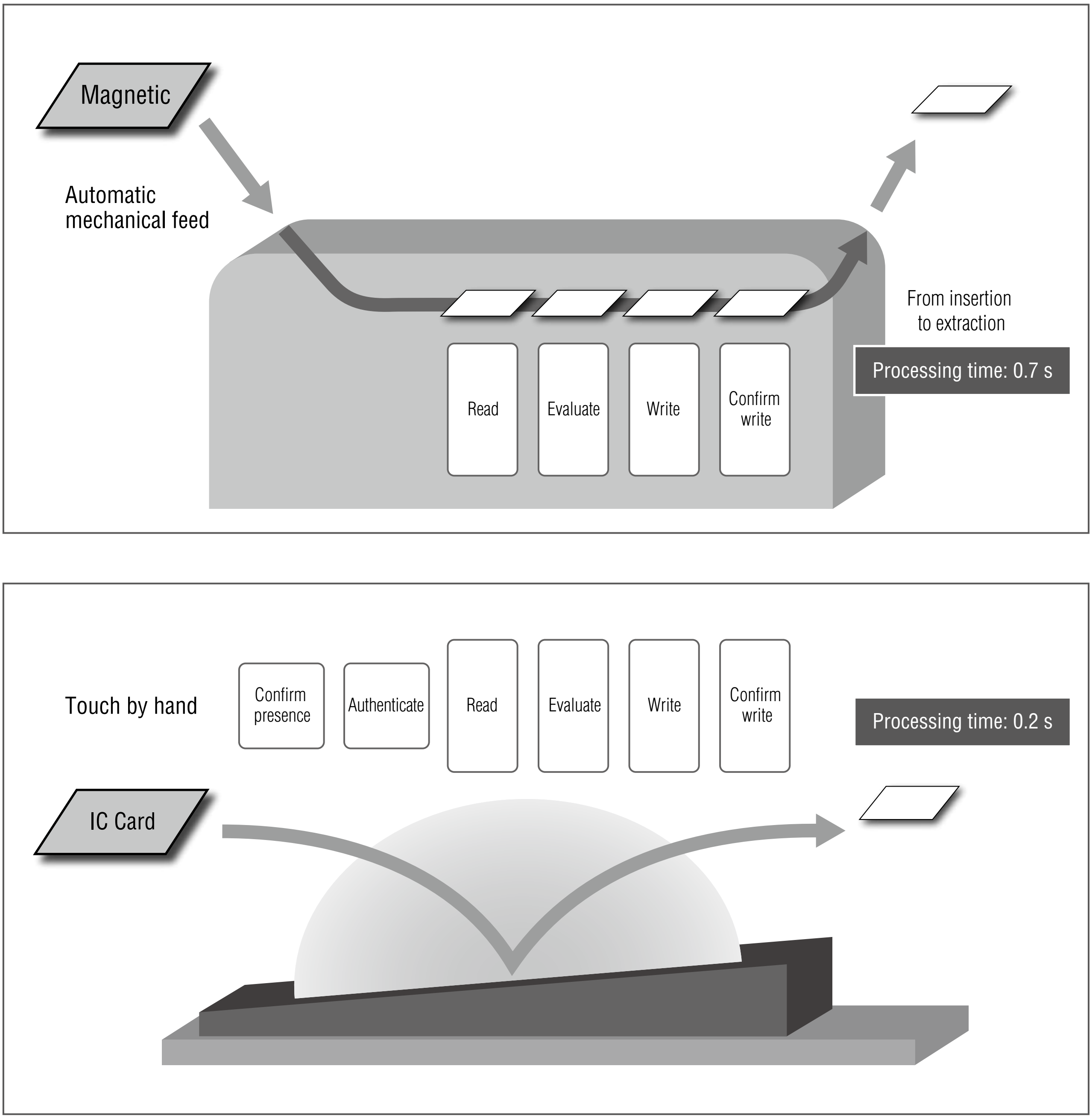
The development concept took into account the following points as conditions for introducing a contactless IC card ticket system.

- Coexistence with current magnetic system
- Cost reduction compared to current magnetic system
- Processing capacity and reliability equivalent to or better than current magnetic system
- Ability to add new services

Processing with IC Card Ticket System

Card processing differs between magnetic and contactless IC card ticket gates in several ways. Processing at magnetic ticket gates is completed in about 0.7 s in four steps: reading data, evaluating ticket validity, writing required data, and confirming data. In contrast, processing at contactless IC card gates, involves confirming the card presence in the signal field and authenticating the card for processing. Then reading, evaluating, writing, and reconfirming data are performed. Field-testing showed that the fastest users put their cards in the reader/writer (R/W) signal field only for about 0.2 s. Considering the gate processing time of

Figure 1 Comparison of Automatic Fare Collection Gate (Magnetic and IC Card) Processing Times

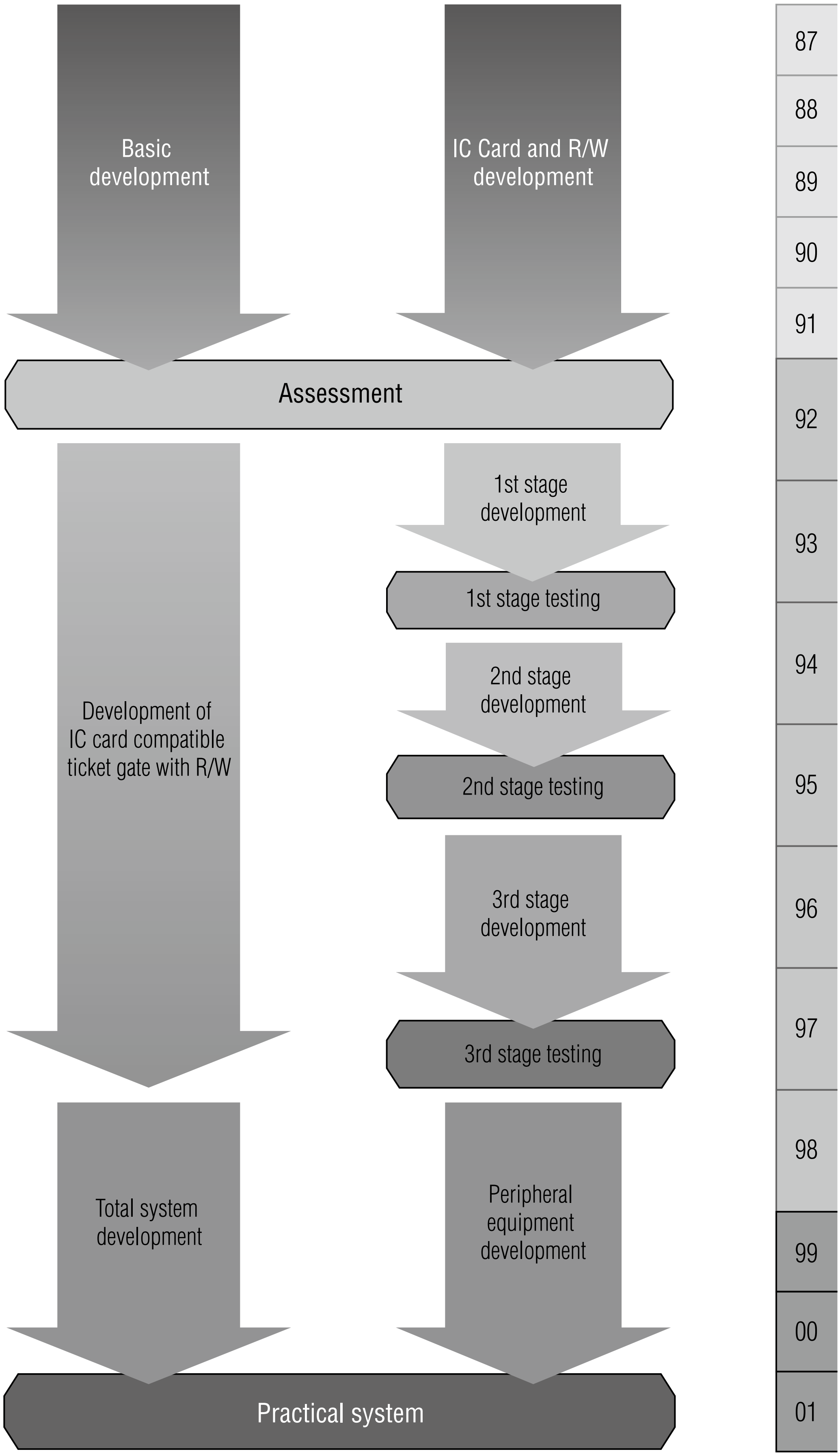


about 0.1 s, the processing time between the card and R/W must be less than 0.1 s so the passenger does not have to pause while passing through the gate (Figure 1). As a result, development focused on achieving high-speed processing between the IC card and ticket gate R/W.

Details

JR East started examining use of contactless IC cards as a next-generation system to replace magnetic ticket systems in 1987, immediately after the company was established. IC cards can be contact or contactless, but because processing would have to be done at a ticket gate while the passenger was moving through, the contactless type was thought to be best. At the time, there were three makers of contactless

Figure 2 IC Card Ticket System R&D



IC cards; two used medium-frequency radio waves and one used quasi-microwaves; all required built-in batteries. Repeated improvements to the cards and testing of stand-alone functions, made it hard to determine the merits of one card over the others but the two medium-frequency cards required addition of an emitter circuit to generate the data transfer signal. While this function could be added to gates reading/writing quasi-microwave cards, the focus shifted to battery-equipped IC cards using quasi-microwaves, which also seemed more practical in terms of processing speed, price, and other factors. By 1993, development had reached the field test stage in actual stations and tests in 1994, 1995, and 1997 verified aspects such as reliability, gate processing capacity, and ease of use (Figure 2). The field tests were conducted at stations by JR East employees. Communications speeds and card application were varied during the course of 30,000 to 170,000 tests in each set. The third test set achieved the same performance as the existing magnetic system. An important change was made after the third-stage testing. Due to the thickness and longevity issue of the batteries, Suica became battery-free; its power is now provided via electromagnetic induction.

Stabilizing Processing between IC Card and Terminal

The human eye cannot see the signal field between a gate and IC card, so each person 'waves' the IC card over the R/W in a slightly different way. Field tests showed that the average card residence time in the signal field was 0.52 s, while the shortest time was 0.2 s. At this point, the system could not be speeded up any further to achieve shorter processing times. As a result, a 'touch-and-go' style (Figure 3) was formulated to secure sufficient processing time by making the user move the card in a V-shaped arc and lightly touch the reader, reducing the read/write failure rate to the same level as the magnetic system (Table 1).

Overview of Autonomous Decentralized IC Card Ticket System

The IC card ticket processing relies on people moving the card over the R/W by hand, a process that is inherently variable and unstable. Furthermore, gate failure would instantly create chaos in a station. To overcome these risks and continue operating with failed equipment, the system was designed with an Autonomous Decentralized Architecture,

Figure 3 Touch–and–Go Style

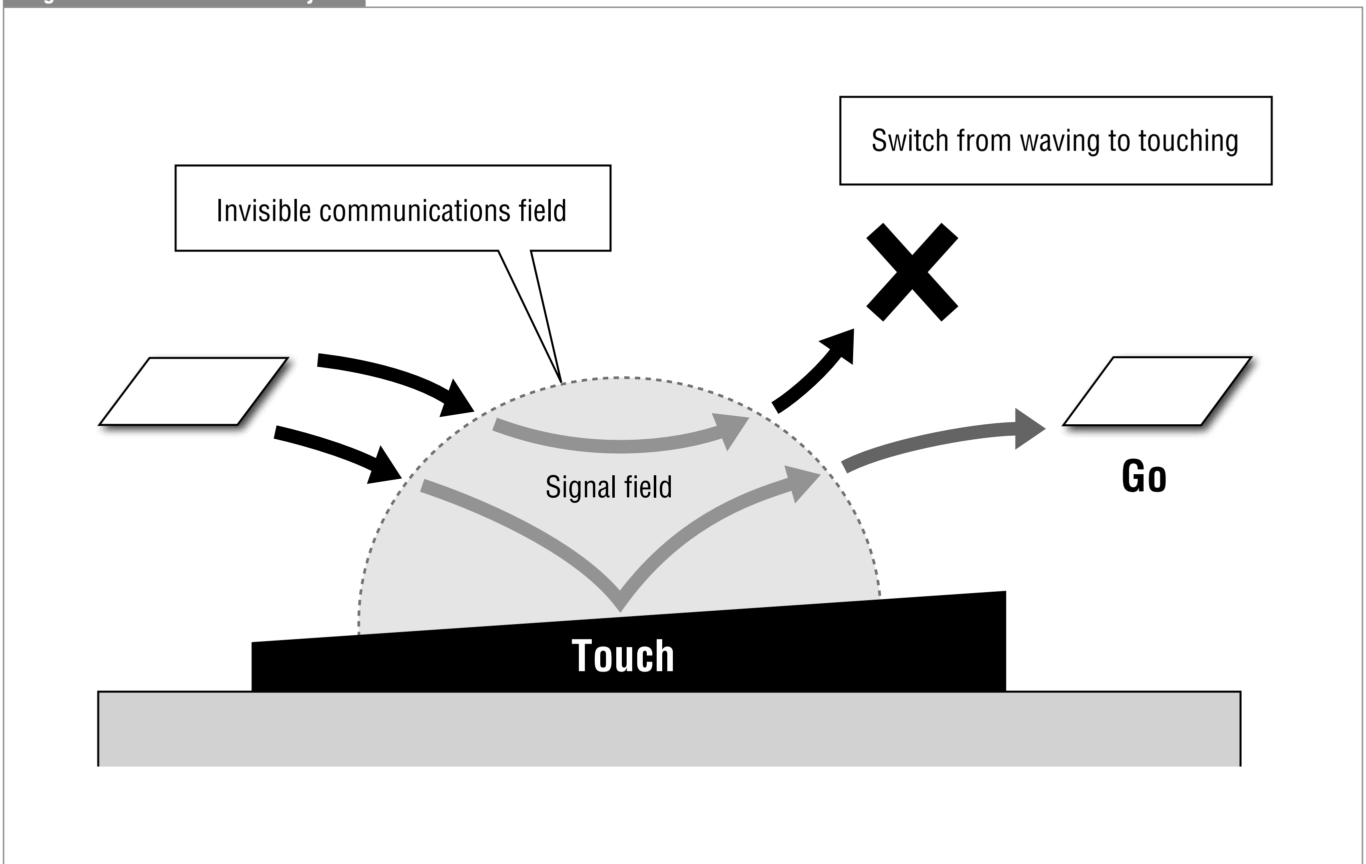


Table 1 Results of Suica Field Tests

Item	1st stage testing	2nd stage testing	3rd stage testing
Test period	14 Feb – 15 Mar 1994 (1 month)	3 Apr – 2 Oct 1995 (6 months)	21 Apr – 25 Nov 1997 (7 months)
Scope of tests	8 stations 18 gates Approx. 400 testers	13 stations 30 gates Approx. 700 testers	12 stations 32 gates Approx. 800 testers
Data rate	70 Kbps	**250 Kbps**	250 Kbps
Card application	Wave	Wave	**Touch & Go**
Total communications cycles	29,900	176,000	174,000
Failure rate (compared to magnetic system)	More than 20 times	Approx. 4 times	Same as magnetic system

featuring autonomous control and autonomous coordination. Ticket gates autonomously process IC cards at high speed and store data for fixed time periods without accessing the centre server. Likewise, the centre server stores data from terminals for fixed periods and performs data matching using Autonomous Data Consistency Technology to secure high reliability. As a result, even if some equipment fails, the overall system remains unaffected. Moreover, the centre acquires information on terminal operation and takes autonomous measures such as restarting and stopping to improve reliability.

Merging Heterogeneous Aspects

The railway business must assure the flow of large numbers of passengers and continuity of services from the first to last train everyday, non-stop, year-round. A large part of these operations is calculating fares and checking for ticket fraud. The following explains the specifics of the system configuration satisfying the above conditions.

The system is composed of IC cards, terminals (automatic gates, etc.), station servers, and a centre server. Assuring the minimum operation even when equipment fails is essential to prevent chaos so the Autonomous Decentralized Architecture was adopted. Data are collected and processed by wireless communications between passengers' IC cards and terminals (ticket gates). Smooth passenger flows are achieved by asynchronous online real-time processing in 0.2 s. At the same time, gates, ticket vending machines, and station servers are connected by local area network (LAN), and the station servers and centre server are connected by a wide area network (WAN). Collected data is processed across these networks. To assure high reliability for fare data, the information system uses database processing. A key feature is how to merge the different control/information systems, wired/wireless technologies, and LAN/WAN protocols to harmonize the conflicting needs for high-speed processing and high reliability. The system processes data by the second, hour, and day. It is described as a Heterogeneous Autonomous Decentralized IC card ticket system.

Specific Suica Composition

Figure 4 shows the specific composition of the JR East Suica system. Suica cards are purchased at card vending machines where stored fares can also be added. Automatic ticket gates support both Suica cards and older magnetic tickets but JR East has introduced simplified Suica gates supporting only

Figure 4 Composition of Autonomous and Decentralized Data Processing Suica System

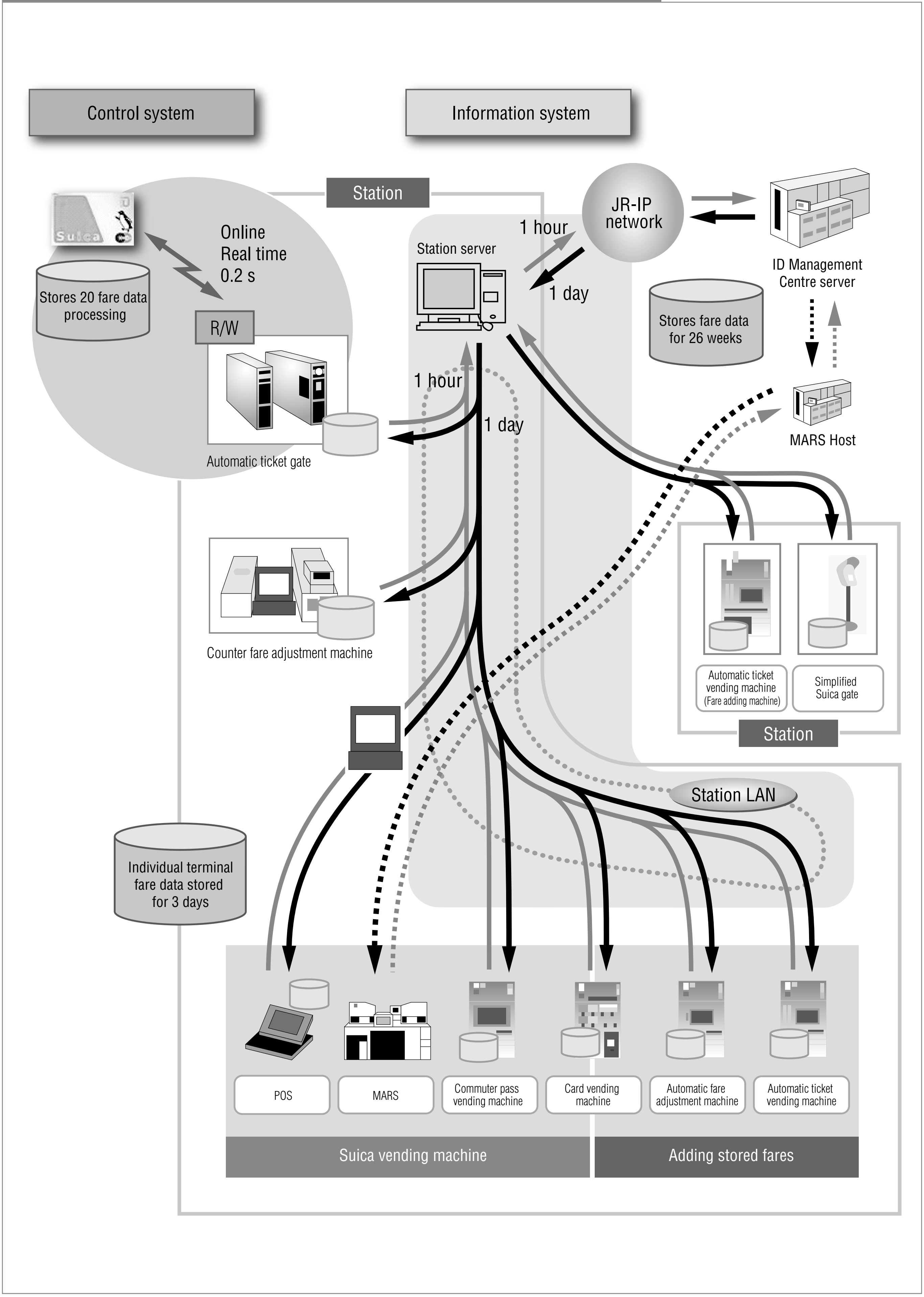
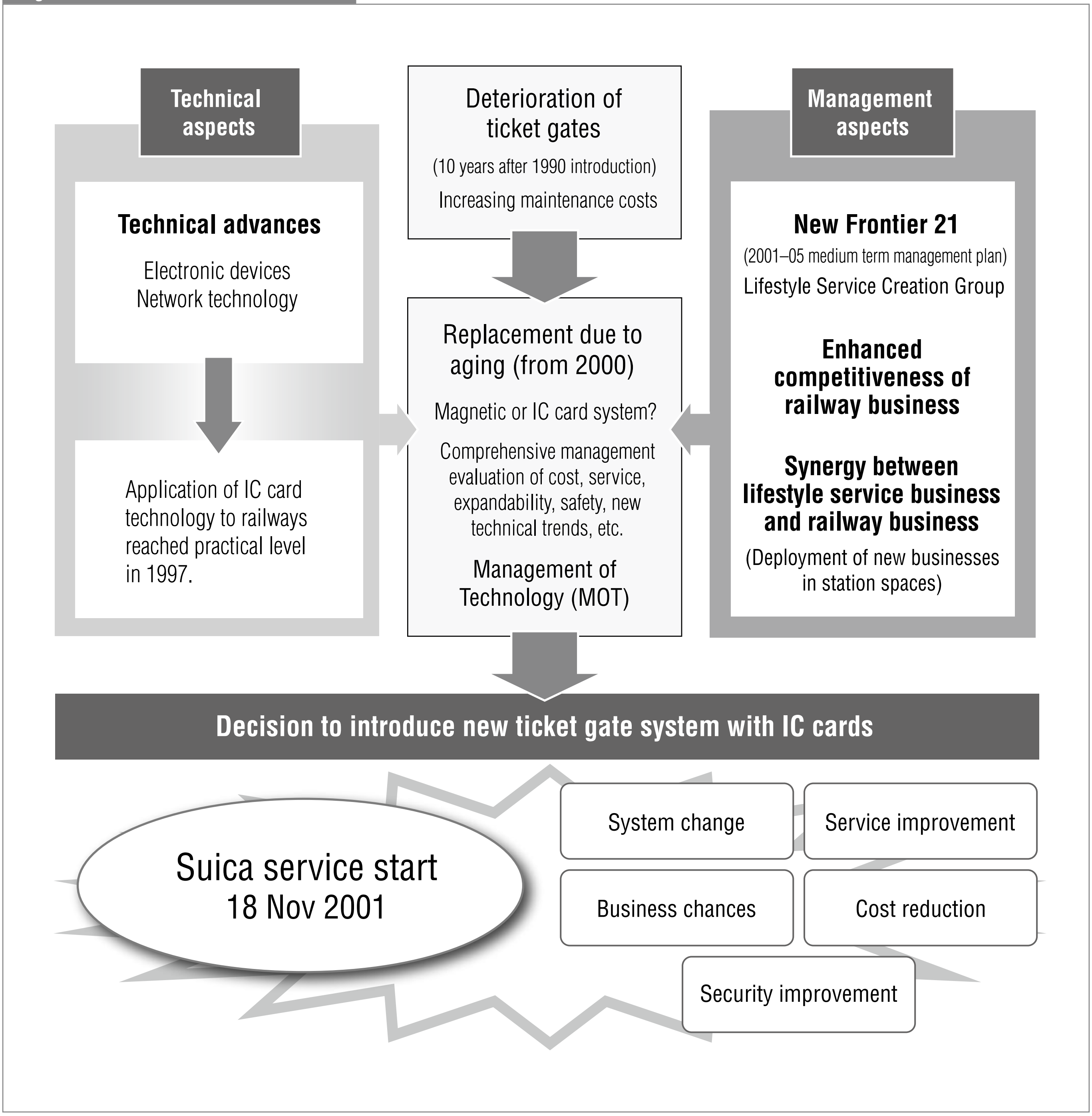


Figure 5 Suica and MOT Introduction



Suica (and PASMO) at some stations where the automatic ticket gates were not installed.

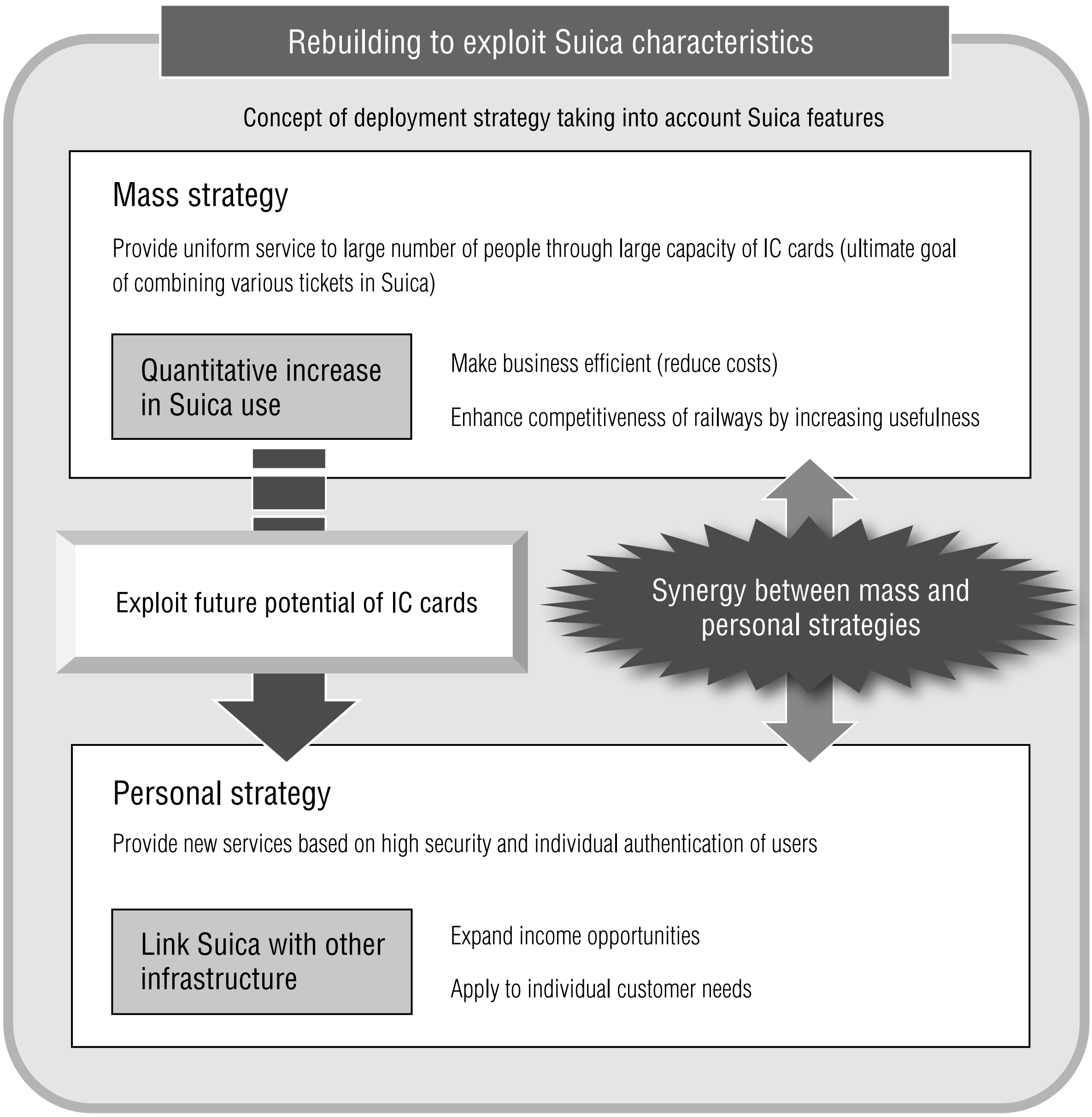
Every Suica card has a unique identification number allowing the history of each card's usage to be consolidated at the central Suica server. This supports uniform management of ticket information and detection/disabling of fraudulent IC cards to achieve higher reliability.

However, because each gate operates autonomously, the system remains unaffected overall even when terminals fail. If a station server fails, data will not be transferred between that station and the centre server, so some functions will be disabled but because gates can store data (damming), basic operations continue in the meantime.

Damming is conducted as follows:

1. Cards are processed autonomously at each gate. The most recent 20 data processings are stored on the card and 3-days worth of processings can be stored in the gate.
2. When a communications line is secured to the station server, data stored in gates is uploaded and stored on the server.
3. When a communications line is secured to the centre

Figure 6 Future Suica Development Strategy



server, data stored in the station server is uploaded to the centre server, which can store 6 months of data.

4. If a communications line is not secured, the ticket gate at stations can operate for 3 days.
5. Once the communication line is recovered, the collected data is sent to the centre server.

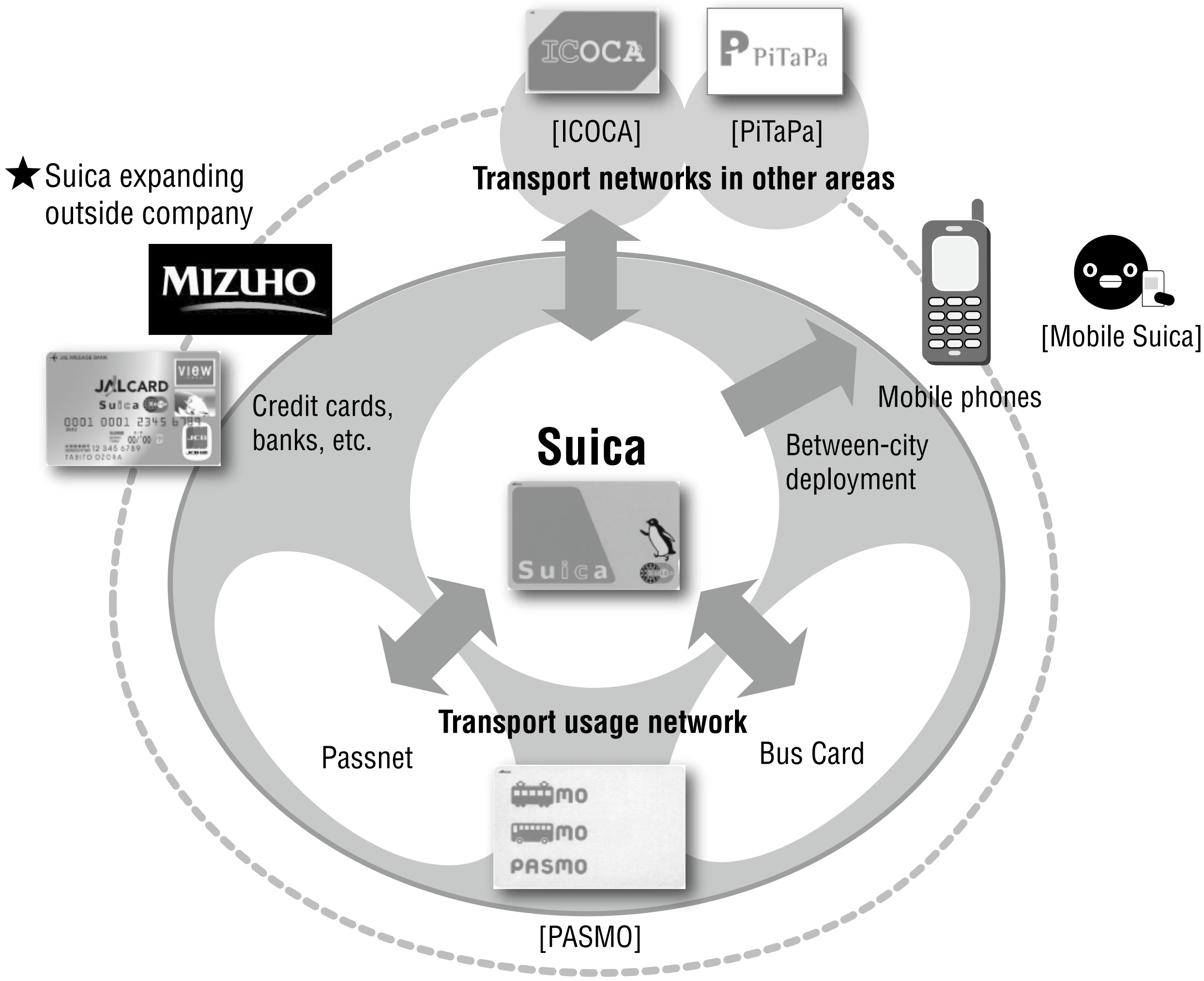
This technology of storing data for later processing is called Autonomous Decentralized Data Consistency Technology. As soon as a fraudulent/stolen card is identified, information suspending its use is sent to terminals in real time, greatly improving security.

In the 10 years following JR East's 1990 introduction of mechanical magnetic ticket gates, maintenance costs were rising and by 2000, the company was facing a huge expense for replacing first-generation gates. Meanwhile, by 1997, developments in IC electronics and network technology had reached the level for practical application of IC card ticket systems. At the same time, the company's New Frontier 21 medium-term management plan aimed to strengthen the

Figure 7 Transformation of Suica into Social Infrastructure

Until now

JR East infrastructure with high technological level



Future

Transform to open, large-scale infrastructure ➡ Suica becomes social infrastructure

(Primary infrastructure) Railways: Social foundation	(Secondary infrastructure) Suica: Lifestyle foundation
Securing coexistence of primary and secondary infrastructure and stable system operation	

railway business, and promote lifestyle services. Based on the previously described MOT strategy (Figure 5) it was decided to replace the worn-out magnetic ticket gates with a new ticket system using IC cards (Figure 6) to achieve improved service; reduced costs; new business opportunities, and improved security. Suica's technical characteristics have led to two strategies—mass and personal—that can be deployed individually or in combination for a synergistic effect.

The mass strategy uses the large data capacity of Suica to provide the same high-quality service to a large number of people, improving competitiveness through increased business efficiency (cost reduction) and convenience. It seems to have been successful judged from the 20+ million cards that have been issued (at April 2007), 60% adoption rate at ticket gates (March 2007), and increase in short-term revenues.

The personal strategy aims to expand use of Suica in business by offering new services meeting individual customer's needs based on the high-security individual authentication function. This strategy shows future promise for railway and bus companies issuing large numbers of transport cards that can be authenticated individually. As one example JR East is deploying Suica linked with its in-house credit card service to targeted market segments, such as women and retirees. JR East has also tied up with other companies such as airlines and home appliance retailers to issue co-branded credit cards.

Suica Transformation into Social Infrastructure

In the 7 years since Suica was introduced, there have been few major problems.

Interoperability with PASMO IC cards of other transport companies as well as the start of Mobile Suica services incorporating Suica functions into mobile phones has expanded the system beyond JR East into a large-scale social infrastructure. Mobile Suica was introduced in January 2006, and currently has more than 1.2 million users. As a result, Suica has become indispensable to passengers in greater Tokyo. If railways are a primary social infrastructure, it is no exaggeration to say that Suica has become a secondary infrastructure and lifestyle foundation. As a result, stable operation of this giant is the most important future issue for JR East. However, the system size and its spread into all aspects of Tokyo's society means that industry, government and other groups will be forced to cooperate in building sustainable frameworks. ■

Co-branded credit card with home appliance retailer

Further Reading

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After graduating from the Department of Mechanical Engineering at Saitama University in 1976, Dr Shiibashi joined Japanese National Railways and became a JR East employee in 1987. He started R&D into IC card ticket systems in 1994, taking charge of the Suica System Promotion Project from 1998. He gained his doctorate in engineering from Tokyo Institute of Technology in 2006 and is a member of The Japan Society of Mechanical Engineers and the Institute of Electronics, Information and Communications Engineers.