Introduction and Future Development of Suica Non-contact IC Card Ticketing System

Akio Shiibashi

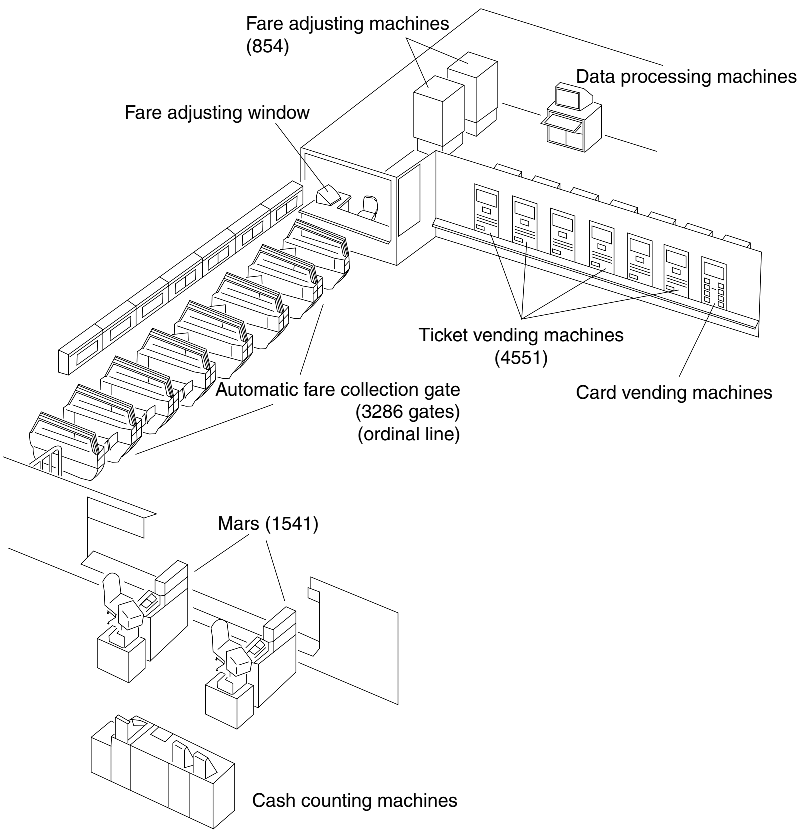
Introduction

East Japan Railway Company (JR East) is one of the six passenger railway companies created at the privatization and division of the former Japanese National Railways (JNR) in 1987 and it is the largest company in the JR Group. Its service area covers the eastern half of the main Japanese island of Honshu and includes Tokyo. The company carries some 16 million passengers each day over a route length of about 7500 km.

JR East aims to provide its customers with safe and reliable transport services based on its main business as a trustworthy railway company.

As one part of this concept, in 1987, the new company started examining development and testing of non-contact IC cards to provide user-oriented services meeting future passenger needs. As part of its medium-term business strategy, JR East launched the *New Frontier 21* plan in which the company announced its intent to actively introduce new technologies, starting with information technology (IT). As a result, each of the companies comprising the JR East group started examining active introduction of IT to its business. As one concrete example, JR East greeted the 21st century by launching its leading-edge Super Urban Intelligent Card (Suica) non-contact IC card ticketing system on 18 November 2001. This article describes the development and deployment of Suica, as well as well as some future plans for the system.

Figure 1 Automatic Fare Collection System



Outline of Automatic Ticketing System

Figure 1 shows the station ticketing system used by JR East. Basically, it is composed of a network of vending machines and gates plus a back-office for managing collected fares and performing remote monitoring. The vending machines are composed of ticket vending machines, card vending machines and season ticket vending machines. There are also fare adjustment machines near the gates. In general, all the machines are passenger operated.

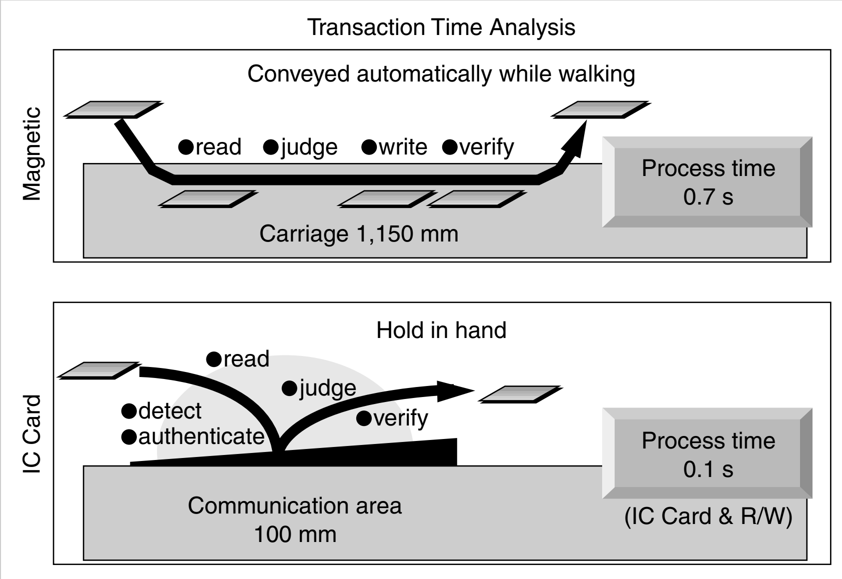
After 1990, to eliminate the workload of manual ticket clippers at gates, JR East introduced a magnetic ticket and gate system centred on lines in Tokyo Metropolitan Area. The system is now complete at some 340 stations with 3200 gates covering a radius of about 100 km around Tokyo. The 5 million or so commuters who use magnetic commuter passes to travel in the metropolitan area have become thoroughly familiar with this automated system in the 10 years since its introduction.

Following the introduction of this magnetic ticketing system, new services such as stored fare (SF) cards were introduced from 1991. In this system, fares are debited from a prepaid magnetic SF card (called an IO Card by JR East). The customer inserts a prepaid card into the gate on starting the journey and the fare is calculated and deducted automatically from the card when the card is inserted into the exit gate on completing the journey. This eliminates the inconvenience of buying tickets one at a time as well as problems with fare adjustments when travelling beyond the original fare destination for some reason. As a consequence, the IO Card rapidly became very popular with passengers and annual sales currently stand at more than 20 million cards for a revenue of about ¥60 billion (US$1 = ¥125).

As the magnetic ticketing system developed in popularity, JR East started examining development of a next-generation ticketing system using non-contact IC cards that could offer advantages of expanded functionality, lowered costs, and greater protection against ticket fraud.

R&D into IC card ticketing systems had already been started when JR East was established in 1987.

Figure 2 Non-contact IC Card System



Development Concept of Non-contact IC Card Ticketing System

Examination of the concept of introduction of non-contact IC cards as passenger tickets soon showed that it would be practically impossible to substitute such cards for the current magnetic tickets in a single step. As a consequence, it was realized that use of the current magnetic tickets would have to continue in parallel with development of the IC card system until the best specifications for the system could be determined.

Comparison with the current magnetic ticket system led to the establishment of the following development concepts as prerequisites for introducing a non-contact IC card ticketing system.

- The new system must co-exist with the current magnetic ticket system
- The new system must be less expensive than the current magnetic ticket system
- The new system must have at least the same or better processing performance and reliability as the current magnetic ticket system
- The new system must be able to offer new added-value services

Figure 2 shows the differences in transaction time between magnetic ticket and non-contact IC card gate systems. In the magnetic system, as soon as the ticket is put in the gate, the ticket data is read, evaluated, written and verified in a series of four serial processes taking about 0.7 s. By contrast, in the non-contact IC card system, first, the presence of the card in the radio-wave field is detected and the card is authenticated. Then the data is read, evaluated, written and verified in quick succession. In a feasibility study, the company soon found that these processes must be completed within about 0.1 s to prevent passengers pausing momentarily in their progress through the gate. Achieving this speed between the non-contact IC and gate reader/writer (R/W) was difficult using the available technology at that time, and the most important point was developing high-speed transaction processing between the IC card and R/W.

The development details are described below.

Development of Non-contact IC Cards

JR East started focusing attention on the possibility of using non-contact IC cards for next-generation ticketing systems immediately after the company was established in 1987. IC cards can be classified into contact and non-contact types, but when using IC cards for tickets, the transaction must be performed as the customer walks through the gate, so the non-contact type of IC card should be best.

First, JR East tested single non-contact IC cards using medium-wave and quasi-microwave frequencies to examine possible commercial applications.

As a result, in 1992, it seemed that quasi-microwave non-contact IC cards with a built-in battery looked like the best possible solution in terms of providing nearly satisfactory processing speed and price. Three field trials (Table 1) were conducted in railway stations from 1994 onwards to evaluate whether the functionality reached the required levels. Specifically, the trials examined whether the system reliability, gate processing

Table 1 Results of Field Test in JR East

	1st Trial	2nd Trial	3rd Trial
Test period	14 Feb 1994–15 Mar 1994 (1 month)	3 Apr 1995–2 Oct 1995 (6 months)	21 Apr 1997–25 Nov 1997 (7 months)
Test scale	8 stations 18 gates 400 persons	13 stations 30 gates 700 persons	12 stations 32 gate 800 persons
Communication speed	70 Kbps	25 Kbps	250 Kbps
Card movement	Waving	Waving	Touch & Go
Number of total transactions	29,900	176,000	174,000
Error rate compared with magnetic card	More than 20 times	About 4 times	Nearly equal

performance, and card usability satisfied passengers' needs.

First Field Trial

Outline

The first field trial was held for 1 month in January and February 1994. To determine the user convenience, two types of R/W were used: a horizontal type and a vertical type.

Results and problems

The trial results showed that the processing performance between the non-contact IC card and the R/W was unsatisfactory and the error rate preventing passage through the gate was 20 times the error rate of the conventional magnetic tickets. The causes were twofold; the rugby-ball shape of the communications field hindered speedy completion of processing when the IC card was near the R/W; and absorption of quasi-microwaves by the water content of the passenger's bodies reduced the size of the communications field.

Moreover, although 90% of monitors said it was convenient not to have to remove the season ticket from a wallet to pass it through the gate, close to 50% said the transaction speed was too slow. Additionally, the horizontal type R/W was found to be easiest to use.

Second Field Trial

Outline

The second field trial was held for 6 months between April and October 1995 to examine the remedies for the problems exposed by the first trial. There were three main improvements: communications at shorter wavelengths, change in shape of radio-wave field to hemispherical, and faster communications speed.

Additionally only the horizontal-type R/W was tested based on the results of the previous field trial.

Results and problems

The error rate improved to just four times that of the magnetic ticket system. This was due to randomness in the positioning of the card over the R/W because the monitors could not see the area of the radio-wave field.

In addition, after about 3 months of trials, the internal batteries in the cards began failing and the cards became inoperable. It was soon realized that use of even a long-life internal battery was impractical.

In terms of transaction speed, the trial confirmed that the number of people passing through the gate slightly exceeded the conventional magnetic ticket system because the communications speed had been increased.

Third Field Trial

Outline

For the third field trial of about 7 months between April and November 1997, two points were improved based on the results of the second trial. To reduce randomness in the positioning of the card, the position of the R/W antenna field was clearly marked and the method was changed from simply bringing the card close to the R/W to using a so-called 'Touch and Go' method (Fig. 3). In addition, instead of using cards with internal batteries, power was supplied to the card from the R/W by radio-wave induction.

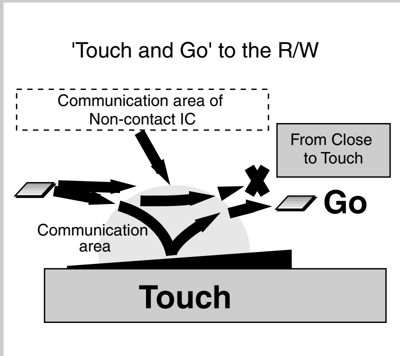
Furthermore, a new SF card function (called IO card) was added to the commuter pass function.

Results and problems

The most serious pending problem of the high error rate was immediately improved to the same level as the conventional magnetic ticket system due to the high effectiveness of the Touch and Go method.

Ignoring a few initial teething problems, the batteryless cards worked faultlessly through the trial period. In addition, the newly added SF card function also

Figure 3 Major Improvements of Third Field Trial



produced good results with no major problems.

Prerequisites for Railway Non-contact IC Cards

Up to this point, the R&D and field trials had clarified the prerequisites for a non-contact IC card for railway ticket applications. The prerequisites are explained further below.

To use a non-contact IC card as a railway ticketing system, the system must have a high communications and transaction speed plus reliable data processing. These advantages help compensate for the disadvantages of non-contact IC cards; in contrast to the convenience of non-contact cards, their transaction efficiency relies upon how a passenger positions the card over the R/W; a major disadvantage is that the card processing may not be completed properly depending on how the passenger positions the card. Reducing the occurrence of incomplete data processing requires high-reliability data processing at high communications speeds.

Achieving high-speed high-reliability processing is an absolute prerequisite for suppressing gate error rates to levels that are lower than seen in conventional magnetic ticket systems. If this requirement cannot be satisfied, the smooth passage of people through stations would be hindered, causing great confusion, possible accidents, and even problems with delayed train departures. As a result, JR East undertook extensive R&D over many years as well as extensive field trials before settling on the following three concrete technical specifications for a practical and internationally competitive commercial system using non-contact IC cards.

- Transaction speed: 0.1 s min.
- Communications speed: 212 Kbps min.
- Communications range: 100 mm radius min.

I would like to explain the importance of communications speed in some more detail. Some people believe that if the total transaction time can be kept below 0.1 s, the communications speed does not matter. However, this is a mistake. In the Suica system, the processing is completed when the R/W side receives the data items processed by the card side. This final communications cannot be completed if the card has moved outside the field in which communications are possible and this in turn depends on how the passenger handles the positioning of the non-contact IC card. In this case, the data at the card side is updated but the data at the R/W side is not updated, resulting in a serious data mismatch problem. High-speed communications greatly reduces the incidence of incomplete data processing and high-speed communications is an important precondition for actively reducing the occurrence of the problem.

Introduction of Non-contact IC Card System

As a result of the three above-described field trials, JR East decided that it would be possible to achieve successful commercial introduction of a non-contact IC card ticketing system and started investigating a plan for introduction from 1998. The so-called Committee for Promoting Introduction of the IC Card Ticketing System was formed with JR East Vice President Kiyomi Harayama as Committee Chairman; related companies in the JR East group also put systems and people in place to tackle the various problems that would arise before the introduction. In total, there were more than 200 people working on the introduction.

Business Model and Introduction Concept

An important subject in introducing the IC card ticketing system was ensuring that it would be a cost-effective investment. Even if it used the latest leading-edge technology, JR East could not introduce it unless there were demonstrable investment merits. As a consequence, the business model for introducing the system was investigated as described below.

Testing business model

Since automatic gates for handling conventional magnetic passenger and season tickets had already been installed in stations for a radius of about 100 km around Tokyo, simply changing the medium of passenger tickets from magnetic cards to IC cards seemed unlikely to be an efficient investment. However (and luckily), more than 10 years had passed since the introduction of the magnetic ticketing system and the time had come to renew the original aging gates. Consequently, some financial calculations were made on the feasibility of introducing the new IC card system at the same time as the gate renewal. The total capital investment required for the IC card ticketing system was calculated at ¥46 billion broken down into ¥33 billion for renewing the aging equipment and ¥13 billion for costs related to the IC card system. The ¥33 billion for equipment renewal was the cost required to renew the magnetic ticketing system even without introducing the IC card system. Furthermore, when a detailed financial analysis was made, it was found that the effect of introducing the IC card system would be to greatly reduce maintenance and capital costs through the reduced count of wearing parts in gates. This reduction over a 10-year period was estimated at ¥13 billion, cancelling out the cost of the initial investment related to introducing the IC cards.

Furthermore, introduction of the non-contact IC cards would increase the levels of both customer service and security and was also forecast to lead to development of new business opportunities.
As a result of these analyses, it was decided to greet the 21st century in 2001 by introducing a new next-generation ticketing system using non-contact IC cards.

Introduction concept

The following concepts for introducing the new system were developed on the basis of the above-described analyses.

- Changed systems
  Reduce station administration through changeover to cashless and ticketless passenger transport.
- Reduced costs
  Reduce station equipment levels by cutting the numbers of machines and mechanical parts.
- Improved service
  Reduce ticket problems, promote through ticketing and expand station usage opportunities.
- Improved security
  Eliminate ticket fraud and forged and altered tickets
- New business opportunities
  Develop new business using features of IC cards (large data capacity and high security)

IC Card Name, Types and Features

The Suica name given to the card is the abbreviation for Super Urban Intelligent Card but it also conveys the impression of smooth and easy transport based on the Japanese adverb *suisui* (lightly).
The Suica that combines the season ticket function with the SF card function is called the Suica Commuter Pass while the Suica that only has the SF card function is called the Suica IO Card (Fig. 4).

Suica features

The unique features of Suica are listed below:

- Charging function (adding money)
  Each time any fare stored in the Suica becomes exhausted by usage, the stored fare can be topped up again using the so-called charging function rather like recharging a rechargeable battery. The charging is actually done by the passenger at ticket vending machines, Suica card vending machines and at fare adjustment machines simply by inserting the card and putting money into the machine.
- Rewrite function
  The Suica commuter pass has a rewritable surface to rewrite the information (validity dates and stations, etc.) printed on the card surface. In other words, when the validity of a purchased card expires or when the commuting route changes, the card can be reused with up-to-date information reprinted on its surface.
- ID Function permitting reissue after loss or theft
  A unique user ID is stored in the Suica so that the central Suica server can manage the card usage history. As a consequence, if the Suica is lost or stolen, a new card can be issued after confirming the identity of the owner and the lost or stolen card can be disabled, preventing further illegal use.

Suica Monitoring Trials

There were no major problems with card errors during the test period. The functioning of the cards, gates, and machines as well as the opinions of station staff handling the system and customer opinions were all monitored to obtain a precise impression of how well the system was working. In the first full-scale test of commercial use from 8 April to 8 July 2000, the initial intent was to issue 10,000 monitors with 8500 Suica commuter passes and 1500 Suica IO cards for use in a general function trial at the 27 stations between Ebisu and Kawagoe stations on JR East's Saikyo Line.

Figure 4 Functions of Two IC Cards

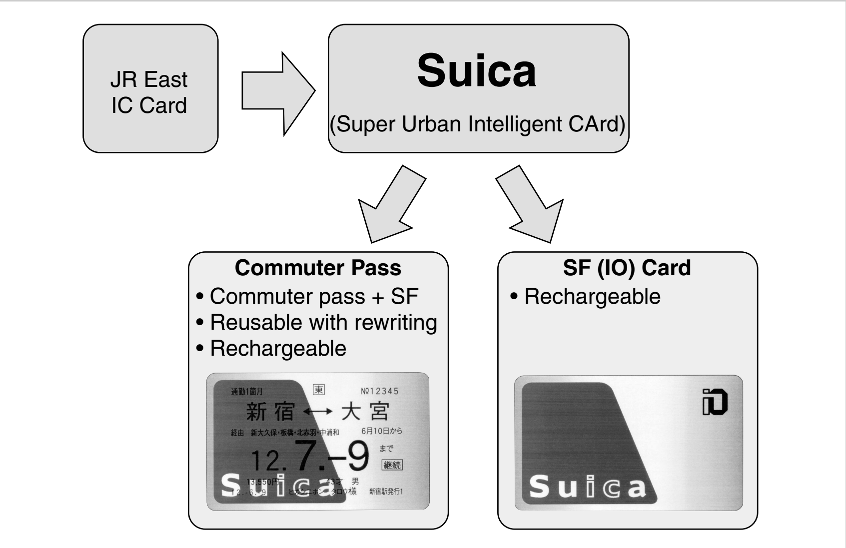


Figure 5 Outline of IC Card System

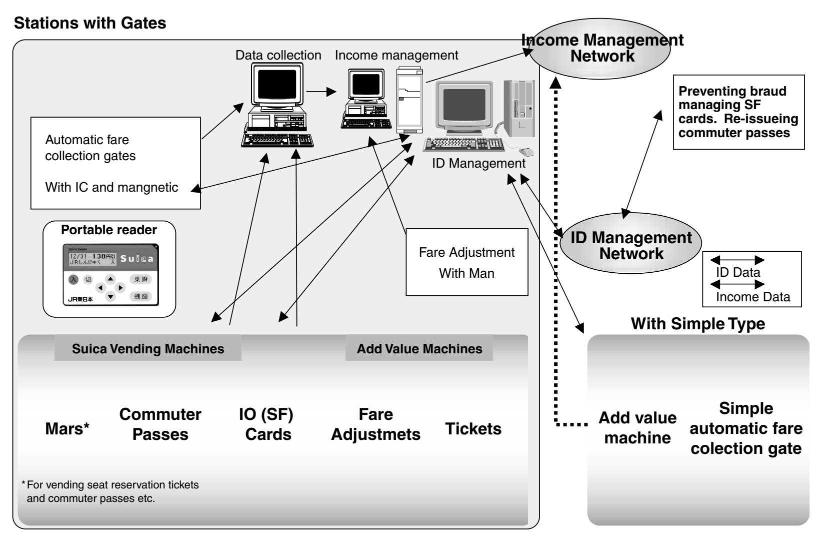
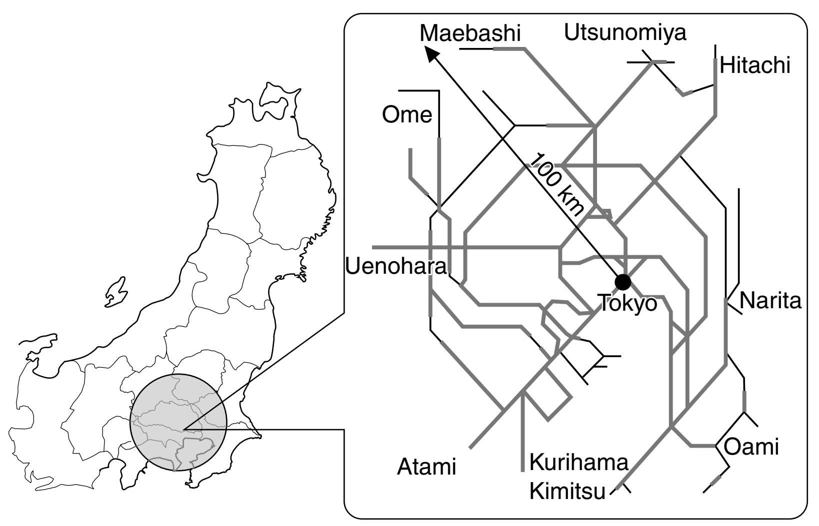


Figure 6 Non-contact IC System Implementation Area



Conditions for participating in test

Although more than 30,000 people applied to be one of the 10,000 test monitors, only 8600 were eventually chosen (7200 Suica commuter passes and 1400 Suica IO cards). The cards were used some 174,000 times during the test period (excluding use between commuting stations). The SF function of the Suica commuter pass was used mostly at weekends while there was no daily difference in the use of the Suica IO cards. The most common charging amount was ¥1000 yen per time and only 1% of chargings were for ¥10,000.

Users' opinions

The most strongly expressed opinions were the convenience of the non-contact function due to not having to remove the commuter pass from a wallet or holder to pass it through the gate mechanism; the ease of making a fare adjustment automatically using the SF card when exiting a gate after having travelled beyond the commuter stations; and the security of having the pass reissued in the event of loss or theft. It was gratifying that customers appreciated one of the original aims of introducing Suica—better customer services. On the other hand, there were some adverse opinions about the inconvenience of travelling outside the test area, the slow response times of the gates and problems of the Touch and Go method when the pass was in a bag, etc. More than 80% of monitors said that they had been able to pass easily through the gate and more than 90% said that the system was convenient.

Test conclusion

As a result of conducting this test, it was clear that some parts of the system equipment needed revision, station employees needed more training and the system usage would have to be better explained to users. However, it proved extremely useful in demonstrating that the system was nearly ready for full-scale introduction.

Outline of Introduction of Suica Ticket System

Figure 5 shows the composition and main elements of the Suica ticketing system. The existing gates, ticket vending machines and fare adjustment machines were upgraded to handle the new Suica card and a new network with a central Suica server was installed to handle the Suica ID and card history functions and thereby prevent the previously described problems with ticket fraud and lost and stolen commuter passes. In addition, since it is impossible to visually check the data stored in a Suica, a simple credit-card

These machines can check and print the Suica SF amount and usage history as well sell magnetic tickets. (JR East)

sized card reader (read-only) was designed and distributed to JR stations outside the area where Suica was to be first installed as well as to stations of other railway operators inside the Suica area and to station offices and conductors in the area.

The final stage was to bring the Suica system online in the JR East service area for some 100 km around Tokyo (Fig. 6).

Step 1 on 18 November 2001

The first part of the Suica system was brought online on 18 November 2001 at about 350 stations where automatic ticket gates had already been installed on some 3200 routes covering an area of about 100 km around Tokyo; passengers were able to travel freely through any of these stations using either the conventional magnetic tickets and cards or Suica commuter passes and Suica IO cards.

Step 2 on 31 March 2002

The second step on 31 March 2002 added simplified gates that can read Suica to a further 110 stations (including unmanned stations) on some 350 routes, permitting more passengers at these stations to use Suica services. (However, some 70 of these stations had already started using Suica from step 1.)

Conditions After Suica Introduction

More than 6 months have passed since Suica first came online as a next-generation ticketing system for improving passenger services in the JR East service region and there have been no major problems at all. In addition, since the takeover of Tokyo Monorail by JR East on 21 April this year, Suica can now be used at 470 stations in Greater Tokyo (461 JR East stations and 9 Tokyo Monorail stations). On 27 May, there were a total of 4 million Suica holders composed of 2.16 million Suica commuter passes and 1.79 million Suica IO cards. Moreover, the peak number of Suica transactions per day (excluding use in commuter pass sections) exceeded 20 million.

The features that Suica customers like most are smooth passage through gates without needing to remove Suica from

Portable Suica reader (JR East)

wallet or card case, no need to line up at fare adjustment machines, and the security of being able to have card re-issued if lost or stolen. On the other hand, the missing feature that customers would most like to see is expansion of Suica usability such as joint use on lines operated by other railway companies and the ability to be able to use Suica for other rail services such as shinkansen.

Furthermore, the contribution of the Suica system to Japanese society was recognized on 17 April when it won the Prime Minister's Awards at the 31st Japan Industrial Technology Awards and people have high expectations for its future success and development.

In addition, when we analyze ticket data before and after the Suica introduction, we find that: 1. there has been an approximate 10% drop in revenue from ticket vending machines; 2. there has also been a slightly larger than 10% drop in revenues collected by fare adjustment machines; 3. there has been an approximately 60% increase in revenue collected at gates; 4. there has been an approximate overall 5% increase in revenues for short distance journeys from selected stations. Clearly, the introduction of Suica has led to changes in the structure of revenues at stations. This data was collected 2 months after the Suica introduction and we wonder if this trend will become even more striking in the future. It is a very interesting result when considering the structure of gates, etc., in future stations.

Future Developments

The Suica non-contact IC card ticketing system recently introduced by JR East is the world's largest such system and features more than 7000 machines networked over an area encircling Tokyo by a radius of 100 km that are used by more than 4 million IC cardholders each day.

JR East is still examining how to use this huge installed infrastructure base to improve its customer services even further as well as how to develop it in the future to improve JR East business.

An important point in considering future development of IC card systems is the IC card infrastructure, which requires a massive capital investment that cannot be supported unless it provides sufficient returns.

JR East was fortunate this time because its superannuated ticketing and gate systems were ready for upgrading but there may be cases where an efficient business model is hard to establish. In particular, it is very important to consider who will provide the infrastructure and how it will be provided. It is important to grasp the infrastructure usage range when examining future IC card development. There are three broad fields as described below.

The first is railway IC card infrastructure, especially how to promote joint use on the lines of other railway operators. Joint use definitely increases passenger convenience and it is also important in raising competition in the railway business. Moreover, JR East is examining how to expand the usage of Suica on its own infrastructure, especially shinkansen and the networks of large regional cities. As IC card usage spreads, we expect to see great changes as much of the work of stations becomes cashless and ticketless.

The second field of expansion is active development of the present IC card infrastructure.

Currently, Suica cards with SF functions can be used in a radius of 100 km around Tokyo. This SF function can be used a prepaid railway ticket but in technical terms it is identical to electronic money. For example, if the JR View Card—a JR East credit card held by about 2.14 million people—was converted to an IC card and the credit card and SF card functions were combined, it would be possible to use the combined card to pass through stations using the Suica infrastructure and to purchase goods and souvenirs, etc., using the credit card functions. We are already looking at this possibility and are preparing for a usage trial in late FY2002.

The third field of expansion is development through cooperation with the existing social infrastructure.

The convenience store and mobile telephone are two good examples of so-called social infrastructure that are widespread throughout Japan and their functions could be linked with Suica. For example, if a Suica IC chip was built into mobile phones, people could purchase rail tickets anytime and anywhere. In addition, it would also be possible to offer various products and service contents by mobile telephone, which would both increase customer satisfaction levels and generate new business.

IT needs to be more widely adopted to further the future development of Suica, and we are examining the potential of combining IT (including Internet and wireless technologies) with railway business. To ensure speedy uptake, we are establishing a promotion group called the IT Business Promotion Project under the leadership of JR East's Executive Director for IT Business Projects.

Summary

To assure the highest levels of convenience for its passengers travelling up to 100 km around Tokyo, JR East has invested huge management and financial resources in introducing its world-beating Suica non-contact IC card infrastructure. In addition, the company plans to extend the Suica system to the shinkansen and regions outside the present 100-km service range as well as to joint service on lines of other railway operators. This will be achieved by integrating the JR ViewCard and Suica and by adding electronic money functions, etc., to promote ticketless and cashless railway business. Moreover, links with existing social infrastructure such as mobile telephones will extend service levels and offer new business opportunities.

The recent IT revolution is having a huge impact not only on business activities but also on people's daily lives, causing huge changes in the economies of societies. JR East's introduction of its Suica system is based on its positive adoption of leading-edge technologies and ensures that the company is well positioned to offer new safe 21st-century transport services tailored to its customers' needs. ■

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