



Contactless smart card AFC trials in East Japan Railway

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Abstract

East Japan Railway Company (JR East) has installed a magnetic automatic fare collection (AFC) system with stored fare facility in Tokyo Metropolitan area to modernize the transport system. In parallel to these developments, we are investigating a new customer-based ticketing system as proposed at WCRR'94[1], and have been developing the contactless smart card (CSC) as an essential component.

The third field trial from April to November 1997 showed that a new batteryless CSC together with a newly designed gate solved most of the problems which had been made clear by the past two trials. The rate of denial that a passenger did not pass the gate with a valid ticket became practically as low as a conventional magnetic gate. Moreover, we successfully introduced a new facility of combining season ticket with stored fare (SF) function.

We consider the trial has proved that the AFC system with CSC is technically feasible even in the severe condition of commuter transportation of Tokyo Metropolitan area, and also hope that it should be the first step toward a new customer based ticketing system.



1 Introduction

East Japan Railway Company (JR East) serves about 17 million passengers and operates 12 thousand scheduled trains daily on about 7,500 km of routes covering the eastern half of the main island of Japan. Its operation covers urban area commuter trains serving Tokyo Metropolitan Area, as well as both inter-city trains including Shinkansen and regional local trains.

In 1990, it began introduction of a magnetic automatic fare collection (AFC) system. A special feature of the system was the adoption of a stored fare (SF) card called 'IO Card'. IO Card improved the traditional and fundamental relationship between a passenger and the railway company in the sense that he is relieved from buying a ticket beforehand his trip,. The system has been received well and made a positive contribution to the management.

In parallel to these developments, we have been investigating a new ticketing system with smart card for the next generation. After some analysis in the early stage of the investigation, we concluded that a contactless smart card (CSC) would be most fitted for transportation use especially the Japanese commuter environment, and began development of the CSC more than 10 years ago. Having confirmed that the CSC of ISO size could be mass produced, we ran two field trails in the past before one described hereafter. Recently, at least two AFC systems began to use CSC commercially, namely in Hong Kong and Seoul. However, the processing speed of their gates seems to be a little too slow to fit for the severe conditions in Japan so that we have to develop our own system to cope with them.

2 Problems in the past trials

The CSCs, of which the specifications are listed in Table 1 were tested in the three trials described in Table 2, respectively.

Table 1 Specifications of CSC

	1st Trial	2nd Trial	3rd Trial
Size	54*85.6*0.76mm(ISO size)		
User memory	500bytes	1000bytes	1200bytes
Carrier frequency	2.4GHz	32MHz	13.56MHz
Communication rate	70kbps	250kbps	
Battery	with battery		batteryless

Table 2 Scale of the field trials

	1st Trial	2nd Trial	3rd Trial	
			1st phase	2nd phase
Period	1 month	6 months	1 month	6 months
	(Feb. 1994 -Mar.1994)	(Apr.1995 -Oct.1995)	(Apr.1997 -May.1997)	(May.1997 -Nov.1997)
Stations	8	13	12	
Gates	18	30	32	
Monitors	400	700	300	800
Application	season ticket			season ticket with SF

Although 90% of the monitors in the second trial felt that the CSC was convenient suggesting the system would be welcomed by the public, some issues yet to be solved remained. We focus the discussion to the third trial and state the problems of the second trial first.

2.1 Battery

We found that the movement of the card became unstable due to the voltage changes of the battery after several months' use. We concluded the CSC with battery was not suitable for the long term use.

2.2 Passenger's interface (Cover design of the Reader/Writer)

26% of monitors couldn't realize the right position of the reader/writer(R/W) at first sight. We understood that any attracting mark or lighting around the R/W should not exist except one showing the position of the target.

2.3 Broken transaction

We define the term 'broken transaction' as a transaction which has caused time out after a card is recognized by the R/W. It may either be recovered by an automatic or manual retry, or cause a passenger go back out of the gate, which we call 'denied transaction' or simply 'denial'. Although most transactions completed within 100 ms on the second trial, the rate of broken transaction amounted 4.8%, and about a half of them led to the denial in total six months, caused by the above mentioned problems and partly by the inadequate behavior of the monitors. For

even more certainty we realized the need that some restriction should be imposed to passengers when using the CSC at a practical system.

3 Solutions in the third trial

3.1 New problem caused by batteryless CSC

We adopted a CSC without battery based on the conclusion of the second trial. However this caused a new problem that the communication range became narrower. In the previous trials, we did not pose monitors any restriction to use the card but to recommend to bring the CSC close to the R/W, in order to observe their natural behavior. As the closeness was not a definite conception, however, the monitors felt hard to realize how close they should bring the card to the R/W. We could easily anticipate that the narrower communication range of the new card might make the problem more explicit. Therefore we decided to induce monitors to touch the R/W with the CSC so that it would remain at the communication range long enough to complete transaction without their being conscious of closeness.

3.2 Transaction time

The past experiences showed that some monitors felt the transaction time of 200ms a little tardy, and the second trial did achieve the speed of about 100ms for the restricted function of season ticket only. As the third trial included some security measures and a new function described below, we settled the target of transaction time to 150 ms, and measured the staying time of the CSC within the communication range of the new R/W by several volunteers in advance(Fig. 1).

While 91% of over 200 transactions stayed within the range for longer than 150ms, some dared challenge the lower limit of transaction time. We analyzed that all the data below 150ms were caused by their special will so that we could safely say that the CSC usually remained over

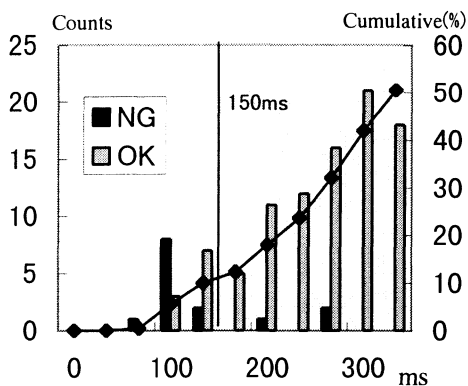


Fig. 1 Preliminary measurement of existing time

150ms in the communication range if passengers used it in a ‘touch and go’ manner.

3.3 Change of R/W cover design

The cover design of the reader/writer plays an important role for the passengers’ action, which becomes a vital element for the throughput of the gate. Forced to change the design entirely from the second trial, we made five mock-ups depicted at Fig. 2 for basic shapes of the cover and analyzed the behavior of passengers who didn’t know the CSC system. The first two are for the shape of antenna cavity and the last three are for the overall shape of the cover. We concluded the combination of types B and C was suitable for leading passengers to a movement of ‘touch and go’.

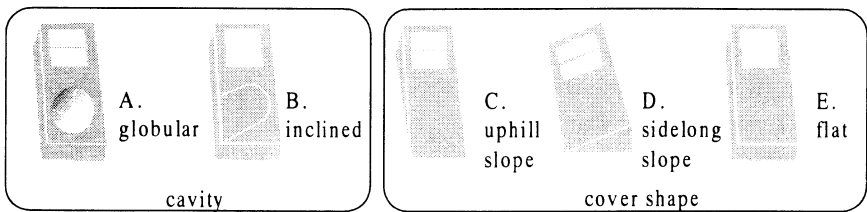


Fig. 2 Mock-ups used to behavior analysis

The resulting design is shown in Fig. 3. It has an uphill slope for a passenger to realize the position of R/W easily and to be induced to ‘touch and go’. A green luminous circle clearly indicates the position of the R/W. Any other marks or lights are omitted from near the circle, and a result indicator is located as far apart from the circle as possible.

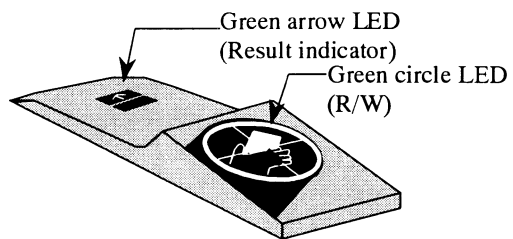


Fig. 3 Cover design on 3rd trial

3.4 Instant retry prompting

If a transaction should not complete because of too short stay of a CSC in the communication range, the R/W changes the state to retry mode. The

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green circle LED flashes, an alarm chime rings, the result indicator indicates 'Touch again' by a red LED and any other card but the first would not be accepted. The series of these warnings will induce the passenger to touch the R/W again without getting back out of the gate as is the case for a magnetic gate. In fact we did adopt the function at the second trial, too, we nevertheless concealed it to find out the monitor's natural reaction. We confirmed its effectiveness and decided to emphasize the mode to reduce the overall blockage of the gate.

4 Addition of new service

A new function introduced to the third trial is combining a season ticket with stored fare (SF) facility within a single CSC.

IO Card, a stored fare (SF) card introduced to our AFC system in 1991, has got a favorable reputation by most users and is expanding the sales as Fig. 4 because a passenger neither worries about the fare nor makes line before the ticket machine. But he is forbidden combining an IO Card entry with an exit using another season or multiple-ride ticket because his trip do not complete within the card.

The new card entirely solves the inconvenience even if the passenger travels beyond the range of his season ticket. We hope that the scheme will offer the first step toward our vision of customer-based ticketing system[1].

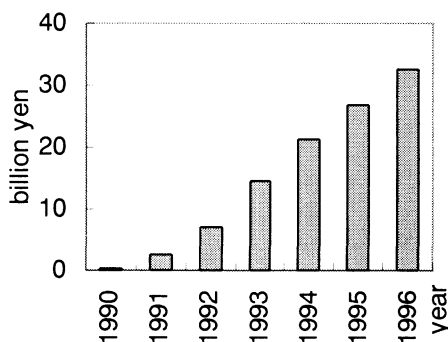


Fig. 4 Sales of IO Card

5 Results of the third trial

The third trial was divided into two phases: The first month was devoted for the single function of season ticket merely checking whether the system was actually improved from the second trial. Confirming the good performance, we proceeded to the second phase of six months with combined function mentioned in the former section. We got total 174 thousand transactions through two phases.

We evaluated the trial by taking statistical data gathered from all the gate machines and also from questionnaires to the monitors after each phase.

5.1 Passenger's interface (Cover design of the Reader/Writer)

According to the questionnaire after the first phase, 100% of the monitors realized the right position of the R/W proving the excellency of the design. No serious trouble were reported originated by the card itself.

5.2 Gate performance

99.9% of unbroken transactions finished within 150ms on the third trial. The questionnaire showed that 54% of the monitors felt transaction time 'quick' or 'very quick', while 17% felt 'rather slow' or 'slow'. The CSC gate accepted maximum about 90 passengers per minute, while a conventional magnetic gate does about 60.

We observed how long learned monitors held the CSC in the communication range with the same way as the preliminary measurement for three days in September and got more than 200 samples(Fig. 5). In contrast to the preliminary measurement, the minimum of the holding time was 230ms proving the effect of learning in the actual use.

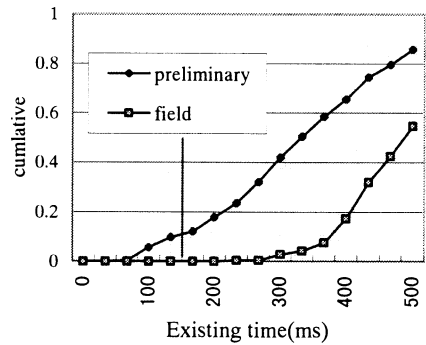


Fig 5. Monitors' Behavior

5.3 The rate of broken transaction

In the second trial, about a half of the broken transaction were recovered by the quick retry, resulting the overall denial rate of 2.2%.

The average rate of broken transaction was 1.4% in last three months which showed the stable performance by the learning of monitors. Two third of them were recovered by the new quick retry scheme and the denial rate

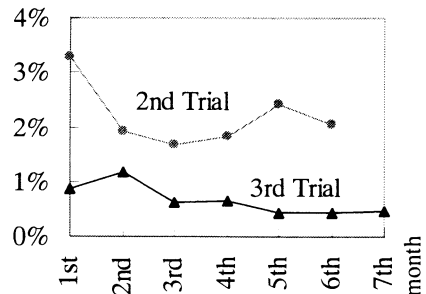


Fig. 6 Improvement of denial rate



became as low as 0.44%, the minimum being 0.42% for the sixth month(Fig. 6).

The figure was satisfactory for the actual implementation because it was approximately equivalent to the measured denial rate of magnetic gate with valid tickets in daily operation, although the latter case was caused mostly by magnetized paper tickets creased by passengers. However, the denial rate seemed still too high compared to the facts of sections 5.2 and 5.3. We found that some 'dead time' existed in the process to postpone the overall transaction time, which could be able to cut in the actual implementation.

6 Concluding remarks

We have described in this paper some technical aspects of our development of the CSC and the related gate machine. Our system proved to be faster than and as stable as the conventional magnetic gate system. Tokyo is known throughout the world for its commuter crush. Ticket gate is one of the major bottlenecks for commuter traffic through railway stations, and that is why JR East is actively expanding its AFC systems to cope with crowds of passengers. We believe our new CSC system will relieve these situation even in our severe environment.

There are other aspects concerning the CSC ticketing system. Although the CSC might make way to a new ticketing system as we discussed in [1], there are several bars against it. Unlike the case in Hong Kong or other European countries, a visible display of contents might be vital in Japan, so that we are investigating several alternatives on this matter. Security measure will also become the more important the more the card adopts the function like common ticket between different mode of transportation, common operation among multiple service providers or electronic money. We think our CSC will bear these requirements fairly enough.

References

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