USE OF RFID AT LARGE-SCALE EVENTS

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Radio Frequency Identification (RFID) devices and related technologies have received a great deal of attention for their ability to perform non-contact object identification. Systems incorporating RFID have been evaluated from a variety of perspectives. The authors constructed a networked RFID system to support event management at NetWorld+Interop 2004 Tokyo, an event that received 150,000 visitors. The system used multiple RFID readers installed at the venue and RFID tags carried by each visitor to provide a platform for running various management and visitor support applications. This paper presents the results of this field trial of RFID readability rates. It further addresses the applicability of RFID systems to visitor management, a problematic aspect of large-scale events.

Key Words: RFID, Internet, EPC network, Event management, Field trial

1. EVENT MANAGEMENT AND RFID SYSTEMS

Radio Frequency Identification (RFID) devices and related technologies have received a great deal of attention for their ability to perform non-contact object identification. RFID is one kind of wireless object-identification technology and is composed of devices that record information on identifiers called RFID tags and RFID readers that read the information so recorded.

The advantage of using RFID in management applications for events such as exhibitions and seminars is that it offers wireless, automatic, non-contact identification and sufficient number space to identify each individual.

Nevertheless, it is difficult to take full advantage of the characteristics of such systems merely by attaching identifiers. For event management purposes, the readers and applications must not simply be linked but must link groups of readers with groups of applications used at various locations and for various purposes. The authors solved this problem by employing EPC network[1] architecture[2], the standard for networked RFID systems. Using an EPC network enabled the organization of information from multiple RFID readers and relay of the appropriate information to the appropriate application. Such systems are capable of becoming part of the intelligence infrastructure at large events where many participating exhibitors make a wide range of demands on the applications used.

To evaluate the EPC network architecture under real-world conditions, the authors conducted field trials using management-support and visitor-support applications. The trials were conducted at NetWorld+Interop 2004 Tokyo[3], an exhibition of Internet technology and networking equipment. Held since 1994, in 2004 the three-day event drew 141,605 visitors[4]. Each visitor was given an RFID tag and various experiments were conducted.

This paper primarily addresses RFID readability in RFID systems for management and administration of large-scale events with great numbers of visitors. It then discusses RFID applicability for visitor management, a problematic aspect of large-scale events.

1.1 Information processing at events

Information processing technology is used at events to accomplish two things: 1) reduce the workload for management and 2) facilitate the flow of information between visitors and exhibitors. At large-scale events in particular, it is difficult to achieve these goals without automation. RFID and related technologies offer solutions to these challenges.

Entities related to events can be divided into the following three categories:

Visitors: Those who participate for the purpose of viewing exhibits.

Exhibitors: Those who participate by establishing booths for the display of exhibits.

Management: Those who gather together visitors and provide exhibitors with the opportunity to exhibit.

From the visitor perspective one tends to emphasize the provision of information from event organizers and exhibitors to visitors but organizers and exhibiters are most interested in knowing who came and in what information they were most interested. It has become common at recent events for visitor profiles to be pre-registered, generating statistical information for marketing and other purposes. For NetWorld+Interop 2004 Tokyo, where the field trials for this paper were conducted, web-based registration was conducted in advance (Figure 1).

Visitor-related management activities include same-day registration processing and recording venue entry (including admissibility tracking as needed). Recently such tasks have increasingly involved the use of barcodes and hand-held devices to provide a link to registration information.

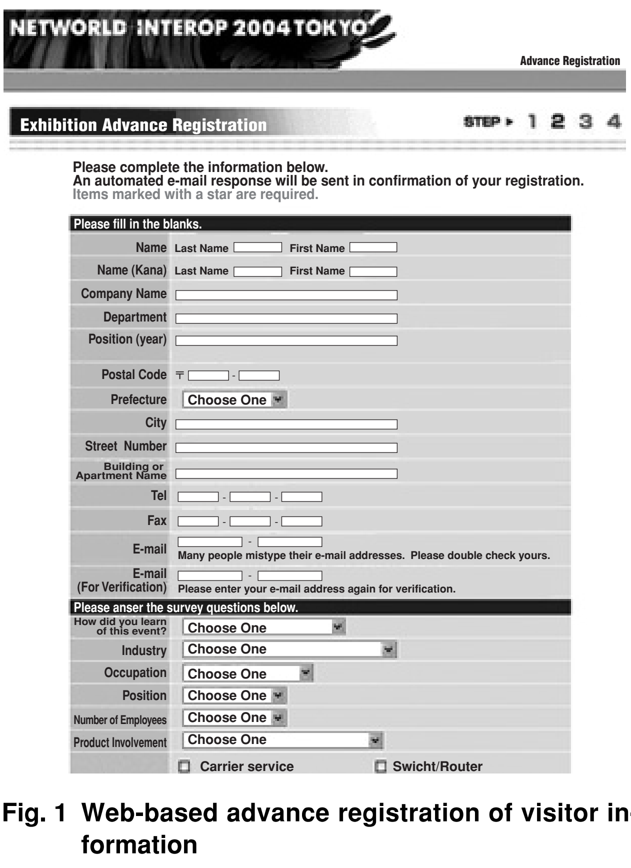
NETWORLD INTEROP 2004 TOKYO
Advance Registration
Exhibition Advance Registration
STEP ▸ 1 2 3 4
Please complete the information below.
An automated e-mail response will be sent in confirmation of your registration.
Items marked with a star are required.
Please fill in the blanks.
Name Last Name First Name
Name (Kana) Last Name First Name
Company Name
Department
Position (year)
Postal Code 〒 -
Prefecture Choose One
City
Street Number
Building or Apartment Name
Tel - -
Fax - -
E-mail - Many people mistype their e-mail addresses. Please double check yours.
E-mail (For Verification) - Please enter your e-mail address again for verification.
Please anser the survey questions below.
How did you learn of this event? Choose One
Industry Choose One
Occupation Choose One
Position Choose One
Number of Employees Choose One
Product Involvement Choose One
Carrier service Swicht/Router

Fig. 1 Web-based advance registration of visitor information

1.2 Networked RFID systems

RFID systems enable computerization of object-related information. When looking at techniques for managing such information, RFID systems can be divided into two types: data carrier RFID systems and networked RFID systems. Data carrier RFID systems focus on RFID tags as storage media, using object-related information recorded on RFID tags physically attached to the objects. Although the concept of having the objects carry their own information is sound, a number of practical challenges – such as the need to have the object before you in order to access its information, limitations on information volume set by RFID tag memory capacity, and long write times that make actual operation difficult – raise the need for a different architecture.

Networked RFID systems were developed to address such challenges. In such systems, RFID devices record only simple identifiers while necessary information processing (recording, searching, finding relationships) takes place as a result of interactions between peripheral systems connected through the network. The EPC network mentioned previously is the networked RFID system on which the greatest progress has been made in terms of standardization.

The EPC network is an RFID system architecture proposed by the Auto-ID Center, which was founded in 1999 and centered on the Massachusetts Institute of Technology (MIT). Standardization efforts continue today by successor organization Auto-ID Labs[5] and EPCglobal[6].

EPC stands for Electronic Product Code and has the serial number space for identification at the level of the individual item. The EPC network is a collection of standard specifications built around EPC, including peripheral systems generally.

The architecture of the EPC network is described in Figure 2. Components built around applications that use the EPC network include EPC tags that contain the EPC and are attached to products, readers that read the EPC from the EPC tags, filter and collection middleware that compiles information from readers and sends it to applications, EPCIS (EPC Information Services), and ONS (Object Name Services) that map appropriate EPCIS to applications.

2. EVENT MANAGEMENT SUPPORT USING RFID

The authors used networked RFID technology in the form of the EPC network to create a prototype for

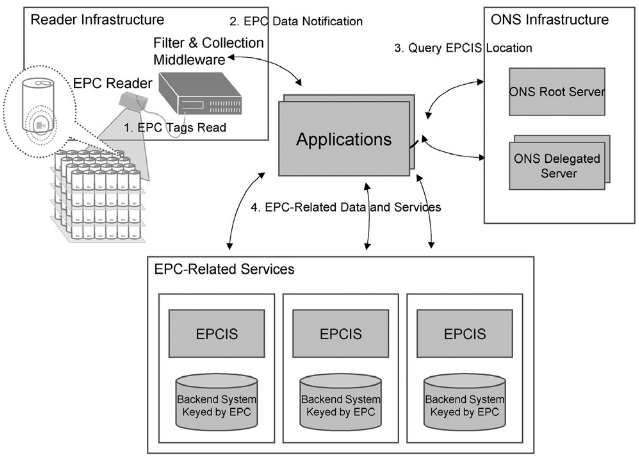

Fig. 2 EPC network

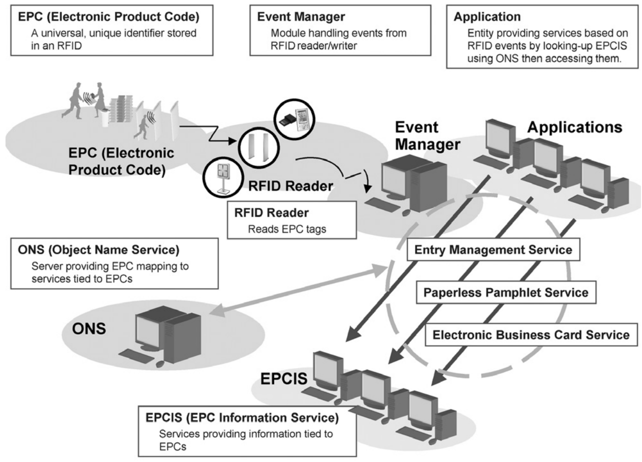

Fig. 3 System architecture

supporting the work of large-scale events. Making the prototype suitable for actual use in the future requires an engineering evaluation of the level of precision needed for it to function. The authors focused on determining the number of visitors to a large-scale event, conducting measurements under real-world conditions.

2.1 Event management support system using the EPC network

Event-related tasks include various processes based on the movement of people. Systems supporting event management, therefore, must be based on processing visitor-related information (data collection, recording and presentation) in accordance with the demands of visitors, exhibitors and management.

Information processing includes both all-purpose and event-specific processes. The former include data collection and recording processes while the latter include processes performed by the individual applications that use the information. In order to develop a prototype system capable of functioning as an all-purpose event management support platform, the choice was made to separate data collection and processing functions, with support for multiple applications running on top of them. Prototype system architecture is described in Figure 3.

The system is based on the EPC network architecture, with all entities (people, objects) handled by the system assigned an EPC. Visitor behavior is recognized by the RFID readers and sent to the Event Manager as an EPC event. The Event Manager then routes the EPC event to the appropriate applications. The application takes this information and records it in the EPCIS (EPC Information Service) component as information to be accessed by other applications. This architecture creates an environment where it is possible to run multiple independent applications simultaneously.

Although the support system was a prototype, it had practical functionality as a platform for running multiple event support applications. Some of the applications supported by the event management support system are described below.

Exhibit award voting system (Figure 4)

A voting system was implemented to determine awards for the best exhibits. Instead of ballot boxes, visitors voted by holding their RFID tags up to readers.

RFID stamp rally (Figure 5)

Instead of pressing stamps in a book, visitors held their RFID tags up to RFID readers placed around the venue. Visitors could receive prizes for visiting all designated RFID readers.

Electronic business card-less system (Figure 6)

Instead of dropping off a physical business card, visitors were able to hold their RFID tag up to RFID readers at exhibitor booths to supply their contact information based on their advance registration.

Paper-less pamphlet system (Figure 7)

Visitors were able to record a request for exhibitor pamphlets by holding up their RFID tag. Exhibitors, working through management, were then able to send electronic versions of pamphlets to the visitors who had requested them.

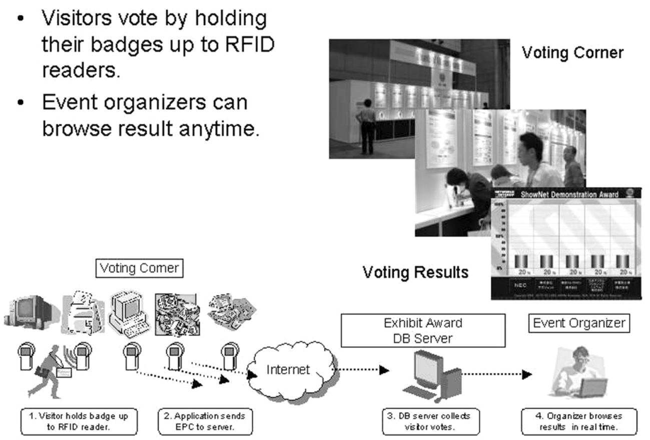

Fig. 4 Exhibit award voting system

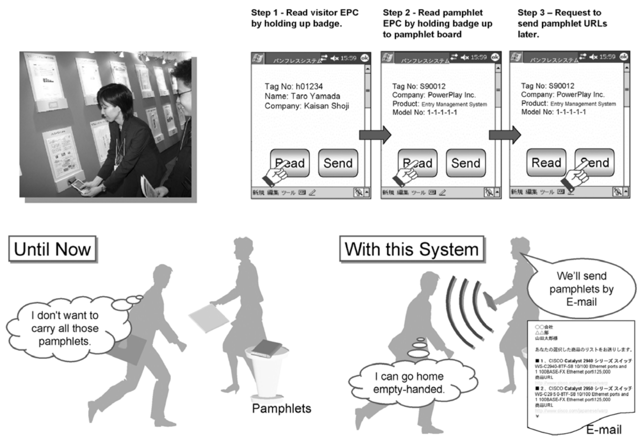

Fig. 7 Paper-less pamphlet system

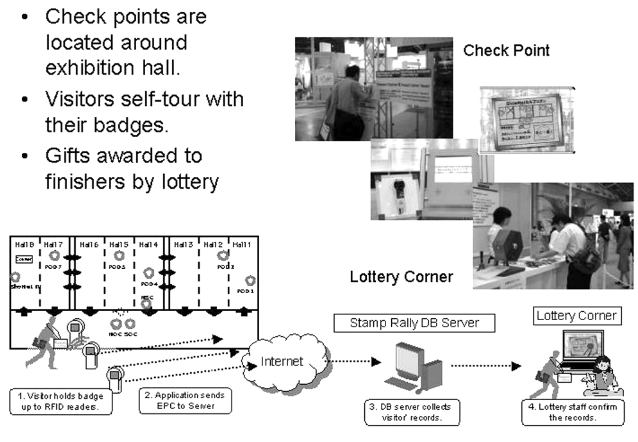

Fig. 5 RFID stamp rally

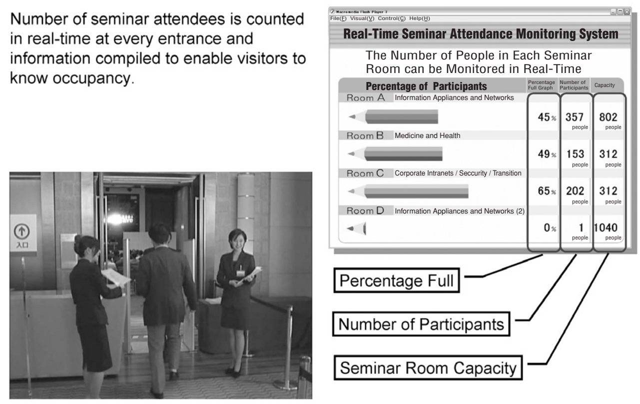

Fig. 8 Real-time monitoring system

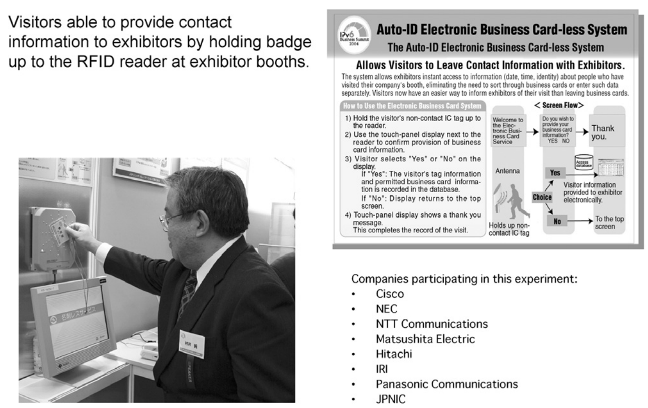

Fig. 6 Electronic business card-less system

Real-time monitoring system (Figure 8)
Monitoring of visitor attendance numbers in very close to real time.

2.2 Field testing of readability rates

Field tests undertaken to calculate readability rates are described below. To reduce the time required for on-site registration, almost all visitors to NetWorld+Interop 2004 Tokyo were encouraged to register in advance. After registering in advance, visitors were sent visitor identification badges printed with a visitor number bar code. Visitor numbers were unique and were used to distinguish visitors. Those who did not register in advance went through the registration process and received a visitor number at the same-day registration desk.

In order to provide assistance to visitors at the venue, visitor identification badges carried their visitor numbers (Figure 9). For the tests, visitor badges were equipped at this point with ISO 15693 compliant card-sized RFID tags that recorded each bearer's own XXX visitor number. These numbers formed the base for the various processes conducted by the event support system.

Fig. 9 Visitor badge

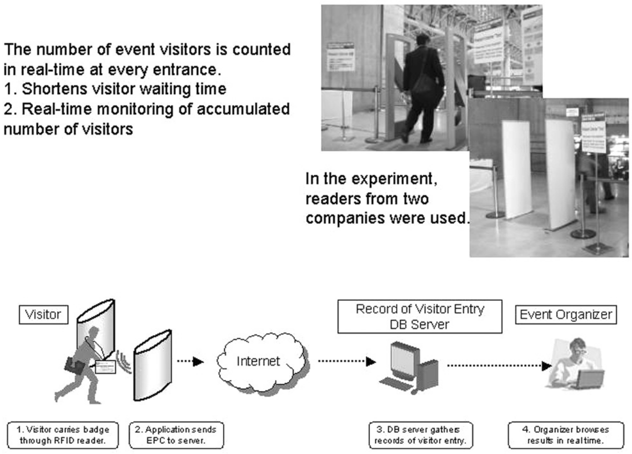

Fig. 10 Gate RFID reader and barcode reading

For the field test, existing systems were used for advance and same-day registration. RFID was then used to record entry.

Six entrances (Figure 10) were established at the venue. All visitors who had completed either advance or same-day registration passed through these entrances.

Each entrance was equipped with both an ISO 15693 compliant gate-style RFID reader that read visitor entry numbers automatically and staff who manually read the badges using barcode readers. Although both processes collected the same data it was important to do a complete count with barcode readers to satisfy the goal of investigating RFID readability rates.

RFID admission data was collected and processed through the visitor entry support system (Figure 11). Each gate-style RFID reader was connected to a network and accumulated data in the EPCIS. Monitoring and data pro-

Fig. 11 Visitor entry support system

cessing applications could access the EPCIS to use the accumulated data. ISO 15693 compliant gate-style RFID readers from two separate vendors were used.

3. CALCULATING RFID READABILITY RATES

The method for calculating readability rates and concrete steps of the process are presented below. In terms of the accuracy of the RFID visitor count, readability rate was defined as what percentage of actual visitors were captured through RFID. Given a total number of visitors A who passed through the gates and a total number of visitors B who were captured by the RFID readers, readability rate R_{ratio} can be expressed in Formula 1 below (unit = %):

$$R_{ratio} = A/100B \quad (1)$$

A and B in Formula 1 were calculated based on the data from the barcode readers and the RFID readers. Since all visitors to NetWorld+Interop 2004 Tokyo were captured using barcode readers the number of actual visitors A could be derived from the data recorded by the barcode readers.

Entry data captured by barcode readers was obtained once each time a given visitor passed through the entrance. Visitor entry data was recorded in CSV (Comma Separated Value) format and included the barcode reader ID, the last digits of the visitor ID and a time stamp.

Entry data captured by RFID readers was obtained multiple times and stored in a SQL database whenever a given visitor passed through the entrance. Figure 12 (Pre-Aggregation) lists VALUES phrases from INSERT statements, exported in the database dump format, for some of the visitor data recorded by the RFID readers. Each VALUES phrase includes the visitor ID, the RFID reader

```
Before Aggregation Processing

    (112773,6,'2004-06-30 10:34:15');
    (102656,5,'2004-06-30 10:34:15');
    (102656,5,'2004-06-30 10:34:16');
    (112773,6,'2004-06-30 10:34:16');
    (105520,5,'2004-06-30 10:34:16');

After Aggregation Processing

    (112773,6,'2004-06-30 10:34:15');
    (102656,5,'2004-06-30 10:34:15');
    (105520,5,'2004-06-30 10:34:16');
```

Fig. 12 RFID sample data and aggregation processing

ID and a time stamp.

A review of Figure 12 (Pre-Aggregation) reveals that the same visitor and same RFID reader are recorded multiple times. When a visitor enters, the entrance is either not recorded (RFID read failure), is recorded once (RFID read success) or recorded multiple times (RFID read success).

In order to derive the number of visitors recorded by RFID B from this database records, instances of multiple entries recorded in succession must be calculated as a single entry. To this end, a filter was defined as in Formula 2 below:

$$F_{filter}(ReadTrial) = \begin{cases} 0 \cdots (Read\ Failure) \\ 1 \cdots (Read\ Success) \\ 1 \cdots (Multiple\ Read) \end{cases} \qquad (2)$$

Applying the filter in Formula 2 to the sample RFID data in Figure 12 (Pre-Aggregation) renders the data in Figure 12 (Post-Aggregation). Using the data in its post-aggregated form makes it possible to derive the number of people recorded by the RFID readers(B).

Based on the above, the RFID readability rate R_{ratio} for a given sample of N operations can be derived using the defined filter F_{filter}, as shown in Formula 3 below (unit=%):

$$R_{ratio} = \frac{1}{100N} \sum_{p=1}^{N} F_{filter}(ReadTrial_p) \qquad (3)$$

4. EVALUATING VISITOR RFID READABILITY RATES

The field tests at NetWorld+Interop 2004 Tokyo were applied to all visitors throughout the entire period of the event. Although event management was cooperative in providing the data, the experimenters were required to enter into a confidentiality agreement committing them to use the data only within a range that did not reveal overall attendance trends. In accordance with this agreement, calculation of readability rate was based on a limited sample of the available data. Specifically, calculation of readability rate was based on data recorded by barcode readers and RFID readers at all entrances over a limited period of time.

For this paper, readability rates were calculated using six samples. Each sample is made up of data recorded by barcode readers and data recorded by RFID readers. Each of the sample data sets was processed and the readability rate calculated.

In order to identify any differences in performance between RFID reader vendors the six samples (Table 1) were selected to include data from all of the RFID readers used in the experiment. All samples were based on data recorded by barcode and RFID readers over a set period of time on 2 July 2004. Entrances were numbered 1 through 6 and include all venue entrances used for the event.

Figures 13 and 14 describe two of the test samples. Vertical axes indicate visitor ID while horizontal axes indicates the passage of time. Each dot on the graph represents a record of a visitor passing through the entrance. Note that because it was not possible to synchronize the barcode readers used in the tests, the start and end time for the left and right graphs do not necessarily match.

Turning to the vertical axes for each graph, note that visitor IDs below 100,000 were test IDs used by staff performing system management and so do not appear on the left-side graphs. Visitor IDs in the 100,000s were assigned randamly to those who registered in advance and the dots overall seem generally to exhibit an even distribution. Visitor IDs in the 200,000s were assigned to those who underwent same-day registration and received their IDs for the first time on-site. Such registrations increase in a roughly linear fashion over time and indeed the dots on the graph show a tendency to a simple increase over time.

Table 1 Sample details

Sample No.	1	2	3	4	5	6
Entrance No.	1	2	3	4	5	6
RFID Reader Vendor	Company A		Company B		Company A	
Date Data was Obtained	2 July 2004					

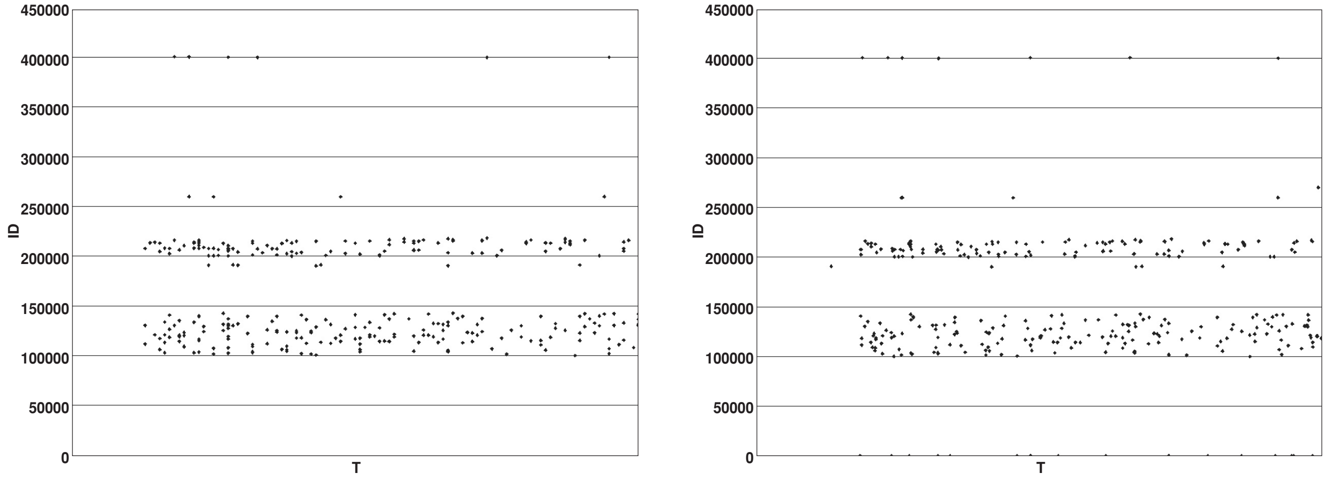

Fig. 13 Reading events from sample 3 (Left = Barcode: Right = RFID Gate)

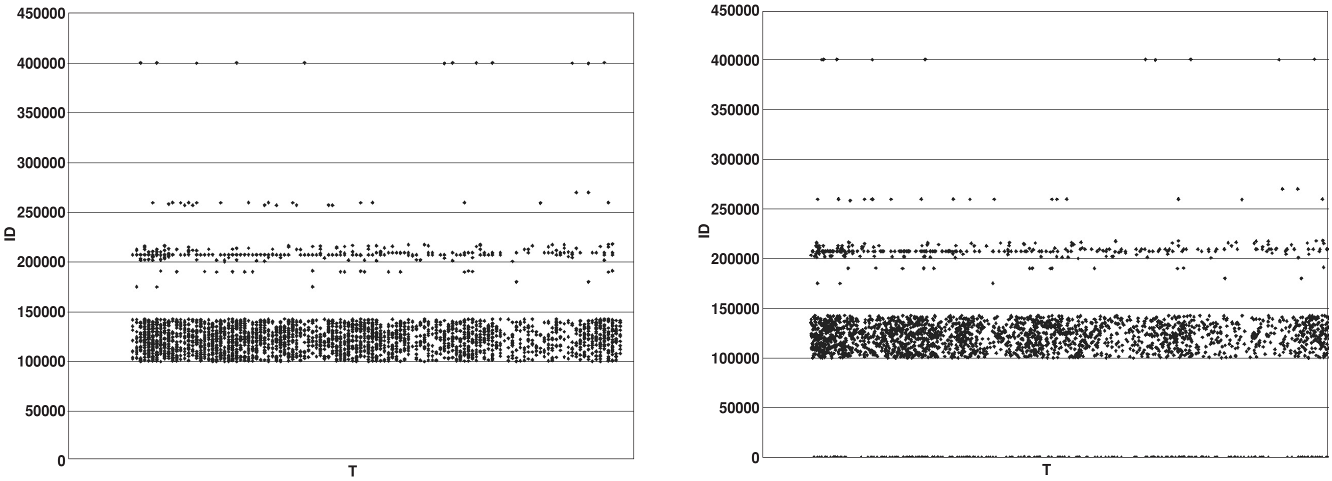

Fig. 14 Reading events from sample 6 (Left = Barcode: Right = RFID Gate)

A quick comparison of the graphs on the left with those on the right in Figures 13 and 14 shows that both recorded the visitors entries in substantially the same way. Seen in detail, because the smallest unit of time for the barcode reader was one minute there appears to be a more uniform distribution in the graphs on the left than on the right.

4.1 Evaluating field trial readability rates

Readability rates were derived for each of the six samples by applying Formula 3. Results are compiled in Table 2. The average readability rate for all samples was 96.80%. The highest readability rate among the samples was 99.80%; the lowest was 93.78%.

Table 2 Readability rates for each sample

Sample No.	1	2	3	4	5	6
RFID Tags Read Counts	2,026	1,551	314	180	633	2,620
Barcodes Read Counts	2,030	1,642	328	188	675	2,703
Readability Rate(%)	99.80	94.46	95.73	95.74	93.78	96.93

A comparison of gate antenna reader vendors is presented in Table 3. The readability rate by vendor is based on significance testing using the bootstrapping method with a null hypotheses that "the sample populations for the company A's reader and Company B's reader are identical." In more concrete terms, the bootstrapping method was used to conduct sampling that divided the two vendors' samples randomly in numbers equal to those of Company A's samples and Company B's samples. Sampling was conducted 10,000 times and a frequency table composed of the differences in readability rate. Evaluating the difference in readability rate between the two vendors as actually measured against the frequency table, the null hypothesis could not be rejected at a threshold of significance of 80% and so no significant difference was found. (The bootstrapping method provided a value of 84.24% but given the possibility of sampling error 80% was used instead.)

Table 3 Readability rates by vendor

	Company A	Company B
RFID Tags Read Counts	6,830	494
Barcodes Read Counts	7,050	516
Readability Rate(%)	96.88	95.74

The experiment enabled the collection of basic data from measurements of the movement of people at event venues using RFID tags and gate antenna readers. In particular, while a large number of experimental subjects exhibited various behavior it was possible to hide measurement error caused by arbitrary behavior and achieve results with little bias.

Followings are two possible reasons why the readability rate was not perfect.

There were a few people without RFID tags:

The field test was conducted in accordance with "the Guidelines for Privacy Protection with regards to RFID Tags"[7] recommended by the Ministry of Economy, Trade and Industry of Japan and the Ministry of Internal Affairs and Communications of Japan. In accordance with Article 4 of those guidelines, visitors were able to elect not to carry an RFID tag. In other words, there is a slight discrepancy between the population measured by barcode readers and the population measured by RFID tags. The confidentiality agreement entered into with event management prevents release of both the number and percentage of visitors who elected not to carry RFID tags, but it is possible to report the percentage alone. The percentage of visitors who elected not to carry RFID tags during the experiment fell well short of 0.1%.

In addition, it is also conceivable that some visitors may have intentionally destroyed or concealed their tags, although the number of people who would behave in such an arbitrary manner is presumed to be well within the experiment's margin of error.

Obstruction of radio waves by visitor belongings:

Some visitors also may have been carrying working RFID tags that were not read correctly. Because the test took place at an exhibition of networking equipment, many visitors carried laptop computers or other non-RFID electronic equipment, creating conditions conducive to radio wave attenuation or shielding. Readability dropped markedly when visitors entered with laptops or other luggage clutched to their chests. Likewise, carrying a mobile phone on a lanyard around the neck can, depending on the location of the RFID tag, create difficulties in reading the tag.

Most of the readability difficulties experienced for this experiment are believed to be due to this second reason.

5. SUMMARY AND DISCUSSION

This paper evaluated the accuracy of information in a visitor support system designed to capture the number of visitors to large events.

The experiment involved the development and operation of a system for collecting data from RFID tags carried by each visitor using gate-style RFID readers installed at venue entrances. The experiment was carried out at NetWorld+Interop 2004 Tokyo, a large-scale event with 150,000 visitors, and meaningful data was collected. This paper defined the accuracy of visitor numbers captured using RFID as "readability rate" and calculated the readability rate based on six samples selected from the collected data. Samples were selected in a way to enable recognition of any difference in readability rate by vendor. The average readability rate for all samples was 96.80% with the highest readability rate at 99.80% and the lowest at 93.78%. Furthermore, the null hypothesis that "the sample populations for the company A's reader and Company B's reader are identical" could not be rejected at a threshold of significance of 80% and so no significant difference was found. These readability rates revealed that the actual number of visitors was between 1.01 and 1.07 times the number of visitors recorded by RFID. The paper also discussed how the primary reason the readability rate did not reach 100% was likely the use of laptop computers and other electronic equipment by visitors.

Generally speaking, it is extraordinarily difficult to attain perfect read accuracy using today's RFID technology. In this experiment, situations were observed where the influence of carried items prevented accurate reading. At events where RFID tags must be carried by individuals, some improvement in readability rates might be gained by using signs instructing people to keep electronic devices away from their RFID tags as they pass through the gate readers but even then it would be difficult to reach a readability rate of 100%.

The debate should shift, therefore, to the selection of applications that are meaningful even at readability rates of less than 100%. From the point of view of visitor RFID reader behavior, event-use RFID applications can be classified in the following two groups:

1) Applications requiring rigorous successive readings.
2) Applications that do not require rigorous successive readings.

Category 2 can further be divided into the following two sub-categories:

2a) Applications for which repeated readings are both necessary and possible.
2b) Applications for which repeated readings are unnecessary or impossible.

According to this classification, systems for event entrance admissibility management systems using gate-style RFID readers fall into category 1. In the same way, the voting and stamp rally systems fall into category 2a while the visitor entry support system falls into category 2b.

Given the readability rate results calculated in the preceding section, it is feasible to create a category 2b application to capture the overall number of visitors using the visitor entry support system. The application categorizations presented here are not a numerical index and there is probably a need to define the level of rigor that separates categories 1 and 2.

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