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Impacts Of Smart Cards On Transit Operators: Evaluation Of I-110 Corridor Smart Card Demonstration Project

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Impacts of Smart Cards on Transit Operators: Evaluation of I-110 Corridor Smart Card Demonstration Project

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**IMPACTS OF SMART CARDS ON TRANSIT OPERATORS:
EVALUATION OF I-110 CORRIDOR SMART CARD DEMONSTRATION
PROJECT**

FINAL REPORT

by

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IMPACTS OF SMART CARDS ON TRANSIT OPERATORS:
EVALUATION OF I-110 CORRIDOR SMART CARD DEMONSTRATION PROJECT

Abstract

This report presents the evaluation results of the first transit smart card demonstration in California. The transit smart card system, configured by Echelon, was deployed on one bus line of each of the three participating transit agencies (LA DOT, Torrance Transit, and Gardena Transit). This study assesses the cost and benefit implications of the smart card system to transit agencies, using data obtained from interviews of transit personnel, independent onboard observations, and personal communications with Echelon.

The evaluation indicates that the smart card system works smoothly and reliably in real-world conditions during this six-month demonstration period. Passengers and all transit personnel like smart cards due to perceived convenience and faster fare transaction speed than other fare media, particularly cash fares. In addition, smart cards are found to reduce fare transaction time, vehicle down time, and driver workload and stress. Just as importantly, the smart card system can be a much more cost-effective means of collecting improved transit data (than methods currently used) for planning and reporting purposes.

Key words: smart card, transit, bus operation, transit data

EXECUTIVE SUMMARY

Transit "smart cards" are an automated fare technology with an integrated circuit, memory, as well as processing and communication capabilities. The field operational test (FOT) of smart cards, which took place between August 1994 and January 1995, was the first for California. Its primary purpose was to demonstrate whether a transit smart card system would work well and reliably in real-world bus operations. Three transit agencies (LA DOT, Torrance, and Gardena) participated in this FOT. One bus line from each agency was selected for the smart card demonstration -- LA DOT Commuter Express 448, Torrance Route 2, and Gardena Route 1. A total of 15 buses equipped with smart card units were used on these bus lines.

With a modular system design, the smart card system implemented in this FOT had fare collection capability, automated vehicle location, speed and acceleration monitoring, passenger and driver interface, and data storage. The smart card system was also capable of providing displays, printing, stop/promotional announcements, and automated passenger counting, with limited tests conducted on the first two capabilities during the FOT.

Two types of smart cards were used -- radio frequency (RF) proximity smart cards for LA DOT and Torrance, and GEMPLUS (contact) smart cards for Gardena. RF smart cards are activated by passing them within 3 to 5 inches of the card reader, and contact smart cards by inserting them into the card reader. About 600 smart cards were issued to passengers of the three transit agencies. Each smart card stores pre-purchased trips, which were debited each time the card was used.

Research Objective

The objective of this research is to assess the cost and productivity implications of the smart card system to transit agencies, as well as transit personnel perceptions of the smart card system.

Research Methodology

The assessments of the cost and productivity impacts of smart cards as well as the perceptions of transit personnel were accomplished through personnel interviews and independent onboard observations.

Principal Research Findings

Relative Costs of Fare Collection Utilizing Smart Card and Fare Box Technologies

The total cost of a fare collection system includes the capital, administration, maintenance, repairs, and data collection and retrieval costs. The annual total cost of fare collection utilizing the smart card system ranged from being similar to about 34 percent lower than that utilizing fare boxes (i.e., \$1,300-2,513 per bus per year for the former versus \$1,970-2,518 per bus per year for the latter).

Productivity Implications

The productivity impacts determined for the smart card system relative to the fare box include: productive use of vehicle (passenger boarding times, vehicle dwell times at bus stops, and vehicle down-time due to malfunctions of the fare collection system), amount and quality of data, driver performance and workload, perception of transit personnel, and fare fraud. It was found that smart cards reduced average passenger boarding time by up to 150 percent relative to cash fares. Boarding times for smart card users were also much more predictable than those for cash passengers. However, vehicle dwell times at bus stops with or without smart card use were not significantly different. Vehicle down-time due to malfunctions of the fare collection system for the smart card system was about 0.10 to 0.15 times that for the fare box.

Smart cards enable transit agencies to collect existing transit data more cheaply and reliably, virtually eliminating the labor required for manual data collection activities. Smart cards also allow transit agencies to collect new data for use in transit planning that cannot be done with data currently available from fare boxes plus supplemental ride-checking. Managers of the three participating transit agencies considered these potential data benefits to be a particularly important incentive for deploying smart card systems.

Drivers of the participating transit agencies preferred smart cards to cash fares and passes. They perceived that smart cards had positive impacts on their workload and performance. Smart cards also gave drivers considerable job satisfaction because they knew passengers liked using smart cards. Managers, dispatchers, route supervisors, and maintenance crew of the three transit agencies all preferred smart cards to the fare box. They were all satisfied with the reliability and performance of the smart card system during the FOT.

Opportunities Due to Systemwide Smart Card Use

Systemwide use of transit smart cards would provide opportunities for transit agencies to improve transit services and operations; for example:

- * The use of multi-line and/or multi-modal smart cards will enhance customer service and convenience.
- * Systemwide use of transit smart cards will enable transit agencies to establish low-cost, quality transit management information systems. Improved transit data in turn will enable transit agencies to do more demand-responsive planning, routing, and scheduling aimed to increase transit ridership and revenue.
- * Extensive use of smart cards will facilitate the implementation of innovative fare policies to increase ridership and revenue, as well as to capture new markets.
- * Extensive use of smart cards will provide the opportunity for some transit agencies to adopt advanced fare collection systems that integrate a smart card system with an advanced electronic fare box.

Constraints Pertaining to Systemwide Deployment of Smart Cards

There is currently no "road map" to guide transit agencies from this successful but limited FOT toward systemwide implementation of smart cards. Issues related to systemwide deployment of smart cards faced by transit agencies include: funding for large capital expenditures; clearing houses for administration, sales, and marketing of smart cards; procedures for distributing revenue to transit agencies providing services (in multi-line or multi-modal transit markets); requirements of additional skilled personnel (a particularly important issue for small transit agencies); and the flexibility of hardware and software design to meet differing needs of different transit agencies.

Conclusions

The first smart card FOT in California has demonstrated that smart card systems worked well and reliably in real-world bus operations. The popularity of smart cards with bus riders exceeded expectation of the participating transit agencies. Personnel of these agencies believe that smart cards are a superior fare technology to existing fare boxes.

The capital cost for first-generation smart card systems, such as the one deployed in this FOT, is higher than the that for a fare box. However, the capital cost for a smart card system is likely to decrease with greater use and/or as component technologies mature. Operating costs for the smart card system are lower than those for a fare box, resulting in the annual total cost for the smart card system to range from being similar to 34 percent lower than that for a fare box.

This first smart card FOT was limited in the implementation scope, objective, and duration.

Therefore, all estimates of cost and productivity implications of the smart card system presented in this report should be considered as preliminary (albeit the best approximations) at this time.

CHAPTER ONE

INTRODUCTION

1.1 LITERATURE REVIEW

A variety of automated fare card technologies exist for transit. When classified by communication technique (i.e., methods to transfer information between the card and the read/write unit), these technologies can be grouped into magnetic stripe, integrated circuit (IC) contact, radio frequency (RF), close coupling (capacitive), remote coupling (inductive), laser/optical, and bar-coding. Within each group, the cards can be further classified by whether they are "smart" (i.e., containing a microprocessor). Magnetic stripe fare cards have limited capacity to store information; dirt, chemicals or grime can easily interfere with the contact to degrade performance. At the present time, many transportation professionals consider RF and IC cards to be promising advanced fare technologies (Bushnell, 1995).

RF smart card systems have the ability to do fare collection remotely, without requiring contact between the card and card reader. Depending on read distance and transaction speed requirements, RF systems may be short range (proximity) or long range. The former usually has a range of less than a few feet, while the latter about 20-50 feet. The potential read distance of RF systems can be limited by factors such as frequency and signal strength. RF transit smart cards use so little RF power that Federal Communication Commission (FCC) licensing is not required.

IC contact systems typically use embedded microelectronic circuits connected to metallic contact pads on the card surface. Information is communicated between the card and card reader through electrical contacts. Therefore, the card must be inserted into the reader to transmit information. The primary concern for IC contact smart cards is the wearing of the surface contacts, although the cards generally withstand water and dirt quite well.

There are currently few applications of transit smart cards in the U.S. However, several cities and counties have pursued or are currently pursuing the deployment or field testing of transit smart cards. They include (e.g., Bushnell, 1995):

- o Northeastern Illinois Regional Transportation Authority, Chicago, adopted an IC contact card system for paratransit services in 1992. It automated rider-carrier transactions, prepared payment and performance reports, and certified cardholder access to paratransit services. About 6,000 cards were issued to frequent users. Each card had a memory capacity of 16K bits.
- o Ann Arbor Transportation Authority established an RF system test bed for buses and parking (i.e., a multi-modal application), with a view to: testing RF smart cards in real-world conditions; evaluating the viability of RF smart cards for transit services; and determining the feasibility of integrating an advanced fare system with an advanced vehicle location system. Three options were considered -- a card with a button to activate an alarm at a bus stop or parking lot (thus acting as a personal security device); a card providing real-time traveler information about vacant spaces in parking lots; and a card providing better customer usage information.

- o Greater Manchester Passenger Transport Executive in England was scheduled to adopt RF Proximity smart cards in 1994. Initial implementation called for the use of 500,000 cards for 2,700 buses and 350 rail and Metrolink locations. About 800 card renewal locations were planned. The smart cards were debit cards. The cards could be read at a distance of up to 3.5 cm from the card reader. The typical communication cycle including reading and writing took about 0.3 seconds.
- o Other transit smart card projects in the U.S. include: Washington D.C. Metro Area Transit Authority (RF coupling system); and O' Hare International Airport's ground transit system in Chicago (RF system).

1.2 CALIFORNIA FIELD OPERATIONAL TEST (FOT)

The field operational test (FOT) of a smart card system presented here is the first of its kind for California. The primary purpose was to demonstrate whether a transit smart card system configured by Echelon (to be called the Echelon smart card system) would work reliably in real-world bus operations. Three transit agencies (LA DOT, Torrance, and Gardena) participated in this FOT. The Institute of Transportation Studies (ITS) of the University of California at Berkeley (UCB) was charged with evaluating the impacts of smart card use on the transit agencies. Specifically, the evaluation focuses on the cost and productivity implications and transit personnel's perceptions of the smart card system. The University of Southern California (USC) was charged with assessing the perceptions of smart card users and the reliability of the smart card system. The USC's research and findings are presented in a separate report (Giuliano and Moore, 1995).

Many organizations were involved in implementing this FOT -- Caltrans, Caltrans District 7, Echelon, and the three transit agencies. From the outset of the planning phase, it was agreed that the FOT would not disrupt normal operations of the participating transit agencies. Caltrans District 7 and Echelon were in charge of the planning as well as installing, testing, and disassembling the smart card system. Caltrans District 7 was also in charge of recruiting smart card users and issuing smart cards. Echelon was responsible for maintenance, repairs, "trouble shooting", and data retrieval. No costs were incurred to the three transit agencies; their involvement was to designate one bus line each to receive the Echelon smart card system.

Echelon Smart Card System

The Echelon smart card system deployed during the FOT consisted of the vehicle unit and the card. The vehicle unit consisted of an integrated control plus passenger interface box, and a driver interface box. With a modular system design, the smart card system provided a fare collection function, automated vehicle location (with a Global Positioning System receiver), speed and acceleration monitoring, passenger and driver interface (schedule adherence, passenger transaction data, and operational status), and a control unit (data storage). Limited tests of the display, and printing/receipt transfer systems were conducted during the FOT. Although not deployed during the FOT, the smart card system was also capable of providing stop/promotional announcements and automated passenger counting systems.

Two types of smart cards were used during the FOT -- radio frequency proximity cards

(RF smart card) were used on the LA DOT and Torrance lines, and GEMPLUS cards (contact smart cards) were used on the Gardena line. The RF card is activated by passing it within 3-5 inches of the card reader, and the contact card by inserting it into the card reader.

About 600 smart cards were issued to passengers of the three transit agencies during the first month of the FOT. Each smart card stores a certain number of pre-purchased trips, which were debited each time the rider boarded a bus and the card was used. When a rider boarded a bus again at a different time, another trip was debited from the card. Because only one bus line of each of the participating transit agencies was equipped with the smart card system during this six-month demonstration, smart cards could not be used when riders transferred onto different bus lines. Paper transfers were still issued by bus drivers.

The smart card could be renewed once during the FOT. For the LA DOT line, renewals were done onboard the bus by drivers. For the Torrance and Gardena lines, renewals were done at the Caltrans District office and remotely. The latter was accomplished by Caltrans providing Echelon with the card numbers to be renewed. This information was then input into the vehicle control unit, and the card renewal took place automatically while paying for a trip.

Designated Bus Routes

The Echelon smart card system was used on LA DOT Commuter Express 448, Torrance Route 2, and Gardena Route 1. LA DOT Commuter Express 448 operates during peak periods between downtown Los Angeles and Palos Verdes. Existing fare media are cash, tokens, and passes. This bus line uses four buses, and six buses were equipped with smart card units. LA DOT does not operate a bus fleet, but competitively contracts for operation of its bus services.

Torrance Route 2 provides a combination of local and commute trips. The existing fare medium is primarily cash (50 cents for a local trip and one dollar for an LA-bound trip). This bus line uses three buses, and five buses were equipped with smart card units. Altogether, Torrance operates 63 buses on nine bus lines and a shuttle route.

Gardena Route 1 provides a combination of local and commute trips. Existing fare media are cash and tokens. This bus line uses 8 buses, and 10 buses were equipped with smart card units. Gardena operates a total of 50 buses and 4 bus lines.

1.3 RESEARCH OBJECTIVES

The objectives of this research are to assess:

- * The cost and productivity implications of the smart card system to the transit agencies, relative to fare boxes.
- * The perceptions of various personnel of the transit agencies of the smart card system relative to fare boxes.

1.4 RESEARCH METHODOLOGY

Many transportation professionals believe that potential benefits of transit smart cards lie in the improvement of transit system performance. Transit system performance, which can be represented by customer service and system productivity, is influenced by a myriad of variables; for example, policy decisions, operating practices, maintenance practices, fare policy, fare collection technology, and line and office personnel.

Customer Service

In the context of smart card use, customer service includes: customer satisfaction with fare collection, the ease of fare payment, and the convenience of acquiring and renewing smart cards.

Productivity

Transit agency's productivity is usually expressed as system efficiency and effectiveness. Efficiency is the extent to which system inputs are employed to produce outputs. For smart card use, efficiency can be measured by the following criteria:

- * Costs of fare collection and related activities, which include both fixed and variable costs.
- * Productive (or efficient) use of vehicle, which includes: passenger boarding time; vehicle dwell time at bus stops; and vehicle down-time due to malfunctions, failures and repairs of the fare collection system.
- * Amount and quality of data available from the fare collection system.
- * Driver performance and workload.
- * Perceptions of transit personnel.
- * Fare fraud.

This research focuses on the evaluations of these six efficiency criteria. Each evaluation involves comparing the criteria between the Echelon smart card system and the fare box. Data input for the evaluations comes from two sources -- interviews of personnel of the participating

transit agencies, and onboard observations conducted by the research team.

System effectiveness is related to transit ridership and revenue. Changes in transit ridership and revenue as a result of the smart card FOT are not examined in this report for a number of reasons. First, the FOT was limited in the number of bus lines involved and smart card users. Second, the FOT's period was too short to enable detection of meaningful changes in these quantities.

Interviews of Transit Personnel

We conducted interviews of bus drivers, dispatchers, supervisors, maintenance personnel, and managers of the three transit agencies toward the end of the field operational test (December 1994 and January 1995). This was in order to allow these personnel to have as much experience operating the smart card system as possible. For each transit agency, the personnel were interviewed individually. Overall, a total of 11 bus operators, six supervisors, six dispatchers, two maintenance persons, and six managers from the three agencies were interviewed.

Onboard Observations

Some information needed for the evaluation was not available from personnel interviews; for example: passenger boarding times, vehicle dwell times at bus stops, and onboard interactions between bus drivers and passengers. These data were collected by means of onboard observations conducted by the UCB's researchers, with assistance from the USC's researchers. Table 1.1 shows the information collected during these onboard observations.

Table 1.1: Data Elements Collected in Onboard Observations

Bus stop location
Time
Number of passenger boarding
Number of passengers using cash
Number of passengers using tokens
Number of passengers using passes
Number of passengers using transfers
Number of passengers using smart cards
Number of passengers requesting transfers
Number of passengers asking about fares
Number of passengers paying fares after the bus takes off
Number of passengers being reminded of insufficient fares
Number of passengers asking drivers questions
Total boarding time
Vehicle dwell time
Did boarding or alighting take more time?
Unusual events

For each bus line, onboard observations were conducted for 3 days in the period before the start of the FOT (June-July 1994, the "before" period), and for 2 days during the smart card deployment (the "after" period). For the LA DOT line, the after period was in November 1994. For the Gardena and Torrance lines, the after period was in December 1994.

1.5 ORGANIZATION OF THE REPORT

The remaining portion of this report consists of four chapters. Chapter two presents the comparison of costs of fare collection utilizing the smart card system and the fare box. Chapter three presents the impact of smart cards on the transit agencies' productivity -- productive use of vehicle, data quality, driver performance and workload, perceptions and workload of other transit personnel, and fare fraud. Chapter four describes opportunities for transit agencies to improve services and operations as a result of extensive smart card use. Finally, chapter five presents conclusions of this research.

CHAPTER TWO

FARE COLLECTION COSTS

This chapter compares the costs of fare collection between the Echelon smart card system and the fare box. For fare collection utilizing fare boxes, the capital cost is the price of the fare box; the operating costs include maintenance/repairs of the fare box, data retrieval, supplemental data collection, and printing bus transfers. For fare collection utilizing the smart card system, the capital cost consists of the prices of the card and the vehicle unit; the operating costs include administration, sales, and marketing of smart cards, as well as maintenance and repairs. Because the smart card system automatically records, stores, and retrieves data, it does not incur manpower costs for manual data retrieval and supplemental data collection activity. Also, the smart card system essentially eliminates the cost of printing bus transfers.

The comparison of costs between the Echelon smart card system and the fare box involves comparing their total annual costs, as shown in Table 2.1.

Table 2.1: Annual Costs of Smart Card System and Fare Box

Cost Component	Annual Cost Per Fare Box Per Bus	Annual Cost of Smart Card System Per Bus
<u>Capital</u> vehicle unit card	\$220 - \$543 n/a	\$734 - \$1,468 \$21 - \$106
Administration, sales, marketing	n/a	\$500 - \$1,000
Maintenance, repairs	\$850	\$45
Data retrieval	\$550	negligible
Supplemental data collection	\$225 - \$450	n/a
Printing transfers	\$125	n/a
Total	\$1,970 - \$2,518	\$1,300 - \$2,513

The capital costs are fixed costs incurred once at the outset. The remaining cost components are annually recurring costs. For comparison purposes, the capital cost is annualized by distributing it over the entire service life of the system, using the following formula:

$$\text{Annualized capital cost} = (\text{Fixed capital costs}) \times (\text{CRF})$$

CRF, the cost recovery factor, is expressed as:

$$\text{CRF} = \frac{i(1+i)^n}{(1+i)^n - 1}$$

where i is interest rate
 n is the service life

Table 2.1 indicates that the annual total cost of fare collection utilizing the fare box ranges from \$1,970 to \$2,518 per bus per year, while that utilizing the Echelon smart card system ranges from \$1,300 to \$2,513 per bus per year. Therefore, the annual total cost utilizing the smart card system ranges from being similar to about 34 percent lower than that utilizing the fare box. Please note that these relative annual total costs of the two systems do not reflect the fact that more and better quality data are available from the smart card system than from the fare box plus supplemental surveys.

Details of various cost components for the two systems are separately presented below.

2.1 FARE COLLECTION UTILIZING FARE BOX

2.1.1 Capital Costs

The 1993-1994 purchase price of each fare box (plus necessary software) used by the three transit agencies range from \$1,500 to \$3,700. The lower-end price of \$1,500 (for LA DOT's fare boxes) is lower than typical prices of most fare boxes.

The annualized values of these amounts, based on an assumed service life of 12 years and a 10% interest rate (commonly used for transit services), are \$220 to \$543 per fare box per year.

2.1.2 Maintenance Costs

The coin mechanism of a fare box frequently requires minor fixing due to jammed coins/money and daily wear-and-tear. Many interviewed bus drivers and route supervisors indicated that up to 90 percent of jammed-box incidents are probably corrected by bus drivers themselves without involving maintenance crew or exchanges of fare boxes. Based on information obtained from transit personnel interviews, we estimate that maintenance personnel are required to fix the coin mechanism about 15-20 times per fare box per year. This task can be accomplished in 15-20 minutes. An estimated cost for fare box maintenance is on the order of \$200 per fare box per year.

2.1.3 Repair Costs

Major repairs of fare boxes can be performed by the manufacturer through a service contract issued for each fare box. This service contract can be purchased for around \$600 per year per fare box. This contract covers both parts and labor, but not shipping (which is assumed to be another \$50 per fare box per year). The cost of a service contract plus shipping (a total of \$650) can be viewed as an average repair cost per year for a fare box.

2.1.4 Costs of Data Retrieval

Money counting and fare-box data retrieval are done manually by transit personnel. From interview information, we estimate that money counting requires about 8 to 12 person-hours per year per fare box. Fare-box data retrieval requires another 10 person-hours per year per fare box. Therefore, the total costs of counting money and retrieving fare box data are estimated to be \$550 per fare box per year.

2.1.5 Costs of Collecting Supplemental Data

In addition to fare box data, transit agencies also regularly collect ridership data through some kind of onboard survey. For example, LA DOT conducts quarterly onboard surveys to count passenger boarding and alighting for each bus line. These surveys typically involve a supervisor riding in a bus and checking passenger boarding and alighting. The cost of conducting supplemental surveys is likely to vary from agency to agency, and has been reported by one study (Echelon, 1995) to be about \$225-\$450 per bus per year.

2.1.6 Costs of Printing Bus Transfers

The cost of printing bus transfers has been reported by one study (Echelon, 1995) to be up to \$125 per bus per year.

2.2 FARE COLLECTION UTILIZING SMART CARD SYSTEM

2.2.1 Capital Costs

The capital cost for the Echelon Smart Card System consists of the card and the vehicle unit. The price of the card depends on how many functional capabilities the system provides, and the amount of required computer memory. A higher number of functional capabilities (and thus greater required memory) increases the cost per card. At the present time, each smart card is estimated to cost between \$2 and \$10 (depending on the amount of required computer memory) for the kinds of functional capabilities desired by most transit agencies (Rebeiro, 1995). This cost is expected to be lower with mass production. GEMPLUS contact cards are expected to last four to five years, with the contact being the vulnerable component. RF smart cards are expected to last longer, barring manufacturing defects or severe use abuses. In determining the capital costs of smart cards per bus, we assume that the average number of card users per bus is the same as that during the field operational test (i.e., about 40 smart cards per bus). This yields the capital cost of \$80-\$400 per bus over the service life of the cards. The annual value of this amount, based on a five-year service life of the card and a 10% interest rate, is \$21 to \$106 per bus per year.

For the vehicle unit, a card reader alone costs about \$150-\$300 (Rebeiro, 1995). Additional components (e.g., vehicle location system, automated passenger counting system, printer, etc.) add substantially to the purchase price. A complete system that provides fare collection, vehicle location, speech production, automated passenger counting, printing of receipts, and data upload and download is estimated to be between \$5,000 and \$10,000. This cost includes

the complete system, software, installation, testing, and one-year service (Echelon, 1995).

The Echelon smart card system does not have enough on-the-road experience to permit the determination of the vehicle unit's service life under real-world operating conditions. For the annual cost estimation purpose, the vehicle unit is assumed to last for at least 12 years. Its annual capital cost, based on a 12-year service life and a 10% interest rate, is \$734-\$1,468.

Components of the Echelon smart card system, like any new technology that still lacks maturity, are likely to need upgrading every 2-3 years as advanced technologies mature over time. At the present time, it is not possible to determine the costs of such upgrades.

2.2.2 Administration, Sales, and Marketing Costs

The smart card deployment involves administration, sales, and marketing of smart cards. Transit personnel are needed to perform these tasks, as well as to address stolen and lost cards. Evidence from this field operational test indicates that lost and stolen cards account for up to 3 percent of all cards issued. This percentage is likely to be higher than that in future systemwide smart card use, due to the novelty of the first field demonstration.

Assuming that one full-time staff person is needed to handle all of these tasks for each transit agency, the administration, sales, and marketing costs of smart cards per year are estimated to be about \$500-\$1,000 per bus.

2.2.3 Maintenance/Repair Costs

Components of smart cards are mostly electronic. In case of failure of an electronic component, it is likely to be more economical to replace the component (or module) than to repair it. A diagnostic program, incorporated as an integral part of the smart card system, helps to test and warn of any impending component failure. The above estimated purchase price of the vehicle unit includes this diagnostic capability.

At the present time, the Echelon smart card system does not have enough on-the-road experience to permit a reliable assessment of time-to-failure for the various components. Components that may need replacement during the service life of the unit are the driver-unit key pad, power supplier, and printer, particularly if they are subjected to rough use or mishandling. A "guesstimate" of the costs for maintenance, replacements, stockpile of spare parts, and labor during the lifetime of the vehicle unit is on the order of 5 percent of its purchase price (Rebeiro, 1995). This yields an estimate of maintenance and replacement costs for the smart card system of about \$45 per bus per year.

Evidence from this FOT suggests that the above estimate of maintenance and replacement costs for the vehicle unit is probably quite reasonable. During the FOT, maintenance and repairs of all smart cards and vehicle units were done by Echelon, without involving personnel of the three transit agencies. The cards themselves were found to have good reliability during the FOT. Echelon (1995) reported that the contact smart cards incurred one failure for every 1,000 card transactions. The RF cards experienced two failures in about 24,000 card transactions.

The number of person-hours required for repairs of the vehicle unit during the six-month

FOT follows:

- o For Gardena, there were two recorded equipment incidents, one of which required replacement of a screen. Both incidents required less than 0.4 person-hours to remedy (excluding problem diagnoses).
- o For LA DOT, there were four recorded equipment incidents, one of which required replacement of power blocks. These four incidents combined required about 0.5 person-hours (excluding problem diagnoses).
- o For Torrance, there were three recorded equipment incidents, none of which required replacement. The three incidents required about 0.1 person-hours (excluding problem diagnoses).

2.2.4 Costs of Data Collection and Retrieval

During the FOT, Echelon's staff retrieved data from the smart card system once a week, by mechanically (manually) pulling the equipment off the vehicle unit. Then, the computer files containing the data were processed by Echelon, using pre-written software. The entire data retrieval could be accomplished in a matter of minutes. In future deployments of similar smart card systems, this entire process will be fully automated, and data can be transmitted on-line. This will eliminate labor costs for data collection and retrieval.

Please note that the smart card system can potentially generate revenues for the transit agency through the use of speech production, display and printer capabilities for on-vehicle advertisements. Estimations of such revenues are not included in this study; neither were these capabilities utilized during the FOT.

CHAPTER THREE

PRODUCTIVITY IMPACTS OF SMART CARDS

This chapter presents the assessment of the productivity impacts of the smart card system relative to the fare box -- productive use of vehicle, data quality, driver performance and workload, perceptions and workload of other transit personnel, and fare fraud.

3.1 PRODUCTIVE USE OF VEHICLE

Transit smart card systems could conceivably enhance productive use of vehicle by, for example, reducing boarding times of individual passengers, vehicle dwell times at bus stops, and vehicle down-time due to malfunctions of the fare collection system. The impacts of smart cards on passenger boarding times and vehicle dwell times were assessed using data collected during onboard observations. The evaluation of vehicle down time uses data collected from transit personnel interviews and malfunction and repair records.

3.1.1 Passenger Boarding Times

Boarding times for individual passengers were recorded by onboard observers. A boarding time for each passenger is defined as follows: for the first passenger in line, it is the time between the instant he/she reaches the top step inside the bus and the instant he/she turns away from the fare unit; and, for the next passenger in line, the boarding time is the difference between the instant he/she turns away from the fare unit and the instant the preceding passenger turns away from the fare unit. If there is discontinuity in boarding (e.g., the next passenger drops money and has to pick it up, talks to fellow passengers, etc), then this next passenger is treated as the first passenger in line for the purpose of recording his/her boarding time.

The evaluation of the impact of smart card use on boarding times involves comparing boarding times for individual passengers using different fare media. At each observed bus stop, boarding times of individual passengers and the fare media used were recorded.

The numbers of observed individual boarding times by fare medium for the three bus lines are summarized in Table 3.1.

Table 3.1: Number of Passengers by Fare Medium in "After" Period

Bus Line	Fare Medium	No. of Riders
LA DOT	Smart card	58
	Cash	15
	Token	16
	Pass	29
Torrance	Smart card	19
	Cash	143
Gardena	Smart card	44
	Cash	169
	Token	17

Table 3.1 indicates that:

- * For the LA DOT line, excluding the use of transfers, about 49 percent of observed passengers used smart cards, 13 percent cash fares, 14 percent tokens, and 24 percent passes.
- * For the Torrance line, excluding the use of transfers, about 12 percent of observed passengers used smart cards and the other 88 percent cash fares.
- * For the Gardena line, excluding the use of transfers, about 19 percent of observed passengers used smart cards, 74 percent cash fares, and 7 percent tokens.

The relatively low percentages of observed smart card users for Torrance and Gardena are due to the fact that the onboard observations for these two agencies took place during the last month of the FOT. Smart card renewals had long stopped by that time, and users had already been told of the impending end to the FOT.

Results of two analyses are presented below -- the comparison of boarding times between users of RF and contact smart cards; and the comparison of boarding times between users of smart cards and cash, tokens, or passes.

3.1.1.1 Boarding Times Between RF and Contact Smart Cards

There are a total of 77 recorded boarding times for users of RF smart cards (58 for LA DOT and 19 for Torrance), and 44 recorded boarding times for users of contact smart cards (for Gardena). Table 3.2 compares boarding time statistics between users of RF and contact smart cards.

Table 3.2: Comparison of Boarding Times Between RF and Contact Smart Cards

Card Type	Sample Size	Boarding Time (seconds)		
		Mean*	S.D.	Range
RF	77	3.5	2.7	1-18
Contact	44	3.3	2.3	1-13

* Result of a two-sample t-test indicates that these two means are statistically equal (p-value for the test is 0.32).

Table 3.2 indicates that observed mean boarding times and standard deviations for the two types of smart cards are very similar. The means are 3.5 and 3.3 seconds, and the standard deviations 2.7 and 2.3 seconds, for RF and contact smart cards respectively. Results of a two-sample t-test indicate that there is no statistically significant difference in average boarding times between users of RF cards and contact cards.

Figure 3.1 show cumulative distributions of individual boarding times for users of RF smart cards in LA DOT and Torrance, and for users of contact smart cards in Gardena.

3.1.1.2 Boarding Times for Users of Smart cards, Cash fares, Tokens, and Passes

Comparisons of recorded boarding times between users of smart cards and other fare media for each bus line are summarized in Table 3.3. The table indicates that users of smart cards consistently show much smaller boarding times than cash fare users for all three bus lines, as follows:

For LA DOT Line

During the FOT, the LA DOT line used RF smart cards in addition to cash fares, tokens, and passes. Means, standard deviations, ranges, and medians of boarding times for these fare media are shown in Table 3.3. The table indicates that mean boarding times for users of RF smart cards and passes are similar, and that both are the smallest among all fare media. At the other extreme, cash fares show the highest mean boarding time (about 2.5 times the mean for smart cards). Tokens also show a higher mean boarding time than RF smart cards (about 1.6 times the mean for smart cards). These differences are statistically significant. Table 3.3 also indicates that median boarding time for cash fare users is twice as large as that for users of RF smart.

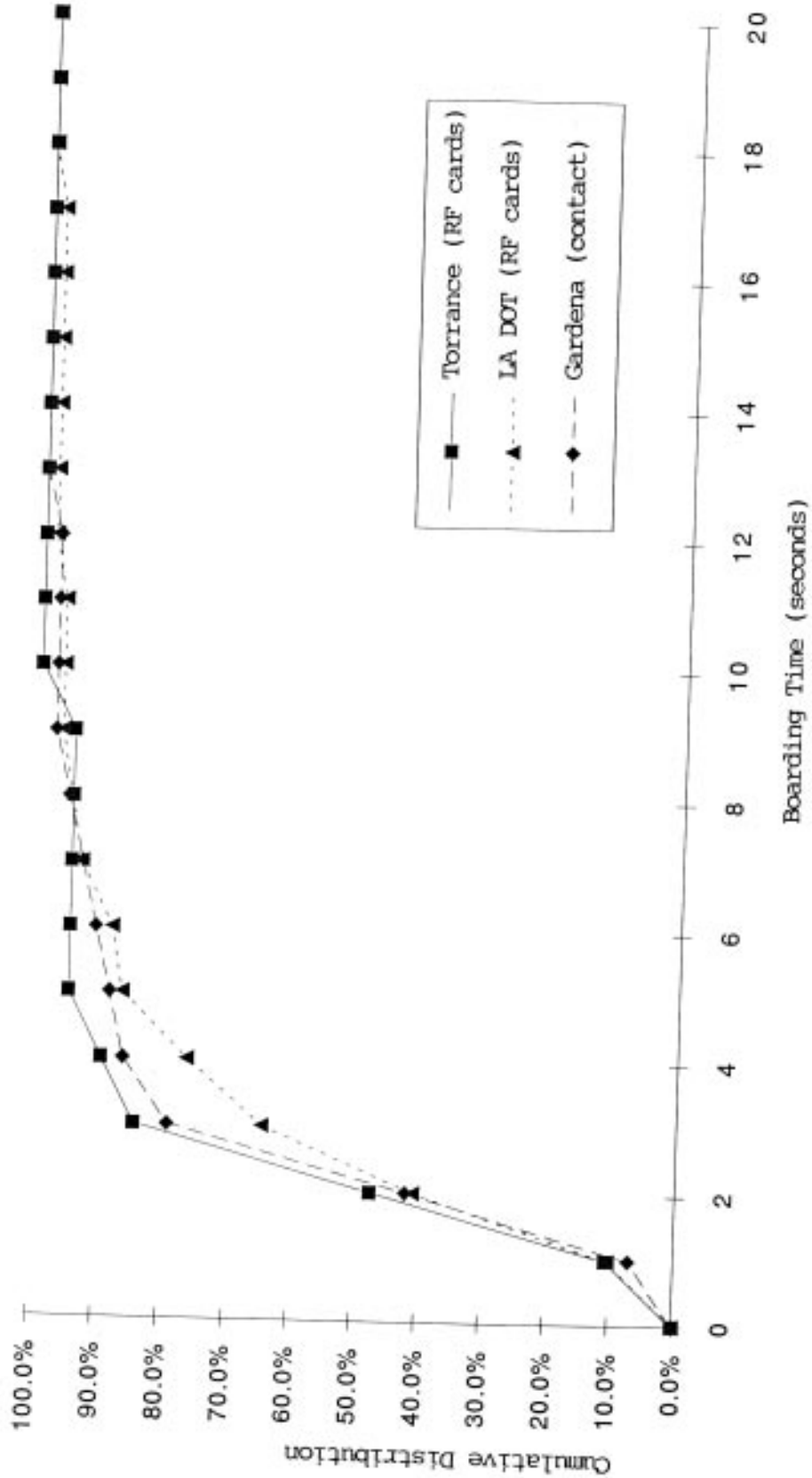


Figure 3.1 CUMULATIVE DISTRIBUTIONS OF BOARDING TIMES FOR THREE TRANSIT AGENCIES

Table 3.3 Comparison of Boarding Times Between Smart Cards and Other Fare Media

Bus Line	Fare Medium	Boarding Time (seconds)				P-Value for Test of Means of Smart Card vs Each Fare Medium
		Mean	S.D.	Range	Median	
LA DOT	Smart Card	3.7	2.9	1-18	3	N/A
	Cash	9.3	8.4	1-31	6	0.00001*
	Token	5.8	4.9	2-22	4	0.017*
Torrance	Smart Card	3.0	2.0	1-10	2.5	N/A
	Cash	7.9	10.3	1-60	5	0.017*
	Token	3.3	2.2	1-13	3	N/A
Gardena	Smart Card	4.7	4.8	1-37	3	0.026*
	Cash	3.3	1.4	1-6	3	0.500**
	Token	3.3	1.4	1-6	3	0.500**

* Mean boarding time for smart card is significantly smaller than that for the other fare medium at $\alpha = 0.05$.

** Mean boarding time for smart card is not significantly different from that for the other fare medium.

Figure 3.2 shows cumulative distributions of boarding times for users of RF smart cards, passes, and combined cash fares and tokens for the LA DOT line.

Cash fare and token users show much larger variation in boarding times than RF smart card users. The standard deviation for RF smart cards is about 0.35 times that for cash fares, and 0.59 times that for tokens. These results clearly suggest that, in addition to faster passenger boarding, the uses of RF smart cards also result in much more predictable passenger boarding times relative to cash fares and tokens.

For Torrance Line

During the FOT, the Torrance line used RF smart cards and cash fares. Like the LA DOT line, boarding times for users of RF smart cards are much smaller and more predictable than those for users of cash fares. The observed mean boarding time for cash users is 2.6 times that for smart card users, and this difference is statistically significant. The observed median boarding time for cash fares is twice as large as that for RF smart cards. The standard deviation of boarding times for users of RF smart cards is only 0.19 times that for cash users.

Figure 3.3 shows cumulative distributions of boarding times for users of RF smart cards and cash fares for the Torrance line.

For Gardena Line

During the FOT, the Gardena line used contact smart cards, cash fares, and tokens. Contact smart cards and tokens show similar mean boarding times and standard deviations. Both show significantly smaller mean boarding times and standard deviations than cash fares. The mean boarding time for users of contact smart cards is 0.70 times that for cash fares, and this difference is statistically significant.

Figure 3.4 shows cumulative distributions of boarding times for users of contact smart cards and cash fares for the Gardena line.

3.1.2 Vehicle Dwell Time

The comparison of boarding times for users of smart cards and other fare media indicate that the smart card system results in up to 60 percent faster boarding times than cash fares, consistently across all three bus lines. It is of interest to determine whether, and to what extent, such savings in boarding times of individual smart card users might lead to reductions in the time

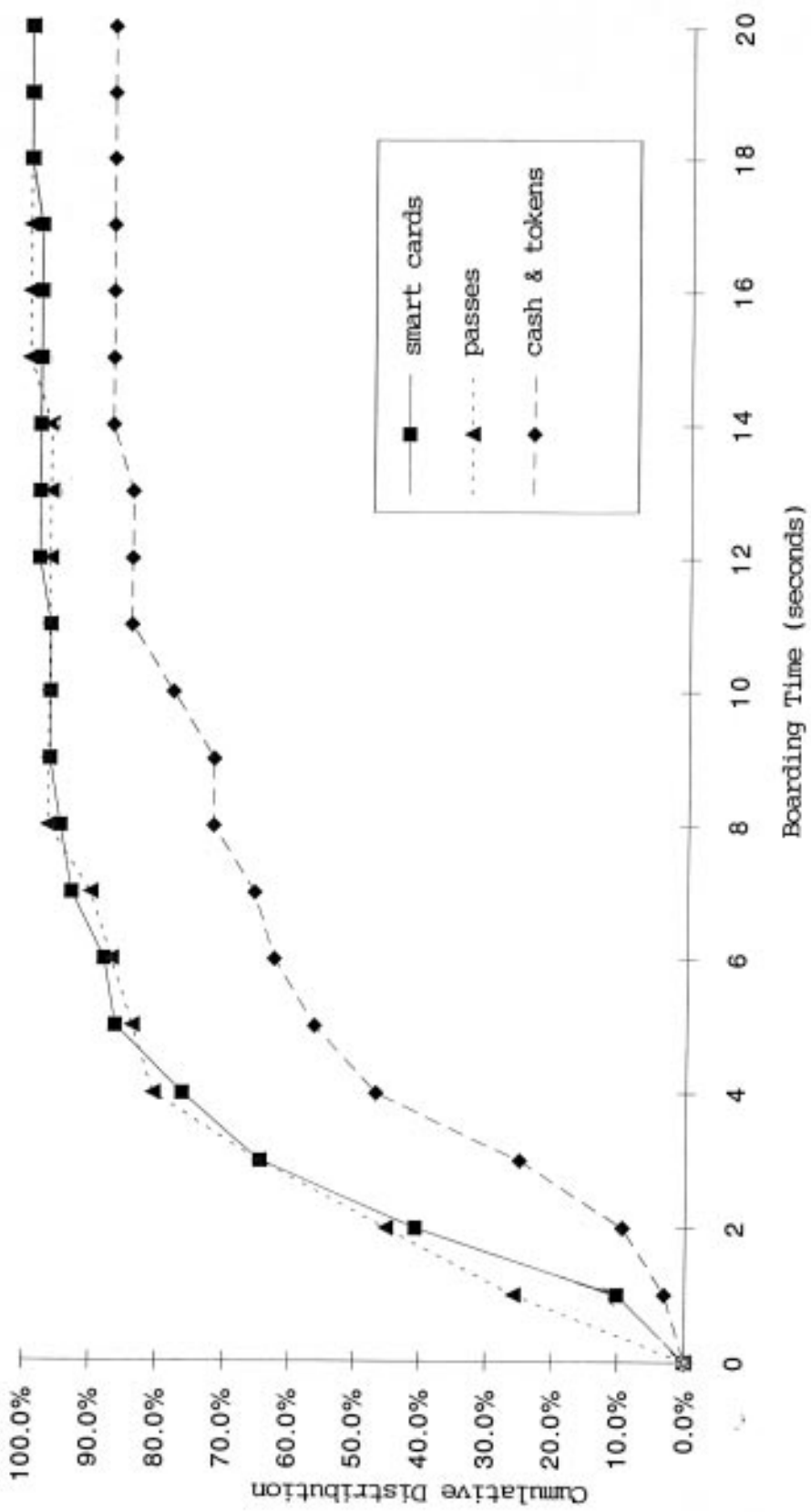


Figure 3.2 CUMULATIVE DISTRIBUTIONS OF BOARDING TIMES FOR LA DOT IN "AFTER" PERIOD

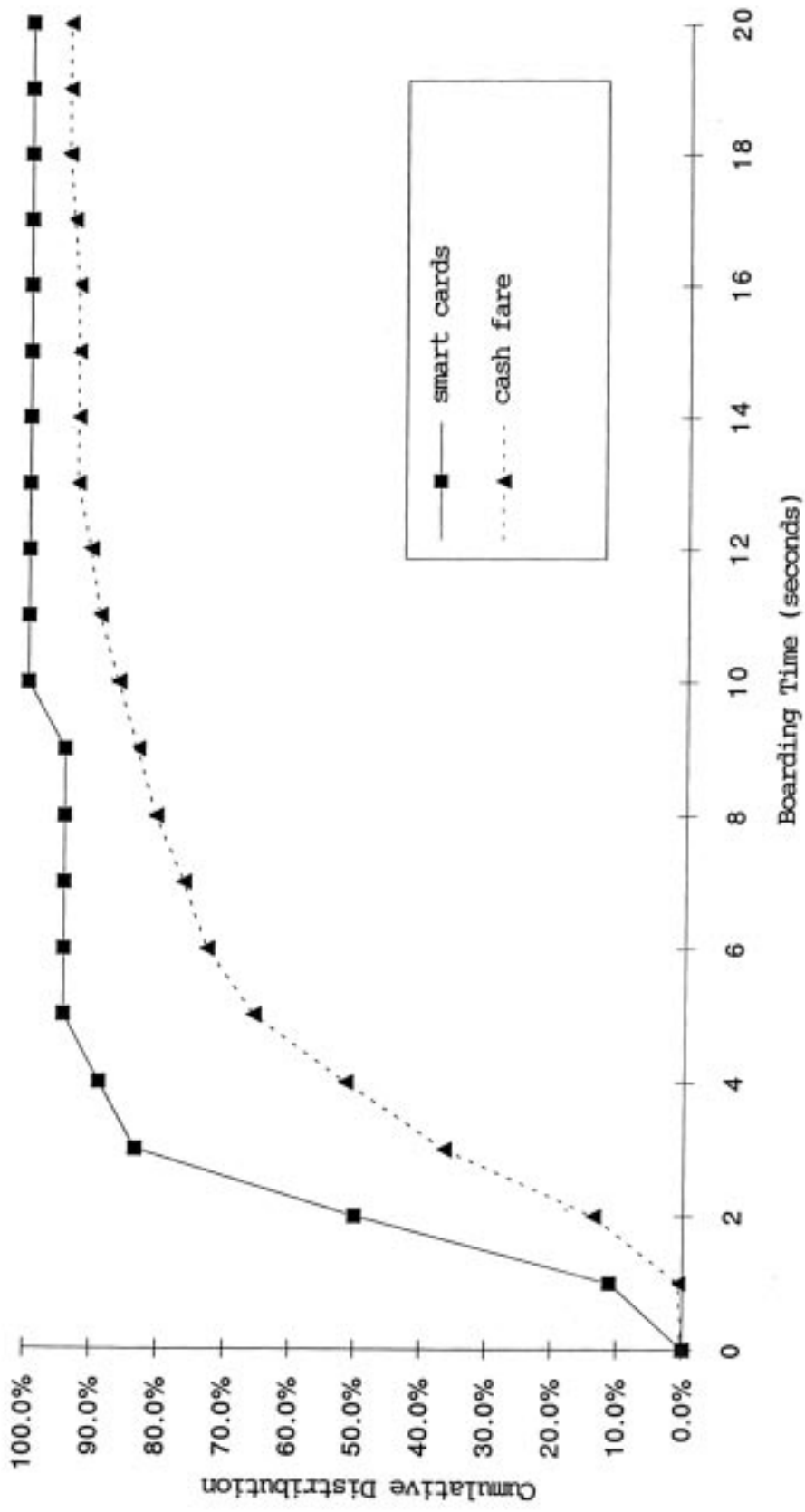


Figure 3.3 CUMULATIVE DISTRIBUTIONS OF BOARDING TIMES FOR TORRANCE IN "AFTER" PERIOD

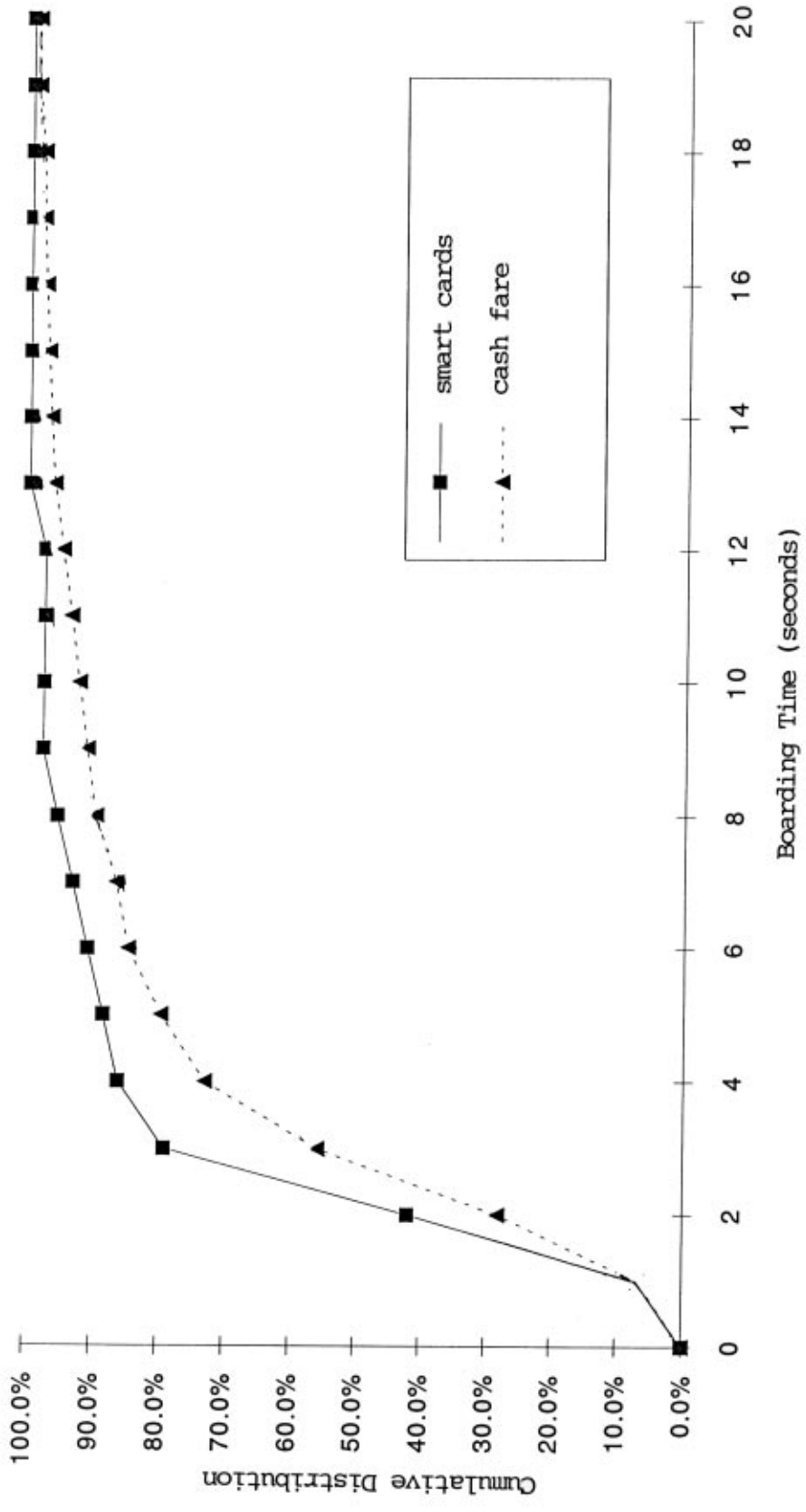


Figure 3.4 CUMULATIVE DISTRIBUTIONS OF BOARDING TIMES FOR GARDENA IN "AFTER" PERIOD

the bus spends at bus stops (to be called vehicle dwell time, or vehicle stop time), when only a portion of boarding passengers use smart cards. Reduced vehicle dwell time helps to improve the system efficiency by reducing bus travel time and enhancing bus schedule adherence.

Vehicle dwell time is defined as the amount of time the bus spends at a bus stop. It is the time between the instant when the bus stops and the instant it starts moving again. The majority of vehicle dwell time is due to passenger boarding and/or alighting. Of the two, the onboard observations reveal that boarding always took longer than alighting at all observed bus stops along the LA DOT line. For the Torrance line, boarding took longer than alighting at about 92 percent of all observed bus stops. For the Gardena line, boarding took longer than alighting at about 88 percent of all observed bus stops. This evidence strongly suggests that it is generally passenger boarding (as opposed to alighting) that controls the length of vehicle dwell time at bus stops.

As the number of boarding passengers increases, vehicle dwell time is expected to increase. In addition, incidents such as jammed fare boxes, handicap boarding, and the bus waiting for passengers running from another bus can also increase vehicle dwell time significantly.

Vehicle dwell times were recorded at individual bus stops for all three bus lines, before and after the smart card deployment. The analysis of vehicle dwell time involves comparing vehicle dwell times between bus stops with at least one smart card user and those without any smart card user, adjusted for the number of boarding passengers. Dwell times associated with smart card use could only be observed during the smart card deployment (i.e., "after" period), whereas dwell times without smart card use were observed for both the before and after periods.

To adjust for the effect of the number of boarding passengers on vehicle dwell time, separate evaluations were performed for different numbers of boarding passengers of one through four. Evaluations for more than four boarding passengers were not performed due to the small sample size of recorded vehicle dwell times with smart card use.

The evaluation results for each bus line are as follows:

For LA DOT Line

For the LA DOT line, nearly 50 percent of observed passengers in the "after" period used RF smart cards. Table 3.4 shows the means, standard deviations, ranges, and medians of vehicle dwell times for bus stops with at least one smart card user versus those for stops with no smart card user, for one through four boarding passengers. The table indicates that average vehicle dwell times increase with higher numbers of boarding passengers, as expected.

Table 3.4: Vehicle Dwell Times at Stops with and without Smart Card Use (LA DOT)

Number of Boarding	Smart Card User?	Sample Size	Vehicle Dwell Time (sec)			
			Mean	S.D.	Range	Median
1*	Yes	17	7.41	2.69	4-15	7
	No	64	7.18	6.88	3-55	7
2*	Yes	11	10.91	2.34	7-15	11
	No	22	13.32	5.14	8-32	12
3*	Yes	12	16.58	4.83	13-30	14
	No	12	14.33	4.73	9-26	14
4*	Yes	10	20.10	7.58	15-36	17
	No	12	20.75	9.83	13-48	17

* A t-test for each level of boarding passengers indicates that the mean vehicle dwell times for stops with and without smart card use are statistically equal.

For each level of boarding passengers, results of a t-test indicate that average vehicle dwell times between stops with and without smart card use are not significantly different. This implies that the use of smart cards by nearly 50 percent of passengers did not lead to statistically significant reductions in vehicle dwell time. This finding can be explained as follows:

- o Cash users (who have been shown to incur longer boarding times than smart card users) often control the length of vehicle dwell time. When some cash passengers take a long time to find exact change, they contribute to particularly long vehicle dwell time.
- o In the event of fare-box malfunctions, extra delays are likely.
- o Third, non-fare payment events can also increase vehicle dwell times; for example, handicap and wheelchair boarding, the bus waiting for passengers running from another bus, drivers answering questions from passengers, and drivers adjusting vehicle components (e.g., driver seats, mirrors, etc.). As a result, the savings in boarding times accumulated by passengers using smart cards generally are not nearly enough to offset the delays caused by these other factors.

For Torrance Line

For the Torrance line, about 12 percent of observed passengers in the "after" period used smart cards. Table 3.5 shows the means, standard deviations, ranges, and medians of vehicle dwell times for bus stops with and without smart card use, for one through four boarding passengers. The table indicates that average vehicle dwell times increase with higher numbers of boarding passengers, as expected.

Table 3.5: Vehicle Dwell Times at Stops With and Without Smart Card Use (Torrance)

Number of Boarding	Smart Card User?	sample Size	Vehicle Dwell Time (sec)			
			Mean	S.D.	Range	Median
1**	Yes	4	7.50	1.73	6-9	7
	No	113	9.07	4.95	3-33	7
2*	Yes	8	10.87	5.00	4-20	9
	No	47	14.79	8.55	6-51	12
3**	Yes	2	19.00	7.07	14-24	-
	No	21	20.29	9.07	11-42	17
4**	Yes	1	14.00	-	-	-
	No	14	21.14	7.12	12-33	19

* A t-test indicates that the mean vehicle dwell times for stops with and without smart card use are statistically equal.

** Statistical tests were not performed due to small sample size for stops with at least one smart card user.

A t-test was performed for the number of boarding passengers of two (the only category with a reasonable sample size). The results indicate that mean vehicle dwell time for stops with smart card use is not significantly different from that for stops without smart card use. This implies that the use of smart cards by about 12 percent of passengers did not lead to statistically significant reductions in vehicle dwell time. This is consistent with the finding for the LA DOT line, and can be similarly explained. It is cash users who often control the length of vehicle dwell times at most bus stops. Events contributing to particularly long vehicle dwell time include: passengers had difficulty inserting money into fare boxes, jammed fare boxes, money fell on the floor, passengers took a long time looking for exact change. In addition, events not related to fare payment also affect vehicle dwell time; for example: the bus waiting for passengers running from another bus, and handicap/wheelchair boarding.

For Gardena Line

For the Gardena line, 19 percent of observed passengers in the "after" period used smart cards. Table 3.6 shows the means, standard deviations, ranges, and medians of vehicle dwell times for stops with and without smart card use.

Table 3.6: Vehicle Dwell Times at Stops With and Without Smart Card Use (Gardena)

Number of Boarding	Smart Card User?	Sample Size	Vehicle Dwell Time (sec)			
			Mean	S.D.	Range	Median
1*	Yes	11	6.91	2.02	4-11	7
	No	105	7.59	5.02	2-34	7
2*	Yes	9	14.67	6.87	7-29	13
	No	71	12.78	6.53	3-33	11
3**	Yes	4	16.75	5.19	12-23	16
	No	34	15.06	5.51	8-27	14
4*	Yes	7	17.86	8.17	13-36	14
	No	25	18.64	9.12	9-53	17

* A t-test indicates that the mean vehicle dwell time at stops with and without smart card use are statistically equal.

** Statistical test was not performed due to small sample size of vehicle dwell times at stops with smart card use.

For the numbers of boarding passengers of one, two, and four, results of t-tests indicate that the mean vehicle dwell time at stops with smart card use is not significantly different from that at stops without smart card use. This implies that the use of smart cards by nearly 20 percent of the passengers did not lead to statistically significant reductions in vehicle dwell time. Again, this finding is consistent with those for the LA DOT and Torrance lines, and can be similarly explained.

All Three Bus Lines Combined

Vehicle dwell times from the LA DOT, Torrance, and Gardena lines were combined to increase the sample size (Table 3.7).

Table 3.7: Vehicle Dwell Times at Stops With and With Smart Card Use (All 3 Bus Lines)

Number of Boarding	Smart Card User?	Sample Size	Vehicle Dwell Time (sec)		
			Mean	S.D.	Are the two means equal?
1	Yes	32	7.25	2.33	Yes*
	No	282	8.22	4.75	
2	Yes	28	12.11	5.07	Yes*
	No	140	13.54	7.10	
3	Yes	18	16.89	4.84	Yes*
	No	67	16.57	7.10	
4	Yes	18	18.89	7.53	Yes*
	No	51	19.26	7.80	

* Based on t-tests.

For each level of boarding passengers (one through four passengers), results of a t-test indicate that the mean vehicle dwell time for bus stops with smart card use is not significantly different from that for bus stops without smart card use.

The above findings suggest that:

- o To reduce vehicle dwell time, boarding times of cash fare users as well as their variability need to be reduced. Many factors contributing to very large variance of boarding times for cash fare users are passenger related (e.g., passenger taking a long time to find exact change), and cannot be easily altered by the transit agency. Nevertheless, events such as fare box malfunctions, if they can be minimized, could result in reductions in average vehicle dwell time.
- o Evidence from onboard observations suggests that the proportion of cash-fare users may have to be quite small (i.e., most passengers use smart cards) in order for smart cards to significantly reduce vehicle dwell time. Empirical data collected for this study suggests that the use of smart cards by 50 percent of all passengers is not enough to significantly reduce vehicle dwell time.

3.1.3 Vehicle Down Time

Relative to fare boxes, smart card units are expected to have far fewer malfunctions because their components are mostly electronic with few moving parts. On the other hand, fare boxes are known to have frequent problems, the most common of which are jammed fare boxes. These incidents often result in vehicle down-time while the problems are being corrected.

Vehicle down time is defined as the time the bus remains idle due to malfunctions or

failures of the fare collection system. Estimations of vehicle down times associated with the fare box and the smart card system are presented below.

3.1.3.1 Vehicle Down Time Due to Fare Box

Bus drivers and supervisors of the three transit agencies were asked to recall recent fare box malfunctions, their frequencies, and remedies. They all agreed that jammed coins/dollar bills were common with fare boxes. However, bus drivers differed widely about the frequencies of fare box malfunctions. They also differed about actions to correct fare box problems. Some said that they mostly fixed the problems themselves, while others said that they always requested help from maintenance personnel.

Based on interview information, we estimate that vehicle down-time due to fare box malfunctions is probably on the order of 13-19 hours per bus per year. This estimate consists of two components as follows:

- o According to interviewed transit personnel, fare box problems that bus drivers are able to correct (e.g., jammed fare boxes, difficulties in inserting dollar bills) probably account for about 90 percent of all malfunctions. Because these incidents do not involve maintenance personnel or exchanges of fare boxes, they usually result in small vehicle delays (on the order of a few minutes per incident). An estimate of such fare-box malfunctions is about 3-4 incidents per bus per week. This results in an estimated vehicle down-time of 8-11 hours per bus per year.
- o When fare-box malfunctions require calling supervisors and/or maintenance personnel or exchanging of fare boxes, they incur much longer vehicle down-time. We estimate that these kinds of incidents occur about 15-20 times per bus per year. This results in an estimated vehicle down-time of 5-8 hours per bus per year.

3.1.3.2 Vehicle Down Time Due to Smart Card Unit

During the FOT, there were two recorded smart card equipment incidents for Gardena resulting in about six hours of vehicle down-time. For LA DOT, there were four recorded equipment incidents resulting in about seven hours of vehicle down-time. For Torrance, there were three recorded equipment incidents resulting in about four hours of vehicle down-time. There were a total of 21 buses equipped with smart card units for all three transit agencies (six of which were spare buses) during the six-month FOT. Therefore, an estimate of vehicle down-time due to malfunctions of smart card units is on the order of two hours per bus per year.

3.2 DATA QUALITY

In addition to the fare collection function, the smart card system also provides a tremendous potential for the transit agency to improve quality of transit data. The smart card system automatically collects information on transit operation, revenue, and patronage, with a level of detail currently not available. In fact, managers of the three transit agencies stated that a primary reason for them to participate in this FOT was the expectation of obtaining quality data from the smart card system, which include:

- o Existing data that the transit agency collects through the fare box and supplemental surveys (or ride-checking) can be more cheaply and reliably collected with the smart card system. The smart card system virtually eliminates the needs for surveyors, ride checkers, and manual data retrieval from the fare box. Further, because the smart card system collects data automatically while the bus is in revenue service, the accuracy, consistency, and timeliness of passenger counts and revenue data are enhanced.
- o The smart card system enables new data on transit operation, ridership, fares, revenue, origins-destinations, and user demographics to be collected. During the FOT, the smart card system automatically collected the following data: bus users by location; bus users by time of day, day of week; bus users at individual bus stops and load profiles; bus on-time performance statistics; and average vehicle speed by segment and route. Without the smart card system, the costs of collecting these new data would be prohibitive and deemed impractical by most transit agencies.

With the smart card use, the transit agency's tasks of collection and reporting of transit data could be greatly facilitated. An example of the transit agency's reporting responsibility is Section 15 of the Federal Transit Act (Federal Transit Administration, 1994), which requires transit operators receiving Section 9 funds to submit financial and operating reports to the Federal Transit Administration (FTA) for use as basic input for public sector investment decisions. The FTA encourages all transit operators to report this information even though agencies with five or fewer vehicles are exempted. The Section 15 report consists of a summary of transit characteristics, as well as financial and non-financial operating statistics for all services provided or purchased by the transit agency (e.g., ridership, passenger miles, vehicle revenue miles, vehicle revenue hours, number of vehicles, service days, expenditures, and revenue).

The above-mentioned new data enable the transit agency to assess ridership profiles and the performance of specific routes and subsystems with a view to modifying and fine-tuning the services as necessary. These data could also help the transit agency develop strategies to enhance vehicle schedule adherence. Finally, different transit agencies could have consistent ridership and revenue data of uniform quality, which are collected by similar data collection methods. This could lead to increased trust and accountability among transit agencies in the same region.

3.3 DRIVER PERFORMANCE AND WORKLOAD

The use of smart cards could have significant impacts on the performance and workload of bus drivers. Evaluations of driver preference between the smart card system and the fare box, as well as changes in driver workload and performance as a result of smart card use, are presented below.

3.3.1 Driver Preference Between Smart Cards and Fare Boxes

Eleven drivers, representing about 38 percent of all bus drivers with experience in operating buses equipped with smart card units, were asked to state their preference between the smart card and the fare box. Almost all of these drivers indicated strong preference for the smart card over the fare box, as follows:

- o Nine drivers stated that they preferred smart cards to cash fares and passes, with the most commonly cited reasons being: smart cards are faster; smart cards are easier to deal with than fare boxes; fare boxes frequently malfunction; and passengers like smart cards.
- o Of the remaining two bus drivers, one said that he was indifferent between the smart card and the fare box. The other bus driver stated preference for the fare box over the smart card because he perceived that smart cards slowed down fare payment. His perception is contrary to that of other bus drivers, and is not supported by the results of onboard observations (see Section 3.1.1).

These 11 drivers were also asked to identify changes and improvements to the smart card system that they wish to see. Ten drivers did not feel that the smart card system needed improvements or changes. One bus driver said that he would like the vehicle unit to display (for the bus driver) whether the trip is local or LA-bound, and that the currently displayed "number of trips remaining" should be shielded from passengers to eliminate passenger disagreement over this number.

3.3.2 Impacts of Smart Card System on Driver Workload

The impacts of the smart card system on the performance and workload of bus drivers were assessed using the information obtained from driver interviews and onboard observations.

3.3.2.1 Evidence From Driver Interviews

The nine drivers who stated preference for the smart card over the fare box said that the former definitely had positive impacts on their workload and performance, for the following reasons:

- o Relative to the fare box, the smart card system has made their jobs easier. The drivers perceived that smart cards were much faster than cash fares. Further, with smart cards, the drivers did not have to count or pay attention to the amount of cash paid. As for the smart card versus passes, when passengers show their

passes, bus drivers are still required to keypunch appropriate keys on a keyboard.

- o Jammed coins and stuck dollar bills, common problems of fare boxes, can be stressful to both bus drivers and passengers. On the other hand, the drivers generally perceived that the smart card system was very reliable.

- o The use of smart cards results in drivers having less interactions with passengers, which in turn has made their job less stressful. These interactions include: fare disputes; passengers paying insufficient fares; assisting passengers to insert dollar bills; collecting "zone checks" (applicable to Torrance only) from LA-bound passengers before the bus leaves the Torrance city limit, which requires the driver to get up from his/her seat; answering questions about fares, etc. Many drivers indicated that fare disputes were not uncommon; neither were passengers paying insufficient fares.

- o Bus drivers felt strongly that passengers really liked using smart cards, which gave them considerable job satisfaction.

During the FOT, bus drivers had to monitor both the smart card unit and the fare box. They stated that this did not increase their workload or work difficulty.

For Gardena and Torrance, which did not allow onboard smart-card renewals, bus drivers said that they would not like to handle onboard smart card renewals. For bus drivers from LA DOT (which allowed onboard smart card renewals), one said that onboard smart card renewals were easy. Another driver thought that this activity was difficult initially, and that more training on onboard renewals would have been helpful.

3.3.2.2 Evidence From Onboard Observations

Interactions between bus drivers and passengers were recorded for all three bus lines during the onboard observations. Interactions between bus drivers and smart card users, as well as between bus drivers and non-smart-card users, which could affect driver performance and workload are presented below.

Interactions Between Drivers and Smart Card Users

The onboard observations reveal that interactions between drivers and smart card users are minimal. During the six days of onboard observations on the three bus lines in the "after" period, the observers noted only two interactions between drivers and smart card users. Both involved smart card users having to pass the smart card twice over the card reader before the card was registered.

Interactions Between Drivers and Non-Smart-Card Users

The onboard observations reveal the following interactions between bus drivers and cash users which could conceivably affect driver workload:

- o It is not uncommon for some passengers to take a long time finding exact change while boarding the bus. These passengers might take so long to complete

fare payments that they stepped aside and were still searching for exact change after the bus had moved away from the bus stop. These actions can affect safety as well as driver workload, because the driver has to drive and at the same time assure a correct fare payment. The onboard observations reveal that about 28%, 12%, and 7% of cash users on the LA DOT, Torrance, and Gardena lines respectively did exactly this.

- o About one to three percent of cash users on the three bus lines asked bus drivers questions about fares. This small percent is consistent with information obtained from driver interviews.

- o Less than one percent of observed cash users who, after having paid the fares, were reminded by the driver of insufficient fares.

- o Bus drivers often have to "unjam" fare boxes, or to assist passengers in inserting dollar bills. These affect driver workload and delay the bus departure. The onboard observations reveal that the occurrence rate of these events is about one per 50-60 bus stops.

3.4 PERCEPTIONS OF OTHER TRANSIT PERSONNEL

Perceptions of managers, dispatchers, route supervisors, and maintenance crews of the smart card system were assessed through interviews. Interviews with accounting personnel were not conducted because they were not involved in, or affected by, the FOT.

3.4.1 Supervisors and Dispatchers

Perceptions of route supervisors and dispatchers, who share a number of common tasks, are combined. Route supervisors and dispatchers assign runs, supervise bus drivers, assure schedule adherence, interface with passengers, and do "trouble shooting" on the road as problems arise. Three supervisors and three dispatchers (one of each from each agency) were interviewed.

Preference Between Smart Cards and Fare Boxes

The six supervisors and dispatchers all preferred the smart card system to the fare box because: smart cards are faster; passengers love smart cards; bus drivers prefer the smart card system to the fare box; and the smart card system has far fewer problems than the fare box.

The supervisors of Gardena and LA DOT expressed satisfaction with the reliability of the smart card system during this FOT. The dispatcher and supervisor of Torrance were more cautious. They said that it sometimes took several "re-boots" in the morning to activate the vehicle unit. Nevertheless, they said that the smart card system was more trouble-free than fare boxes.

Impacts of Smart Cards on Workload of Dispatchers and Supervisors

The interviewed supervisors and dispatchers perceived that, relative to fare boxes, the smart card system could make their work easier. First, the smart card system had far fewer malfunction problems than the fare box, thus there was less need for "trouble shooting". Second, smart card use could help to improve vehicle schedule adherence because smart card users took less time in paying fares and vehicle boarding than cash users.

All interviewed supervisors and dispatchers said that it was easy to train bus drivers to operate the smart card system.

3.4.2 Managers

Six management personnel of the three transit agencies were interviewed -- two from Torrance (Administrative Analyst, and Service Manager), one from Gardena, and three from LA DOT (Senior Transportation Engineer, Project Manager, and Terminal Manager).

Preference Between Smart Card System and Fare Boxes

All six managers stated strong preference for the smart card system over the fare box. They indicated that smart cards were so popular with bus riders that many more smart cards could have been issued during the FOT. Managers of LA DOT and Torrance wish to see extensive deployment of smart cards on their buses in the future. They believed that smart cards enhanced customer service, and would economically provide more and better quality data for reporting and planning purposes. All managers expressed satisfaction with the reliability of the smart card system during the FOT.

Desired Changes and Improvements to Smart Card System

Most managers said that they would like to see the smart card system with the following capabilities:

- o Automated passenger counting that captures details such as time of use, origin-destination, number of users by bus line, user demographics, etc.
- o Smart cards showing the cash amount, as opposed to the number of trips.
- o Integration of the smart card with the electronic fare box because there will always be a need for a fare box to accommodate cash riders in a foreseeable future.

Impacts of Smart Card System On Manager's Workload

This field operational test did not affect day-to-day operations or internal organization of the three transit agencies. As a result, all managers interviewed said that their responsibilities and day-to-day work were not affected.

3.4.3 Maintenance Personnel

Interviews of maintenance personnel were conducted for LA DOT (Maintenance Supervisor, Heavy Duty Mechanic) and Torrance (Service Manager). These personnel said that they considered the field operational test to be a success. Even though they were not involved in the maintenance and repairs of the smart card system during this FOT, they believed that the smart card system would be relatively maintenance free, compared with the fare box. They perceived that existing maintenance crews will need training, particularly in electronics and computers, in order to be able to perform maintenance and repairs of smart card units.

3.5 FARE FRAUD

Fare fraud includes fare underpayment/evasion and fare disputes. Both result in loss of transit revenue, and can be stressful to bus drivers. It is not possible to accurately determine the frequencies of such incidents because the transit agencies do not keep such records. Nevertheless, some bus drivers said that they encountered fare disputes and fare underpayment on a daily basis, and that certain routes were worse than others. According to a manager of one transit agency, fare underpayment may total a few hundred dollars per fare box per year.

As for the smart card system, the managers stated that smart cards could also have fraud problems, for example: lost or stolen cards, and passenger disputes over the number of trips (or money) left on the card. Some bus drivers encountered passengers disputing the number of remaining trips about 3-4 times during the FOT. These disputes, however, should be fairly easily settled because the smart card system has the capability to provide the passenger with a detailed record of past transactions.

Even though there are no hard data to determine and compare potential revenue loss due to fare fraud between the fare box and the smart card system, the fact that smart card use means less cash is carried onboard the bus is likely to lead to reduced opportunities for fraud and thefts relative to the fare box.

CHAPTER FOUR

OPPORTUNITIES AND CONSTRAINTS

This section describes opportunities for transit agencies to enhance their services and operations as a result of adopting extensive implementation of smart cards. It also identifies probable constraints associated with systemwide deployment of smart cards.

4.1 OPPORTUNITIES

As previously mentioned, transit smart card systems can incorporate many additional features in addition to fare collection capability. Therefore, extensive use of smart cards can open up many opportunities for transit agencies, some of which are described below.

4.1.1 Opportunity to Promote Transit Use and Build Up Ridership

Very clear evidence has emerged from this first FOT of smart cards that passengers like smart cards because they are faster and more convenient than cash fares, and passengers do not have to worry over exact change. Further, in a city/county where different transit services are provided by different operators and/or different transit modes, multi-service and multi-modal smart cards would automatically handle different fares for these different markets. As a result, a passenger could patronize all these services with just one smart card. This would represent extreme convenience for transit users, and confusion and burden related to fare payments could be minimized. In this way, smart cards could help to narrow the gap between private transportation and public transportation. This in turn could attract more people to transit, and existing transit patrons may increase frequencies of transit use (e.g., by substituting some auto trips with transit trips, making trips not previously made). Managers of the participating transit agencies foresee significant improvement in customer service when multi-modal transit smart cards are implemented at a countywide level.

4.1.2 Opportunity to Establish Reliable, Low-Cost Management Information Systems

Many transportation professionals, including managers of the three participating transit agencies, are convinced that transit smart cards hold promise for low-cost acquisition, compilation, and processing of rich transit information (e.g., passengers, ridership, revenue, and transit operational characteristics). Further, smart card systems virtually eliminate manual labor needed for conducting ridership surveys, money counting, and data retrieval from fare boxes.

Most transit agencies regularly submit reports to various government entities. Existing data obtainable from the fare box plus supplemental surveys generally lack detail and consistency between different transit agencies. The smart card system can help to address these limitations by automatically recording, storing, and downloading these data while the bus is in revenue service. In this way, quality of the data is not affected by the collection procedure employed, resource constraints, or human performance.

Potential data benefits of smart cards go beyond just providing low-cost transit data collection and reporting. They also provide a unique opportunity for the transit agency to revamp its existing management information system. For many transit agencies, this means the availability of new data needed for better planning, such as: passenger counts by bus route, location, time of day, and time of year; passenger boarding and alighting profiles (at all bus stops) by bus route; better revenue data by bus route; more accurate passenger miles; schedule adherence information; passenger origin-destination data; and passenger demographics.

Managers of the participating transit agencies consider the opportunity to establish reliable, low-cost information management systems as one of the most important benefits of smart card systems.

4.1.3 Opportunity for Demand-Responsive Transit Planning, Scheduling, and Operation

Many transit agencies currently use data from fare boxes plus supplemental surveys for reporting and justifying new services. These data tend not to have adequate detail to support more sophisticated demand-responsive transit planning, scheduling, and operation. Smart card systems can address these data shortcomings. Examples of analyses to support more demand-responsive planning are: line-by-line passenger loading and costs; schedule adherence; and scheduling by time of day, week and year. Quality transit demand data to be available from smart card systems could also facilitate the development of new services such as paratransit services and ADA demand-responsive transit services.

4.1.4 Opportunity for Innovative Fare Policies

Smart card systems will facilitate the implementation of innovative fare policies designed to increase revenue and capture new transit markets, which are difficult to achieve under flat or zone fares. Examples of innovative fare policies include: market-based pricing (e.g., "deep discount" fares; Oram 1994), time-of-day pricing, distance-based pricing, and pricing to attract new/special markets (e.g. special user groups, corporations, small to medium sized employers).

4.1.5 Opportunity to Develop Advanced Integrated Smart Card and Fare Box Systems

Some transit agencies may view transit smart card systems as an opportunity to revamp the entire fare collection system. For example, managers of the participating transit agencies wish to see more field tests and developmental work to advance the smart card technology toward maturity, as well as simultaneous development of advanced electronic fare boxes for eventual integration with smart card systems.

4.2 CONSTRAINTS

The FOT of smart cards indicates that they work reliably in real-world operating conditions. However, there is currently no "road map" for transit agencies to move from this limited FOT to systemwide implementation. It appears that there exist a number of issues and constraints pertaining to extensive deployment of smart cards. Some of these are described below.

4.2.1 Capital Expenditures

Revenue to cover large capital costs for the equipment and start-up activities will be needed for the transit agency to implement systemwide smart cards. Capital expenditures required by transit agencies will vary, depending on the size of the operation. Managers of the three participating agencies indicated that it would be ideal to have public/private partnership contributing to these capital expenditures.

4.2.2 Administration, Sales, and Marketing of Smart Cards

For systemwide smart card use, there will be costs associated with: marketing, sales, and renewals of smart cards; responding to lost/stolen cards, card malfunctions, and passenger grievances; and reimbursing transit agencies for the services rendered in a multi-service and/or multi-modal market, which may call for some kind of a clearing house and procedures to handle distribution of fare proceeds.

Existing staff of the transit agency may lack skills required, or there may be an inadequate number of existing personnel, to perform these new tasks. In addition, it is conceivable that many transit agencies will be opposed to smart card renewals by bus drivers onboard the bus, out of reservation about adding extra work for bus drivers and bus drivers handling large sums of cash onboard the bus. Managers of the three participating transit agencies believed that the sales, card renewals, and agency reimbursement should be handled by a centralized clearing house and transit outlets. They also believed that county government agencies would be best equipped to do these tasks. For example, most major metropolitan transit authorities already have existing transit outlets through which sales and renewals of smart cards can be handled.

4.2.3 Reorganization of Transit Personnel

Smart card use can affect the responsibilities and tasks of current personnel of the transit agency, by possibly eliminating some existing tasks and adding many new ones. In particular, work of the following personnel could be affected: supervisors, maintenance crew, accounting and finance staff, computer and information system staff. The transit agency may need to add new skilled personnel to its staff to accommodate the smart card deployment. Even if an outside agency is charged with the administration, sales, and marketing of smart cards, qualified agency staff would still be needed for a number of tasks -- responding to malfunctions of the cards or vehicle units; performing maintenance and repairs of the smart card system; handling smart card systems' software; etc. Existing personnel of most transit agencies do not possess all of these skills. Small transit agencies are particularly concerned about their ability to recruit these qualified personnel.

4.2.4 Standardization

Different transit agencies may have different requirements for the smart card system's hardware and software. Many agencies may wish to make their own choices about the hardware and software to adopt. This implies that smart card systems for large-scale deployment

may need to have flexibility to accommodate differing requirements of different agencies. This issue requires further research.

4.2.5 Leadership Support for Smart Card Implementation

For each participating transit agency, the decision to join this FOT was an easy one. This is because the transit agency was not called upon to make any financial contribution toward the costs of the field operational test or to implement internal reorganization. Large-scale smart card use will certainly require approval from the agency's administrator and the city council. Therefore, several factors, besides the technical merits of smart card systems, may become very important. Decision makers may desire more information derived from more extensive deployment of smart cards, such as inter-agency interface, institutional issues, benefits, costs, and public opinions.

4.2.5 Investment Strategy

Regardless of the scale of smart card deployment and use, there is likely to be continued need for cash fares and fare boxes in the foreseeable future. The questions facing the transit agency include: when would it be a good time to implement systemwide smart cards; and how to justify such a major investment.

Transit agencies who have just recently installed new fare boxes on their buses may understandably be less willing to consider adopting another, totally different, fare collection technology so soon afterward. Some transit agencies may be more willing to adopt a smart card system if it enables them to revamp the entire fare collection system; for example: being able to integrate the smart card system with advanced electronic fare boxes.

CHAPTER FIVE

CONCLUSIONS

The first smart card FOT in California has demonstrated that smart card systems worked reliably in real-world bus operations. The popularity of smart cards with bus riders exceeded the expectation of the participating transit agencies; and a large number of passengers not selected to receive smart cards during the FOT expressed enthusiasm of getting one. All participating transit agencies believe that smart cards are a superior fare collection technology to existing fare boxes, and that this FOT was a resounding success.

Results of this FOT indicate that, in addition to enhanced customer satisfaction, smart cards also improved the transit agency's productivity. Evidence from this research indicates that, relative to fare boxes, smart cards can reduce annual total fare collection costs, passenger boarding times, vehicle down-time due to malfunctions of the fare collection system, driver workload and stress. The capital cost for the smart card system was higher than the that for a fare box, but operating costs for the former were lower, resulting in the total annual cost for a smart card system to range from being similar to about 34 percent lower than that for a fare box. It is likely that the capital cost for smart card systems will decrease with greater use and as component technologies mature. In addition, the smart card system provided better quality data than those currently obtainable from fare boxes plus supplemental ride-checking, as well as new data elements currently not being collected. The smart card system enabled collection of consistent and uniform transit data among different transit agencies.

This study compares some cost and productivity aspects between the Echelon smart card system and the existing fare box in order to assess whether the smart card system might be a viable fare collection technology. The limited scope of this six-month demonstration project, plus the fact that the participating transit agencies were not required to finance the smart card demonstration or undergo any organizational changes, makes it necessary for us to limit the evaluation to such a direct comparison between the two systems.

This smart card FOT was limited in the objective, implementation scope and duration. Therefore, estimates of cost and productivity implications of the smart card system to the transit agency presented here should be considered as approximations (albeit the best approximations) at this time.

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