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# Evaluation of the I-110 Corridor Smart Card Demonstration Project

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# EVALUATION OF THE I-110 CORRIDOR SMART CARD DEMONSTRATION PROJECT

Final Report

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## ABSTRACT

This Report presents an evaluation of the Phase II Smart Card Demonstration Project. The goal of the project is to develop a transit fare payment system for commercialization that will improve transit efficiency and effectiveness. Phase I of the project included a review of various fare card technologies and an assessment of feasibility of advanced fare payment systems. The major focus of Phase II is the testing of selected technologies in revenue service. Two types of fare payment cards were selected: a contactless radio frequency (RF) card and a contact card. The advanced fare payment system includes passenger transaction units installed on buses and the associated control and communications system.

The Phase II evaluation covers the following areas: functional performance of hardware and software components, impacts on transit management, operations and efficiency, transit passenger responses and perceptions, and institutional and organizational issues related to the planning and implementation of the Field Operational Test (FOT). The evaluation was conducted as a joint project with the University of California, Berkeley and the University of Southern California. The UC Berkeley portion of the evaluation is presented in Volume 1 of the Final Report. This Volume presents the USC portion of the evaluation.

The Phase II field operational test was an unqualified success. Performance of the advanced fare payment system was better than anticipated. Card failures and other types of mechanical problems were extremely rare. Transit passengers enthusiastically endorsed the cards, and transit managers were very satisfied with the results of the field test. The project greatly benefitted from the technical skills and commitment of the system designer and from the management and coordination provided by the Caltrans District 7 California Advanced Public Transportation System group. The Smart Card advanced fare payment system offers significant potential for increasing transit productivity and service quality.

Keywords: FOT, Advanced Fare Payment, APTS, Public Transit, Smart Card

# EXECUTIVE SUMMARY

New transportation technology can potentially increase the efficiency and effectiveness of public transportation services. One of the most promising areas of new technology is advanced fare media. The traditional systems of cash, tokens, and passes represent a significant part of transit operating costs, and make differentiated fare structures difficult to manage. Passes are subject to theft and fraud, while cash is cumbersome and makes both passengers and bus operators the potential target of personal crimes. Traditional media also provide limited information to the transit provider, since revenues are only rough indicators of ridership.

An advanced fare payment system includes the following elements: a fare medium, some means of recording and processing use, and some means of verification. This research evaluates the performance of the Smart Card. Essentially a small computer, the Smart Card contains a micro-processor and memory sufficient for an application program, data storage, and value storage.

## PURPOSE OF RESEARCH

The purpose of this research was to evaluate Phase II of the Federal Transit Administration's Advanced Fare Payment Media Research and Development project. Its goal is to develop a transit fare payment system for commercialization that will improve transit efficiency and effectiveness. Phase I of the project included a comprehensive review of the various card technologies and an assessment of feasibility of advanced fare payment systems. The major focus of Phase II was the field testing of the selected technologies in revenue service. Two types of Smart Cards were selected for testing: a contactless radio frequency (RF) card and a contact card. The cards have similar capabilities from a fare card usage perspective.

The Phase II evaluation addresses the following: 1) functional performance of hardware and software components; 2) impacts on transit operations, management, and efficiency; 3) transit passenger responses and perceptions; and 4) institutional and organizational issues related to the planning and implementation of the Field Operational Test (FOT). Evaluation of item 2, impacts on transit operations, management and efficiency, was conducted by University of California, Berkeley. Results are presented in a separate report.

## THE FIELD OPERATIONAL TEST

The FOT was a joint effort sponsored by the Federal Transit Administration's Advanced Public Transportation Systems (APTS) new technology program. It took place in the I-l 10 (Harbor Freeway) corridor in Los Angeles County. Echelon Industries, Inc. won a contract from the Federal Small Business Innovation and Research (SBIR) program to develop a commercially viable advanced fare payment system. Echelon, Inc. was joined by the California Advanced Public Transportation System (CAPTS) Group at the California Department of Transportation (Caltrans) District 7, which acted as the oversight and funding pass-through agency. Field testing required the participation of transit agencies. Gardena Bus Lines, Torrance Transit, and the Los Angeles Department of Transportation (LADOT) agreed to participate.

### The Smart Card System

The system developed by Echelon is termed the **Fare** Transaction and Vehicle Management/Monitoring System, or FareTrans VMS. The system developed for the FOT has the following elements: 1) a Passenger Interface Unit (PIU), which reads the Smart Card and performs the fare transaction; 2) a Driver Interface Unit (DIU), which allows the driver to control and communicate with the system; 3) a Control Unit which performs processing, data storage and input/output for the system; and 4) a Global Positioning Satellite (GPS) receiver which tracks the geographic location of the vehicle.

The FareTrans VMS has extensive capabilities and applications. The installed hardware supports printers and voice announcement. The data provided by the system can be used to monitor schedule adherence, or examine ridership patterns on a stop-by-stop basis. The system allows for the integration of fare payments across transit agencies, and, in concept, the cards can be linked to other electronic debit systems. The FOT focussed only on the viability of the system for fare payment. A subsequent phase will test additional capabilities of the system.

### The Smart Card FOT

The FareTrans VMS was field tested for a six-month period from August 1994 through January 1995. Two types of cards were tested. A contactless RF Card was tested on the Torrance and LADOT routes; a contact Smart Card was tested on the Gardena route. A total of 350 Smart Cards and 500 RF Cards were made available for purchase. Over the test period, 541 cards were sold and about 48,000 card transactions were logged.

## EVALUATION RESULTS

### Functional Performance

Functional performance of the FareTrans VMS is considered to be very good. First, we examine transaction errors. A type I error occurs when the intended transaction does not take place. A type II error occurs when unintended transactions (usually multiple transactions) take place. Since multiple transactions are more a matter of system management than technology, they are not a critical determinant of technical performance. Type I errors were so rare that little analysis could be performed. A total of 3 1 type I errors in 24,564 transactions were recorded for the contact Smart Cards, yielding a success rate of 99.9%. The RF Card performance was even better, with just two type I errors in 23,416 transactions, resulting in a success rate of 99.99%. There were no cases of type II errors (multiple transactions) for the Smart Card and 10 cases for the RF Card.

Second, we consider the performance of other system hardware and software elements. The FareTrans VMS is a relatively inexpensive system constructed of components manufactured to commercial standards rather than to industrial standards. A key question is whether commercial components could perform acceptably in the environment of a public bus. While system performance was very good during the field test, six months is not long enough to assess lifecycle costs of the system.

The system's design and performance are consistent with the standards provided by the scientific literature to the extent permitted by the bounds of the test. We also note that system performance improves over time, as passengers and bus drivers have more experience with the system. While both cards performed very well relative to market standards for technologies such as magnetic stripe cards, the Smart Card had a failure rate that is likely to be unacceptable in a transit context. Bus drivers process so many transactions that any fare payment system must be extremely reliable to add value to the operation. On the other hand, performance of the RF Card suggests it has significant promise for large-scale deployment.

**User Response**

If Smart Card technology is to be widely adopted, it must be found acceptable by transit patrons. The purpose of the user response evaluation is to examine the following issues: 1) willingness to purchase and use the Smart Card; 2) experiences using the card, including problems encountered; 3) overall satisfaction with the card; 4) possible differences between the two card technologies; and 5) relationships between social and demographic characteristics and response to the fare cards.

We conducted an on-board survey of passengers on the three routes in November and early December 1994. Of the 784 valid responses received, 150 respondents had purchased a Smart Card. Passenger characteristics are quite different across the three routes. The LADOT line is a long-distance express commuter service; most patrons are employed full-time, have access to a private vehicle, and report household incomes above the 1990 County median. The Torrance line provides local service within Torrance as well as express service to downtown Los Angeles. Torrance respondents include many young persons. Household incomes are moderate, and many passengers are transit dependent. Like Torrance, the Gardena line is a combination local and express service. Gardena respondents consist mainly of the working poor: they report the lowest household income, the largest households, and the greatest degree of transit dependency. Surveys were offered in both English and Spanish, and about 40 percent of the responses were in Spanish.

Response to the Smart Card was overwhelmingly positive. Nearly all users reported being satisfied or very satisfied overall with their Smart Card. There were no differences across card types, suggesting that there are no major problems associated with using either type of card. Smart Card users reported few problems with using the cards; these problems apparently did not affect satisfaction. These positive results are likely a function of how problems were handled; users were allowed to ride free when card problems were encountered.

While satisfaction with the cards does not vary with respondent characteristics, the likelihood of having purchased a card does vary. Spanish-speaking respondents were far less likely to have heard about or purchased a card. Purchase of a card is associated with higher household income and full-time employment, as would be expected.

We conclude from our survey results that transit patrons find the advanced fare card a convenient and reliable fare medium. On the demand side, there are no apparent barriers to widespread use of such media.

**Institutional Issues**

New technology demonstrations often require a level of coordination and cooperation among public agencies and private companies far beyond that required for regular day-to-day operations. In addition, the risk and uncertainty associated with tests of new technology may require mid-course changes in plans, quick responses to unforeseen problems, and adjustment of time schedules as a result of unanticipated delays.

New technology tests therefore require effective management, flexibility, and good working relationships among participants if they are to succeed. All of these requirements were met. Over the course of the project, early apprehensions of the participating transit agencies faded, and the FOT was deemed an unqualified success by all parties. We attribute the success of the FOT to the following: project ownership, both on the part of Echelon and Caltrans CAPTS-District 7; effective project management; and the limited scale and scope of the FOT. The system developer, Echelon Industries, Inc., created a product that is sensitive to the needs of transit operators, and conducted the equipment installation, driver training, and monitoring and maintenance in a manner responsive to the concerns of transit management. The CAPTS oversight team actively participated in the project by solving problems and building consensus among participants. Finally, the restriction of the FOT to three small transit agencies and to the performance of the fare media made it possible to conduct a detailed and thorough field test, given management and budget constraints.

## CONCLUSIONS

The Smart Card FOT demonstrated the feasibility of using advanced fare payment media in public transit. Testing of two different card types made comparative evaluation possible, and showed that the contactless RF Card was the more reliable technology for widespread implementation. Response to the Smart Card by transit patrons is overwhelmingly positive, and leads to the conclusion that from the transit demand side, use of Smart Cards would be enthusiastically endorsed. Transit managers were also very satisfied with the results of the FOT; most stated a willingness to participate in future tests, and an interest in seriously considering permanent adoption of the cards. This FOT is only a first step in demonstrating the benefits and capabilities of Smart Cards.

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CHAPTER ONE

# INTRODUCTION

## 1.1 Project Overview

New transportation technology holds promise for increasing the throughput and capacity of our existing transportation system, for providing better integration between alternative transport modes, for more effective pricing and marketing of transportation alternatives, and for more efficient provision of transport services. New technology applied to public transportation systems can increase productivity and efficiency and make transit a more attractive alternative mode. Effective use of new technology requires extensive experimentation and field testing. The pace of development is rapid, and many competing products are being marketed to transit operators and funding agencies.

One of the most promising areas of new technology is advanced fare media. The traditional systems of cash, tokens, and passes are relatively inefficient and ineffective. They represent a significant part of transit operating costs: fare boxes and equipment must be maintained and revenues must be counted. Traditional media make differentiated fare structures difficult to manage, and thus contribute to poor revenue performance. Passes are subject to theft and fraud, while cash is cumbersome and makes both passengers and bus operators the potential target of personal crimes. Traditional media also provide very limited information to the transit provider, since revenues are only rough indicators of ridership. Advanced technology has the potential for addressing many of these problems.

An advanced fare payment system includes the following elements: a fare medium, some means of reading and altering the medium to reflect payment and system use, and some means of verification (Hansen, Qureshi, and Rydzewski, 1994, p. 10). Magnetic stripe cards are currently the most widely used advanced fare medium; they are in use in BART, Washington METRO, MBTA (Boston), and other metropolitan rail systems. Magnetic stripe cards are most commonly a form of debit card: customers purchase a card with a fixed cash or trip value and use the card until the value is depleted. The magnetic stripe cards have a limited capacity to store information, although data can be both read from and read to the card. Magnetic stripe cards are relatively easy to duplicate, thereby encouraging fraudulent use.

The Smart Card is essentially a small computer; it contains a micro-processor and memory sufficient for an application program, data storage, and value storage (Echelon, 1992, p. 8). Communication of electronic information can occur either through some form of physical contact with external devices, or some form of radio transceiver frequency via an antenna embedded within the card. The Smart Card can store hundreds to thousands of characters, and is extremely difficult to duplicate. Smart Cards are also far more reliable than magnetic stripe cards; the Smart Card failure rate is 1 per 1,000 to 15,000 transactions, compared to 3-15 per 100 transactions for the magnetic stripe card.

The purpose of this research was to evaluate Phase II of the Federal Transit Administration's Advanced Fare Payment Media Research and Development project. The goal of the project is to develop a transit fare payment system for commercialization that will improve transit efficiency and effectiveness. Phase I of the project included a comprehensive review of various fare card technologies and an assessment of feasibility of advanced fare payment systems. Phase II included an extensive evaluation of various hardware/software configurations. The major focus of Phase II was the testing of the selected technologies in revenue service. Two types of Smart Cards were selected for testing: a contactless radio frequency (RF) card, and a contact card. Both cards have similar capabilities from a fare card usage perspective. In addition to the Smart Cards, the advanced fare system included passenger transaction units (PTU) installed on buses that performed Smart Card communications functions and were linked to a Global Positioning System (GPS), as well as hardware and software communications with a central control center. (See Chapter Two for a full description of the PTU system).

Phase II is the Field Operational Test (FOT) portion of the project. Its goal was to demonstrate key aspects of a prototype system in actual operating environments. The final phase will demonstrate all aspects of the commercial version of the system in a multi-agency environment.

The Phase II independent evaluation presents a comprehensive analysis of the FOT. It covers the following areas:

1. functional performance of hardware and software components;
2. impacts on transit operations, management, and efficiency;
3. transit passenger responses and perceptions; and
4. institutional and organizational issues related to the planning and implementation of the FOT.

## 1.2 Description and purpose of the demonstration

The fare payment system that emerged from Phase I was far more than a new type of fare collection system. The Smart Card technology makes it possible to collect ridership information by vehicle location and time of day. When GPS is incorporated in the system, it is possible to automatically (no driver action) charge distance-based fares, and to evaluate in-service vehicle performance. Thus the system adds greatly to transit management's ability to monitor and analyze service operations and passenger demand. However, the Phase II FOT was focussed specifically on the testing and performance of the Smart Cards.'

The original FOT plan included participation of transit agencies and at least two large employers. Participating employers were to link other services to the cards (for example transit pass discounts or parking charges) and to perform clearinghouse functions for the cards. Employers could use the information provided by the cards as part of their trip reduction program compliance activities. The original FOT plan also anticipated a significantly larger demonstration in terms of both cards and vehicle equipment. Changes in the FOT objectives are summarized in Table l-l. These changes shifted the emphasis of the FOT to functional and technical performance.

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'Per Echelon, we understand that the field tests also included limited tests of printers, processing and storage systems, power supply and protection, and display and key pad systems.

## TABLE l-l SUMMARY OF PROJECT CHANGES

| DEMONSTRATION OBJECTIVES | CHANGES |
|---|---|
| Equip 25-35 buses with card reader/writers | Equip 21 buses, with total of 25 units available |
| Supply up to 3,000 cards | Supply up to 800 cards |
| Program cards and readers | No change |
| Link cards, reader/writers, pass distribution, and documentation | No change |
| Conduct demonstration on existing, real-time bus routes | No change |
| Test effectiveness and utility of Smart Cards | Test both RF and Smart Cards |
| Extract data regularly from bus readers for analysis and reporting | No change |
| Assess reliability of Smart Cards on buses | Test both RF and Smart Cards |
| Test data collection and reporting value with regard to Reg. XV | Not applicable; no corporate site included in FOT |
| Operation of Transit Centers for pass distribution | Cards distributed at transit agencies and at Caltrans; Caltrans performs Transit Center function |
| Conduct corporate test site for collection of Reg. XV data | No corporate site included in FOT |
| Survey users for opinions of cards and system | User survey to assess both RF and Smart Cards |
| Demonstrate the function and uses of a ‘clearinghouse | No ‘clearinghouse’ function included in FOT |

The actual FOT included three transit agencies using two different card technologies. The contact-based Smart Card was tested on Route 1 of Gardena Bus Lines. The contactless RF Card was tested on Route 448 of Los Angeles Department of Transportation (LADOT) and Route 2 of Torrance Transit. All three routes operate in the I- 110 (Harbor Freeway) corridor area of Los Angeles County. Table 1-2 gives number of buses equipped and cards sold for each transit agency/route.

**TABLE l-2 EQUIPMENT AND CARDS TESTED BY AGENCY/ROUTE**

| | GARDENA/RTE 1 | LADOT/RTE 448 | TORRANCE/RTE 2 |
|---|---|---|---|
| Route type | local/commuter | commuter express | local/commuter |
| # buses assigned to peak service | 8 | 4 | 3 |
| # buses equipped | 10 | 6 | 5 |
| Card type | Smart Card | RF Card | RF Card |
| # cards issued | 281 | 149 | 111 |

Various discounts were offered with the initial purchase of cards to assure that a sufficient number of cards for the analysis would be sold. The discounting eliminated any possibility of examining the effect of the cards on transit demand. These changes substantially altered the Phase II evaluation plan and led to development of a revised plan approved by Caltrans in August 1994.

## 1.3 Description and purpose of the evaluation

The purpose of the Phase II evaluation is to provide an overall assessment of the FOT that will help to inform further technology development and investment. The evaluation covers the four general areas briefly described below.

### 1.3.1 Functional performance of hardware and software components

The primary purpose of the Phase II FOT was to demonstrate operational feasibility of the advanced fare payment system. Thus, functional performance is a key part of the evaluation. Functional performance includes examination of capabilities and performance expectations, review of the technical developer's testing program and results, and analysis of in-use performance. In-use performance must be compared against the benchmarks of expected performance characteristics and industrial performance standards. System malfunctions, card failures, and other problems must be described and explained. The functional performance evaluation provides information on the overall reliability and function of the test system.

### 1.3.2 Impacts on transit operations, management, and efficiency

The potential impact of the advanced fare payment system on the transit agency is significant. As noted earlier, the system can provide significant efficiency benefits. However, implementation of the system involves some costs: training drivers in the use of the new equipment, changing fare collection procedures, and establishing policies for dealing with equipment or card malfunctions. Once the implementation is accomplished, efficiency benefits should be observed. A critical part of the FOT is to compare operations with the new system to conventional operations to determine whether the anticipated benefits of the system are in fact realized.

### 1.3.3 Transit passenger responses and perceptions

Widespread use of advanced fare media depends on their acceptance by individual travelers. The user response evaluation examines the extent to which transit passengers are willing to try the cards, and the characteristics of those willing to try them. Experiences with the cards -- including how they are purchased and renewed and how well they work -- must be monitored and examined in the context of the user's perception of the card. Card use and attitudes about the cards are evaluated across passenger socioeconomic and demographic segments to assess the feasibility of introducing Smart Cards on a broad scale.

### 1.3.4 Organizational and institutional issues

The demonstration and implementation of new technology require interaction between project sponsors, system developers, and participating transit agencies. The FOT also requires an ability to respond to unforeseen changes and problems that are part of any test of new technology. The public/private aspect of this FOT places the sponsors in a unique and challenging position that cuts across organizational boundaries. How this role is developed and refined is important to understanding how such partnerships may be fostered. The perceptions of agency participants are also important. Success in proving the feasibility of using new technology elements is a necessary but not sufficient condition for widespread implementation; rather, general implementation depends on agency assessments of the use and effectiveness of the product and its overall impact on the organization. Monitoring the process of interagency negotiations and interactions can provide valuable insight on how FOTs are effectively accomplished.

## 1.4 Contents of Volume 1 and Volume 2

The Phase II evaluation was conducted as a joint project with UC Berkeley and USC. The UC Berkeley team conducted the project literature review and the evaluation of impacts on transit operations, management, and efficiency. The USC team conducted the evaluations of functional performance, user response, and institutional impacts, and also collected transaction data to support the UC Berkeley analysis. Finally, both research teams performed an overall assessment of the FOT with respect to their respective research tasks. UC Berkeley research results are presented in Volume 1 of the Final Report, and USC team research results are presented in Volume 2 of the Final Report.

## 1.5 Organization of Volume 2

The remainder of this Final Report is organized as follows. Chapter Two presents a general overview of the project and describes the FOT. The functional analysis is presented in Chapter Three. User response is discussed in Chapter Four, and Chapter Five contains the institutional analysis. Chapter Six presents conclusions of the evaluation and discusses the potential of Smart Card technology to improve transit productivity and effectiveness.

# CHAPTER TWO
# PROJECT DESCRIPTION

## 2.1 History of Project Development

The Federal Transit Administration sponsors the Advanced Public Transportation Systems (APTS) new technology program to encourage the development and adoption of technology improvements for the transit industry. The FTA issued a request for proposals under the APTS program to promote research on applications of Smart Card technology in public transit. The funding in this case was from the Federal Small Business Innovation and Research (SBIR) program. As such, the main objective of the program is to develop a viable commercial product for the industry. Echelon Industries, Inc. won the contract and began work on Phase I of the Advanced Fare Payment Media Feasibility Program in 1992.

The purpose of the Phase I work was to demonstrate the feasibility of advanced fare payment technologies. Phase I activities included the following:

1. Review of prior studies and demonstrations of advanced fare media
2. Evaluation of alternative technologies and systems
3. Survey of needs, practices and priorities related to fare collection and potential advanced technology applications within the transit industry
4. Development of potential applications
5. Design of a test program

This work was performed independently by Echelon, Inc. Completion of the first three activities led to the decision to orient potential applications around problems that transit agencies wanted to solve, which in turn led to the concept of a “passenger transaction system” (Echelon, 1992). Table 2-1 summarizes the characteristics and functions of the passenger transaction system.

## TABLE 2-l CHARACTERISTICS AND FUNCTION OF THE PASSENGER TRANSACTION SYSTEM

| CHARACTERISTICS | FUNCTIONS |
|---|---|
| A fare card that can be issued and recharged by a variety of means (e.g., through the transit agency, the employment site, or a clearinghouse), or via a telephone call | Integrate transit fare payment with other types of payments and subsidies (e.g., employer-provided rideshare credits) |
| A fare card that can record, debit, credit, and verify all passenger transactions | Reduce fare-related fraud and theft |
| A fare transaction unit that is linked with a vehicle locator system | Charge distance-based or “needs-based” fares<br>Monitor schedule adherence |
| A passenger boarding/alighting counting system | Develop a detailed data base of ridership characteristics |
| A video surveillance system | Improve security |
| A bus stop announcement system | Address ADA requirements |
| A transfer and receipt printing system | Improve data keeping<br>Reduce transfer costs |
| A vehicle monitoring system | Improve vehicle utilization |

Such a system implies a fare card that can read, write, and store information and that can be linked to a variety of subsystems. Hence the Smart Card (fare card with microprocessor) was selected for the FOT. Finally, because the ultimate goal of the program is a commercial product, system production and operations costs are also a major consideration.

## 2.2 The Phase II Project

### 2.2.1 Participants and Roles

The Phase II FOT required the participation of transit agencies so that the demonstration equipment could be installed on buses and tested in a real operating environment. In the search for volunteer agencies, Echelon turned to Caltrans. Caltrans had an interest in the project, because federally-funded new technology research and development is by state law subject to Caltrans oversight. In addition, the evaluation component of Phase II qualified as part of the California PATH (Partners for Advanced Transit and Highways) program. Thus Caltrans functioned as both the oversight and funding pass-through agency for Phase II. Oversight took place within the California Advanced Public Transportation System (CAPTS) Group at Caltrans-District 7, while the pass-through function and monitoring of the evaluation research took place within the CAPTS Group at Caltrans Headquarters. Day-to-day project management was performed by a subcontractor, TRANSCON (See Figure 2-l).

Knowing that Echelon would go ahead with the Phase II of the project, Caltrans submitted a proposal to the Federal Transit Administration for the project with Echelon as a partner. Their efforts started in April 1993, when the contract for technical managers with Caltrans was finalized. At this time, the Volpe Center approved the inter-agency agreement and Caltrans transferred funds to the Center. Transit agencies had already been approached and MOUs (Memorandums of Agreement) were being reviewed by the agencies at this time. The Smart Card Phase II technical contract was finally approved and signed by the Volpe Center in late July 1993. FTA's responsibility amounted to the provision of a percentage of the administrative costs of the project. The contract officially started on August 1, 1993, with Echelon as the technical contractor for the project. The project kick-off meeting was held on August 19 and included representatives from Caltrans Headquarters, representatives from transit properties, and others.

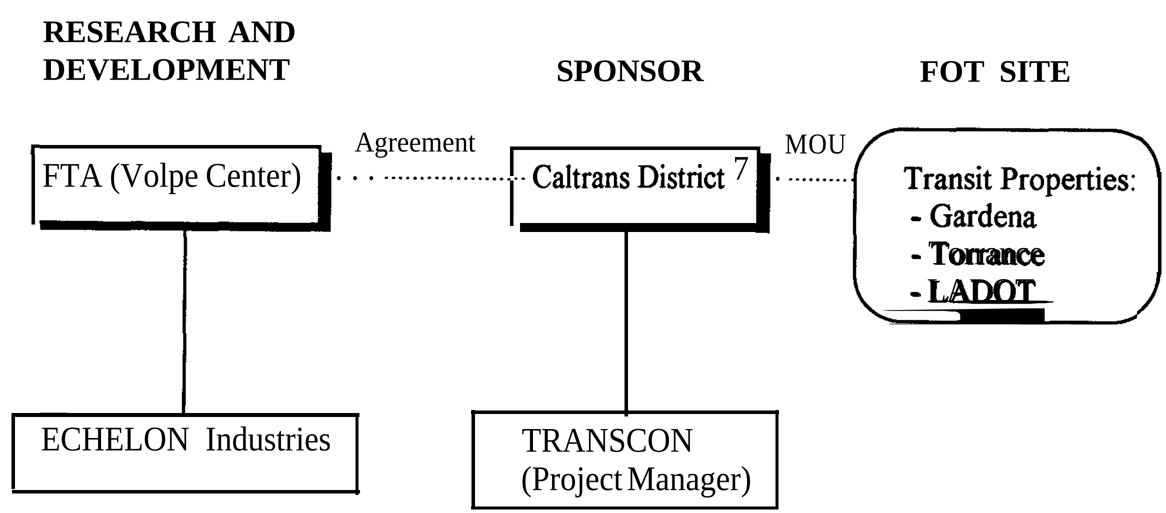


**FIGURE 2-l ORGANIZATIONAL STRUCTURE**

Through the joint efforts of Echelon and Caltrans, three transit agencies agreed to participate in the demonstration:

Gardena Bus Lines, a small municipal operator serving the City of Gardena. Gardena provides mostly local service, but also offers commuter service to and from downtown Los Angeles.

Torrance Transit, a small municipal operator serving the City of Torrance. Like Gardena, Torrance also operates a commuter service to and from downtown Los Angeles.

Los Angeles Denartment of Transnortation. The City of Los Angeles operates commuter service between downtown Los Angeles and several suburban communities.

### 2.2.2 Location of the POT

The FOT was located within the I- 110 (Harbor Freeway) corridor. The I- 110 extends south approximately 25 miles from downtown Los Angeles to the Los Angeles Port area. Each transit agency selected one route within the corridor for the demonstration, as shown in Figure 2-2. Gardena Route 1 provides local service through the City of Gardena, accesses the I-l 10 at El Segundo Blvd., exits I-l 10 at Martin Luther King Boulevard, and provides local service around downtown. Torrance Route 2 provides local service through Torrance and Gardena, and then provides parallel service to Gardena Route 1. LADOT Route 448 is a peak-only route that serves commuters in the Palos Verdes and South Torrance residential areas. It accesses the I-l 10 at Pacific Coast Highway and also exits at Martin Luther King Boulevard, serving limited stops within downtown. Figure 2-2 also shows the stops along each route and the portion of the I-l 10 used by all routes. Table l-2 in Chapter One gives the number of buses equipped and type of card tested for each route.

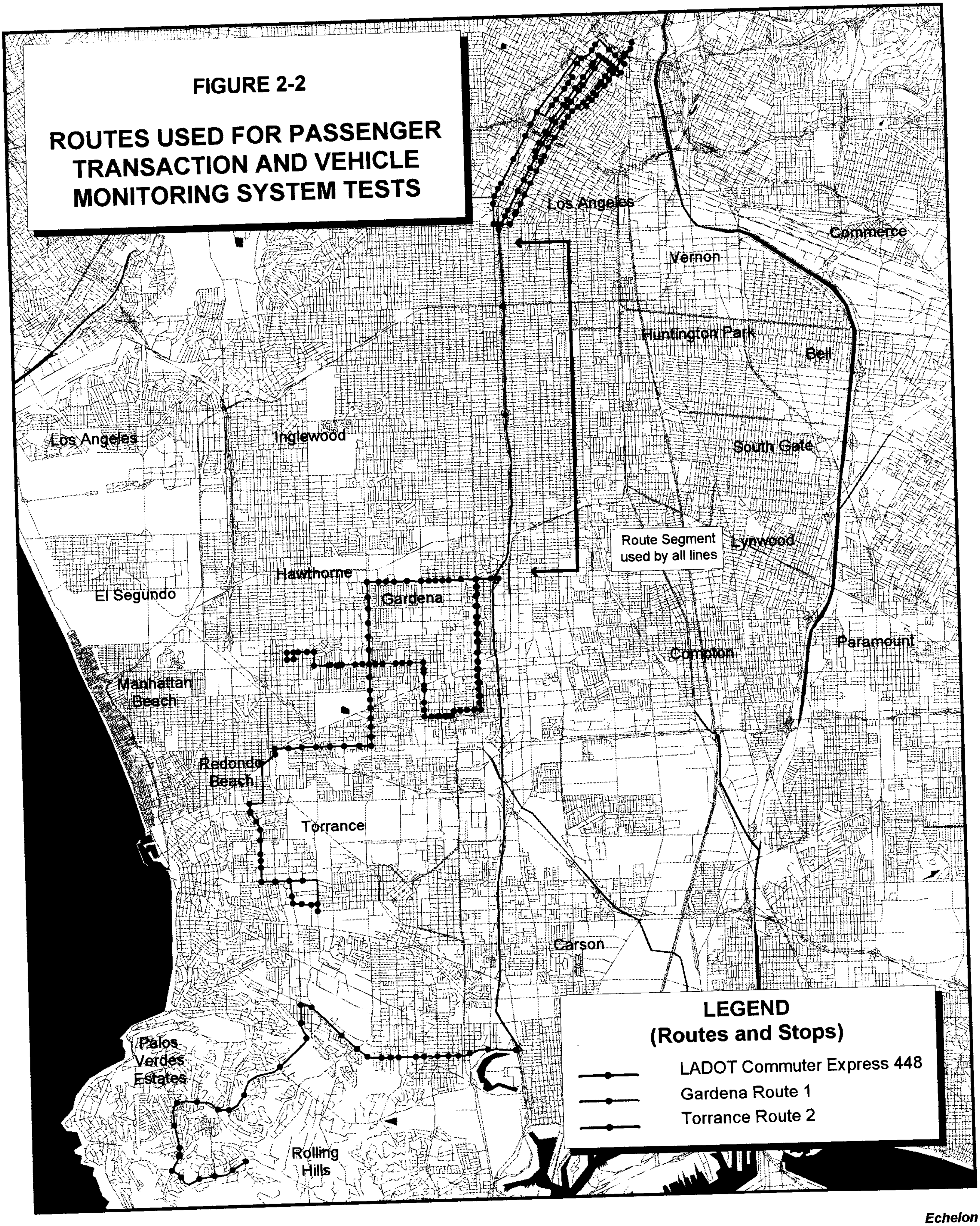
FIGURE 2-2
ROUTES USED FOR PASSENGER TRANSACTION AND VEHICLE MONITORING SYSTEM TESTS
Los Angeles
Commerce
Vernon
Huntington Park
Bell
Los Angeles
Inglewood
South Gate
Route Segment used by all lines
Lynwood
Hawthorne
El Segundo
Gardena
Paramount
Compton
Manhattan Beach
Redondo Beach
Torrance
Carson
LEGEND
(Routes and Stops)
LADOT Commuter Express 448
Gardena Route 1
Torrance Route 2
Palos Verdes Estates
Rolling Hills
Echelon

SCARD08 wor

## 2.3 **The Smart Card System**

The system developed by Echelon is termed the **Fare** Transaction and Vehicle Management/Monitoring System, or FareTrans VMS. Since a key objective was to design a system that could be sold profitably to transit agencies for less than $10,000 per bus, it was necessary to use readily accessible "off the shelf' hardware and software components manufactured to commercial specifications. The operating environment of a public transit bus may be more rugged than commercial components are designed for. Thus the reliability of commercial components in such a quasi-industrial environment is a fundamental issue to be addressed in the FOT.

To address specific transit agency needs, Echelon chose a modular system design that could be expanded or changed over time. The hardware components to be installed on the buses had to be designed to address safety, environmental, and maintenance needs, as well as to be conveniently accessible to both the driver and boarding passengers. The FareTrans VMS developed for the FOT has the following elements:

1. Passenger Interface Unit: This card reading unit performs the fare transaction. The unit reads a specific type of card, and is designed to allow for reading of magnetic stripe, Smart, or RF Cards. It is also designed to accommodate visual displays and speech messages. The Passenger Interface Unit was installed near the passenger side of the farebox, with the actual location varying by type and layout of the vehicle.
2. Driver Interface Unit: This unit is used by the driver to control and communicate with the system. It allows the driver to control the visual and sound displays of all units, to access various types of information (e.g., passenger counts, bus speed and location), and to process fare card actions. The Driver Interface Unit was mounted between the farebox and the steering wheel, with actual location depending on the vehicle layout.
3. Control Unit: This unit performs processing, data storage and input/output for the FareTrans VMS. The basic components include a standard 486/40 MHZ processor on a standard 8/16 bit ISA bus. It accommodates the fare transaction,

vehicle location, speech messages, etc. The Control Unit was placed where space was available, usually in the radio compartment or behind the driver seat.

4. GPS Receiver: The Global Positioning Satellite receiver tracks the geographic location of the vehicle.

Figure 2-3 shows the FareTrans VMS block diagram of system elements comprehensively tested in the FOT. The system has additional capabilities, such as voice announcement, but these were not part of the FOT (see Chapter Three for a full description of VMS capabilities). Figures 2-4a and b are photographs of the PIU and DIU as they were installed on the bus.

As noted earlier, the FOT incorporated two types of fare cards. The RF (radio frequency) card operates by passing it within a few inches of the Passenger Interface Unit. These cards were used on Torrance Transit and LADOT. The Smart Card operates by inserting it into the Passenger Interface Unit. Power is delivered through the contacts in the PIU. The Smart Card was tested on the Gardena route.*

## 2.4 The Smart Card Demonstration

The demonstration involved a six-month field test of the Smart Card fare cards and equipment. Several activities are required to conduct such a test:

1. The manufacturer constructs and laboratory tests prototypes of the various system components.
2. The project participants review the test system.
3. The transit agencies and Caltrans develop and implement a plan for marketing, issuing, and renewing cards.
4. The transit agencies and Echelon develop and implement a plan for equipment installation and driver training.

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[2]An attempt was made by Echelon to include an advanced mag-stripe card in the FOT program. The new card was supposed to be more reliable and fraud-resistant. However, the manufacturers were unable to deliver the reader printers in time for the FOT.

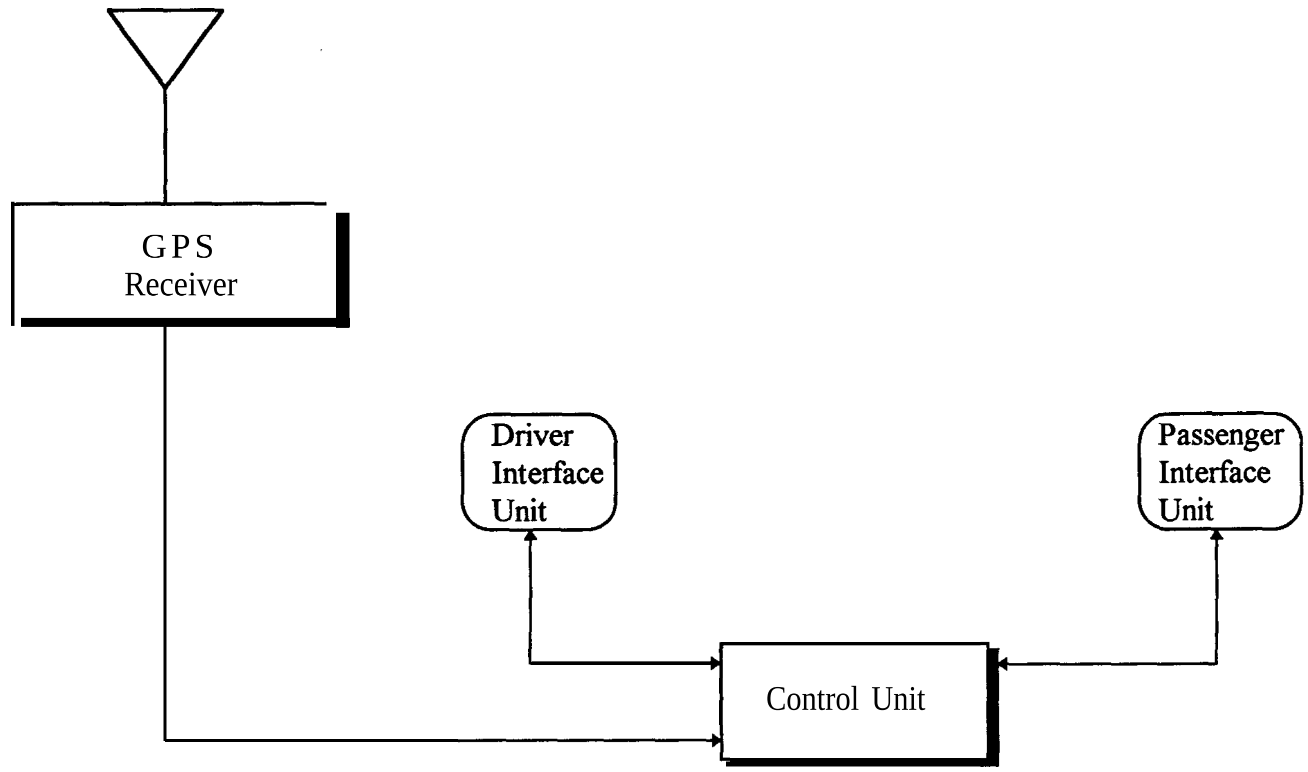



**FIGURE 2-3 FARETRANS V M S USED IN THE F 0 T**

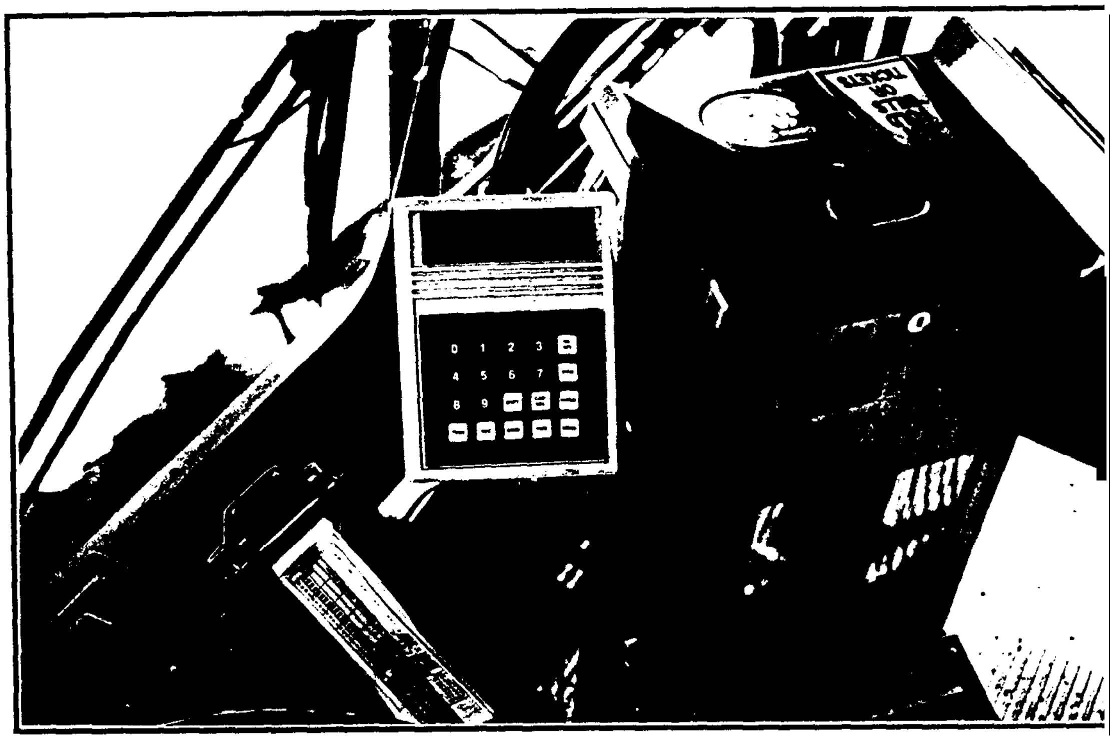



**FIGURE 2-4a DRIVER INTERFACE UNIT**


**FIGURE 2-4b PASSENGER INTERFACE UNIT**

**FIGURE 2-4 INSTALLED SYSTEMS COMPONENTS**

The project officially started on August 1, 1993. Although the demonstration sites had been selected at this time, the MOUs for the transit properties were still under review. Experimentation with the various technologies started immediately in a laboratory environment under the auspices of Echelon. Echelon provided table-top demonstration of the Smart Card and RF Card technologies to the project team in October 1993. In November 1993, Echelon provided a demonstration of its "mock-up" technology testing facilities to the project group.

Echelon continued tests with different technologies in the subsequent months. Monthly meetings continued to be held to acquaint the project team of Echelon's progress. In April 1994, plans were made for installation of equipment on the buses belonging to the three transit agencies. Most of the equipment components were ready for installation at this time. On-board installation of all equipment began in May, and installation of all hardware was completed in July. Solicitation for cards began in July, and over 240 passengers signed up during that month.

On August 1, 1994, cards were activated for use and the actual on-board test started. By September, all the Smart Cards assigned to Gardena were sold out. LADOT and Torrance continued to issue new RF Cards at this time. By the third week of September, as many as 508 cards had been issued by the three agencies. By November, a total of 36,000 fare transactions were completed with the card technology. During this month, the evaluation team from University of Southern California conducted an on-board passenger survey. The demonstration ended in January 1995 with the withdrawal of the card technology from the vehicles. By this time, as many as 541 cards had been issued and over 48,000 transactions were completed. A simple FOT chronology is shown in Figure 2-5.

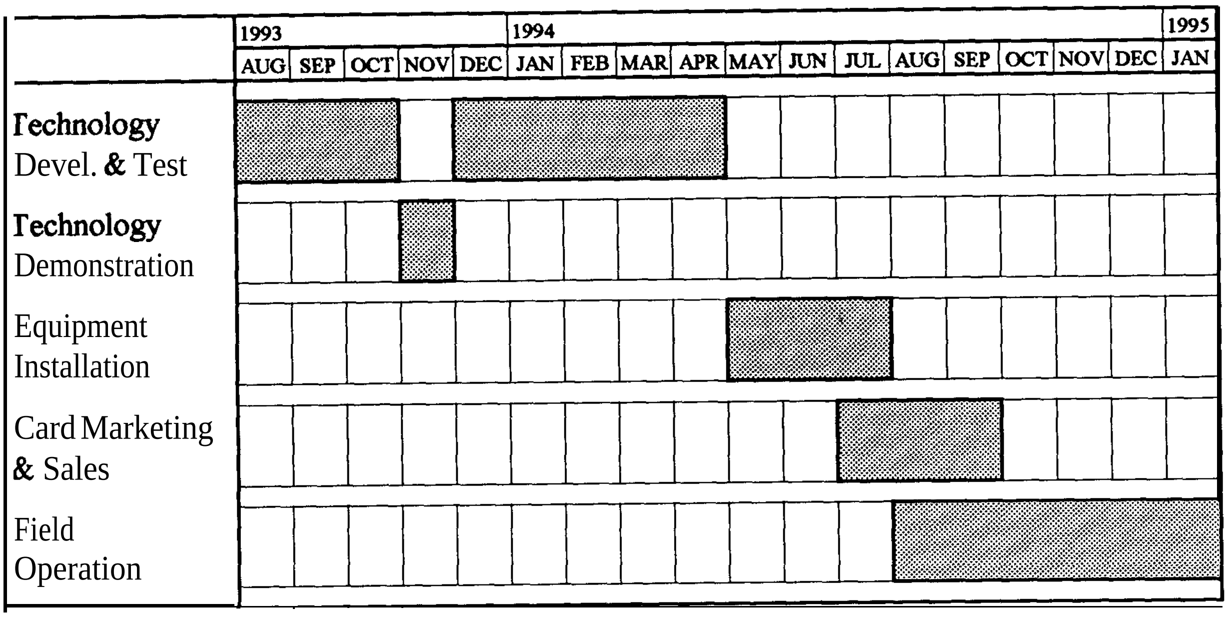



**FIGURE 2-5 FOT CHRONOLOGY**

### 2.4.1 Card Distribution

A key issue in the planning of the FOT was how many cards should be tested. The number of cards tested of course depends upon the willingness of transit users to purchase and use the card. Since no previous tests of this type had been performed, there was no information available on the probable share of passengers that would purchase the cards. The total number of cards obtained for the test was therefore determined by the minimum number needed for comprehensive functional performance testing, and by assuming that about half of the eligible passengers (those using the test routes) would elect to try the cards. Thus 350 Smart Cards and 500 RF Cards were made available for purchase.

Since the most critical aspect of Phase II was functional performance testing, project participants decided that discounts would be offered to provide an incentive for purchase and use of the card. Caltrans funded the discounts in conjunction with the I-l 10 TMP/TDM (Transportation Management Program/Transportation Demand Management) Incentive Program. These arrangements were up to the discretion of the transit agency, and consequently each agency offered a different discount package. All three agencies offered initial discounts; after August 15 Gardena and Torrance reduced the discount, and LADOT cards were priced at the regular fare. Table 2-2 summarizes the card prices for each transit agency. Discounts are relative to regular fares.

**TABLE 2-2 SMART CARD PRICES BY AGENCY AND TIME PERIOD**

| | BEFORE 8/15/94 | | AFTER 8/15/94 | |
|---|---|---|---|---|
| | Price | Discount (%) | Price | Discount (%) |
| Gardena | $20/80 trips | 75% | $40/80 trips | 50% |
| Torrance | $20/80 trips | 75% | $40/80 trips | 50% |
| LADOT | $58146 trips | 26% | $78146 trips | none |

Transit agencies also established the process for purchase and renewal of cards. Caltrans District 7 served as the clearinghouse for card purchase. Application forms and checks for the cards were sent to Caltrans. Purchasers could either have the card sent to their home address or pick up the card at Caltrans during designated days and times -- generally two days per week from 8:00 AM to 4:30 PM. Caltrans also sold cards during these periods to those who had not received applications. Card renewals were performed on board the LADOT buses. Gardena and Torrance patrons were not able to renew cards on the bus; Gardena patrons had to renew the card at Caltrans. About halfway through the FOT, Torrance began offering card purchase and renewal at the transit agency office. However, only a few card purchases took place at the Torrance office, and most Torrance renewals were also done at Caltrans.

Finally, it was necessary to establish policies for card malfunctions and other problems. For card malfunctions, passengers were asked to surrender the card to the bus driver and were allowed to ride free. The card was then returned to Echelon for diagnosis. If a card was reported as lost or stolen, a new card was issued. If a card was no longer valid, passengers were asked to pay the cash fare. Drivers were instructed, however, to avoid conflicts with passengers, and did not eject passengers who refused to pay.

### 2.4.2 Marketing

Although a marketing plan was part of the FOT, the marketing element was eliminated early in Phase II. Thus, only minimal information about Smart Card was distributed. Card purchase offer packets were developed and produced by Caltrans university student interns in both English and Spanish. Packets were distributed by high school student interns on board the buses of the Gardena, Torrance, and LADOT routes. An example of the information packet is included in Appendix A. Flyers were also posted on the buses. Table 2-3 gives the number of offer packets distributed for each route. The Table also gives the most recent daily ridership information (in terms of one-way trips) available to give a rough indication of the proportion of passengers that received the information. Note the large proportion of Spanish language packets distributed on the Gardena line.

**TABLE 2-3 DISTRIBUTION OF SMART CARD INFORMATION PACKETS**

| | RIDERSHIP | INFORMATION PACKETS DISTRIBUTED | | |
|---|---|---|---|---|
| | Weekday trips/day” | English | Spanish | Total |
| Gardena[b] | 2121 | 596 | 393 | 989 |
| Torrance[c] | 1583 | 320 | 93 | 413 |
| LADOT[d] | 156 | 160 | 0 | 160 |

[a] Daily one-way trips, excludes evening
[b] Source: Gardena Bus Lines Line-by-Line Analysis Report 1988, updated
[c] Source: Torrance Transit Line-by-Line Analysis Report 1992
[d] Source: LADOT average daily ridership estimate

### 2.4.3 Card Purchase and Use

The Smart Cards proved to be far more attractive to passengers than anticipated. By the August 1 start date, 241 cards had been issued. By September, all the Smart Cards assigned to Gardena were sold out. Over the six-month period, 541 cards were sold and 48,000 card transactions were logged. The card purchases were distributed as follows: 28 1 at Gardena, 111 at Torrance, and 149 at LADOT.[3]

[3]A total of 594 cards were actually issued. The difference between cards sold and issued reflects re-issues of lost or stolen cards as well as test cards.

# CHAPTER THREE

# FUNCTIONAL ANALYSIS

## 3.1 Purpose of the Functional Analysis

The purpose of functional analysis of Echelon Industries' Advanced Fare Payment System is to assess the demonstration system's technical performance. The goal of the analysis is to provide insight into the design and appropriate implementation of new technology for public transit, particularly advanced fare payment and related systems. The assessment addresses the degree to which the system deployed by the project partners

1. meets the partners' stated objectives for the system,
2. conforms to the standards suggested in the scientific literature defined for the system's technology, and
3. performs in terms of generic measures of system reliability.

The two most important technical questions associated with the field test were:

1. Are the technologies tested appropriate for the application? and
2. Can an advanced fare payment system constructed from components manufactured to commercial specifications function acceptably in the quasi-industrial environment of a public bus?

As in any field exercise, other technical questions were revealed during the course of the test. Two important questions relate to

1. management of transaction speeds, and
2. the effects of static discharge on contact Smart Cards.

The functional assessment identifies these and other findings bearing on constraints, implementation, innovation, and further work; and describes these results in terms relevant to

1. the program sponsors and participants,
2. potential sponsors and participants,
3. transportation research organizations,
4. technology vendors, and

5. other public and private entities affected by new transportation technologies.

The best way to describe the system is to provide a clear mental model of the various interfaces involved, including

1. human to human,
2. human to machine, and
3. machine to machine interfaces.

Preferred measures of system performance include

1. system reliability under a range of operating conditions;
2. Mean Time To Failure (MTTF) across the system, subsystems, and components; and
3. a parametric characterization of the Increasing Failure Rate (IFR) distribution.

Unfortunately, these ideal measures are rarely achieved. This field test is no exception, but the literature on system reliability provides considerable guidance with respect to how to best characterize system performance.

## 3.2 Technical Summary of the Advanced Fare Payment System

Echelon Industries' Advanced Fare Payment System is an abbreviated version of a larger scale Fare Transaction Vehicle Management System (FareTrans VMS) (Echelon, 1995). Such a unit automates fare collection, but also provides transit properties with new classes of management data and operating alternatives, particularly with respect to pricing. A simplified block diagram of a Fare Transaction VMS is shown in Figure 3-l.

The system management information provided by such a system includes the identity of the card, the category of the card holder, the stop where the transit user boards the bus, the bus number, the route number, the number of riders on board the bus when the new boarding occurs, the exact location of the bus, the time of the boarding, and other related data. The information provided to the transit user is equally relevant, including system and stop announcements in the language associated with the identity of the card, visual announcements, and hard copy such as

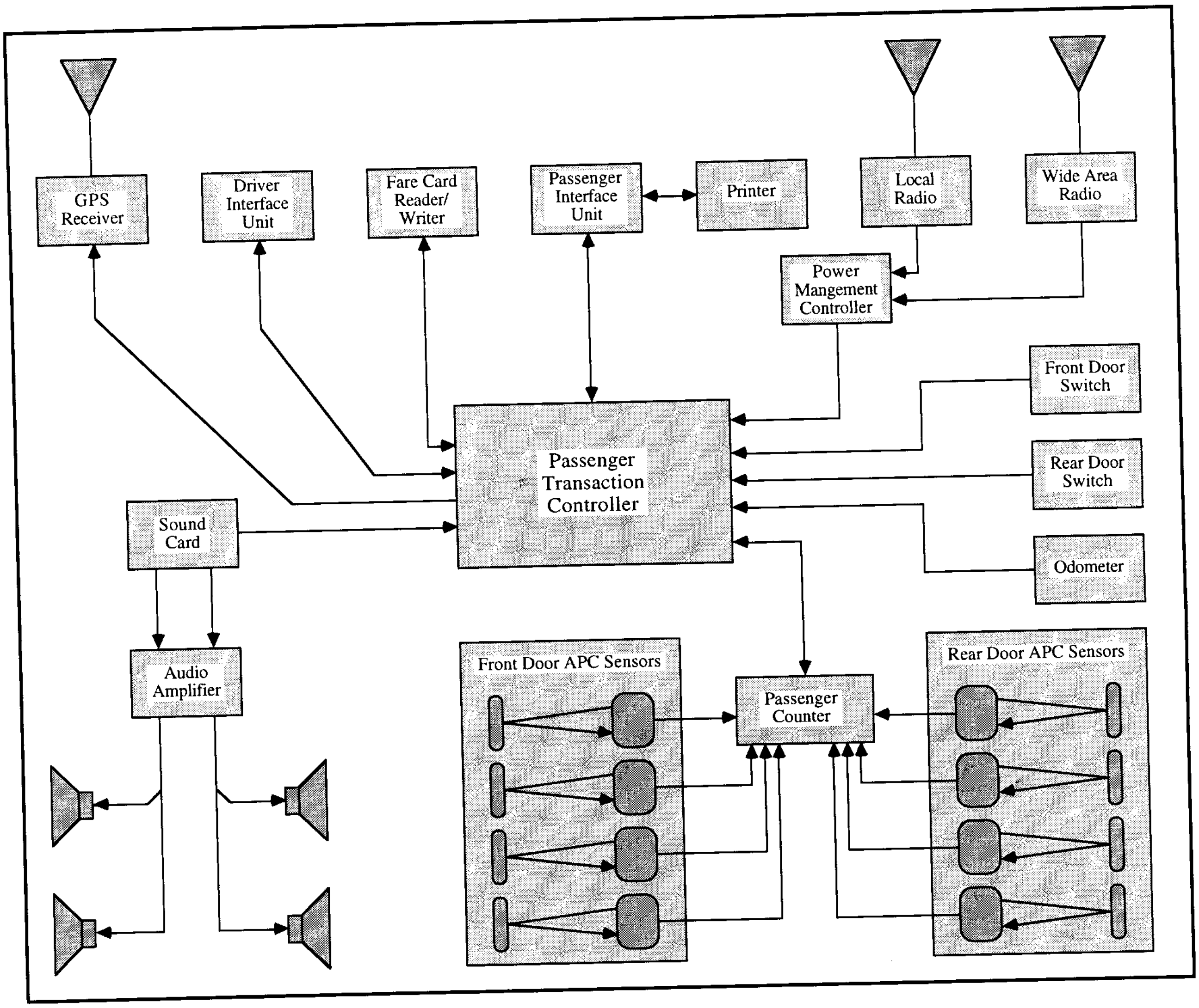



**FIGURE 3-1 BLOCK DIAGRAM OF A PASSENGER TRANSACTION UNIT DESIGNED FOR BUS TRANSIT SERVICE. (ARROWS INDICATE DATA FLOWS)**

transfers and receipts. Short-range radio is used to read transaction and system performance data stored in the Passenger Transaction Controller when vehicles reach a designated location in the transit properties' maintenance facilities. This same communications system updates the data stored in each controller to include changes in the status of user accounts.

A full-scale FareTrans VMS is scheduled for deployment in the next phase of the program. The system field-tested in the current phase consists of an Advanced Fare Payment System, summarized in Figure 3-2. Note that the field-test system excludes a number of elements to be introduced in the next phase of the program, including door sensors, language sensitive system announcements, mechanical performance sensors, some system redundancies, and radio update and retrieval of on-board data. Accumulated on-board data was updated and retrieved during the field test by Echelon via a hard-wire interface with each Passenger Transaction Controller. The field-test system accommodates a printer, but there is no substantive field testing of printing equipment. The Advanced Fare Payment System is designed to be expandable to a full-function FareTrans VMS (Echelon, 1995).

As Figure 3-2 indicates, two types of fare media were deployed for the test. The technologies and the philosophies behind these media are quite different. The Smart Cards are state-of-the-art, second-generation designs (Bright, 1988) with sophisticated internal logic and operating systems capable of accommodating multiple debit accounts. The cards are intended for use as electronic wallets, combining extensive on-board memory and intelligence, allowing fare transactions taking place in the field to be processed by the card.

The design capacities of these cards greatly exceed the information processing requirements of the Field operational test. However, the physical conditions of the test present a standard transit environment that any fare card system must be designed to tolerate. The complexity of full-function Smart Card designs might present constraints in use that can only be identified in a field test. Given that Smart Cards are likely to be made available for a combination of public and private transactions (Hornsby, 1994; Williams, 1994), including transit and Electronic Benefits Transfers (EBT), it is important to determine if Smart Cards function acceptably in a realistic environment.

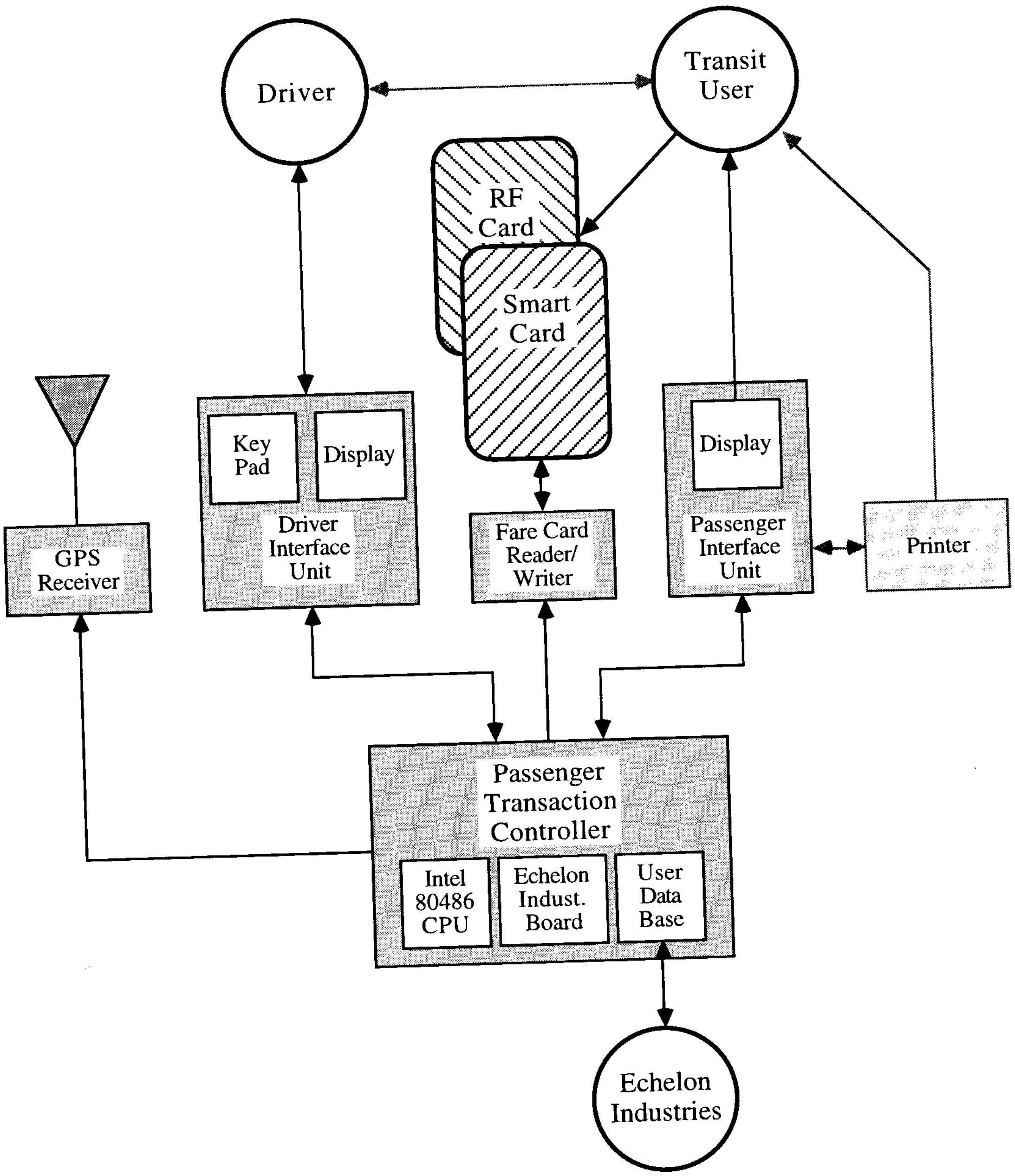



FIGURE 3-2 ECHELON INDUSTRIES' ADVANCED FARE PAYMENT SYSTEM. (ARROWS INDICATE DATA FLOWS)

The Radio Frequency (RF) ID cards deployed for the test are quite different from the Smart Cards. Both types of cards are consistent with the International Standards Organization (ISO) standards for Integrated Circuit (IC) Cards. However, the RF Cards have a much more limited information processing capacity than the Smart Cards. The RF Cards are wired logic cards that include a degree of dedicated intelligence, but cannot provide the range of applications available from a card-based central processing unit. The RF Cards do not include the distributed intelligence of the Smart Cards. Instead, intelligence is concentrated in the card reader/writer units onboard the buses. First and foremost, the RF Cards are memory cards, and employ a propriety ferromagnetic random access memory technology applied by the manufacturer under license.

But most important of all, the RF Cards are proximity cards: they do not require physical contact with the card read/write units to complete a transaction. The Smart Cards are contact cards, and from the users' perspective are put into service in a fashion similar to a magnetic stripe bank card. In contrast, the RF Cards, while presenting a degree of convenience potentially exceeding that of even a flash pass, are from users' perspective a completely new technology for which few reference points exist.

Appendix B provides a technical summary of IC Card Technology. The summary is representative of the technologies deployed in the field operational test. Table 3-1 provides a comparison of the Smart and RF Card technologies. As noted in Chapter One, Table 1-2, the Smart Card was tested on the Gardena routes, and RF Cards were tested on Torrance and LADOT routes.

## 3.3 Data Sources

The functional elements of the field operational test are a success by any objective standard. This is encouraging from a scientific perspective, as well as in terms of technology development and deployment. However, success in the field also constrains the number of new lessons learned about the technology being tested. It is difficult to isolate sources of failure in a successful project.

## TABLE 3-1 COMPARISON OF FARE CARD TECHNOLOGIES DEPLOYED DURING THE FIELD TEST

| Card Technology | User Interface | Intelligence | Erasable Memory | Power Source |
|---|---|---|---|---|
| Smart<br><br>International Standards Organization (ISO) international standards series 7816<br><br>Manufactured by GEMPLUS, France | Contact based<br><br>Similar to magnetic stripe cards | Concentrated on the card<br><br>Card IC includes an 8-bit microprocessor<br><br>External read / write unit required for transaction processing | 8 KBytes of Electronically Eraseable Programmable Read Only Memory (EEPROM)<br><br>Approaches the upper bound of 2nd generation design, some cards have 16 KBytes | ISO compliant<br><br>Contacts permit transfer of data and power from the read / write unit<br><br>Requires no battery |
| Radio Frequency (RF) Identification<br><br>Manufactured by RACOM, United States | Contactless<br><br>No comparable consumer product.<br><br>Proximity access / ID cards provide a comparable experience | Shared between the card and the read / write unit<br><br>Card IC capable of wired logic only<br><br>External read / write unit required for transaction processing | 256 KBits of Ferromagnetic Random Access Memory (FRAM)<br><br>Proprietary memory technology with very fast read / write operations | Card antenna collects radiant energy broadcast from the read / write unit<br><br>Requires no battery |

The most important source of assessment data consists of nontransaction events. These type I errors occur when intended advanced fare system transactions do not take place. This field operational test is particularly parsimonious with respect to type I errors. Data constraints associated with the test include the following:

1. Radio Frequency (RF) card failures have been rare.
2. Contact Smart Card failures have been less rare, but infrequent.
3. Other equipment failures have been rare.
4. And, perhaps most importantly, learning occurs throughout the test on the parts of
   - Echelon Industries,
   - the management of transit properties involved in the test (Gardena, Torrance, and LADOT),
   - drivers, and
   - card users.

Also, Echelon is unable to provide electronic records of card transactions for review and verification. This substantially constrains data available concerning type II errors. These are unintended transactions, usually multiple transactions. However, given the scope of the test and the very high quality of Echelon's overall reporting, this presents no major obstacle to functional analysis. Less is learned from unintended transactions than from nontransactions (type I errors). Multiple transactions only occur when the capabilities of the system are mostly intact. Avoiding type II errors is more a matter of system management than technology, though the management tools available are technology based.

Information on type I errors is better. Card failures are reported first to Caltrans, because Caltrans issues the medium. Caltrans District 7 maintains records of cards returned by users and the nature of the problem prompting the cards' return. In addition, Echelon provides both Caltrans District 7 and the evaluators with hard copies of card transaction records and summary statistics describing card performance. Consequently, complete information is available with respect to type I errors. The USC evaluation team's statistical analysis of card function data is based primarily on these data sources. A summary of transaction errors occurring during the field test appears in Table 3-2.

## TABLE 3-2 SUMMARY OF FOT TRANSACTION ERRORS

| Card Type | Number of Trans-acations | Type I Errors | Type I Errors / 1K Trans-actions | Type II Errors | Type II Errors / 1K Trans-actions | Success Rate for undistres-sed cards |
|---|---|---|---|---|---|---|
| Smart Card | 24,564 | 13 cases of Defective Cards | .54 | 0 cases of Multiple Trans-actions | .00 | 99.9% |
| | | 11 cases of Data Corruption | .45 | | | |
| | | 7 cases of Distressed Cards | .28 | | | n/a |
| RF Card | 23,416 | 2 cases of Defective Cards | .08 | 10 cases of Multiple Trans-actions | .43† | 99.99% |
| | | 19 cases of Data* Corruption | .81 | | | n/a* |
| | | 0 cases of Distressed Cards | .00 | | | |
| Magnetic Stripe | n/a benchmark only | | | | | 85. - 93.% |

* RF Card data corruption is not classified as an error: The cards are easy to reinitialize in the field. In any event, data corruption in Smart and RF Cards can always be avoided by providing memory back-ups on the card. No such memory backups are in place for the field test.

† This count is lower than the value impled by Exhibit 5 in Echelon's (1995) FINAL REPORT. Data corruption is most likely when a transaction is interrupted, and interrup-tions are most likely if multiple transactions are frequent, hence frequencies in these two categories may not be mutually exclusive.

## 3.4 Field Test Objectives for the Advanced Fare Payment System

### 3.4.1 Objectives Provided by Echelon Industries, Inc.

Echelon Industries' (Echelon, 1995) objectives include installation of a system capable of

1. "addressing the full range of fare payment possibilities required of an urban transit system," capable of
2. "expansion to a fully operational and comprehensive Passenger Transaction Unit," accommodating
3. "fixed as well as distance/zone based fares, corporate fares, special event fares, fares based on user classification, route in use, time of day, day of week, and area designation;" and accommodating and accounting for uses that are
4. "inter-system and multimodal." Further, Echelon requires that the system
5. "fit the space available, and in no way degrade
   - operating performance related to passenger boarding and alighting,"
   - "the performance of the bus' power supply,"
   - "bus maintenance/washing activity,"
   - "driver and/or system safety," or
   - "the performance of any other bus equipment;"
6. "significantly decrease or eliminate the potential for fare payment related fraud or payment system misuse,"
7. "provide for more accurate and reliable data on passenger boardings and alightings,"
8. "provide for a potential upgrade in the level of integration of transit and private transportation services,"
9. "provide for advanced equipment diagnostics and failure reporting,"
10. "provide the passenger with a level of 'ease of use' equal to or better than the system presently in use,"
11. "use off-the-shelf equipment,"

12. "be capable of withstanding the full operating environment of a bus," and

13. "have a 10- to 12-year life without requiring any form of maintenance."

These objectives are generally consistent with system requirements identified in the literature describing Smart Card technologies. Most of these objectives are design guidelines that translate into binary performance benchmarks for the field operational test. A few others are abstract enough that objective measures of attainment are unavailable; however, qualitative assessments are possible.

System performance reports provided by Echelon indicate objectives 1 and 3 are successfully met. Objective 2 is one of the motivations for the next phase of the program. It is met to the extent that it can be here, in that the Advanced Fare Payment System deployed in the test is the template for the full-function Passenger Transaction Unit Echelon intends to deploy subsequently. Objectives 4, 5, and 9 are addressed in the companion volume of this report on operator impacts (Chira-Chavala and Coifman, 1995). However, Echelon reports more problems with the Geo Positioning System than with the fare transaction equipment. The reasons include peculiarities in the vendor firmware and undocumented aspects of data reading. Updated firmware and new system software overcome these problems. Objectives 6 through 8 are rationales for advanced fare payment systems. The system is designed to demonstrate that the technology needed to implement these options exists, and it does so. Objective 10 is addressed in Chapter Four: User Response. Overall, user acceptance of the technology is very good.

Meeting objectives 11 through 13 answers different aspects of an important open question. The Advanced Fare Payment System is a relatively inexpensive system constructed of components manufactured to commercial standards. It is by no means certain prior to the execution of the field test that commercial equipment performs acceptably on a public bus. The conditions and maintenance requirements associated with public transit vehicles might require that at least part of the system be constructed from components built to industrial (or higher) standards rather than commercial standards. This would substantially increase the cost of the system.

Objectives 11 and 12 are met completely. The electromechanical performance of the bus equipment elements of the field test shows it is feasible to construct the Advanced Fare Payment

System almost entirely from commercial components, and to use the system to process fares in regular service a public bus. This opportunity presents vendors with considerable latitude for constructing competitive, low cost systems. Objective 13 is met only in part. The equipment is in service during the field test for only six months, and performs well in this window. Results are in every way encouraging, but the short duration of the field operational test provides no conclusive information about lifecycle costs.

### 3.4.2 Objectives Provided by the Smart Card Literature

The scientific literature emphasizes additional objectives for Smart Card systems. Lisimaque (1993) suggests that at the component level Smart Card IC chips must

1. "contain 'enough' protection to push the cost of breaking its security over the value of the system it protects,"
2. "ensure the integrity of the data it protects, even under unanticipated losses of power," and
3. "not only work with the IC manufacturer specifications, it must also refuse to work in other conditions."

Lisimaque explains that any Smart Card component "will be the subject of attacks and its job is to resist the attack by any means or die with secrets it is protecting."

Standard data encryption techniques are used in the test for both the Smart Cards and the RF Cards. The test provides no evidence to suggest that the data exchanges between the cards and the read/write devices on the buses are subject to loss of content due to encryption. The test includes no attempts to defeat the cards' encryption system; though as Table 3-2 indicates, 13 of the Smart Cards laid down their lives anyway.

Data corruption was the most pervasive source of transaction failures during the test, but one of the least important. No back-up memory records exist on either type of card. This is an intentional aspect of the test intended to provide a better comparison of the two technologies, and to increase Echelon' understanding of the events leading to data corruption. If not avoided by use of data back-ups, data corruption is more difficult to correct in the case of the Smart Cards than in the case of the RF Cards. Data corruption occurs for different sets of reasons, none of which pertains to encryption, across the two types of cards.

Russell (1994) identifies the following support facilities required for Smart Cards and read/write devices intended to operate permanently in the field. Support facilities for cards should include

1. "diagnostic tests at a convenient location,"
2. "corrective actions to maintain usability of the card,"
3. "identification of failure
   - types,
   - causes, and
   - component sources," and
4. "tracking and statistical analysis of failures, including identification of the read/write devices with which the card was used."

The field test does not include permanent deployment of equipment. Equipment was in the field for only six months. Consequently, Russell's requirements are not fully represented in the test. The system provides no convenient diagnostic options for users, though limited diagnosis of card problems is done by Caltrans personnel when nonfunctional cards are surrendered by bus patrons. From the user perspective, corrective actions usually consist of obtaining a replacement card. Caltrans' basic correction procedure for any nonfunctional card consists of attempting to reinitialize the data the card is intended to process. The set of corrective actions must be expanded for the Smart Cards. Smart Cards cannot be reinitialized as routinely as RF Cards. Instead, contact cards locked due to data corruption must be unlocked by Echelon with a computer program developed during the field test by the manufacturer, GEMPLUS. Analysis of more serious card failures is undertaken by Echelon and the card manufacturers.

Support facilities (Russel, 1994) required for the operators of read/write devices focus on the detection of marginal equipment. Support includes

1. "installation of software updates to accommodate new features and enhancements;"
2. "diagnostic testing at locations where devices are used;"

3. "corrective actions to restore device function;"
4. "collection of data from failed off-line devices;"
5. "identification of failure
   - types,
   - causes, and
   - sources," and
6. "tracking and analysis of failures."

The limited duration and scope of the field test obviates most of these requirements. The test included approximately 48,000 fare transactions during more than 35,000 hours of bus service. Ten equipment problems sufficient to interrupt revenue service were documented by Echelon during the course of the test. The combined impact of these incidents is reported by Echelon to be a value less than 33 vehicle-hours. Combined repair time is reported to total less than one-person-hour.

The infrequency of on-board equipment failures suggests that the system performed well. These equipment failures are sufficiently rare that they provide only anecdotal evidence concerning the failures likely to emerge during long-term deployment. Only one type of problem was observed more than once. Disconnected cables were identified twice early in the test. Securing the cables provided a permanent solution. Only one Passenger Interface Unit failed in use. Echelon attributes this failure in use to corruption of the Complementary Metal Oxide Silicon (CMOS) memory element of the transaction unit's Basic Input/Output Operating System (BIOS). CMOS BIOS corruption is frequently related to the battery used to maintain the contents of the BIOS memory. Echelon reports that subsequent versions of the system will use EEPROM to perform the BIOS memory function, circumventing potential battery problems.

Echelon attributes a failure in another Passenger Transaction Unit's power conditioning subsystem to an undocumented accident during routine maintenance. The nature of this event and the mechanism by which the subsystem is destroyed is unknown. No satisfactory hypothesis is available, and thus there is no design response available. A problem with one of the Driver Interface Units is attributed to continuous water exposure, and all problems with the driver and passenger interface units are attributed to driver or passenger experimentation with the equipment interfaces, or unobserved vandalism on the part of parties unknown.

The near constant successful operation provides little insight into unanticipated design constraints. Installation requirements for the Passenger Interface Units, Driver Interface Units, and Passenger Transaction Controllers are largely a function of the space constraints associated with different vehicle configurations, and Echelon worked closely with the transit properties involved to select appropriate equipment locations in each of the three bus types involved in the test. The special equipment requirements associated with the test presented problems for properties that routinely rotate buses across lines and runs. But this test constraint disappears if the card reader/writers are standard equipment across vehicles within a given property.

The Advanced Fare Payment System deployed for the test is designed to require little or no intervention on the part of the drivers. If a transit property is committed to precluding driver interaction with the system because of training resource constraints or driver work load, then a case can be made for disabling the key pad on the driver interaction unit. This would reduce opportunities for driver experimentation and potential service interruptions. The general lesson is to keep the interface as simple as it can be. The field test system has lower functionality than the Fare Transaction and Vehicle Management/Monitoring System it is intended to support, and thus might accommodate an even simpler driver interface. However, a full-function FareTrans VMS would almost certainly require a full-function driver interface, and more importantly, a driver trained to operate the system.

How much protection the Passenger Transaction Unit should have from vandalism or other exogenous shocks is an open question. At least one of the ten PTU failures noted in the test might have been prevented by more rugged construction. However, successful vandalism was infrequent, and no effort was made to observe unsuccessful acts of vandalism. Based on the limited evidence from this test it is unknown whether the additional manufacturing cost of a more rugged, vandal-resistant design would be offset by the cost savings associated with less frequent replacements of vandalized equipment.

### 3.4.3 Objectives Provided by the System's Reliability Literature

As noted above, the most general level of functional analysis would combine field test data with reliability theory to provide parametric estimators for the Mean Time To (system) Failures (MTTF) and the Increasing Failure Rate (IFR) distribution used to describe changes in system reliability over time (Bentley, 1993; Hillier and Lieberman, 1995). The state of information necessary to meet this ideal standard is very refined. It is a superset of the information needed to identify the degree to which the system meets the objectives provided by the project partners and the scientific literature.

The narrow scope and relatively short duration of the test does not permit this idealized level of parameterization. However, reliability theory provides sufficient guidance to permit a thorough assessment of the system's performance, and to identify technical opportunities and constraints.

Functional Flow, Information Decision Action (IDA), and Operational Sequence Diagrams (OSD)(Brooks, 1960; Kurke, 1961; Krick, 1962; and Thompson, 1968) provide mechanisms for inventorying and organizing the complexity and information requirements of a fare transaction. IDA diagrams describe graphically systems in which humans and machines interact. This graphic analysis

1. illustrates the major components of the system, both human and machine, and
2. models
    - the operation of the system in terms of the decisions made by each element of the system,
    - the flow of information on which these decisions are based, and
    - the actions taken.

Fault Tree Analysis (FTA) and Failure Mode and Effect Analysis (FMEA) provide frameworks for understanding the mechanisms of system failure, and for identifying weaknesses in system designs. FMEA is an exhaustive, bottom-up analysis of all possible fault modes, causes, effects, and criticalities (Birolini, 1994). All possible fault causes in design, manufacture, and use should be considered. In contrast, FTA is a top-down approach in which a system failure is represented by "and," "or," and "not" combinations of component causes. FTA

1. is simpler than FMEA,
2. takes better account of external influences, and
3. easily treats circumstances in which more than one fault must occur to produce a system failure.

Unlike FMEA, FTA does not necessarily enumerate all possible fault modes.

Learning curve analysis (Belkaoui, 1986) provides a bench marking mechanism for projecting improvements in system performance and productivity as a function of experience. Such improvements are most rapid in the earliest stages of system deployment, and thus can be parameterized even in the context of a short-term field test.

#### 3.4.3.1 Information-Decision-Action (IDA) Analysis

Complete and IDA charts ensure that each decision maker in a system will have all the necessary information to make each decision. For example, a human operator will never be called upon to do something machine elements of the system will not allow. The Advanced Fare Payment System has a fixed interface designed for simplicity. The standard procedure for evaluating such static human-machine interfaces consists of task analysis. This analysis can take several forms, all of which focus on identifying the "discriminations, decisions, and actions necessary and sufficient to operate a mechanism" (Kurke, 1961). Figure 3-3 is adapted from Chapanis' (1965) representation of the interactions between humans and machines. Such tools are conceptually useful, but too simplistic for the analysis of contemporary computer interfaces. However, the approach remains relevant for the analysis of deliberately simple interfaces, such as those associated with magnetic stripe, Smart Card, or RF Card technology.

The most robust and useful form of task analysis consists of constructing an Information-Decision-Action (IDA) diagram or related representation of an operation process. An IDA diagram codes the activities in the system and describes the flow of information through

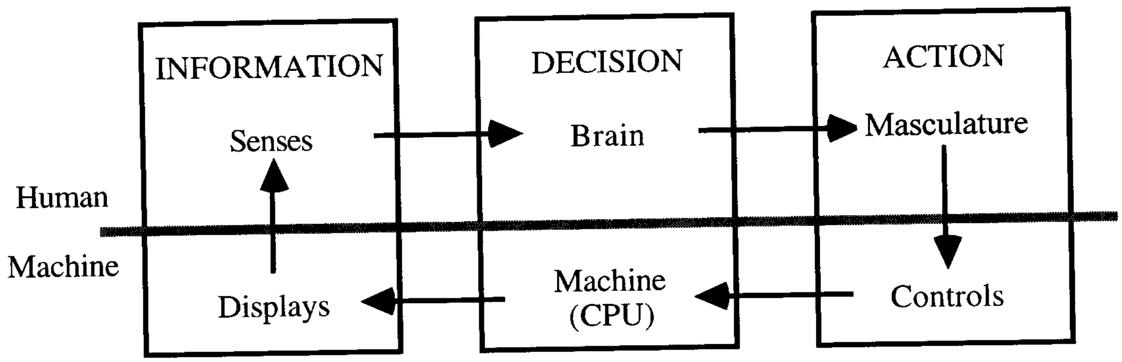


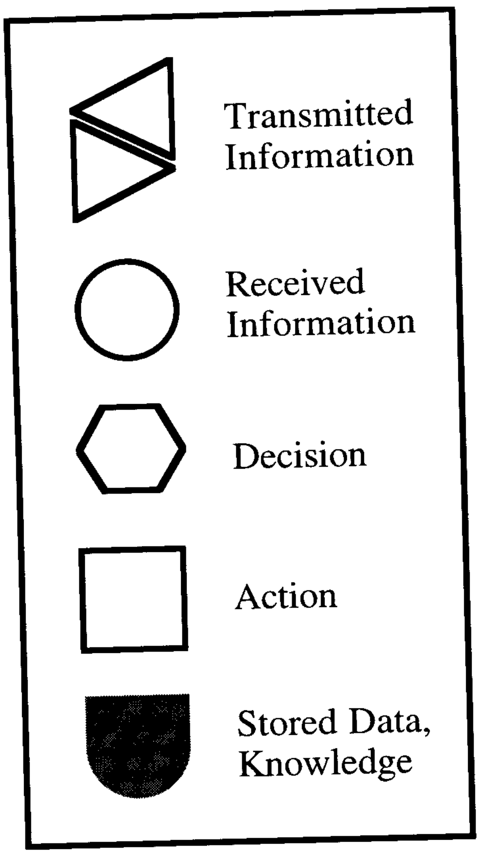

**FIGURE 3-3 THE HUMAN-MACHINE INFORMATION DIALOGUE**

the system, providing a clear representation of the human-machine relationships associated with various degrees of automation. In its more sophisticated forms, such as an Operational Sequence Diagram (Kurke, 1961), and IDA diagram can be a very effective means of evaluating alternative system designs. Communications requirements between operators, users, and computers can be analyzed. Individual IDA sequences for subsystems can be easily coordinated. If operations times are included, the approach can be used to generate design trade-offs involving complexity, speed, expense, and cognitive load. Elements of the human-machine interface requiring improvement can be identified and evaluated against alternatives. Further, experience suggests (Douglas, Junge, and Thompson, 1980) that even a chart constructed at a coarse level of detail provides considerable utility for improvements in task and interface design.

The fare transaction IDA chart constructed here defines the basic information exchange requirements for the system deployed for the field test. A diagram for a full-scale FareTrans VMS would necessarily be more complex, primarily due to the additional information flows across machine-machine interfaces. At a minimum, an IDA chart includes geometric figures defining building block representations of alternative sequences of information, decisions, and actions. Each different type of activity (discrimination, decision, action, etc.) is represented by a different symbol, usually circles for information, diamonds or polygons for decisions, and squares for actions. In fine-grained analyses, these elements may consist of more than one type. Figure 3-4 summarizes conventions and the subset of symbols used here. The automated fare payment system does not have a single interface. It has several, including multiple human-machine interfaces, multiple machine-machine interfaces, and human-human interfaces at both the individual and institutional levels. An IDA diagram can be constructed that integrates all of these.

The IDA diagram used to illustrate the Advanced Fare Payment System appears in Figure 3-5. This abbreviated diagram describes the interactions between four system elements:

1. the passenger transaction unit,
2. the Smart Card or RF Card,
3. the transit user, and
4. the bus driver.



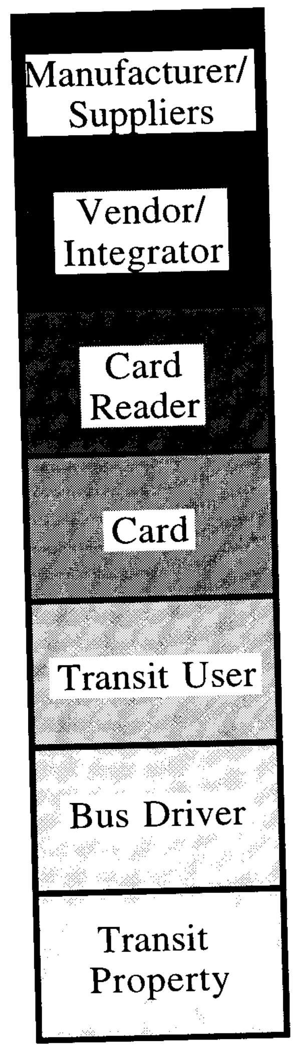




**FIGURE 3-4 LEFT: SYMBOLS USED IN IDEA-DECISION-ACTION (IDA) AND OPERATOR-SEQUENCE-DIAGRAMS (ODS). RIGHT: IDA/OSD SMART /RF CARD INTERFACES**

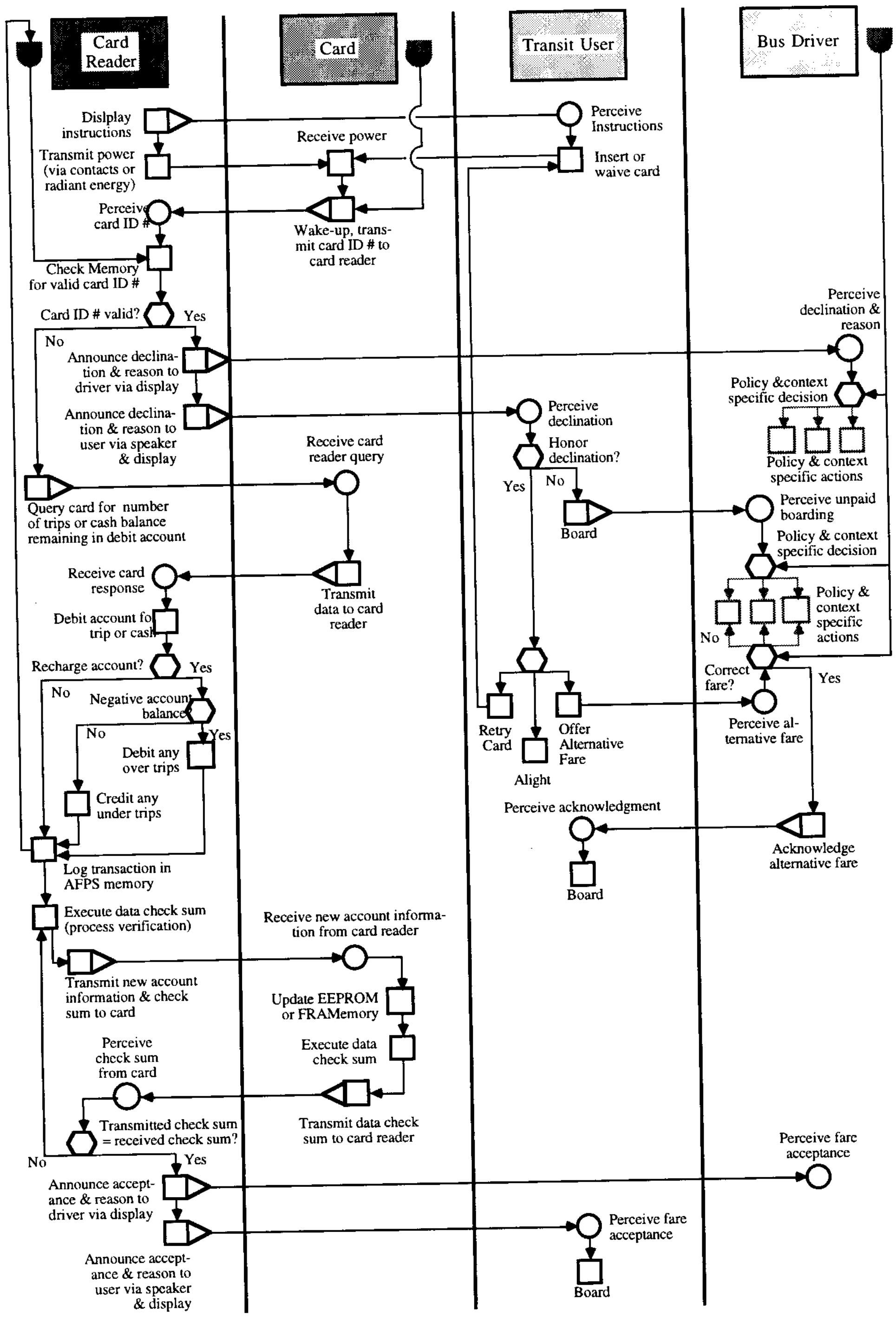



**FIGURE 3-5 SUMMARY IDA DIAGRAM OF SMART/RF FARE CARD USE**

The flows of information, actions, and decisions made by each member of the system are indicated. The chart defines the different temporal paths the system can follow in operation. At the card/card reader interface, the possible results of the operation are

1. acceptance of the Smart or RF Card,
   - proper debiting and/or crediting of the card account, and
   - recording the transaction in the passenger transaction unit's memory; or
2. declination of the card due to any of a number of different reasons.

Other results follow at other system interfaces.

A time line is usually included in design applications, but is omitted here. Adding the time requirements for each activity to the IDA chart traces the overall time requirements for system operations. However, the speed of the memory in the Smart and RF Cards and the simplicity of the transactions involved obviate any need for time measurements: boarding and alighting times greatly exceed transaction processing times. Summary time study of the boarding operation is reported in the companion volume to this report (Chira-Chavala and Coifman, 1995).

If more extensive on-board database checking and updating associated with a FareTrans VMS is added to the system, then the additional processing burden associated with these activities will require that operating time requirements be treated more explicitly. The IDA diagram constructed here provides a template for further analysis of the interface.

#### 3.4.3.2 Fault Tree Analysis

Failure Mode and Effect Analysis is impossible without design-level data, which are unavailable in this case: the system is proprietary. However, the field test provides sufficient empirical data to permit Fault Tree Analysis of type I and type II errors.

As noted above, Fault Tree Analysis enumerates logical event paths leading to system failure. The definition of "system failure" is broad in this case. Generically, failure occurs when a system does not perform its required function. The fundamental function of the Advanced Fare

Payment System is automatic processing of fare transactions. Echelon (1995) identifies two classes of nontransaction events. These are

1. "card failures," including
   - card defects that can be corrected in the field by reinitializing the card, and
   - "data corruption," which cannot be corrected by resetting the card; and
2. "card 'misuse,'" which "occurs when a passenger does not complete a transaction yet completes the ride."

All three outcomes constitute type I errors in which an intended transaction does not occur.

Echelon's classification indicates multiple sources of type I errors, including failures associated with

1. the information processing capacity of the Smart Card,
2. the data storage capacity of the Smart Card,
3. other components in the Advanced Fare Payment System, and/or
4. an inability of a user to successfully negotiate the system interface.

Type II errors are less serious from the perspective of the transit property than are type I errors, because a type II error can only occur when most of the system's technical elements are functioning properly. Type I errors are of more concern to the transit property because correction requires an allocation of resources.

In the field test, one result of a type I error is that the user rides without paying a fare. Since this reduces the burden on the user, type I errors are probably of little concern to users. While type I errors may create the impression the system is unreliable, transit users are likely to regard type II errors as more onerous than type I events. Type II errors present the possibility of a loss of user resources, particularly in the case of a debit card or EBT system.

A Fault Tree for contact Smart Card type I errors appears in Figure 3-6. The fault tree for type II errors is simple enough that it is suppressed. The FTAnalysis provided here could be combined with a manufacturer's FMEAnalysis to complete a standard cause-and-effect chart (Birolini, 1994).

As noted previously, the test identified 13 defective Smart Cards for which the failure mechanism is unknown. Figure 3-6 suggests humidity is a candidate for investigation. Low

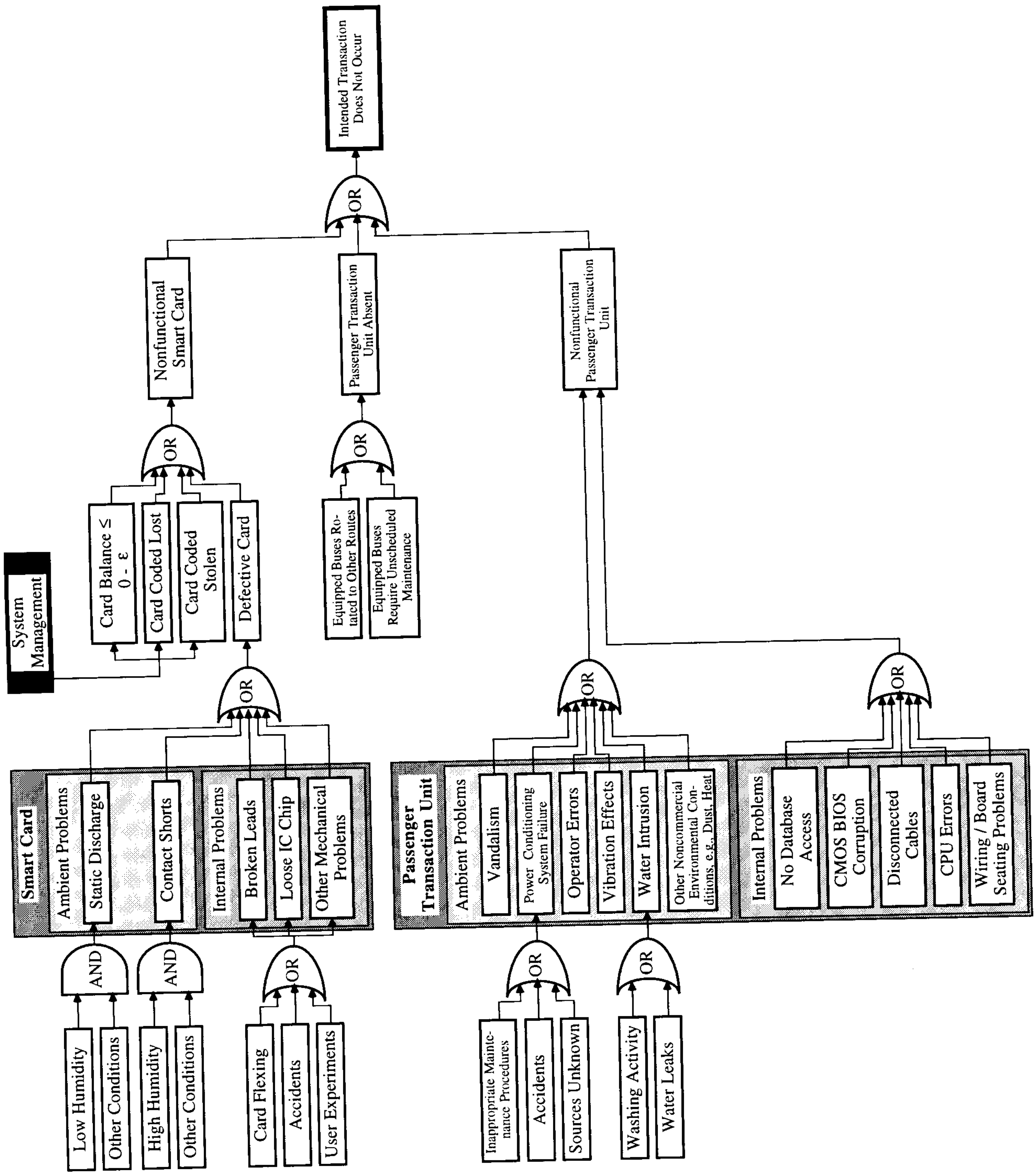



**FIGURE 3-6 A FAULT TREE FOR TYPE I ERRORS IN THE DELIVERY OF AUTOMATIC FARE PAYMENT SERVICES VIA SMART CARDS**

humidity levels increase the likelihood of static discharge, and static discharge might interfere with the operation of the cards. A review of humidity levels and Caltrans District 7 problem reports logs is summarized in Figure 3-7. The Smart Card complaints logged with Caltrans identify 38 circumstances corresponding to card failures not clearly due to physical distress of the card. This number exceeds the 24 cards accounted for by Echelon. Presumably, the 24 cards classified by Echelon as "defective" or subject to "data corruption" are included in this set of 38, as are some of the cards identified by Echelon (but not Caltrans) as "distressed." The status and disposition of the remaining cards in this set of 38 are unknown.

The upper and lower bands shown in Figure 3-7 are smoothed polynomial regressions of the humidity bounds observed during transit service hours. The center band is the smoothed sequence of weighted average humidity levels during service hours. Unfortunately, Figure 3-7 combines card failures due to data corruption, defective media, and (possibly) distress.

Echelon reports that the card manufacturer declined requests to fully classify the status of the 24 defective cards with respect to data corruption. This is unfortunate. Ideally, the cards subject to data corruption would be removed from the set of 38 events. Under current circumstances, the cards cannot be differentiated across failure types. The inability to do so confounds efforts to examine the role of humidity. Careful investigation of humidity effects requires a comparison of the estimated likelihood of card failure against humidity levels. Smart Card failures are concentrated in September and the first half of October, yet Figure 3-7 indicates these are not particularly dry months. The maximum humidity levels in Los Angeles are as high during the summer as they are in the winter, but there is considerably more variance in the minimum humidity levels recorded during the fall. The period from the second half of October through November is the driest, yet card failures are not most frequent during this period. Failures diminish rapidly during December and January, but this could be due to a number of factors.

The number of failures occurring during any time interval is partially a function of the number of transactions occurring during the interval. Wetter conditions may reduce the likelihood of card failures, inclement weather may be suppressing travel, or card use may be reduced as the conclusion of the test neared and cards can not be renewed.

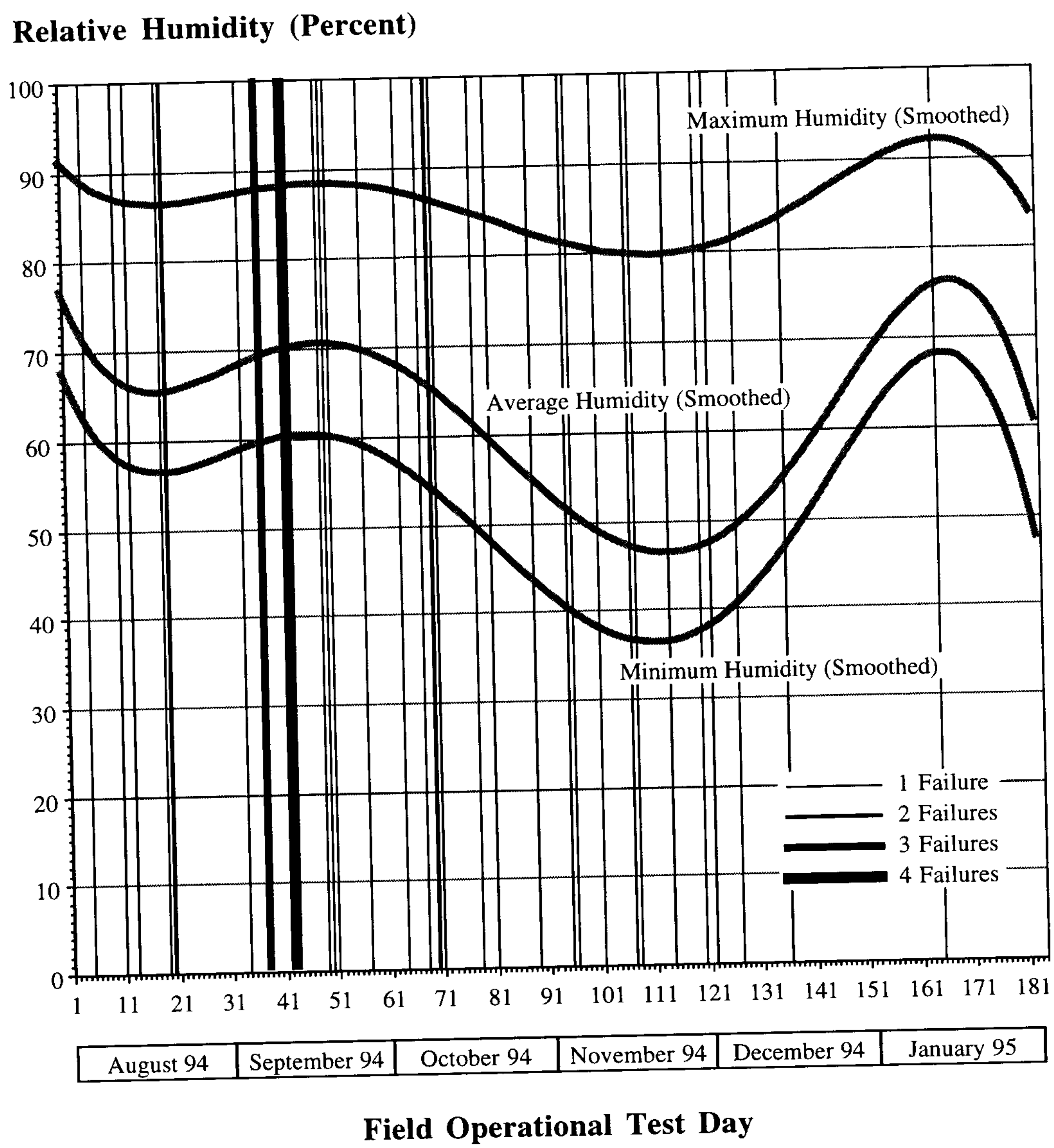



**FIGURE 3-7 HUMIDITY LEVELS VS. SMART CARD FAILURES**

The number of Smart Cards in the field increases as the test progresses, and the number of transactions per day fluctuates. Time intervals must be defined in terms of humidity conditions, which fluctuate hourly. Daily transactions data is the minimum state of information needed to model the frequency of card failures against card use. Unfortunately, proceeding at this level of detail requires an electronic review of Echelon's transaction records, which is not possible. Fortunately, weekly records of cumulative transactions are readily available.

Weekly transactions are compared against card failures in Figure 3-8. Logically, failures are most frequent during periods of most intense use. Given weekly data, the best alternative is to rank the daily humidity levels summarized in Figure 3-7, establish humidity intervals, and estimate daily card use based on the weekly transactions summarized in Figure 3-8. The simplest mechanism for investigating the association between humidity and the likelihood of card failure is a contingency table. This is a conservative, aggregate approach for which the null hypothesis is

H0: No structural association between humidity levels and failure rates.

Unfortunately, the alternative hypothesis is very general,

H1: Not H0.

Any sufficiently pronounced degree of association between humidity and failures, whether simple or complex, positive or negative, will permit the null hypothesis to be rejected. Even if the assumption of no association is rejected, the test may not suggest what the nature of the association might be. Still, the procedure is simple, and appropriate for the data and level of detail available.

Intervals are fairly lengthy to ensure that the expected number of failures in each interval under H0 is sufficiently large to justify treating the sampling statistic with a Chi-squared approximation. Tables 3-3 to 3-6 summarize the results of this analysis. The tests are inconclusive with respect to the influence of maximum humidity, minimum humidity, and humidity range on the frequency of card failures. In all three cases, the null hypothesis cannot be rejected at any conventional significance level. However, the null hypothesis is rejected at the .05 level in the case of weighted average humidity during the transit service interval, suggesting

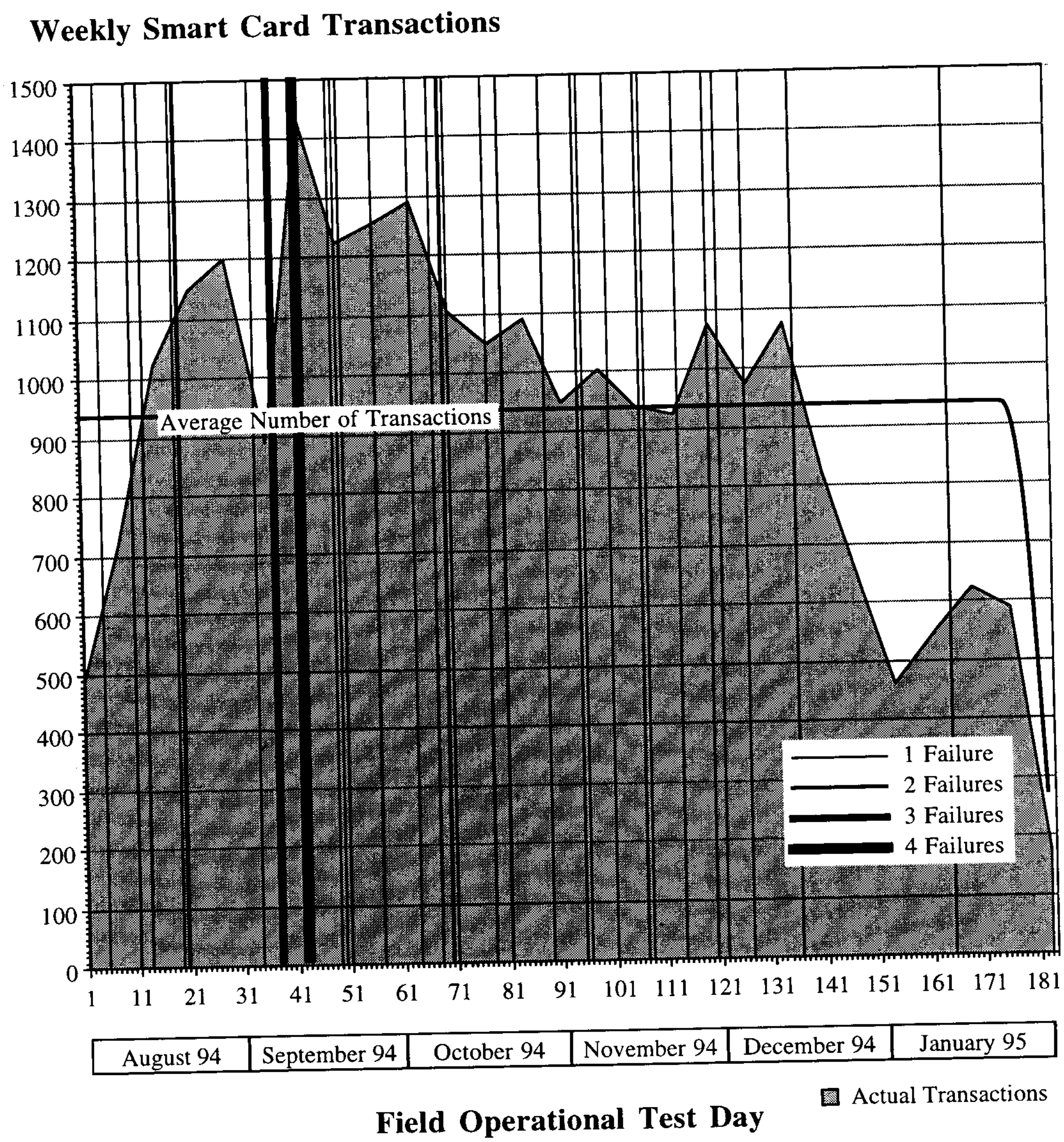



**FIGURE 3-8 SMART CARD USE VS. SMART CARD FAILURES**

## TABLE 3-3 MINIMUM HUMIDITY LEVELS VS. SMART CARD FAILURES: FAILURE TO REJECT THE NULL HYPOTHESIS

| | Minimum Relative Humidity (%) During Operating Hours | | | | | |
|---|---|---|---|---|---|---|
| | 9 % - 29 % | 30 % - 49 % | 55 % - 59 % | 60 % - 69 % | 70 % - 93 % | Row Sum |
| Number of Transactions | 4,032 | 4,861 | 4,160 | 8,735 | 2,775 | 24,564 |
| Reported Smartcard Failures | 9 | 6 | 9 | 9 | 5 | 38 |
| Expected Smartcard Failures $H_0$: No Humidity Effect | 6.24 | 7.52 | 6.44 | 13.51 | 4.29 | 38 |
| Chi-Squared Statistic | 1.221 | 0.307 | 1.018 | 1.506 | 0.118 | 4.17 |
| Critical Value: $\alpha$ = .10, 4 df | Result: Fail to Reject $H_0$ | | | | | 7.779 |

## TABLE 3-4 MAXIMUM HUMIDITY LEVELS VS. SMART CARD FAILURES: FAILURE TO REJECT THE NULL HYPOTHESIS

| | Maximum Relative Humidity (%) in during Operating Hours | | | | |
|---|---|---|---|---|---|
| | 35 % - 79 % | 80 % - 89 % | 90 % - 95 % | 95 % - 100 % | Row Sum |
| Number of Transactions | 5,239 | 7,718 | 7,495 | 4,112 | 24,564 |
| Reported Smartcard Failures | 12 | 11 | 13 | 2 | 38 |
| Expected Smartcard Failures $H_0$: No Humidity Effect | 8.11 | 11.94 | 11.59 | 6.36 | 38 |
| Chi-Squared Statistic | 1.866 | 0.074 | 0.172 | 2.990 | 5.10 |
| Critical Value: $\alpha$ = .10, 3 df | Result: Fail to Reject $H_0$ | | | | 6.251 |

TABLE 3-5 HUMIDITY RANGE VS. SMART CARD FAILURES: FAILURE TO REJECT THE NULL HYPOTHESIS

| | Relative Humidity Range (%) During Operating Hours | | | | | | |
|---|---|---|---|---|---|---|---|
| | 4 % - 21 % | 22 % - 24 % | 25 % - 29 % | 30 % - 34 % | 35 % - 44 % | 45 % - 78 % | Row Sum |
| Number of Transactions | 2,993 | 4,412 | 3,762 | 4,545 | 4,549 | 4,299 | 24,564 |
| Reported Smartcard Failures | 6 | 8 | 9 | 1 | 7 | 7 | 38 |
| Expected Smartcard Failures $H_0$: No Humidity Effect | 4.630 | 6.826 | 5.818 | 7.031 | 7.037 | 6.658 | 38 |
| Chi-Squared Statistic | 0.406 | 0.202 | 1.740 | 5.173 | 0.0002 | 0.018 | 7.539 |
| Critical Value: $\alpha$ = .10, 5 df | Result: Fail to Reject $H_0$ | | | | | | 9.236 |

**TABLE 3-6 WEIGHTED AVERAGE HUMIDITY LEVELS VS. SMART CARD FAILURES: REJECTION OF THE NULL HYPOTHESIS**

| | Average Relative Humidity (%) During Operating Hours | | | | | |
|---|---|---|---|---|---|---|
| | 23 % - 50 % | 50.1 % - 70 % | 70.1 % - 75 % | 75.1 % - 80 % | 80.1 % - 97 % | Row Sum |
| Number of Transactions | 3,441 | 5,320 | 4,270 | 5,850 | 5,682 | 24,564 |
| Reported Smartcard Failures | 9 | 4 | 11 | 9 | 5 | 38 |
| Expected Smartcard Failures $H_0$: No Humidity Effect | 5.323 | 8.231 | 6..606 | 9.049 | 8.790 | 38 |
| Chi-Squared Statistic | 1.346 | 1.268 | 6.189 | 0.00027 | 3.814 | 12.617 |
| Critical Value: $\alpha$ = .10, 4 df | Result: Reject $H_0$ | | | | | 7.779 |
| Critical Value: $\alpha$ = .05, 4 df | Result: Reject $H_0$ | | | | | 9.488 |
| Critical Value: $\alpha$ = .01, 4 df | Result: Fail to Reject $H_0$ | | | | | 13.277 |

a statistical association between weighted average daily humidity and Smart Card failure. Since the 38 cards represented in Table 3-6 combine at least two sources of card failures, the test provides no information about potential relationships between humidity levels and either source of failure. If sufficient information was available, the 25 extraneous cards in the failure set could be deleted, leaving only the 13 Smart Cards that failed for reasons unknown. One way to bound the magnitude of a potential association is to delete these 25 Smart Cards from both observed and expected values in proportion to the number of transactions in each average humidity interval. However, this a nonstandard procedure that risks nonsensical results such as negative frequencies. The comparison would be suggestive at best and misleading at worst.

There is no clearly pronounced pattern in the differences between observed and expected card failures reported in Table 3-6. Card failures from either source are less likely than expected when average humidity is highest, and more likely when average humidity is lowest. However, the largest contribution to the value of the test statistic is provided by outcomes associated with the midrange of observed humidities, in which case failures are much more frequent than expected. If any relationship exists between humidity and Smart Card operations, it may be more complex than the fault tree in Figure 3-6 suggests. In any event, one conclusion is very clear. Given the disparity in the performance of Smart and RF Cards in the field test, humidity effects on Smart Card operations remain worthy of further, structured investigation.

A fault tree for RF Card type I errors is shown in Figure 3-9 . The tree is similar to the previous versions, though the humidity effects suspected in the case of the Smart Cards are presumed to be null in the case of the RF Cards.

#### 3.4.3.3 Learning Curve Analysis

Repeated experience with a fixed set of operations provides learning. Learning tends to increase the efficiency with which resources are consumed by system activities. Learning curve analysis is applicable to all aspects of operations planning and control in which tasks are subject to improvement. These improvements can be sufficiently regular to follow a predictable pattern. In a manufacturing context, parameterizing this effect measures reductions in use of direct labor and other resources consumed per unit output.

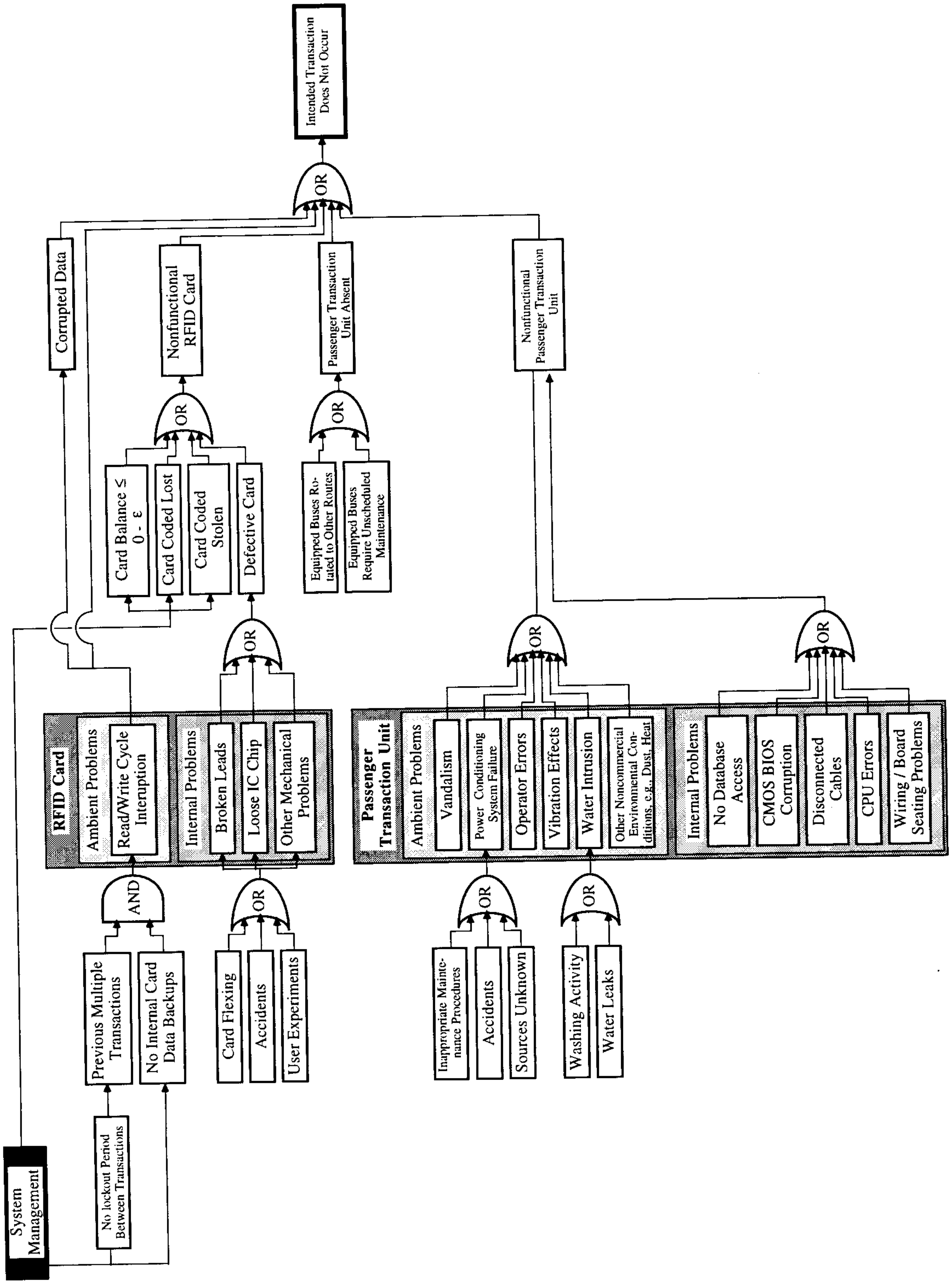



**FIGURE 3-9 A FAULT TREE FOR TYPE I ERRORS IN THE DELIVERY OF AUTOMATIC FARE PAYMENT SERVICES VIA RF CARDS**

The conditions of the field test are more complicated than the manufacturing example. In the test, system performance might be influenced by learning across several different entities, including

1. Echelon Industries,
2. management of the participating transit properties,
3. bus drivers, and
4. card users.

The activities of each of the entities are different, but learning in any of these groups might influence aggregate performance of the system. As system manager, Echelon perceives and responds to unforeseen problems as they occur. Some of these are concerns communicated by participating transit properties, some are identified by Caltrans District 7, and some are observed by Echelon via data records. Echelon's responses might or might not be formulated in consultation with Caltrans or the transit properties. Drivers and card users work with the system in the field. In addition to routine use, members of either group might be subject to novelty effects leading to additional experiments with the system. There are records, for example, of RF Card users unintentionally incurring multiple fares in the course of impromptu experiments. There is evidence some drivers attempted to change system settings via the Driver Interface Unit key pad. All of this is highly stochastic and unpredictable on an individual basis, but might well be parameterized as an average effect across a group.

Numerous parametric specifications of learning curve relationships exist. The most pervasive incorporates the assumption that improvements in productivity are constant as experience increases. This implies a mathematical power function of the form

$$g = K \cdot X^n$$

where

| | | |
|---|---|---|
| $g$ | = | the resources required to produce the Xth unit, |
| $K$ | = | the resources required to produce the first unit, |
| $X$ | = | cumulative output, |
| $n$ | = | $\log_{10} f / \log_{10} 2$ = the learning index, |

f = the learning rate parameter, and

1-f = the progress rate parameter.

The progress rate parameter is the proportionate change in the left hand side of the equation as cumulative production doubles. Alternative modeling approaches might define the equation in terms of average resources or marginal resources as a function of cumulative production. The resources model defined here is adequate for purposes of illustration. Several function representations are cited in the literature, but the log-linear specification is the dominant specification in these applications (Belkaoui, 1986).

Learning curve analysis in the context of the field test requires a redefinition of terms. If learning curve analysis is applied in the most direct way, X might be the cumulative number of (attempted) transactions, and g might be defined as the expected time per transaction. However, this is not a satisfactory approach. Automated transactions are simple operations: They are designed to be simpler than cash transactions. As noted previously, problems occur when intended transactions do not take place (type I errors), or when there are unintended transactions (type II errors). If type I errors are frequent, expected time per transaction will be higher. If type II errors are frequent, expected time per transaction might increase or decrease, depending on the user's state of information. Since learning might reduce the likelihood of either type of error, it is preferable to study changes in error rates as a function of cumulative transactions. These changes in error rates might come from several sources, including interventions on the part of Echelon and/or the transit properties, driver interventions and/or experience, and/or user experience.

The equation is estimated for two sources of type I errors occurring in the use of Smart Cards. Transactions on Gardena Route 1 require that the card be inserted in the Passenger Interface Unit. The degree of attention required, combined with travelers' likely experience with magnetic stripe cards, make type II errors highly unlikely in the case of contact cards. Not surprisingly, no type II errors were recorded in the case of Smart Cards. Results appear in Figures 3-10 and 3-11. Figure 3-10 describes nontransaction events classified by Echelon as "malfunctions," a category spanning incidents of card failure and data corruption. Figure 3-11 includes data on nontransaction events described by Echelon as "card misuse." In the case of

Smart Cards, card misuse can only result from intentional physical deformation of the card. Cumulative transactions is used as a measure of card use. This is a more exact measure of use than time because the number of cards in the field increased during the first months of the test; and because, as Figure 3-8 indicates, use fluctuates over time. Focussing on error rates makes the best possible use of the data provided by Echelon, although the standard log-linear specification induces some data loss. Zero error rates must be purged from the data. Consequently, Figure 3-11 includes only two coordinates.

The rate of nontransaction events is assumed to decrease at a constant rate as experience increases. Figures 3-10 and 3-11 both suggest that the data support this assumption, demonstrating evidence that collective learning is occurring across the groups involved in the test. No statistical tests are performed on the parameters estimated for the relationship, but these are neither feasible nor necessary. The data in Figures 3-10 and 3-11 are monthly averages computed across thousands of transactions per month. There is insufficient information to compute the randomness in these averages, but given the magnitude of the sample and the low frequency of errors, the variances must necessarily be small enough to force any statistical test of model parameters to high significance. The estimated learning rate indicates that approximately 60% of the observed type I errors persists as cumulative experience doubles.

The equation is estimated for type II errors occurring in the use of RF Cards on Torrance Route 2 and LADOT Route 448. Results appear in Figure 3-12, which describes nontransaction events classified by Echelon as "card misuse." This category consists primarily of multiple fare payments.

The RF Card uses Ferromagnetic Random Access Memory (FRAM) technology instead of the Electronically Erasable Programmable Read Only Memory (EEPROM) typically used in Smart Cards. FRAM is the fastest (commercially feasible) memory technology currently available, with a theoretical floor of about 75 milliseconds for fare transactions of the sort processed during the field test. The minimum achievable transaction time in the demonstration is about 90-104 milliseconds due to the inherent design limitations of the RF Cards, but this is quite fast. Echelon' design target is 250 milliseconds. Given such rapid transactions, the

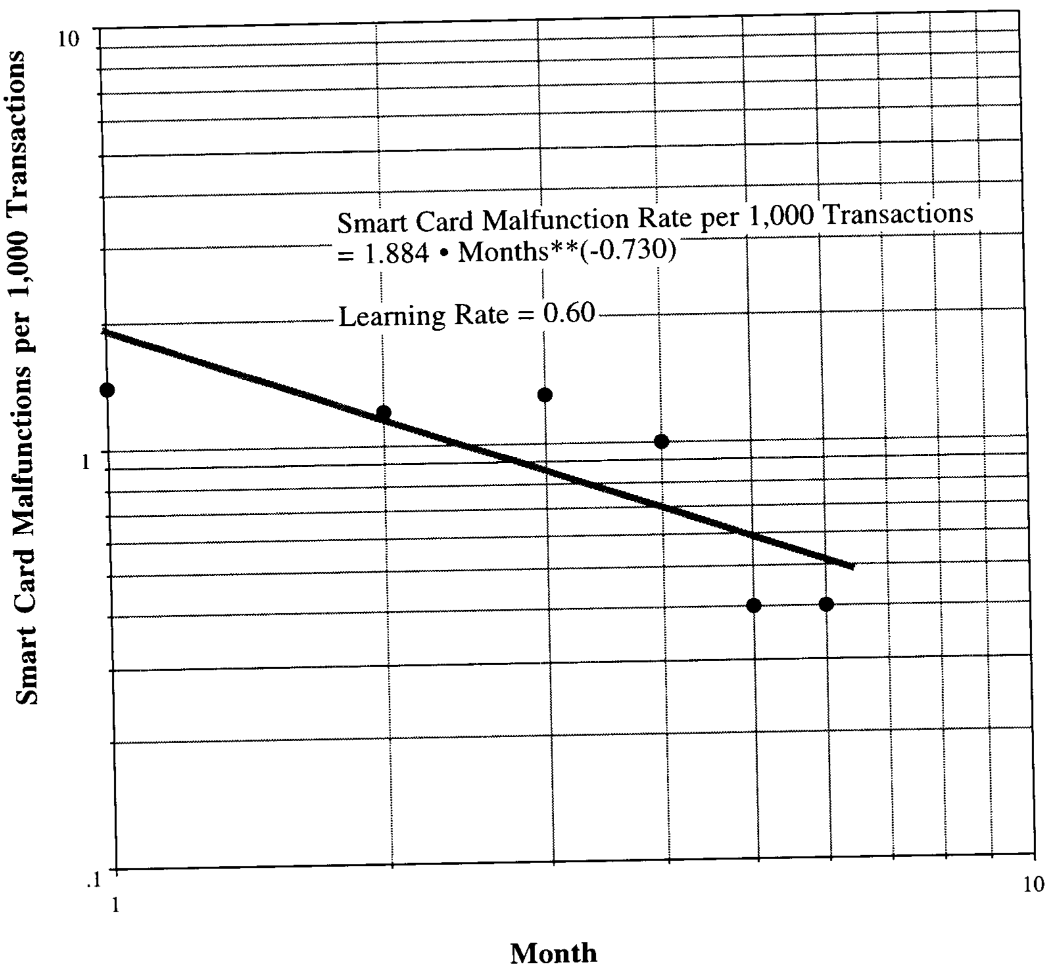



**FIGURE 3-10 ESTIMATED LEARNING CURVE MODEL OF CHANGES IN SMART CARD TYPE I ERROR RATES: LEARNING RATE = 0.60**

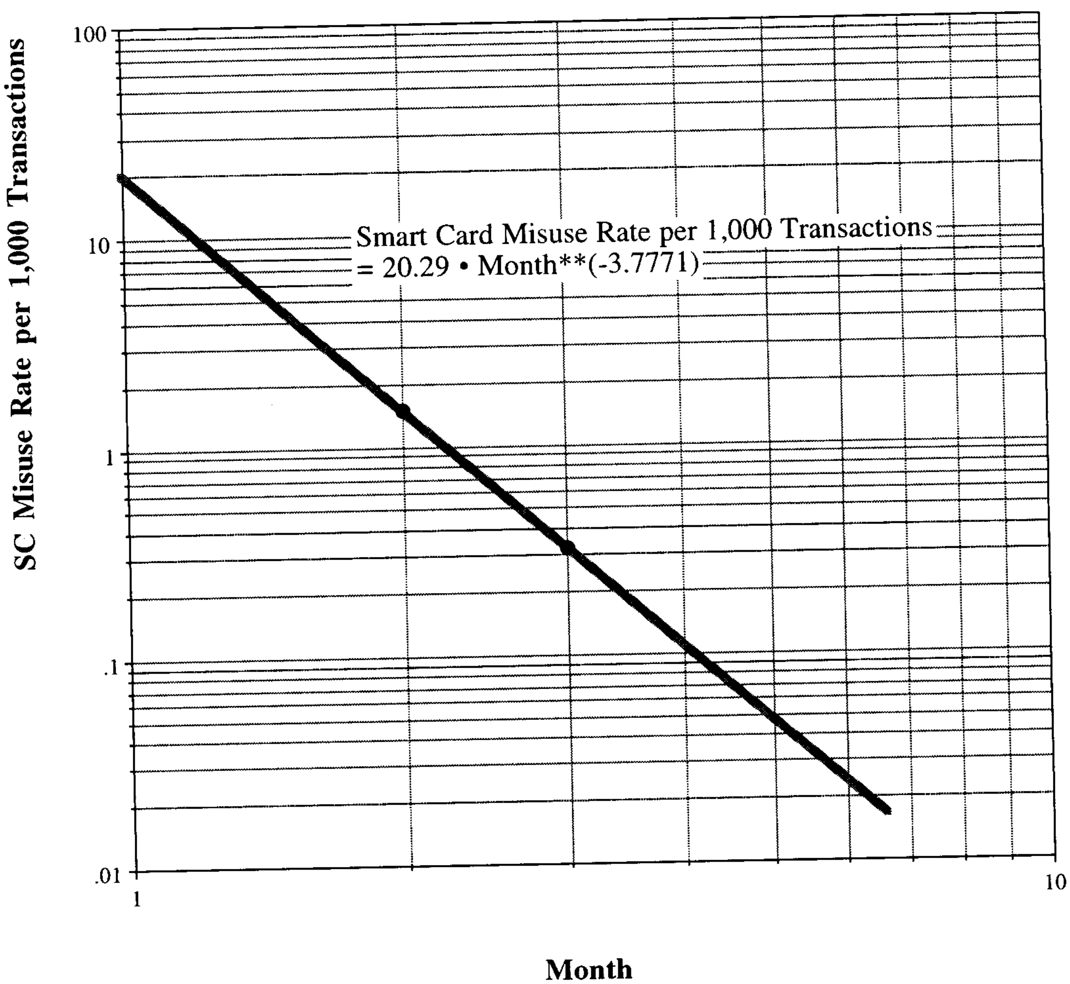



**FIGURE 3-11 ESTIMATED LEARNING CURVE MODEL OF CHANGES IN SMART CARD MISUSE RATES WHEN COORDINATES WITH VALUE ZERO ARE SUPPRESSED**

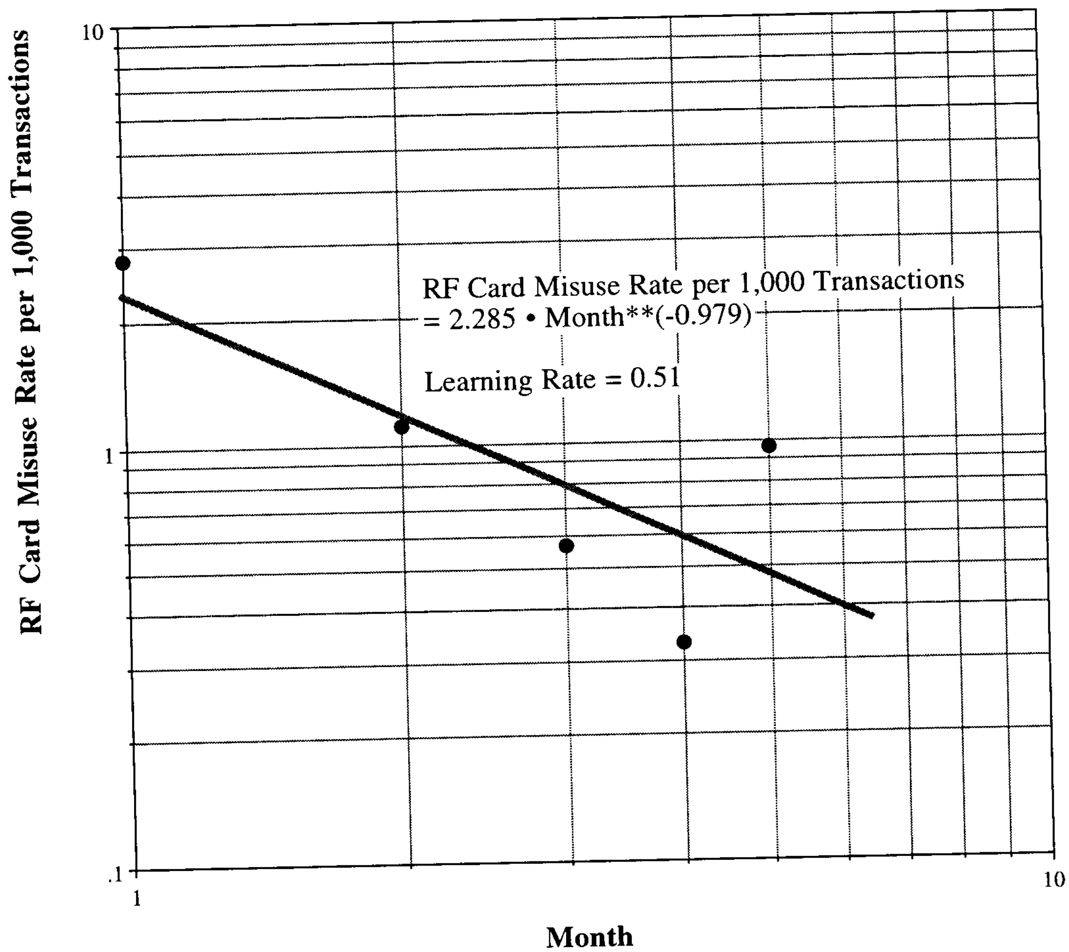



**FIGURE 3-12 ESTIMATED LEARNING CURVE MODEL OF CHANGES IN RF CARD TYPE II ERROR RATES: LEARNING RATE = 0.51**

test results indicate that multiple transactions are likely to occur unless steps are taken to preclude them. In addition, the novelty of RF Card technology may induce travelers to experiment with the card in ways that produce multiple exposures to the card reader/writer's field.

Echelon reduces the likelihood of type II errors by structuring the RF Card transactions to include incrementally longer lock-out periods in the seconds following each fare transaction. By briefly precluding a subsequent transaction each time a transaction occurs, the multiple transaction risks presented by FRAMemory speeds and user experimentation is greatly reduced. Echelon retained no detailed electronic transaction records, but reports that a lock-out period of six to seven seconds following transactions effectively reduces the likelihood of multiple transactions to zero.

Figure 3-10 suggests that, just as in the case of Smart Card type I errors, the rate of Smart Card type II errors decreases at an approximately constant rate as experience increases. Approximately 51% of the observed type II error persists as cumulative experience doubles. This decrement is due in part to Echelon's implementation of incrementally longer lock-out periods.

Data corruption occurred as frequently with use of the RF Cards as it did in the case of the Smart Cards. This is not surprising. Echelon reports that data corruption is most likely when read/write activities are interrupted, and transaction interruptions are most likely when unintentional multiple transactions are taking place. However, unlike the Smart Cards, RF Cards subject to data corruption could be reset in the field and returned to service. Thus RF Card data corruption does not qualify as a malfunction under to Echelon's definition. If the definition of a malfunction is restricted to a card failure that cannot be corrected in the field, then RF Card malfunctions are extremely rare events in this field test. As noted in Table 3-2, only two RF Cards failed to this degree in almost 24,000 transactions. The likely sources of RF Card failures include

1. manufacturing defects, or
2. broken internal contacts or leads due to incidental flexing.

Echelon did not return failed RF Cards to the manufacturer for analysis because the number of failures is lower than the value projected by RACOM for the RF Card production run.

Once it occurs, data corruption in Smart Cards is more problematic. After testing several nonoperational cards forwarded by Echelon, card manufacturer GEMPLUS provided Echelon with software capable of unlocking cards and returning them to service. This is a more complex task in the case of the Smart Cards than in the case of the RF Cards because the Smart Cards are more complex devices designed to deliver a wider range of services. In any case, the frequency of data corruption in use of both card types indicates that commercial deployment of such systems should certainly include storing redundant data sets on the cards. Nontransactions from any source -- correctable, preventable, or otherwise -- provide users with compelling disincentives to use automatic fare payment systems. Providing data back ups on the card provides a path around data corruption events, and allows immediate field recoveries when data corruption occurs. This is standard practice. Echelon is cognizant of the procedure. As noted previously, data redundancies are not part of the field test for reasons of simplicity, cost, and Echelon's desire to verify redundancy requirements. The requirement is verified.

The time required for each transaction is a function of several factors, including

1. processor speed,
2. memory speed,
3. internal card organization, and
4. the read/write operations associated with the transaction.

Obviously, short transactions are unlikely to be interrupted (presuming multiple transactions have been precluded by a lockout period), but the probability of interruption increases with longer transaction periods. Users might inadvertently remove a card before a long transaction is complete, particularly an RF Card.

Echelon's electronic records of RF Card nontransaction events determine where in the card's information cycle interruption occurs. Nontransaction records include the transaction initiation time, date, bus number, and when the transaction was interrupted. In addition, Echelon intentionally extended the time required for some transactions to determine the likelihood of interruption as a function of transaction processing time. These raw data are not available for independent review, but a qualitative assessment of the relationship between the probability of a transaction interruption and required transaction time appears in Figure 3-13. The assessment is based on an interview with Ray Rebeiro of Echelon. At 250 milliseconds, the probability of transaction interruption is under .05.

Even if data back-up procedures are employed to prevent data corruption during a transaction interruption, it is important to maintain a high probability of transaction completion. A fully developed passenger transaction unit supporting a full function Fare Transaction/Vehicle Monitoring System (FareTrans VMS) will involve a more extensive set of read/write activities than the Automatic Fare Payment System deployed during the test. The flexibility provided by a FareTrans VMS permits collection of market data, highly differentiated fares (zone and area based fares, route and time of day pricing, special event and special user fares); intermodal transfers; automatic updates of fare accounts (which might include negative balances); electronic benefit transfers (EBT); integration with corporate transit, rideshare, and parking plans; and other functions. Even if considerable intelligence is available on the fare card, executing these functions will require extensive database searches and updates by the passenger transaction unit. This increases transaction time. Even a basic automatic fare payment system might eventually be subject to a substantial database burden, if transactions must be checked against lists of lost or stolen cards, or cards are automatically being renewed in use. Figure 3-13 provides human factors benchmarks for determining how increases in the complexity of transactions will affect the likelihood of interruption. In more extensive deployments, the definition of a transaction will likely have to be segmented. Processes such as database searching need to be treated distinctly and optimized by algorithms separate from the procedures executing during the remainder of transactions.

## 3.5 Conclusions

Key findings from the functional analysis of the Advanced Fare Payment System fielded in this test are as follows. Echelon' stated objectives for the system are met to the

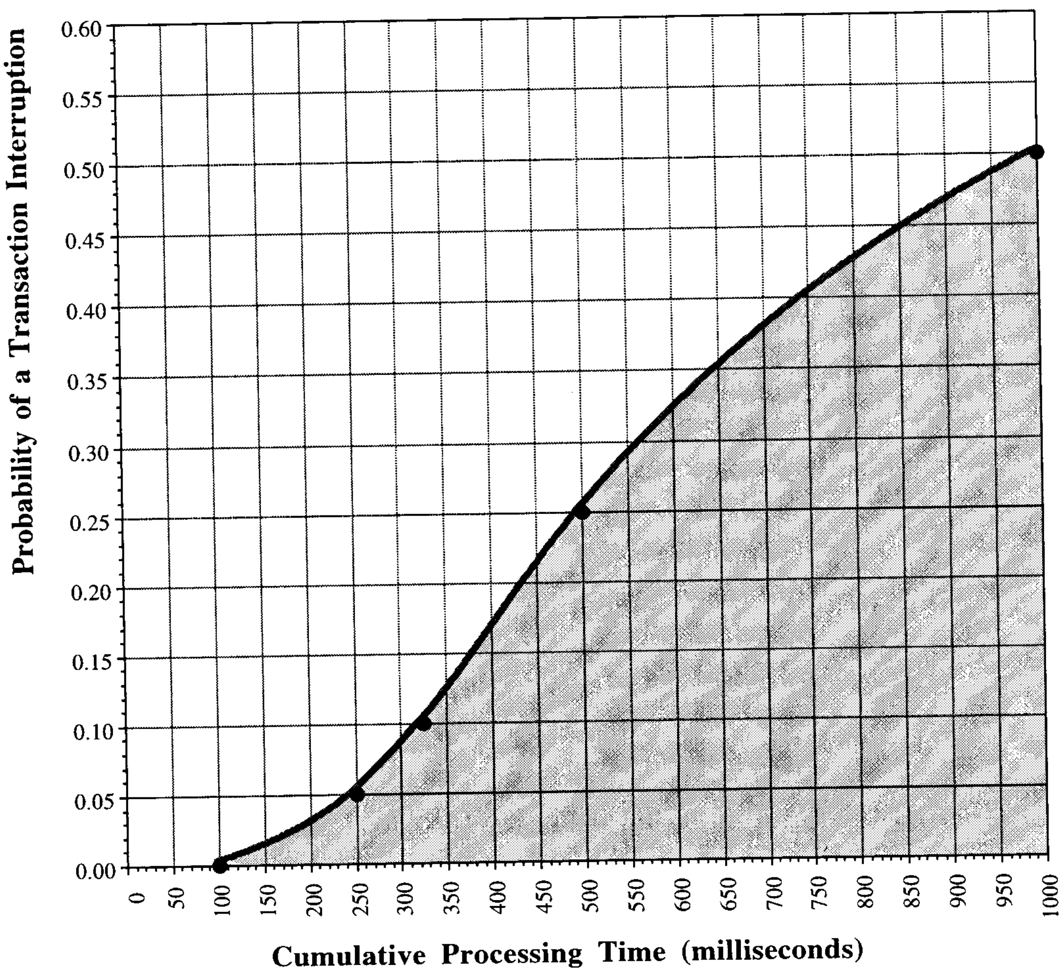



FIGURE 3-13 THE PROBABILITY OF FARE TRANSACTION INTERRUPTION AS A FUNCTION OF PROCESSING TIME REQUIREMENTS

extent test conditions permit. The most important of these is demonstrating that a system of this type, manufactured from components designed to commercial rather than industrial standards, can be fielded successfully. The most important unanswered question relates to lifecycle performance. The system performed very well during the test period, but the field test is too short and the frequency of component failures too low to provide an estimate of lifecycle costs. The payback periods described in Echelon' Final Report (1995) provide an estimate of the lifecycle characteristics required for Advanced Fare Payment System to be cost effective.

The system's design and performance are consistent with the standards provided by the scientific literature to the extent permitted by the bounds of the test. By simultaneously field-testing two very different card technologies dedicated to exactly the same purpose, Echelon's field test provides a unique and important opportunity to compare alternative strategies for expediting fare payments and providing new services. Of the two technologies fielded, the RF Cards performed extremely well, meeting or exceeding all performance standards associated with the application. The Smart Cards performed very well relative to market standards for technologies such as magnetic stripe cards, but still demonstrate a failure rate likely to be unacceptable in a transit context. Bus drivers process so many transactions that any fare payment system, advanced or otherwise, must be extremely reliable to add value to the operation. Even with redundant data back-ups, the frequency of the remaining Smart Card type I errors observed in the field test is likely to be too great to be acceptable to drivers and management. The field data provides evidence of a humidity effect, but this is not conclusive. Smart Cards subject to unknown failure mechanisms, data corruption, and physical distress cannot be classified at the level of detail needed to verify a humidity effect. Echelon reports this classification can only be provided by Smart Card manufacturer GEMPLUS, but that this information has not been made available.

From a systems reliability perspective, the functional elements of the field test provide useful insights for further development of the FareTrans VMS and related systems. Combining Echelon's data with standard analytical tools makes it clear that the performance of the system and the quality of the process being defined, while always good, improve over time in a measurable way. Transit agencies fielding similar systems can expect similar results if their processes are under control. These reflect the importance of the new technology management provided to the participating transit properties by Caltrans District 7 and Echelon. Implementation of the RF Card transaction lock-out period is an excellent example. Echelon provides considerable technical guidance to the transit properties, and properties provide important technical feedback to the vendor. Caltrans' role is more institutional than technical, but is critical to the functional success of the field test. Caltrans identifies, refines, and organizes information needed for decisions that would not otherwise be available to either Echelon or the participating transit properties. The systems reliability elements of the evaluation, while useful, can be improved in future field tests by making more intensive use of the transactions data processed by the technology vendor. Closer coordination of data gathering efforts by technology partners and evaluators will permit more complete parameterization of human factors and systems engineering relationships. This is of particular importance with respect to short-term deployments.

# CHAPTER FOUR
# USER RESPONSE

## 4.1 User Response Evaluation

The Smart Card is an entirely new type of fare medium. If it is to be widely adopted, it must be found acceptable by transit patrons. The purpose of the user response evaluation is to determine the transit passenger's reactions to and perceptions of the cards. More specifically, the following issues are examined:

1. Willingness to participate in the FOT;
2. Experiences using the card, including problems encountered;
3. Overall satisfaction with the card;
4. Possible differences between the two card technologies; and
5. Relationships between social and demographic characteristics and response to the fare cards.

From a user standpoint the Smart Card has many advantages. The card eliminates the need for exact change or tokens. The fare transaction process is rapid and so should speed up passenger boardings. Renewing the card on the bus saves the effort of traveling to a transit office or other ticketing location. On the other hand, using the Smart Card is not as easy as flashing a pass in front of the driver, and is much more fraud resistant. It is therefore possible that passengers inclined to use passes would react negatively to the card.

Using the Smart Card in the context of a field operational test implies some additional risk for the card user. There was no guarantee that the cards and associated equipment would be free of problems, despite extensive laboratory testing. The mechanisms for card purchase and renewal were somewhat "ad hoc," and thus were not as convenient as would be the case in regular use. Finally, drivers were unfamiliar with the cards and equipment, and thus could not be expected to solve problems that might occur.

## 4.2 Research design and methodology

A comprehensive survey of passengers on each participating bus route was identified as the most effective way to determine user response to the two type of cards being tested.

### 4.2.1 The Survey Population and Sample

The survey population consists of all individuals who are offered use of the cards, meaning ideally all current riders on the three demonstration routes. However, we have only limited information on daily ridership, the number of passengers that were offered Smart Card information, and the number of passengers who read the posted flyers. We therefore cannot make a reliable estimate of the survey population.

The potential number of card users was limited by the availability of cards: 350 Smart Cards and 500 RF Cards. As noted in Chapter Two, the selected number of cards to be tested was based on the assumption that about half of the existing passengers would elect to try the cards, assuming daily round-trip passengers of about 1600. The relatively small number of potential users implied that the survey should be aimed at the entire population, and that every effort should be made to obtain as high a response rate as possible.

### 4.2.2 Survey Design and Distribution

We elected to conduct an on-board survey, both because it was the best way to survey comparable groups of card users and non-users, and because a mail-back survey would have an unacceptably low response rate, given the small number of potential card user respondents. Mail-back surveys also must rely on recall information, and we wanted responses to be as accurate as possible. The on-board survey format imposed significant constraints on the survey instrument design. The survey had to be short enough to be completed during the bus ride, and be designed so that it could be filled out on one's lap while the bus is in motion (e.g., big print, heavy paper). The on-board survey format also required that the surveys be distributed and collected in person.

#### 4.2.3 Survey Instrument

The survey instrument was designed as a small eight-page booklet composed of two 8.5" x 11" sheets of paper folded lengthwise and stapled down the middle. It consists of the following parts:

- Screening section: distinguishes users and non-users
- Transit ridership section: obtains information on current trip and usual travel
- Card user section: elicits information on extent of card use, satisfaction, perceived utility
- Attitude section: elicits attitudes regarding new technology
- Demographic section: obtains basic demographic and socioeconomic data

Gardena and Torrance transit users are ethnically diverse, and many do not speak English. Gardena has a particularly large proportion of Latino passengers. Consequently, both English and Spanish versions of the survey were offered to passengers. It bears noting that these transit agencies also serve significant numbers of Asians and other ethnic groups with limited English speaking or writing skills; these people were in effect eliminated from the sample population. A copy of the survey instrument is presented in Appendix C.

### 4.3 Survey Distribution and Collection

Smart Cards were in use beginning August 1, 1994. We selected mid-November as the survey period for several reasons. We wanted to avoid the early months of the demonstration because of possible start-up problems that might be encountered, and because we wanted respondents to be reasonably familiar with the existence and use of the cards. We also anticipated that card use would increase over time (provided that no major card or equipment problems occurred), and we wanted to maximize the probability of surveying card users. Finally, we wanted to avoid periods of non-routine travel such as during summer or major holiday periods.

The surveys were distributed by USC graduate and undergraduate students. Students were organized into two-person teams, and each team was assigned a specific set of bus runs. Our objective was to obtain as many completed surveys as possible, and to cover as many runs as possible. LADOT route 448 is a peak-only service. It was assumed that most passengers would make round trips, hence all PM peak runs were covered. Torrance route 2 is an all-day service. Surveys were distributed on all runs (both directions), beginning at Union Station (downtown Los Angeles) at 8:25 AM and ending at Del Amo Fashion Center at 8:45 PM. Gardena route 1 is also an all-day service. Surveys were distributed on runs in both directions beginning in downtown Los Angeles at 11:15 AM and ending in downtown at 9:00 PM. All but two of the assigned runs were surveyed.

It was necessary to give the students flexibility in choosing the actual date of their survey tasks due to class and work schedule constraints. Thus surveying took place on various weekdays between November 7 and December 11, 1994. Surveys were distributed to all passengers willing to take them. Passengers were given pencils and asked to complete the survey before leaving the bus. Students collected surveys as they were completed. If the passenger had not completed the survey on the bus, he/she was offered a prepaid, addressed envelope and asked to mail back the completed survey to Caltrans District 7. Table 4-1 lists the number of completed surveys by agency and date of collection.

## TABLE 4-1 COMPLETED SURVEYS BY DATE OF COLLECTION, AGENCY

| DATE | LADOT | TORRANCE | GARDENA | TOTAL EACH DAY |
|---|---|---|---|---|
| 11/7 | | 60 | | 60 |
| 11/10 | | 52 | 55 | 107 |
| 11/11 | | 63 | 96 | 159 |
| 11/14 | 21 | | | 21 |
| 11/15 | | | 31 | 31 |
| 11/17 | 13 | | | 13 |
| 11/18 | | 81 | 91 | 172 |
| 11/28 | | 50 | | 50 |
| 11/30 | 29 | | | 29 |
| 12/2 | 35 | 56 | 21 | 112 |
| 12/11 | | | 29 | 29 |
| TOTAL EACH AGENCY | 98 | 362 | 324* | 784 |

* Survey date missing for one survey.

The completed surveys were logged by agency, bus run, and student team. Although records were kept of the number of surveys given to each team for distribution, the teams could not record the number of surveys they actually distributed, thus making it impossible to estimate a survey response rate. Because of the way that surveys were distributed, we cannot consider respondent characteristics to be representative of each route's actual ridership population. Comparisons made in the following analysis therefore cannot be generalized to the general ridership of these systems.

## 4.4 Results

Data and file preparations were performed by USC graduate research assistants. Raw data were entered into spreadsheet files; these files were checked and cleaned, yielding 783 valid survey responses, only one of which was a mailed back response. Frequencies of survey questions are given in Appendix D.

### 4.4.1 Characteristics of Respondents

Table 4-2 gives survey responses by transit agency and language. Spanish language surveys were offered only to Gardena passengers.

**TABLE 4-2 RESPONSES BY AGENCY, LANGUAGE**

| | GARDENA | TORRANCE | LADOT | ALL |
|---|---|---|---|---|
| ENGLISH | 198 | 362 | 98 | 83.9% |
| SPANISH | 126 | 0 | 0 | 16.1% |
| ALL | 41.3% | 46.2% | 12.5% | 100 % |

Comparing the number of completed responses received with estimates of average daily ridership, we find that LADOT has the largest proportion of responses relative to daily ridership (about 65 percent). Gardena has the smallest proportion (about 30 percent), followed by Torrance (about 45 percent). These results are expected. First, surveys were distributed on all of the LADOT PM runs, whereas a subset of peak and midday runs were covered on the other routes. Second, LADOT passengers have the longest trips, and therefore had the most time to fill out the survey. Third, both the Gardena and Torrance routes include a substantial portion of local service, meaning that trips are short and buses make frequent stops, making completion of the survey more difficult. Fourth, some of the Gardena runs were very crowded. Standing passengers could not complete the survey on board, and most of them declined to take the survey and complete it later. Students were also unable to distribute surveys to all passengers on the most crowded buses. Finally, demographic characteristics of the passengers are quite different across the three routes.

#### 4.4.1.1 Demographic Characteristics

Respondent characteristics varied considerably across the three routes, as shown in Table 4-3. LADOT respondents have the highest reported household income, the largest proportion of two-person households, and just over half are within the 40 to 59 years age category. Torrance has the largest number of young respondents (20 years or younger), and reported household income is low, with 50 percent reporting less than $25,000. Gardena respondents report the lowest household income, with 73 percent reporting less than $25,000. The 1990 median household income for Los Angeles County residents is about $35,000. Gardena respondents also report the largest households, and have the largest proportion of younger adults (20 to 39 years). Differences across agencies are statistically significant in all cases.[4]

Further differences are revealed by reported work status, as illustrated in Figure 4-1. Almost all LADOT respondents work full-time, as expected for a commuter express service. Torrance has the largest proportion of unemployed respondents, again reflecting the large share of young (student) passengers. Eighty percent of Gardena respondents work full- or part-time. Gardena respondents are thus primarily low wage workers.

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[4]Chi-square test values: Household Income 180.61, sig. = .0000; Number of Persons in Household 32.17, sig. = .0000; Age 51.82, sig. = .0000.

## TABLE 4-3 DEMOGRAPHIC CHARACTERISTICS OF RESPONDENTS

| | LADOT | TORRANCE | GARDENA | ALL |
|---|---|---|---|---|
| HOUSEHOLD INCOME | | | | |
| < $15 K | 2% | 27% | 48% | 32% |
| $15 - $25 K | 6% | 31% | 25% | 25% |
| $25 - $40 K | 15% | 23% | 15% | 18% |
| > $ 40 K | 77% | 20% | 13% | 25% |
| NUMBER OF PERSONS IN HOUSEHOLD | | | | |
| ONE | 16% | 18% | 14% | 16% |
| TWO | 42% | 23% | 17% | 23% |
| 3 TO 5 | 38% | 51% | 53% | 50% |
| 6 OR MORE | 4% | 9% | 16% | 11% |
| AGE OF RESPONDENT | | | | |
| < 20 YRS | 0% | 22% | 11% | 14% |
| 20 TO 39 | 42% | 48% | 50% | 48% |
| 40 TO 59 | 51% | 22% | 33% | 30% |
| 60 OR OLDER | 7% | 7% | 6% | 7% |

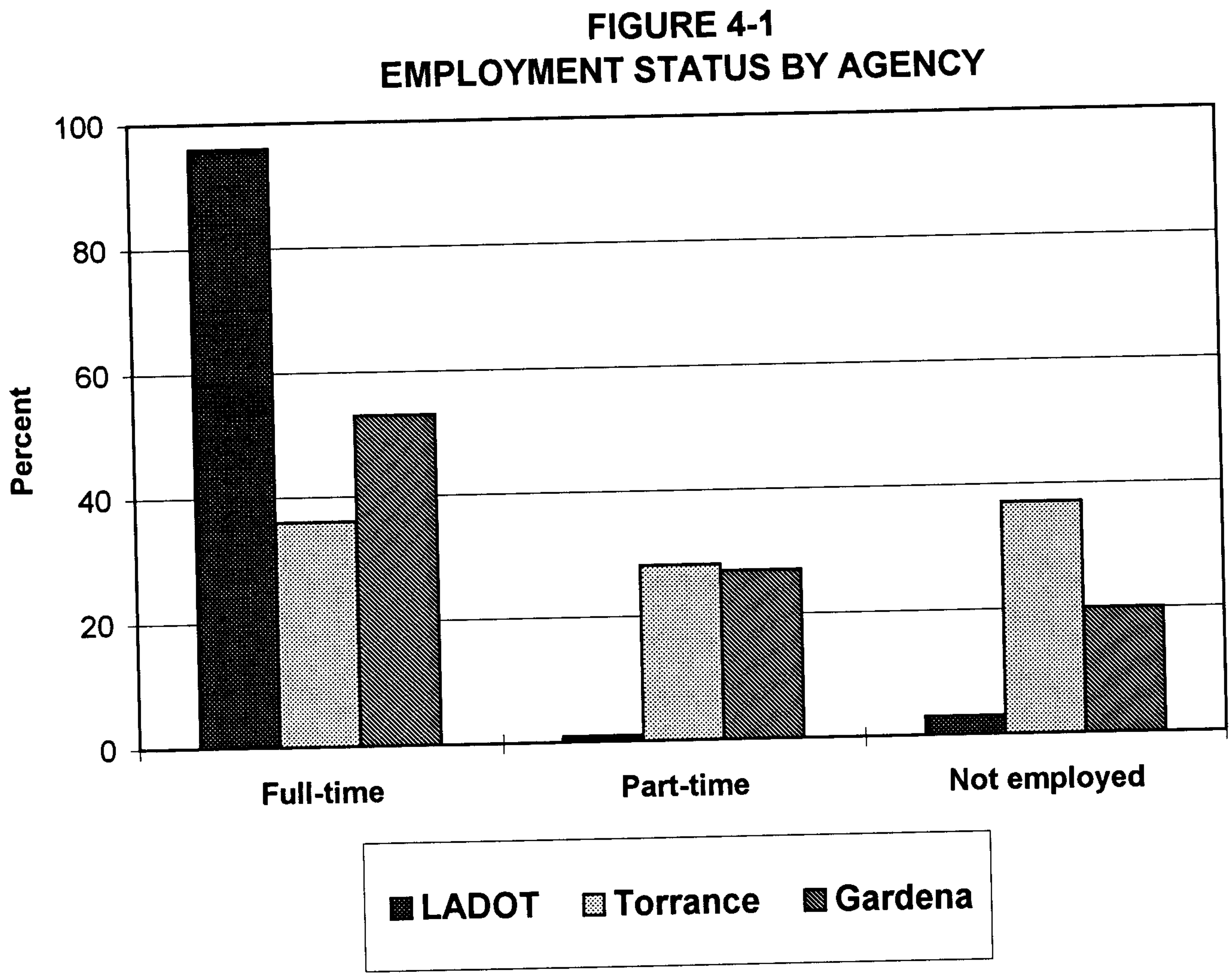


FIGURE 4-1 EMPLOYMENT STATUS BY AGENCY

There is a high degree of transit dependency among Torrance and Gardena respondents, while LADOT respondents are clearly passengers by choice. Table 4-4 gives two measures of transit dependency across the three routes. In contrast to Torrance and Gardena respondents, very few LADOT respondents have no vehicles available. Note also that half of Gardena respondents do not have a driver's license. Since there are fewer young persons among Gardena respondents, the difference in transit dependency between Torrance and Gardena respondents is likely greater than the percentages in Table 4-4 suggest.

**TABLE 4-4 MEASURES OF TRANSIT DEPENDENCY BY AGENCY**

| | LADOT | TORRANCE | GARDENA |
|---|---|---|---|
| No vehicles available in household, percent | 2% | 23% | 26% |
| No driver's license, percent | 1% | 45% | 50% |

Differences among the three respondent groups are significant. LADOT respondents are mainly middle income commuters. Torrance respondents include a large number of young people, as well as lower income workers of all ages. Gardena respondents are mainly very low wage workers; many are Spanish-speaking, and many are transit-dependent.

#### 4.4.1.2 Travel Characteristics

Most respondents are regular transit users; 87 percent usually use the bus for the trip they were taking at the time of the survey, and 79 percent travel by bus 3 or more times per week. Most respondents also have long trips. The average trip time is 45 minutes for all respondents. The average trip time is much longer for LADOT respondents (69 minutes) than for Torrance or Gardena (45 and 39 minutes respectively), reflecting the longer distance of the LADOT route. Cumulative distributions of reported travel times are plotted in Figure 4-2.

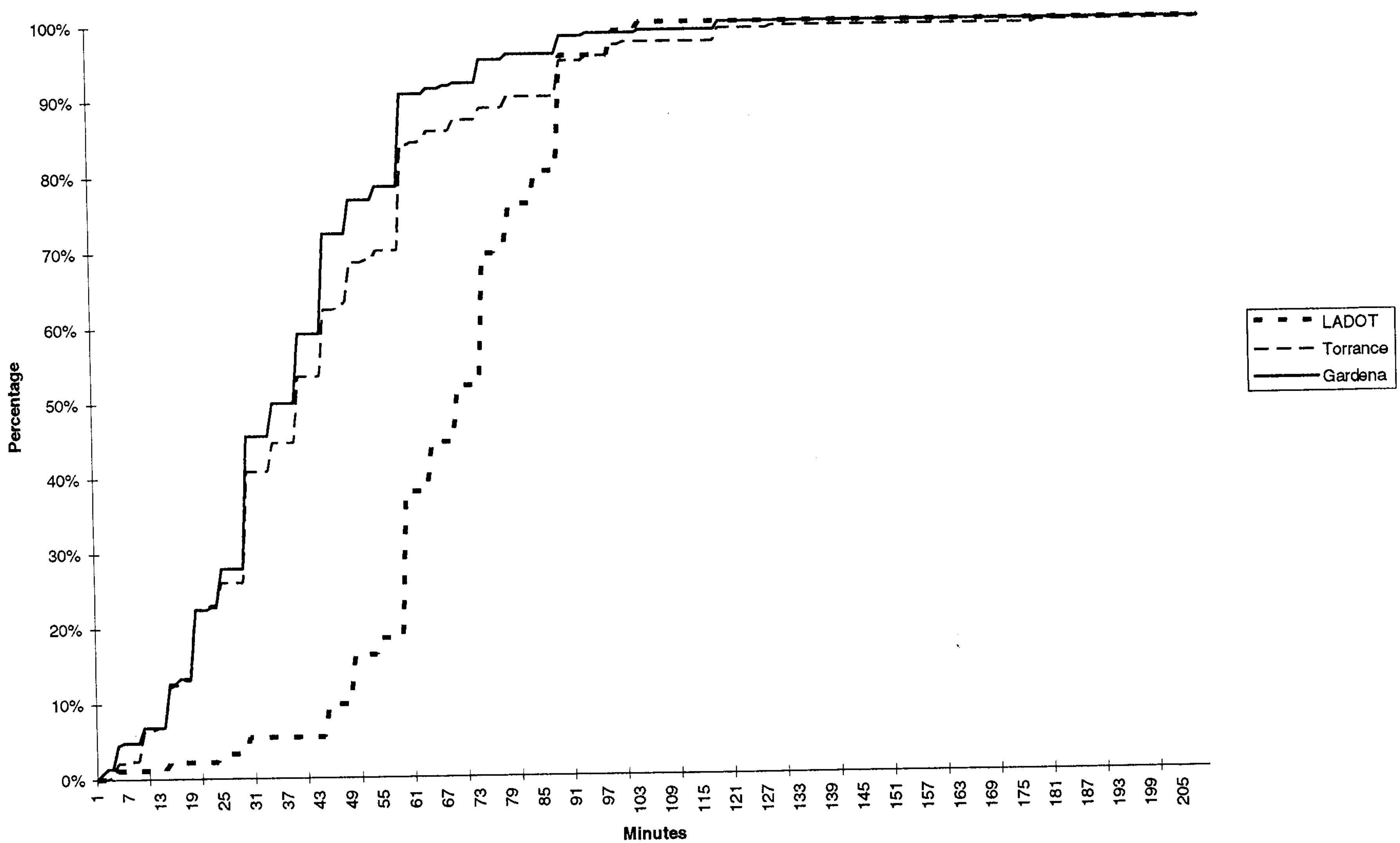


**FIGURE 4-2 CUMULATIVE DISTRIBUTIONS OF TRAVEL TIME FOR THREE AGENCIES**

### 4.4.2 Use of Smart Card

Respondents were asked a series of screening questions to determine their awareness of the Smart Card and their willingness to purchase it. Results by agency group are given in Table 4-5. Percentages show the share of each group answering "yes." LADOT respondents had the greatest awareness of the Smart Cards and were the most likely to purchase a Smart Card. Patterns of Torrance and Gardena are similar to each other, with slightly more awareness and card purchases among the Gardena respondents. Of the 257 respondents who had heard of the Smart Card and were aware that they could use it on the given route, 150 (58 percent) actually purchased a Smart Card. When asked how they paid the fare for this trip, 148 stated that they had used the Smart Card. Most respondents purchased their cards in the early months of the program: 37 percent in July, 32 percent in August, and 28 percent in September. The great majority reported that they had used the card many times.

**TABLE 4-5 AWARENESS AND PURCHASE OF SMART CARD BY AGENCY**

| | LADOT | TORRANCE | GARDENA | N of responses |
|---|---|---|---|---|
| Have heard of the Smart Card[a] | 84% | 32% | 43% | 719 |
| Aware that Smart Card can be used on this route (of all those who have heard of Smart Card) | 96% | 81% | 87% | 294 |
| Bought a Smart Card (of all those who are aware card can be used on this route) | 73% | 49% | 57% | 254 |

[a] Percent of respondents within agency category

Additional analysis examines the characteristics of those who purchased Smart Cards. Spanish-speaking respondents were far less likely to have heard about or purchased a card. Of the 126 Spanish-speaking respondents, just 3 had purchased Smart Cards. Differences between language groups are shown in Table 4-6. All are statistically significant. Although both awareness of the card and its availability for use was lower for Spanish language respondents, the greatest difference is with respect to the purchase of a Smart Card. Spanish speakers apparently had more resistance to trying the cards. Our analysis also shows a higher propensity for card purchase among higher income and full-time employed respondents. It is reasonable that regular commuters would be more likely to purchase cards, and that workers from higher income households would be more likely to pay the lump sum required for card purchase. However, these results are also a function of the way the cards were marketed. As noted earlier, informing commuters of the cards' availability was simpler in the case of LADOT's service than in the cases of Gardena or Torrance. The observed relationships between income and employment status may simply be a function of the more effective information distribution and more convenient card renewal arrangements experienced by LADOT respondents. These results are therefore only suggestive.

**TABLE 4-6 AWARENESS AND PURCHASE OF SMART CARD BY LANGUAGE**

| | ENGLISH | SPANISH | N of responses |
|---|---|---|---|
| Have heard of the Smart Card | 45% | 32% | 719 |
| Aware that Smart Card can be used on this route (of all those who have heard of Smart Card) | 89% | 71% | 294 |
| Bought a Smart Card (of all those who are aware card can be used on this route) | 69% | 14% | 254 |

We asked respondents who were aware of the Smart Card but did not purchase one their reasons for not doing so. The most common answers were, "I don't know how to buy a Smart Card" and "other" (Table 4-6). All of those who said they did not know how to use a Smart Card were from the Torrance or Gardena groups. The "other" response allowed for written comments. These included use of different types of passes, infrequent transit use, or being too busy to purchase the card.

**TABLE 4-7 REASONS FOR NOT BUYING SMART CARD**

| REASON | PERCENT[a] |
|---|---|
| Don't know how to buy it | 37% |
| Other | 35% |
| Don't want to buy it | 13% |
| Don't regularly use the bus | 10% |
| Could not use for my trips | 8% |
| N = 104 | |

[a] Sums to more than 100% because multiple answers were allowed

### 4.4.3 Perceptions of Smart Card

Response to the Smart Card was overwhelmingly positive. Nearly all users (99 percent) reported being satisfied or very satisfied overall with their Smart Card, and most users (85 percent) considered the Smart Card easier to use than the fare medium they had used before the Smart Card was available. Responses regarding buying and renewing the Smart Card were somewhat less positive, as shown in Table 4-7.

## TABLE 4-8 PERCEPTIONS ABOUT USING THE SMART CARD

| HOW EASY IS IT TO..... | EASY | OK | DIFFICULT |
|---|---|---|---|
| Buy Smart Card | 70% | 21% | 9% |
| Use Smart Card | 90% | 9% | 1% |
| Renew Smart Card | 62% | 26% | 12% |

Cross-tabulations of these variables with both card type and transit agency were performed to determine whether perceptions about the cards differed across these factors. There are no significant differences across agencies in perceptions about buying the cards. Since all of the cards were purchased initially through Caltrans, this result is expected. There were no significant differences across agencies or card types in perceptions about using the cards. Since each user experienced only one type of card, we cannot draw any conclusions regarding which card might be preferred in a comparative evaluation. The result simply suggests that there are no major problems associated with using either type of card. It also suggests that there are no apparent differences in the way the fare transaction was processed across the three agencies.

There are significant differences in perceptions of renewing the cards.[5] Just 42 percent of Torrance respondents considered renewing the cards to be easy, compared to 73 percent for LADOT and 65 percent for Gardena. Twenty-four percent of Torrance respondents considered renewing the cards to be difficult, compared to 6 and 9 percent respectively for LADOT and Gardena. There is no obvious explanation for these findings. Both Gardena and Torrance issued and renewed cards only through Caltrans in the early months of the FOT. About midway through the FOT, Torrance offered card issuance and renewals at the Transit Agency office as well as at Caltrans. According to the Torrance Transit project manager, no complaints from passengers about purchasing or renewing cards were received. On the other hand, the higher

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[5]Chi square = 10.16, df = 4, sig. = .038.

degree of satisfaction reported by the LADOT card users is expected, since LADOT patrons could renew the cards on the bus as well as at Caltrans.

Smart Card users also reported on problems they may have experienced in using the cards. Few card users experienced damage, lost cards, or card rejection by the driver (Table 4-8). On the other hand, 26 percent reported having the card reader deduct more than one trip, and 38 percent reported riding free due to problems with the card. Drivers apparently followed the policy of allowing passengers to ride free when problems were encountered.

**TABLE 4-9 PROBLEMS WITH SMART CARD**

| SHARE OF CARD USERS WHO REPORTED... | |
|---|---|
| Card Was Lost or Stolen | 7% |
| Card Was Damaged | 7% |
| Bus Driver Would Not Accept | 6% |
| Reader Deducted More than One Trip | 26% |
| Rode Free Due to Card Problems | 38% |

The incidence of problems reported by users is much greater than the incidence of card malfunctions as measured by Echelon (Chapter Three). The difference is explained by how card malfunctions are defined. From a technical standpoint, malfunctions occur only when the card reader fails to read the card because of some problem with the system. For example, an RF Card user might pass the card too far away from the card reader, or the data card exchange between the card and the PIU might be interrupted. These are problems for the user, but are not technical malfunctions. User acceptance of course depends on perceived user experiences, rather than on the particular source of any given problem. The very high degree of satisfaction with the cards despite the incidence of problems is therefore quite significant. We also compared frequency of reported problems across agencies and card types, and found no significant relationships. Both types of cards performed equally well from a user perspective, despite differences in their technical performance.

Perhaps the strongest endorsement of the Smart Card is the response of card users when asked whether they are interested in participating in additional Smart Card or other new technology trials: 86 percent reported interest. Anecdotal evidence also supports this positive response. Caltrans received several requests to continue selling the cards, and many drivers reported that passengers wanted Smart Cards to be permanently available.

### 4.4.4 Attitudes about Smart Cards

The survey includes a series of simple agree/disagree statements to give some indication of general attitudes toward the Smart Card and to allow us do determine whether there are differences in attitudes between those who purchased cards and those who did not. Table 4-9 gives results. Those who purchased Smart Cards had more positive attitudes about the card. A sizable proportion of both groups identified the information made available to others by the cards as a problem. Since the question was asked in general terms, and since users had little knowledge of how the cards work or what information they store, these responses reflect perceptions about the cards, rather than about the user information actually collected. The greatest difference between the two groups is with respect to the possible loss of cards, suggesting that this concern prevented some people from trying the card.

**TABLE 4-10 AGREEMENT/DISAGREEMENT BY SMART CARD PURCHASE, OF ALL THOSE WHO ARE AWARE THEY CAN BUY**

| A PERSONAL DEBIT OR CREDIT CARD LIKE SMART CARD.... | PERCENT WHO AGREE, BY CARD PURCHASE STATUS | | | |
|---|---|---|---|---|
| | BOUGHT SMART CARD | DID NOT BUY SMART CARD | N | SIG. |
| Makes taking bus easier | 92% | 86% | 216 | N/S |
| Gives too much information to transit agencies | 23% | 32% | 209 | N/S |
| Is easy to lose or have stolen | 17% | 41% | 210 | .000 |
| Makes taking the bus safer | 77% | 60% | 204 | .012 |
| Is unreliable | 13% | 20% | 201 | N/S |
| Makes it harder for people to avoid paying the fare | 58% | 44% | 197 | .062 |

## 4.5 Conclusions

Public response to the Smart Cards is very positive. Those who purchased and used cards are extremely satisfied with the experience. Although a large number of users reported having some problem with the card, these problems were not sufficient to dampen enthusiasm about the card. These positive results are also likely a function of how problems were handled; it was prudent to allow users to ride free when problems were encountered. It would have been helpful to obtain more details on the specific problems encountered with each of the cards, and we suggest that this be done in the Phase III evaluation.

Interest in trying the cards was greater than expected, given the limited marketing that accompanied the card offer distribution. Because of the discounts that were offered with the cards, however, not all of the positive perceptions about the cards can be attributed to the fare medium itself. There appears to be some language barrier to willingness to try the card. The card offer and purchase processes may have been difficult to understand for those with limited English speaking skills, or the technology may have been more threatening to some passenger groups. More research on these questions is necessary. Finally, satisfaction with the card is independent of the type of card or the characteristics of the respondent. Both types of cards performed equally well from a user perspective, suggesting that transit agencies have some flexibility in the particular technology they choose to implement once technical performance standards are met.

# CHAPTER FIVE
# INSTITUTIONAL ANALYSIS

New technology demonstrations often require a level of coordination and cooperation among public agencies and private companies far beyond that required for regular day-to-day operations. In addition, the risk and uncertainty associated with tests of new technology may require mid-course changes in plans, quick responses to unforeseen problems, and adjustment of time schedules as a result of unanticipated delays. Thus new technology tests require effective management, flexibility, and good working relationships among participants if they are to succeed.

## 5.1 Data Sources

This chapterreviews the roles of participating organizations and examines the Smart Card FOT process. This discussion is based on three sources of information: attendance at various monthly project meetings, review of Echelon and TRANSCON monthly project reports, and interviews with the key project participants after the conclusion of the FOT. Unfortunately, however, our information about the earlier months of the FOT is limited. The evaluation contract was not funded until several months after the FOT began, and therefore the research team did not attend many of the early meetings. Thus, description of events and attitudes about the FOT are based on retrospective information collected during the interviews and from the printed monthly reports.

## 5.2 Organization Roles

### 5.2.1 Echelon Industries, Inc.

Echelon Industries was the leading force in the Smart Card FOT. As noted earlier, Echelon had won an SBIR grant to develop the Smart Card system technology. To conduct the FOT, Echelon had to recruit transit agencies to participate in the test. This Phase II test was critical to the eventual commercialization and for-profit sale and deployment of the product, which of course is Echelon's primary goal. Echelon therefore had every incentive to locate willing participants and to conduct a successful test.

Recruiting transit agencies was difficult. First, Echelon was an unknown entity in the transit industry. New technology development has taken place primarily within large corporations, many with strong ties to the Federal Government (e.g., Westinghouse, Rockwell Corp.). Working with Echelon thus required transit agencies to take a risk on Echelon's capabilities and reliability. The perceived risk was increased by the fact that most fare transaction hardware for buses is manufactured by just one company (GFI); working with Echelon meant not working with the dominant company in the industry. Second, there were no successful prior tests of similar card technologies. The disappointing Smart Card tests conducted at the LACMTA (Los Angeles County Metropolitan Transportation Authority) were common knowledge among operators in the region, and the fare card demonstrations in other parts of the U.S. either had not yet reached the field test stage, or were not yet releasing information on results. It was therefore critical for Echelon that the Caltrans District 7 CAPTS Group took a lead role in soliciting transit agency participants.

Echelon is headed by Mr. Ray Rebeiro. He has extensive transit industry experience and excellent technical and communication skills. This combination makes it possible for him to both understand the needs of the transit industry and develop the technology to address those needs. It is not surprising that the system Echelon developed can potentially serve a variety of functions, from managing fare transactions to data collection to monitoring revenue vehicle operation. The importance of Rebeiro's transit experience became evident as the FOT proceeded. Positioning of the hardware units was determined by vehicle and driver needs, the installation was completed in time for several dry runs before the FOT's August 1 start date, and training of drivers and other personnel was tailored to each transit agency. His understanding and responsiveness are reflected in the very positive assessments of the FOT (and specifically Rebeiro) given by all three transit agencies.

### 5.2.2 CALTRANS District 7 - CAPTS Branch

The reason given by CAPTS Branch personnel for participating in the FOT was legislative: California State Legislature Bill AB 963 (1991) gave Caltrans responsibility for research and development of the California Pass, a universal fare.medium for all types of public transportation services.

The leadership role taken on by CAPTS exceeded any legislative requirements. Had Caltrans not solicited the transit agencies, acted as the central coordinator of the FOT, and become a participant itself, this FOT might not have been undertaken. The CAPTS group exhibited a strong commitment to the technology test. CAPTS was able to take a lead role in the FOT because it qualified as part of the I-l 10 Traffic Management Plan (TMP). The TMP was designed to reduce traffic during the I-l 10 Transitway construction project. Since the ultimate goal of advanced technology is to increase transit use by improving productivity and convenience, and since the three routes operated on the I- 110, the project qualified as an I- 110 TMP component.

Interviews with the CAPTS group and TRANSCON, its subcontractor, revealed that they understood the challenges of persuading transit agencies to take the risk of testing the fare system. They had worked with the transit agencies serving the I-l 10 corridor on other TMP activities and had established cordial working relationships. The standing of Caltrans added a measure of security to the project that was likely helpful in persuading the three transit agencies to join in the test. The CAPTS group also understood that the test should include small rather than large agencies. Small agencies have fewer layers of management, can make decisions more rapidly, and typically have more flexible work rules -- all important considerations in a field test.

CAPTS and TRANSCON acted as both project managers and interagency mediators. Perhaps more importantly, they were problem solvers. When a private company could not be found to perform the clearinghouse activities, CAPTS took on the responsibility. When marketing funds were withheld from the project, CAPTS developed and produced some basic materials and mobilized a group of summer high school interns to distribute them. The project was kept on schedule through frequent meetings between CAPTS, TRANSCON, the transit agencies, Echelon Industries, Caltrans Headquarters, and the evaluation team, and active monitoring of all activities.

### 5.2.3 Transit Agencies

The incentive for transit agency participation was the opportunity to experiment with the Smart Card without having to purchase the equipment. However, the lack of a precedent for successful tests made transit management reticent. There were other reasons for a less than enthusiastic response by transit agencies. First, though the test would involve no financial cost, it would certainly involve labor costs in the form of project monitoring, training, etc. Second, it would impose an additional burden on drivers (dealing with two kinds of fares) who had no stake in the demonstration. The demonstration project could be viewed as very problematic by drivers, who might perceive the possibility of a card or system malfunction as a source of possible conflict with patrons, or who might resent the technology's potential for monitoring vehicle and route performance. Third, problems with the Smart Cards could alienate passengers. Finally, there was little likelihood of actually experiencing the technology's potential productivity benefits, given the short duration of the project. Transit agencies would logically expect results to be suggestive at best.

It appears that the three agencies were ultimately convinced to participate for the following reasons:

1. Financial risk was minimal, since there was no charge for the use of the equipment, and Caltrans absorbed the cost of the cards and the fare discounts provided.
2. Echelon and CAPTS were able to convince the agencies that the likelihood of a successful test was high, given the Phase I results.
3. By participating, the agencies would be leaders in advanced technology experimentation, especially if the test went reasonably well.

Each agency also had more specific reasons for participating. LADOT was very interested in the concept of a common fare medium. Many of their passengers use the local downtown transit service (DASH) operated by LACMTA, and transfers between the two services have been an issue for quite some time. Gardena, with its extensive local service, saw the potential benefit of speeding up the passenger boarding process. Torrance was interested in simplifying its fare collection process. The FOT made it possible to test some of these ideas at very low cost to the transit agencies.

### 5.2.4 Private Employers and the Clearinghouse

The original FOT plan involved private employers and some private entity to perform the clearinghouse function, that is, to manage the sale of cards, take responsibility for returned cards, and maintain records of card users. Despite major efforts by CAPTS, no private employer could be persuaded to participate in the project. The private employer was to offer Smart Cards as part of their trip reduction program.[6] Use of the Smart Card would give the employer an accurate record of transit use among employees. In addition, the Smart Card could be linked to other travel expenses, such as parking or vanpool fees.

Why were no private employers interested in participating? There are several possible explanations. First, developing a Smart Card program, marketing the program to employees, distributing the cards and operating the program would be very costly and complex, even if all associated financial cost were covered. Second, such an investment of time and effort could likely not be justified for a six-month program, given that any widespread adoption of the Smart Card by transit agencies in the region -- a necessary condition for operation of employer-based programs -- is years away. Third, large employers have little incentive to keep accurate records of employee ridesharing, since such records are not required by existing regulations.

Private companies asked to perform the clearinghouse function also had no incentive. The potential benefit for any company would be the possibility of future profits. A small demonstration of a product from a virtually unknown manufacturer was not sufficiently attractive. Our assessment is that the absence of private companies-turned out to be beneficial to

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[6]At the time of the FOT, all worksites with 100 or more workers in the I-l 10 corridor were subject to Rule 1501 of the South Coast Air Quality Management District. Rule 150 1 requires employers to file and implement a plan for reducing peak period vehicle work trips of employees.

the overall results of the FOT. It greatly simplified the project and made it much more manageable, as will be further discussed in Chapter Six.

### 5.3 The FOT: Experiences and Perceptions

Once the decision to participate was made, the capability, efficiency, and responsiveness of Echelon visibly changed transit agency attitudes over the course of the project. Echelon (Rebeiro) met with agency representatives, provided demonstrations of the system before installation in the buses, and closely monitored system performance throughout the project. By the time of the post-project interviews, transit agency perceptions of the FOT were overwhelmingly positive. When asked about problems encountered during the FOT, transit managers needed prompting to recall them, and, in retrospect, the problems were uniformly viewed as minor. Torrance and Gardena management mentioned vehicle availability problems. At Gardena, there were not enough equipped spare buses to cover vehicle breakdowns. Torrance found it difficult to dedicate the FareTrans VMS equipped buses to the test route, because in regular operations Torrance buses are routinely interlined. All agencies recall problems with the cards, particularly in the early weeks. Both Torrance and LADOT managers are aware of RF Card reader problems. Torrance drivers apparently experienced some difficulties when asking passengers to surrender faulty cards.

Transit managers have no difficulty describing the positive side of the FOT. The favorable response of passengers is identified as one of the greatest benefits. The Smart Cards made the fare transaction faster and easier. Many other ancillary benefits were noted as well, including passenger and driver security, more efficient fare collection, and opportunities for integrated fare systems. All three managers also discussed the data resources associated with the system and recognize the potential for using the data to respond better to passenger travel patterns and monitor system performance. They obviously learned a great deal about the potential of advanced technology by participating in the FOT.

Echelon considered the FOT to be a great success. Rebeiro considered the technical performance of the system to be far better than expected. The Echelon Final Report emphasizes system performance results (especially the near zero card failure rate), and even provides estimates of potential transit agency cost savings attributable to the FareTrans VMS. Rebeiro also noted the positive relationships established among participants, and the cooperative "team spirit" that developed over the course of the project.

CAPTS and TRANSCON also considered the FOT to be a great success. The project remained approximately on schedule, the objectives of the demonstration were accomplished, and the outcomes of the demonstration are far more positive than anticipated.

### 5.4 Conclusions

The interagency cooperation, flexibility, and effective management required for success are quite apparent in this project. Why was this the case, and can it be replicated in future FOTs? There are a number of explanations. First, the project had ownership. The fortunes of Echelon are clearly tied to the successful demonstration of its products; thus the company had every reason to make the FOT work. Echelon was therefore willing to invest whatever time and effort was necessary to achieve success. Second, both Echelon and CAPTS are committed to the technology and took leadership roles in selling the concept to others. They are very effective in communicating the potential benefits of the technology. Their commitment is evident in the level of attention given to the project and by their determination to resolve difficulties as they arose. Third, TRANSCON, the project management sub-contractor, was very effective. Finally, and perhaps most importantly, the FOT was limited; its focus was clearly on field testing the Smart Cards and the fare transaction process. The relative simplicity of the test made it possible to be thorough and attentive to detail at every step of the FOT, and to maintain close communications between transit agencies and the system designer.

# CHAPTER SIX

# CONCLUSIONS

The purpose of this research was to evaluate Phase II of the Federal Transit Administration's Advanced Fare Payment Media Research and Development project. Its goal is to develop a transit fare payment system for commercialization that will improve transit efficiency and effectiveness. The major focus of Phase II was the field testing of the selected technologies in revenue service. Two types of Smart Cards were selected for testing: a contactless radio frequency (RF) card and a contact card. The cards have similar capabilities from a fare card usage perspective.

The Phase II evaluation addresses the following: 1) functional performance of hardware and software components; 2) impacts on transit operations, management, and efficiency; 3) transit passenger responses and perceptions; and 4) institutional and organizational issues related to the planning and implementation of the FOT. Evaluation of item 2 was performed by the UC Berkeley team, and results are presented in a separate report.

Our conclusions are presented in two parts. The first part presents a summary of research results, and the second part discusses lessons learned regarding new technology field tests and evaluations.

## 6.1 Summary of Results

Results from the analysis of technical performance, user response, and institutional considerations are summarized in the following sections.

### 6.1.1 Functional Performance

Functional performance of the FareTrans VMS is considered to be very good. First, we examine transaction errors. A type I error occurs when the intended transaction does not take place. A type II error occurs when unintended transactions (usually multiple transactions) take place. Since multiple transactions are more a matter of system management than technology, they are not a critical determinant of technical performance. Type I errors were so rare that little analysis could be performed. A total of 3 1 type I errors in 24,564 transactions were recorded for the contact Smart Cards, yielding a success rate of 99.9%. The RF Card performance was even better, with just two type I errors in 23,416 transactions, resulting in a success rate of 99.99%. There were no cases of type II errors (multiple transactions) for the Smart Card and 10 cases for the RF Card.

Second, we consider the performance of other system hardware and software elements. The FareTrans VMS is a relatively inexpensive system constructed of components manufactured to commercial standards rather than to industrial standards. A key question is whether commercial components could perform acceptably in the environment of a public bus. While system performance was very good during the field test, six months is not long enough to assess lifecycle costs of the system.

The system's design and performance are consistent with the standards provided by the scientific literature to the extent permitted by the bounds of the test. We also note that system performance improves over time, as passengers and bus drivers have more experience with the system. While both cards performed very well relative to market standards for technologies such as magnetic stripe cards, the Smart Card had a failure rate that is likely to be unacceptable in a transit context. Bus drivers process so many transactions that any fare payment system must be extremely reliable to add value to the operation. On the other hand, performance of the RF Card suggests it has significant promise for large-scale deployment.

### 6.1.2 User Response

If Smart Card technology is to be widely adopted, it must be found acceptable by transit patrons. The purpose of the user response evaluation is to examine the following issues: 1) willingness to purchase and use the Smart Card; 2) experiences using the card, including problems encountered; 3) overall satisfaction with the card; 4) possible differences between the two card technologies; and 5) relationships between social and demographic characteristics and response to the fare cards.

On-board survey results showed response to the Smart Card to be overwhelmingly positive. Nearly all users reported being satisfied or very satisfied overall with their Smart Card.

There were no differences across card types, suggesting that there are no major problems associated with using either type of card. Smart Card users reported few problems with using the cards; these problems apparently did not affect satisfaction. These positive results are likely a function of how problems were handled; users were allowed to ride free when card problems were encountered.

While satisfaction with the cards does not vary with respondent characteristics, the likelihood of having purchased a card does vary. Spanish-speaking respondents were far less likely to have heard about or purchased a card. Purchase of a card is associated with higher household income and full-time employment, as would be expected.

We conclude from our survey results that transit patrons find the advanced fare card a convenient and reliable fare medium. On the demand side, there are no apparent barriers to widespread use of such media.

### 6.1.3 Institutional Issues

New technology demonstrations often require a level of coordination and cooperation among public agencies and private companies far beyond that required for regular day-to-day operations. In addition, the risk and uncertainly associated with tests of new technology may require mid-course changes in plans, quick responses to unforeseen problems, and adjustment of time schedules as a result of unanticipated delays.

New technology tests therefore require effective management, flexibility, and good working relationships among participants if they are to succeed. All of these requirements were met. Over the course of the project, early apprehensions of the participating transit agencies faded, and the FOT was deemed an unqualified success by all parties. We attribute the success of the FOT to the following: project ownership, both on the part of Echelon and CAPTS-District 7; effective project management; and the limited scale and scope of the FOT. The system developer, Echelon, Inc., created a product that is sensitive to the needs of transit operators, and conducted the equipment installation, driver training, and monitoring and maintenance in a manner responsive to the concerns of transit management. The CAPTS oversight team actively participated in the project by solving problems and building consensus among participants.

Finally, the restriction of the FOT to three small transit agencies and to the performance of the fare transaction media made it possible to conduct a detailed and thorough field test, given management and budget constraints.

## 6.2 Lessons Learned

In the case of this FOT, lessons are learned primarily from its positive outcome. Conclusions related to the more general issue of new technology tests are presented in this section.

### 6.2.1 Scale and Scope

We define scale of the project as the size of the FOT, e.g., how many units tested over how much time and how much area. Scope of the project refers the number of items or functions to be tested. As we noted earlier, the small scale and scope of this FOT made it easier to manage. In general, the experience of this FOT suggests that the scale and scope of FOTs should be determined by the minimum necessary to conduct a statistically valid test. In this case, the system developer estimated that at least 200 cards of each type were required to obtain sufficient transaction data, given the six-month duration of the test, and at least 20 buses should be equipped with the FareTrans VMS system. Equipping more buses and distributing more cards would have added significantly to the cost of coordinating and managing the test, but would have generated little additional benefit in terms of test results. It is important to note, however, that the minimum number of cards required for the technical tests is not the same as that required for a valid test of user responses to the card. In this case, the greater than anticipated sales of the cards was fortunate: it provided a reasonably large population sample of users.

Similarly, we conclude that limiting the scope of an FOT makes it possible to conduct a more thorough test. Involvement of a major employer in this FOT would have added substantial coordination costs and data processing and management requirements. As it turned out, it took every effort of the system developer and project managers to accomplish the scaled-down test. A similarly thorough test on a project of greater scope would have exceeded the resources of the project budget.

It also bears noting that the restricted scope of the FOT allowed for changes in the structure of the test. For example, it was possible to offer fare discounts with Smart Card purchase in order to assure an adequate number of card sales necessary for the technical performance test without affecting some other aspect of the evaluation. Had effect on transit demand remained as an evaluation objective, the discounts could not have been offered.

Finally, restricting the size and scope of FOTs also provides for more efficient use of new technology project funds. This is particularly important in cases when the technology proves to be unacceptable, either because of performance problems, lack of a sufficient market for the product, or institutional constraints. An important purpose of tests is of course to determine whether implementation on a larger or permanent scale is justified. Small-scale tests allow for experimentation without excessive costs, even when such tests demonstrate that the technology element under consideration is found to be not worth further development.

### 6.2.2 Role and Participation of Evaluation Team

A better and more comprehensive evaluation of this FOT would have been possible had the evaluation team been available to participate in the FOT design. As noted in the previous section, the decision regarding the number of cards to be offered is illustrative. The number was based on the requirements of the technical evaluation, and not on the user response evaluation. A much larger number of cards would have been required to generate a valid sample of users. The survey generated 150 card users, a sufficient number for some basic analysis, but not a sufficient number for a comprehensive analysis. Effective evaluation requires commitment of project participants to provide the necessary data, sample, etc.

Effective participation of the evaluation team is also related to timing. For evaluation, the “before” conditions are often important. FOTs that are aimed at improving any aspect of system performance require the establishment of an appropriate baseline. In this case, much of the evaluation could be done from cross-sectional observations, and there was adequate time for the “before” data collections required for the transit agency impact analysis.

Finally, we must note that the resources made available for FOT evaluations are generally not sufficient for a thorough evaluation. In this case, for example, resource constraints made it necessary to use student volunteers to conduct the on-board survey, rather than survey professionals. No doubt the likelihood of response depended in part on the student's manner and commitment to the job, a source of error that could easily have been avoided. Given the enormous amount of resources being invested in new technology development, investments in careful evaluation of new technology tests are surely cost-effective,

## 6.3 Conclusions

The Phase II FOT was as unqualified success. Performance of the advanced fare payment system was better than anticipated. Card failures and other types of mechanical problems were extremely rare. Transit passengers enthusiastically endorsed the cards, and transit managers were very satisfied with the results of the FOT. The project greatly benefitted from the technical skills and commitment of the system designer and from the management and coordination provided by the Caltrans District 7 CAPTS group. The Smart Card advanced fare payment system offers significant potential for increasing transit productivity and service quality.

# BIBLIOGRAPHY


Abadi, M., M. Burrows, C. Kaufman, & B. Lampson (1990). Authentication and Delegation with Smart Cards. Palo Alto, CA: Digital Systems Research Center.

Abkowitz, M. D. & M. K. Driscoll (1987). "Automatic Fare Collection in Transit: A Synthesis of Current Practice." Transport Review, 7(1), pp. 53-63.

Bailey, G. (1987). "Towards the Ticketless Society." IATA Review, 3, pp. 17-18.

Beek, T. V. & R.V. Tetterode (1992). "Smart Card Applications Develop Further: NCR Announces New Generation of ATMs Using Contactless Smart Cards." The Urban Transportation Monitor, 6, pp. l-4.

Belkaoui, A. (1986). The Learning Curve: A Management Accounting Tool. Westport, Conn: Quorum Books.

Bentley, J.P. (1993). Reliabilitv and Qualitv Engineering;. Essex, England: Longman Scientific and Technical.

Birolini, A. (1994). Quality and Reliabilitv of Technical Svstems: Theorv-Practice-Management. New York: Springer-Verlag.

Bright, R. (1988). Smart Cards: Principles, Practice. Annlications. Chichester, UK: Halsted Press, a Division of John Wiley & Sons.

Brooks, F.A. (1960). "Operational Sequence Diagrams." Institute of Radio Engineers Transactions on Human Factors in Electronics," 1, pp. 33-34.

Brown P. (1991). "Advanced Magnet Ticketing Systems and Their Application in Singapore," in Planning and Transport Research and Computation International Company Meeting. Proceedings of Seminar Held at the PTRC Summer Annual Meeting, P(348), pp 207-225.

Brucato, P. S. (Ed.) (1990). "A Fare Look at Revenue Collection." Mass Transit, 17(4), pp. 14-19.

Cervero, R. (1992). "Futuristic Transit and Futuristic Cities." Transportation Quarterly, 46(2), pp. 193-204.

Chang, D. (1993). "Reagan Rails at TA's Fare Card Plan." in Daily News, New York, NY, p. D14.

Chapanis, A. (1965). Man-Machine Engineering. New York, NY: Wadsworth.

Chaum, D. (1991). "Smart Card 2000." Selected Papers from the Second International Smart Card 2000 Conference, Amsterdam, The Netherlands. New York: Elsevier Science Publishing. Company.

Chira-Chavala, T. & B. Coifman (1995). Draft Evaluation of the I-l 10 Corridor Smart Card Demonstration Project: Impacts of Smart Cards on Transit Operators. Institute of Transportation Studies. Berkeley, CA: University of California.

Collin, T. & L. Kallstrom (1991). "The Microprocessor Card and the RTI-Environment: The Case of the Transport Payment Card." Proceedings of the DRIVE Conference. Brussels, Belgium, II, pp. 1421-1427.

Cork, J.M. & H.A. Collis (1987). "The Future of Non-Coin Operated Parking Payment Systems." Traffic Engineering & Control, 28, pp. 601-617.

Cork, J.M. & H.A. Collis (1991). "The Many Benefits in AFC Systems." International Railway Journal, January, pp.33-35.

Danns, A. (1992). "A Multi-Mode Approach to ATIS Featuring the Destination Travel Card," in Surface Transnortation and the Information Age: Proceedings of the IVHS America 1992 Annual Meeting, Newport Beach, CA, pp. 563-565.

Darwin, R., R. Rosen, C. Burkhart, M. Gibson, R. Stern, & B. Fowler (1993). "New Technology Comes to New York." International Railwav Journal and Rapid Transit Review , 33(5), May, pp. 67-69.

de Saint-Laurent, B. (1991). "An Information System for Public Transport: The Cassiope Architecture Example of Passenger Information," in Advanced Telemetrics in Road Transport, Vol. II. Proceedings of the DRIVE Conference, Brussels, Belgium, pp. 1186-1203.

Deibel, L. E. & P. Wood (1977). "On-Board Data Collection for Transit Operations." IEEE Transactions on Vehicular Technology, 26(1), pp. 38-42.

Douglas, S.A., M.K. Junge, & D.A. Thompson (1980). "Information-Decision-Action Charts: A Tool for the Ergonomic Analysis of Computerized Control and Information Systems." Paper presented at the IEA/NES Conference, Oslo, Norway.

Echelon Industries, Inc. (1992). Advanced Fare Pavment Media Pronram - Phase. DOT Contract No. DTRS-57-93-C-00091. Walnut, CA.

Echelon Industries, Inc. (1995). Advanced Fare Pavment Media Program - Phase II Final Report. DOT Contract No. DTRS-57-93-C-00091. Walnut, CA.

Federal Transit Administration, Office of Mobilit (1988). Advanced Fare Pavment Media. . Washington, D.C.: Government Printing Office.

Ford, R. (1992). "Smart Cards Dominate Ticket Development." Railwav Gazette International, 148(8), pp.533-538.

Ford, R. (1993). "Automatic Fare Collection." Modem Railwavs, February, pp. 103-l 05.

Gargett, A. R., J. Rowan & M. Witham (1990). "Electronic Ticketing: Friend or Foe?" Australian Transport Research Forum, 15(2), pp. 641-655.

Godwin, B. (1990). "International Fare Collection Systems Shape Public's View of Transit Travel." Mass Transit, 18( 1 1-12), pp. 25-27.

Hansen, M., M. Qureshi, & D. Rydzewski (1994). Improving Transit Performance with Advanced Public Transportation System Technologies. California PATH Research Report, UCB-ITS-PRR-94- 18. Berkeley, CA: University of California.

Hillier, F.S. & G. J. Lieberman (1995). Introduction to Onerations Research, 6th ed. New York: McGraw-Hill.

Homsby, Jr., A. P. (1994). "EBT National Strategy: Creating the Infrastructure, States Role." Proceedings of the CardTech/SecurTech '94 Advanced Card Technologv Conference and Exhibition. Crystal City, Arlington, VA, pp. 933-935.

Huchingson, R.D. (198 1). New Horizons in Human Factors Engineering. New York: McGraw-Hill.

Komanecky, M. R. & D. M. Claus (199 1). "IVHS Applications of Smart Cards." Proceedings of the Vehicle Navigation and Information Svstems Conference. Warrendale, PA: Society of Automotive Engineers, pp. 977-987.

Krick, E.V. (1962). Methods Engineering. New York: John Wiley and Sons.

Kurke, M.I. (1961). "Operational Sequence Diagrams in System Design." Human Factors, pp. 66-73.

Levine, L. (1993). "High-Tech Fare Collection Cuts Costs, Increases Riderships." Metro, 89(3), pp. 32-40.

Lisimaque, G. (1993). "Why a Smart Card Chip Has to Be Different from Any Other Integrated Component." Proceedings of the CardTech/SecurTech 1993 Conference. Crystal City, Arlington, VA, pp. 52-56.

Maybury, J. (1992). "U.S. Still Isn't Wise to 'Smart Cards'." The Sacramento Bee Final, 18 May 1992, p. C2.

Mellor, A. & P. White (1987). "Electronic Ticketing Systems," in Information Technolonv Apnlications in Transport. Utrecht, Netherlands: VNU Science Press, pp. 87-l 04.

Miki, S. (199 1). "Contact-Free IC Cards for New Railway Ticket Systems," in Apnlications of Advanced Technologies in Transnortation Engineering. Proceedings of the second International Conference. American Society of Civil Engineers, New York, pp. 414-418.

Morrissey, J. (1983). Performance Assessment Methods and Results For Transit Automatic Fare Collection Eauipment. Final Report. Washington, D.C.: U.S. Department of Transportation.

Morrissey, J. (1992). "Proposals Solicited for Congestion Pricing Pilot Projects." The Urban Transportation Monitor, 6(23), December 1992, pp. l-6.

Ognibene, P. (1992). "Community Transit Getting "Smart": Smart Cards Are a Prime Example of Emerging Technology That Will Soon Affect Community Transportation." in Communitv Transportation Reporter, 1 0(5), pp. 12- 15.

Papageorgis, J. (1990). "Removing the Seams in Regional Transportation." Portfolio, 3(2), pp. 45-5 1.

Papageorgis, J. (1993). "Smart Cards and the National Agenda." Government Technology, June, pp. 36-38.

Rothengatter, J. A. & J. Harper (1991). "The Scope and Design of Automatic Policing Information Systems with Limited Artificial Intelligence," in Advanced Telemetrics in Road Transport, V. II. Proceedings of the DRIVE Conference. Brussels, Belgium. Elsevier, Amsterdam, pp. 1499- 15 15.

Russell, J. (1994). "Technology Implications on System Implementation." Proceedings of the CardTech/SecurTech '94 Advanced Card Technolonv Conference and Exhibition. Crystal City, Arlington, VA, pp. 257-262.

Slevin R. & M. Conroy (1989). "Stored Value Tickets: Equipment Offers All the Options." Passenger Transport Management Systems Review, pp. 1 O-l 1.

Slevin, R. & M. Conroy (1990). "Smart Cards, the Ultimate Solution to Revenue Allocation Problems?" in Planning and Transnort Research and Comnutation (International) Co. Meeting. London, England, pp. 21-24.

Steele, C. (1990). "Three Years of Crouzet in Australia, Part 1: The system and its implementation." Transit Australia, 45(12), pp. 267-272.

Stein, M. A. (1992). "Fare Cards' Versatility May Put Transit Tokens onto a Sidetrack." L.A. Times, B 1.

Strandbers, K. W. (1992). "Fare Collection System Now and Future." Mass Transit, pp. 47-52.

Teexier, P.Y. (1991). "Automatic Ticketing Systems: An Argument for Viewing the Transport Commodity from a Different Angle," in Recherche-Transnorts-Securite, pp. 3 l-38.

Thompson, D.A. (1968). "A Methodological Approach to Presenting Human Factors Principles to Industrial Engineers." 12th Annual Human Factors Convention.

United States Department of Transportation (1988). Imnrovements in transit fare collection methods. Washington, D.C.: Government Printing Office.

Wanless, D. (1985). "Car Parking Machinery and the Coinage." Traffic Engineering & Control, December, pp. 598-617.

Wanless, D. (1992). "BART Around the Region: Transitlink." Bav Area Monitor,p. 6.

Wanless, D. & M. Hart (1989). "Automatic Ticketing on London Underground." Transport Reviews, 9(1), pp. 361-370.

Waters, B. (1992a). "Smart Cards Dominate Ticket Development," Railwav Gazette International. August, pp. 533-538.

Waters, B. (1992b). "The Destination Travel Card." The proceedings to the 1992 Annual Meeting of IVHS American, 2, pp. 563-565.

Waters, B. (1993). "Technology Pushes the ARC market." Railwav Gazette International, July, pp. 545-547.

Wilinsky, J. (1993). "Toward the Cashless Bus." Bus World, 15(3), pp. 8-l 1.

Williams, J. T. (1994). "Challenges in Implementing EBT: Views from Different Stages of Development." Proceedings of the CardTech/SecurTech '94 Advanced Card Technology Conference and Exhibition. Crystal City, Arlington, VA, pp. 957-959.

Winckler, H. B. & K.M. Shea (1982). "Description and Evaluation of Technical Test of MBTA Magnetic Card Fare Collection System." Technical Task Directive No. 5 Final Report, Washington, D.C.: Department of Transportation.

# APPENDIX A

# SMART CARD INFORMATION PACKET

# APPENDIX A

*C**altrans*** welcomes you to the new ***Smart Traveler*** fare card pilot program. Your participation in this trial program will offer you a unique opportunity to use the new ***Smart Card,*** a sleek and sophisticated personal travel card being test marketed in Southern California.

During the next few months you will use your new ***Smart Card*** instead of cash, tokens or your public transit agency's regular monthly pass.

Your ***Smart Card*** comes with 80 one-way trips for Gardena bus route #1 and is offered to you at a special discounted rate. You may take trips on a daily basis, a few times a week or *whenever* you need to ride the bus. When you use the ***Smart Card*** is up to you and your personal travel needs.

## QUESTIONS & ANSWERS FOR *SMART CARD* TRAVELERS

☑ **How does my new *Smart Card* work?**

A microcomputer chip, programmed with information, including 80 one-way trips, is inside your new ***Smart Card***.

Each time you board the bus, insert your card for a few seconds into the new ***Smart Card*** reader, located near the regular fare box on the bus. If you remove your card too quickly from the reader, you will hear a beeping sound and the reader's electronic message display will tell you to replace your card.

☑ **How will I know when my *Smart Card* is running low on trips?**

Each time you use your ***Smart Card*** the reader's electronic message display will tell you the number of trips left on your card. Be sure to check the display screen whenever you use your card so you'll know when to purchase more trips.

☑ **How do I purchase more trips?**

You'll be able to buy more trips for your ***Smart Card*** as you need them, through December 5, 1994. Simply complete and clip the attached **Fare Renewal Form** and mail with your payment in the postage-paid envelope provided.

***Smart Cards* are valid until January 31, 1995.**

☑ As a ***Smart Card*** traveler you may transfer, *FREE*, from the #1 to any <u>connecting</u> bus line -- just ask your driver for a transfer when you board. Your card will also allow you to ride downtown DASH for *FREE* during peak hours (6:30-9am and 3-6:30pm). Show the DASH driver your ***Smart Card*** when you board.

☑ If your ***Smart Card*** is lost, stolen or fails to work, please ask the driver for an Assistance Card. A replacement card will be issued to you once you've reported the problem.

**(Cut along this dotted line)**

## *Smart Card* Fare Renewal Form

Enclosed is my *Smart Card* and my payment made out to Gardena Municipal Bus lines for an additional 80 one-way trips: [CHECK ONE]

☐ $20 Adult ☐ $8 Student ☐ $4 Senior or Disabled

Pay by personal, company or cashier's check, TransitChek or money order. ***<u>MAKE PAYABLE to Gardena Municipal Bus lines</u>*** ONLY! <u>DO NOT SEND CASH.</u> Incorrect payments will be returned.

PLEASE PRINT

**Name (last, first, middle initial)** **Daytime Telephone**

Your *Smart Card* will be returned Certified Mail and <u>requires your signature upon delivery.</u> We can mail your card to your home or office address. Please mail my Smart Card to: ☐ my home ☐ my office

Company Name (if you check "office")

Address City Zip

# APPENDIX B

# OVERVIEW OF IC CARD TECHNOLOGY

## APPENDIX B
## OVERVIEW OF IC CARD TECHNOLOGY

The literature supplies competing uses of “Smart” as an acronym, but none is subject to common usage. The International Standards Organization (ISO) defines an “integrated circuit card” as a plastic card of standard dimension that carries a semiconductor chip. The definition includes a class of IC memory only cards that (usually) rely on electronically programmable read only memory (EPROM) and lack a microprocessor. Such first generation Smart Cards perform well as data records, but incorporate no data processing capabilities. Data is read in and out of the cards only when the cards are subjected to external commands. The performance characteristics of IC memory cards compare more directly with magnetic stripe and optical memory cards than with cards that include microprocessors.

As the data storage capacity of cards has increased, the benefits and incentives associated with coupling data storage with processing capacity have also increased. Like first generation cards, second generation Smart Cards are portable data storage devices. But in addition, second generation cards include microprocessors, and thus combine a degree of intelligence with “provisions for identity and security” (Bright, 1988). Thus a second generation Smart Card is computer. However, second generation cards’ data processing capabilities cannot be fully exercised without the an independent card reading/writing device.

The functions of second generation Smart Cards imply a densely packaged integrated circuit of no more than 25 $mm^2$ (Stanford, 1994; Russell 1994) that includes the microprocessor, arithmetic processing registers, random access memory (RAM) used during program execution, read only memory (ROM) to house the operating system, electronically erasable read only memory (EEPROM) for data storage, input/output, and an integrated operating system embedded in a credit card sized piece of plastic. The physical configuration, location and dimension of surface chip contacts, electrical characteristics and operating system comply with the International Standards Organization’s (ISO) international

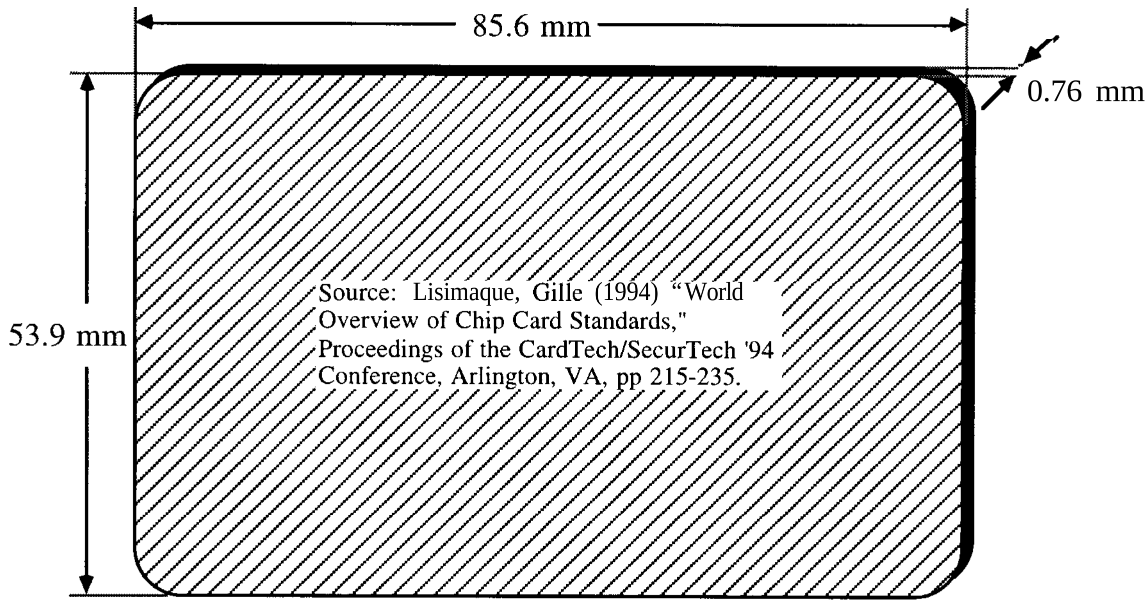



**Figure B-l:** IS0 International Standard 78 16- 1 Governs the Physical Dimensions of IC Cards, Including Smart Cards.

standards 78 16- 1 through 4 respectively. See Figure A- 1 for IS0 compliant Smart Card dimensions.

Figure A-2 (Bright 1988) provides a summary of a second generation Smart Card's basic functions. Figure A-3 (Bright 1988, Mitchell 1993) consists of a simplified block diagram of a Smart Card Integrated Circuit and IS0 compliant arrangement and dimensions of surface mounted chip contacts for communicating with card read/write stations. Figure A-4 summarizes second generation memory functions.

Ugon (1994) expects improvements in operating systems and processors will be sufficient to permit Smart Cards to rival the computing power of the first personal computers by the end of the century. Third generation Smart Card designs will rely on these advances to permit Smart Cards to operate without a physically separate card reader, performing "in a stand alone mode for much of its operational life" (Bright 1988). No published standards are available for third generation cards, but such cards will almost certainly have to include

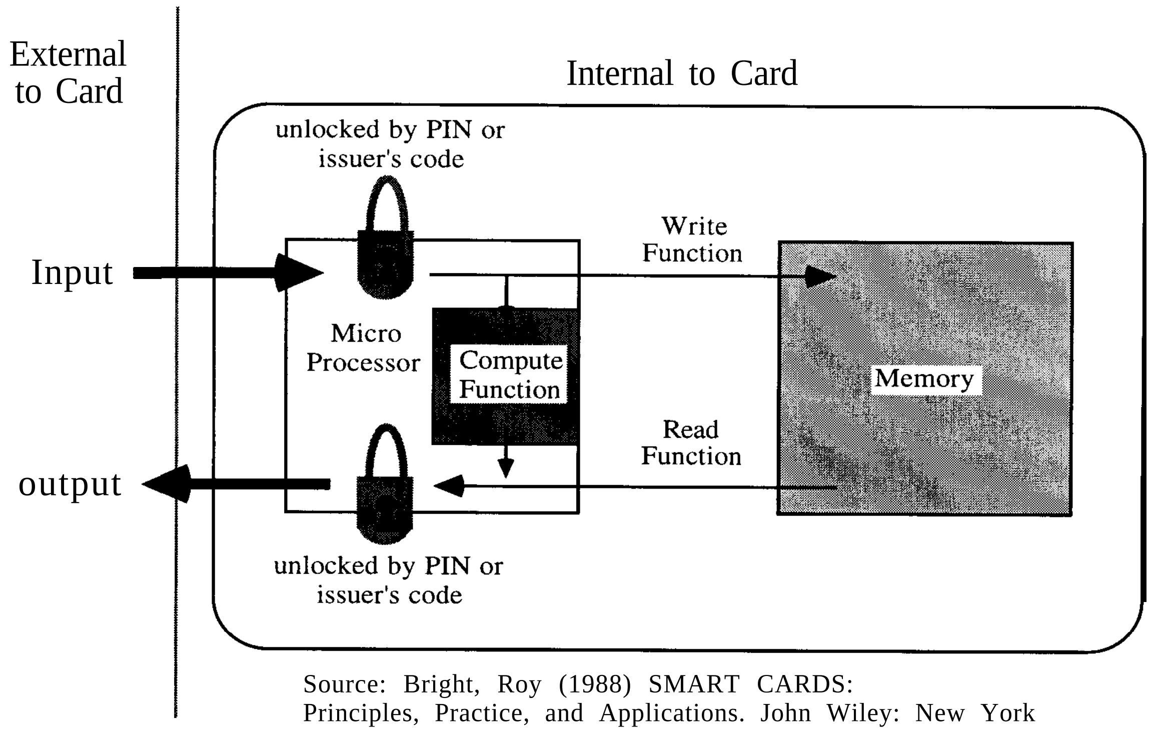
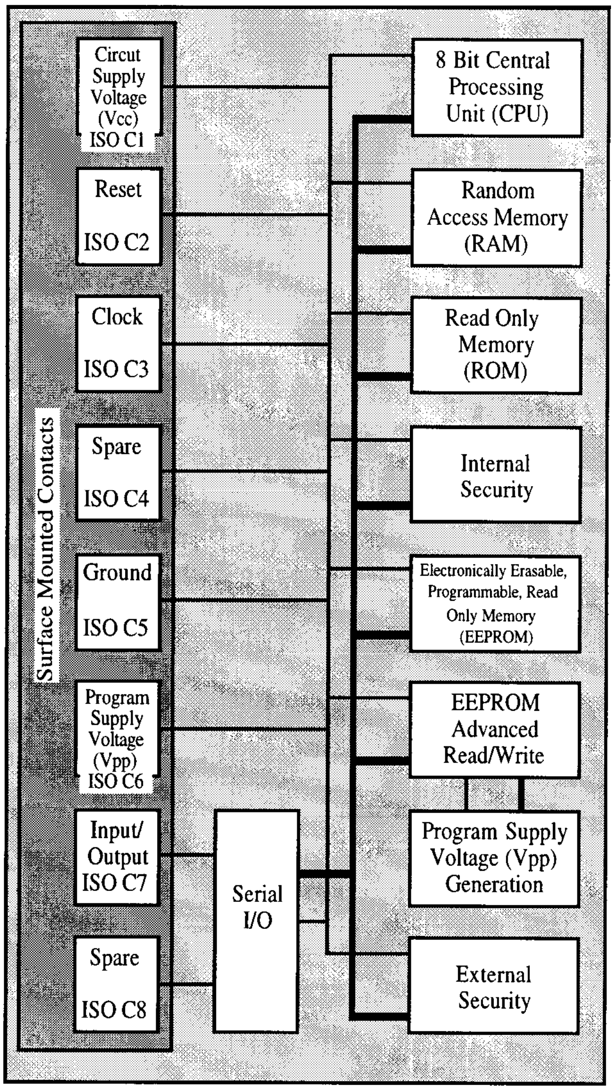
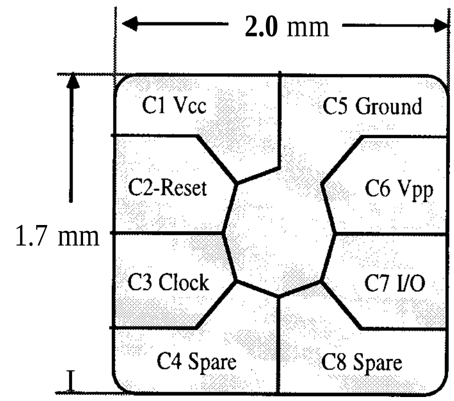



**Figure B-2:** Basic Second Generation Smart Card Functions.

keyboards and displays (Seidman 1994); and, perhaps most importantly, a source of power (Bright 1988). Figure A-5 provides a brief taxonomy of Integrated Circuit card characteristics. Definitions relating to card categories are imprecise and overlap. Further, technology is changing rapidly. Figure A-4 combines information frommultiple sources that are not entirely consistent, and is merely suggestive in light of rapidly evolving technology.

The presumption of intelligence pervades the contemporary definition of a "Smart Card." The language now refers implicitly to a card of at least second generation design, excluding IC memory only cards. Gleason (1994) suggests that 30 to 50 percent of all cards will be Smart Cards by the year 2000. Seidman (1993) projects Smart Card sales of 75 M units in 1995, and IC Card sales of 500 M units. See Figure A-6. Current Smart Card unit price data (Seidman 1994) are summarized in Figure A-7. Price ranges for more complex




Source: Lisimaque, Gille (1994) World Overview of Chip Card Standards," Proceedings of the CardTech/SecurTech '94 Conference, Arlington, VA, pp 215-23.5.

Sources: Mitchell, George (1993) "Submicron Technology and Smart Card Operating Environment Systems," Proceedings of the CardTech/SecureTech '93 Conference, Arlington, VA, pp 57-68; and Bright, Roy (1988) SMART CARDS: Principles, Practice, and Applications. John Wiley: New York.

**Figure B-3:** Block Diagram of a Typical Second Generation Contact Smart Card Integrated Circuit. IS0 International Standard 78 16-2 Governs the Dimension and Location of Surface Mounted Chip Contacts.

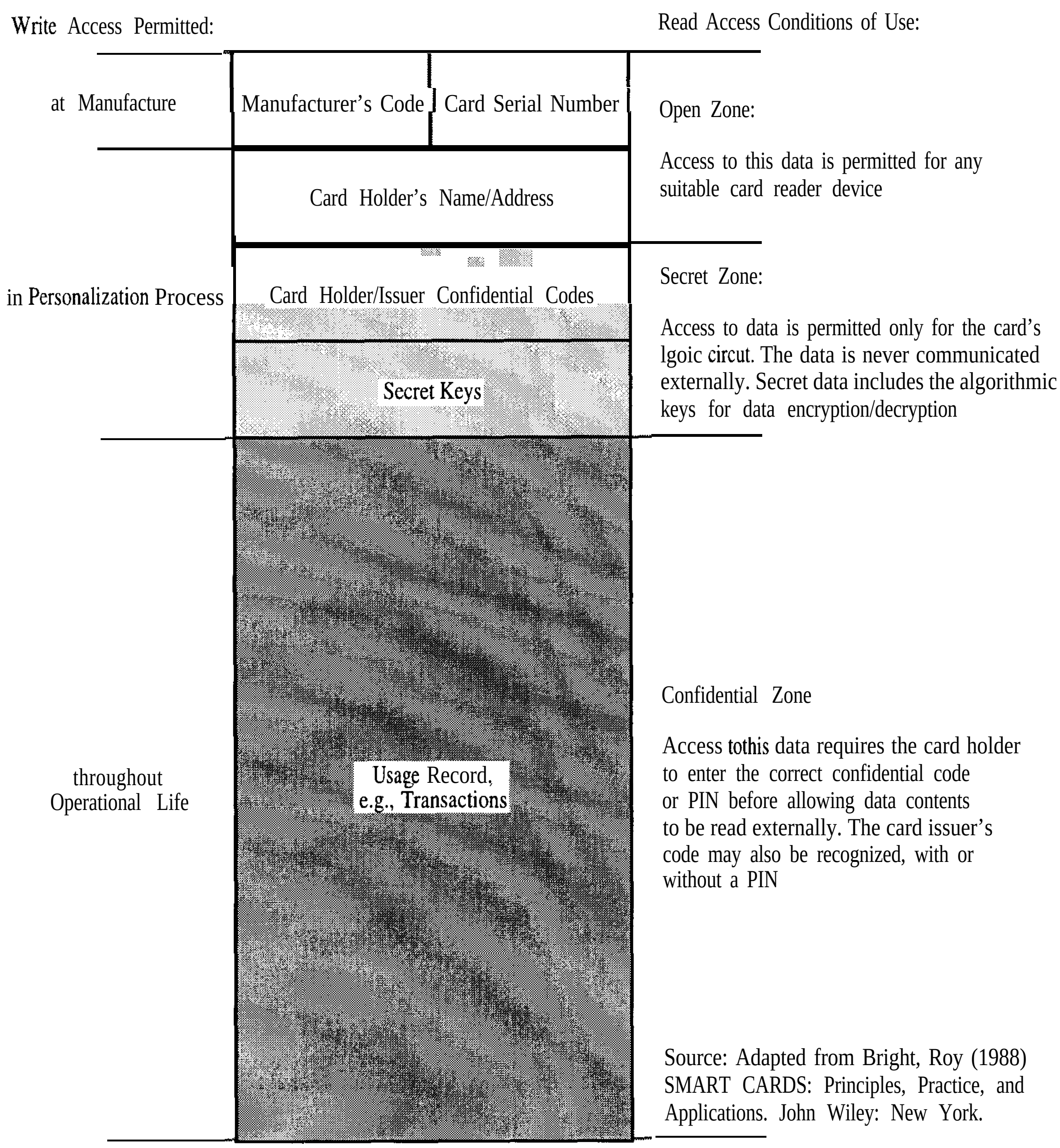



**Figure B-4:** Conventional Structure of Second Generation Smart Card (EEPRO)Memory.

**Figure B-5:** Smart Card Taxonomy.

**Integrated Circut (IC) Cards**
- Satisfy the broadest definition of "Smart Cards"
- Excludes Other Classes of Memory Cards
  - Magnetic Stripe Cards
  - Optical Memory Cards

**(1st Generation) IC Memory Only Cards**
- ISO:
  - Memory ≤ 1 KBit
  - E.g., Telephone Cards
- PCMCIA: Memory ≤ 40 MBytes
- External Read/Write Terminal

**Wired Logic Cards**
- Memory ≤ 2 KBytes
- E.g., Prepaid Cards
- External Read/Write Terminal

**Application Specific IC Cards (ASIC)**
- Memory IC plus Security and Contol Logic
- Memory ≤ 16KBits
- External Read/Write Terminal

**(2nd Generation) Smart Cards**
- X-Bit Microprocessor
- Memory ≤ X KBytes
  - EPROM (permanent)
  - EEPROM (erasable)
- May have DES or RSA Encryption
- External Read/Write Terminal

**Super (3rd Generation) Smart Cards**
- Not Terminal Powered
- Incorporates Terminal Elements
  - Keyboard
  - Display

Sources: Adapted from Bright, Roy (1988) SMART CARDS: Principles, Practice, and Applications. John Wiley: New York,

Seidman, Stephan (1994) "The State of Smart Card Technology," Proceedings of the CardTech/SecurTech 'Y4 Conference. Arlington, VA, pp 205-213,.

Seidman, Stephan (IYY4) "Advanced Card Technologies," Proceedings of the CardTech/SecurTech 'Y3 Conference, Arlington. VA, pp 19-25, and

Krueger, Julie (IYY3) "Microcontrollers, ASICs, and Smart Cards," Proceedings of the CardTech/SecureTech '93 Conference, Arlington, VA, pp 45-51.

card configurations demonstrate considerable variance, even for very large production runs. Simple IC memory cards might be purchased in large batches for an unit price under $ 1. The addition of a microprocessor to a card with modest memory would be expected to multiply unit price by a factor between two and three.

Echelon Industries retains propriety rights to the detailed design of the Smart Card systems implemented in this Field Operational Test. Echelon (1995) fielded both contact cards and contactless Radio Frequency (RF) ID cards. RFID cards can be active or passive (Vossel 1994). Active cards include a battery. Passive cards obtain energy for transmitting identifying information from a burst sent to them from a reader/writer/interrogator units. RFID is distinguished by the absence of a line of sight between the transponder and the reader.

Mitchell (1993) provides a complete physical specification for a typical Smart Card representative of the contact card technology applied in the Field Operational Test. This list is enhanced by details from Lisimaque (1994).

1) Programmable Read Only Memory (PROM) / Electronically Programmable Read Only Memory (EPROM):
2 KBytes - 16 KBytes: Operating System and other fixed data.

2) (Static) Random Access Memory:
64 Bytes - 1 KByte: Buffers and data stacks.

3) Electronically Erasable Programmable Read Only Memory (EEPROM):
256 Bytes - 8 KBytes: User data storage and system data.

4) Circuit Supply Voltage: +5VDC $\pm$ .25V.

5) Program Supply Voltage: +22VDC or none (internally driven).

6) Physical Size: International Standards Organization 7816-1: 85.6 mm X 53.9 mm X 0.76 mm.

7) Surface Chip Contact Configuration: International Standards Organization 78 16-2.

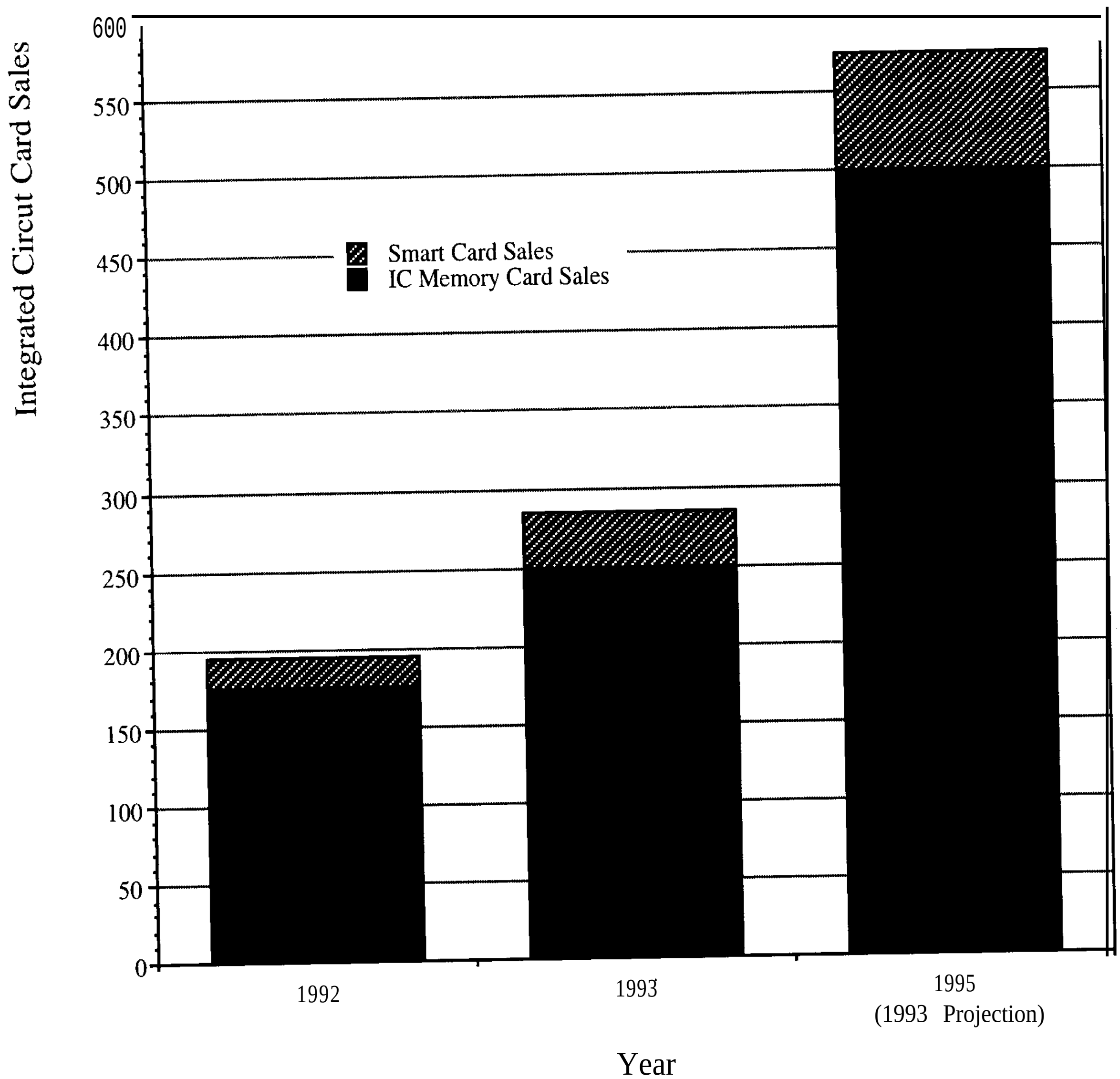



**Figure B-6:** Memory IC and Smart Card Sales.

8) Clock Speed: International Standards Organization 7816-3: 1 MHz - 5 MHz.

9) Baud Rate: International Standards Organization 78 16-3: 9600 baud at

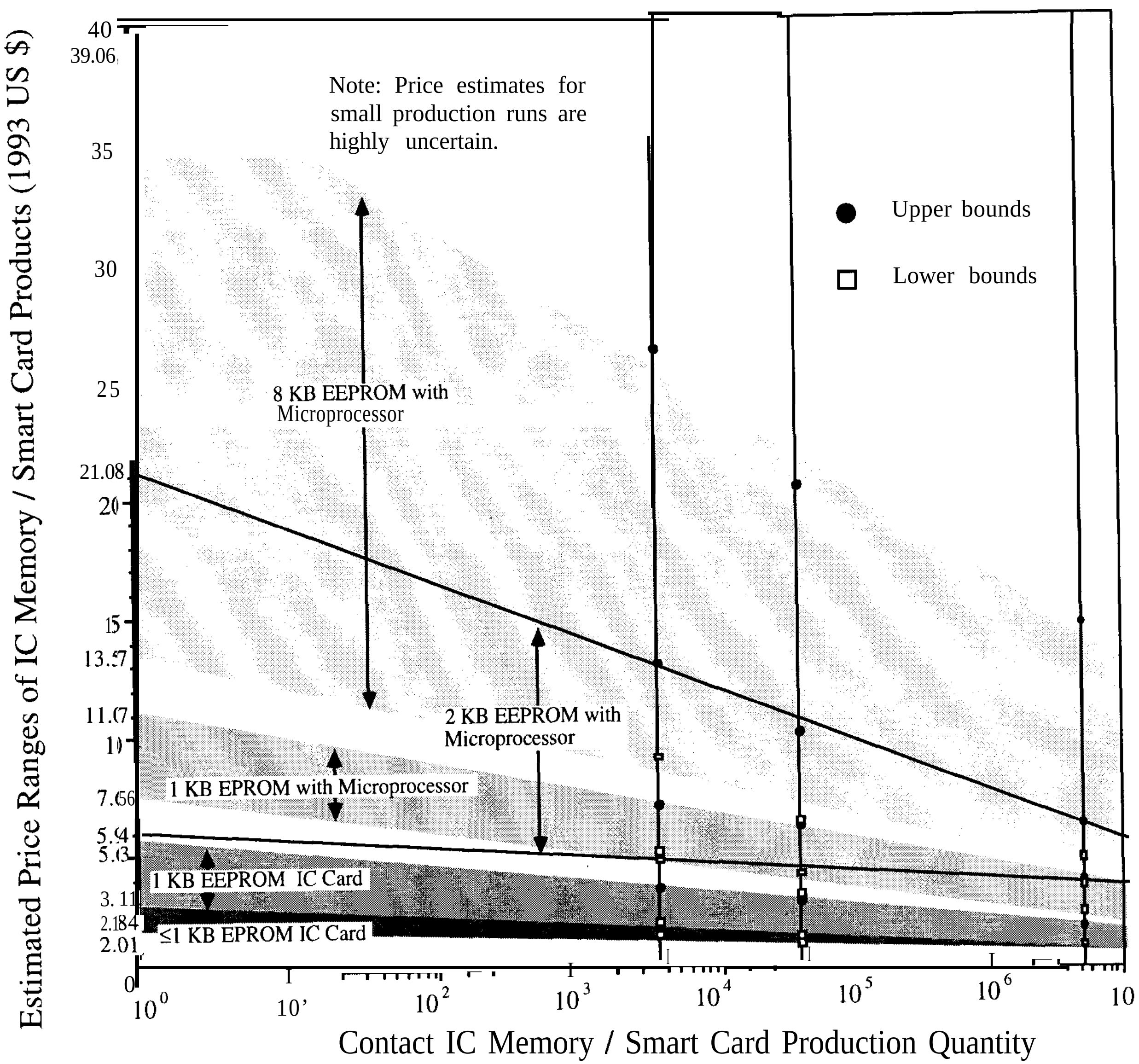



**Figure B-7:** Smart Card Unit Prices as an Estimated Function of Production Batch Size.

operating clock speed.

10) Communication: International Standards Organization 78 16-3: Asynchronous half duplex block protocol T = 1 plus others, e.g., T = 0 and T = 14.

11) Common User Interface: International Standards Organization 78 16-4.

12) Data Encryption: DES, International Standards Organization Draft International Standard (DIS) 8227 (DEA 1).

13) Data Security: Passwords (Hierarchical and Flat).

The card profile is very generic. The RACOM RFID Smart Cards tested on Torrance Line 2 and LADot Line 448 and do not use EEPROM to store user data. The RF cards us Ferromagnetic Random Access Memory (FRAM), a propriety technology applied under license that provides (Stanford 1994) faster read/write cycles, requires low power, and offers the high packing density of Dynamic Random Access Memory (DRAM, approximately three to six times the density of EEPROM). Also, the contact based GEMPLUS Smart Cards fielded on Gardena Line 1 incorporate PCOS (Echelon 1995), an advanced propriety operating system designed to support bank card debit transactions.

# APPENDIX C

# ON-BOARD SURVEY INSTRUMENTS

State of California Department of Transportation
PICTURE YOURSELF A SMART TRAVELER

# CALTRANS-USC PASSENGER SURVEY

This survey is part of a research project on transit fare cards being conducted by the University of Southern California and Caltrans. Please take a few minutes to complete the survey. Your answers are strictly confidential and will be used for statistical purposes only. We greatly appreciate your help. Please return your completed survey to the student assistant.

Please answer the fallowing questions about the trip you are making now

1. Where are you going?

☐1 to work
☐2 to school
☐3 to home
☐4 other________________

2. Do you usually use the bus for this trip?

☐1 yes ☐2 no

3. About how many minutes does it usually take to make this trip, including the time it takes to get to and from the bus stop?

______ minutes

4 How did you pay your fare for this trip?

☐1 cash
☐2 token
☐3 bus pass
☐4 SMARTCARD
☐5 other



State of California Department of Transportation
PICTURE YOURSELF A SMART TRAVELER

Please answer these questions about how you usually travel

5. How often do you travel by bus?

☐1 less than once per week
☐2 once or twice per week
☐3 3 to 5 days per week
☐4 every day

6. What means of travel do you use most often for all the trips you make over a week's time? Check one

☐1 drive alone
☐2 drive with passengers
☐3 ride with others
☐4 bus or train
☐ j walk
☐ 5 bike
☐ 7 other

Please answer these questions and follow the arrows to the next question you should complete.

7. Have you heard of the SMARTCARD?

☐1 yes ↓ CONTINUE ↓

☐2 no ↓ please go to question 18

SOUTHERN CALIFORNIA SMART TRAVELER

State of California Department of Transportation

PICTURE YOURSELF A SMART TRAVELER

8. Are you aware that you can purchase the SMARTCARD to use for trips on this route?

☐1 yes ☐2 no

please go to question 18

9. Did you purchase the SMARTCARD?

☐1 yes ☐2 no → Why not?

Please check all that apply

☐1 I do not regularly use the bus
☐2 The SMARTCARD could not be used for my trips
☐3 I do not know how to buy a SMARTCARD
☐4 I do not want to buy a SMARTCARD
☐5 Other_______________

_______________

Please go to question 17

Please complete this section if you have purchased a SMARTCARD

10. When did you first purchase your SMARTCARD?

☐1 July ☐3 September
☐2 August ☐4 October

SOUTHERN CALIFORNIA SMART TRAVELER

state of California Department of Transportation

PICTURE YOURSELF A SMART TRAVELER

11. How much have you used the SMARTCARD since you purchased it?

☐1 used it many times
☐2 used it a few times
☐3 used it only 1 time
☐4 have not used it at all

12. Please answer the following questrons about using your SMARTCARD

How easy is it to...

| | Easy | OK | Difficult |
|---|---|---|---|
| purchase the SMARTCARD? | ☐1 | ☐2 | ☐3 |
| use the SMARTCARD to pay bus fare? | ☐1 | ☐2 | ☐3 |
| renew the SMARTCARD? | ☐1 | ☐2 | ☐3 |

13 Compared to the way you usually paid your bus fare before you had a SMARTCARD, would you consider the SMARTCARD easier, about the same, or harder to use?

☐1 easier
☐2 about the same
☐3 harder

14. During the time that you have been using a SMARTCARD, have you ever experienced any of the following?. Check all that apply

| | yes | no |
|---|---|---|
| My card was lost or stolen | ☐ 1 | ☐ 2 |
| My card was damaged | ☐ 1 | ☐ 2 |
| The card reader on the bus would not accept my card | ☐ 1 | ☐ 2 |
| The bus driver would not accept my card | ☐ 1 | ☐ 2 |
| The card reader deducted more than one trip for one ride | ☐ 1 | ☐ 2 |
| The bus driver allowed me to ride for free because of problems with my card | ☐ 1 | ☐ 2 |

15. Overall, how satisfied are you with the SMARTCARD?

☐ 1 very satisfied
☐ 2 satisfied
☐ 3 not satisfied
☐ 4 very unsatisfied

16. Are you interested in participating in additional SMARTCARD or other new technology trials?

☐ 1 yes ☐ 2 no



SOUTHERN CALIFORNIA SMART TRAVELER
State of California Department of Transportation
PICTURE YOURSELF A SMART TRAVELER

17. Please indicate whether you agree or disagree with each of the following statements

| | Agree | Disagree |
|---|---|---|
| Having a personal credit or debit card like SMARTCARD for paying bus fares makes taking the bus easier | ☐ 1 | ☐ 2 |
| Using a personal credit or debit card like SMARTCARD gives too much information about me to transit agencies | ☐ 1 | ☐ 2 |
| Cards like SMARTCARD are easy to lose or have stolen | ☐ 1 | ☐ 2 |
| Cards like SMARTCARD make taking the bus safer | ☐ 1 | ☐ 2 |
| Cards like SMARTCARD are unreliable | ☐ 1 | ☐ 2 |
| Cards like SMARTCARD make it harder for people to avoid paying their fare | ☐ 1 | ☐ 2 |

18. How old are you?

☐ 1 less than 20
☐ * 20 - 29
☐ , 30 - 39
☐ 4 40 -49
☐ 5 50 - 59
☐ , 60 or older

19. Including yourself, how many people are there in your household?

_____ people

SOUTHERN CALIFORNIA SMART TRAVELER

State of California Department of Transportation

PICTURE YOURSELF A SMART TRAVELER

SOUTHERN CALIFORNIA SMART TRAVELER

State of California Department of Transportation

PICTURE YOURSELF A SMART TRAVELER

20. How many motor vehicles are available to members of your household?

_____ vehicles

21. Do you have a driver's license?

☐1 yes ☐2 no

22. Are you employed?

☐1 yes → ☐, full time
☐2 part time

Cl, no

23. What is your home zip code?

_ _ _ _ _

24. What is your combined total household income?

☐1 less than 815,000
☐2 915,000 to $25,000
☐3 $25,000 to $40,000
☐4 $40,000 to $80,000
☐5 980,000 or more

25. What is your gender?

☐ male ☐2 female

THANK YOU FOR COMPLETING THE SURVEY. PLEASE FOLD AND RETURN IT TO THE STUDENT ASSISTANT BEFORE LEAVING THE BUS.

FOR SURVEYOR USE:

ORIGINAL DEPARTURE TIME

______________________

SURVEYOR NAMES

______________________

______________________

Survey ID #

# APPENDIX D

# ON-BOARD SURVEY FREQUENCIES

Question 1: Where are you going?

1. to work
2. to school
3. to home
4. other

TPURPOSE

| | | | | Valid | Cum |
|---|---|---|---|---|---|
| Value Label | Value | Frequency | Percent | Percent | Percent |
| | 1.00 | 193 | 24.6 | 26.1 | 26.1 |
| | 2.00 | 43 | 5.5 | 5.8 | 31.9 |
| | 3.00 | 397 | 50.6 | 53.6 | 85.5 |
| | 4.00 | 107 | 13.6 | 14.5 | 100.0 |
| | 99.00 | 44 | 5.6 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 784 | 100.0 | 100.0 | |

Valid cases 740 Missing cases 44

Question 2: Do you usually use the bus for this trip?

1. Yes
2. No

USEBUSTR

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1.00 | 678 | 86.5 | 87.3 | 87.3 |
| | 2.00 | 99 | 12.6 | 12.7 | 100.0 |
| | 99.00 | 7 | .9 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 784 | 100.0 | 100.0 | |

Valid cases 777 Missing cases 7

Question 3 : About how many minutes does it usually take to make this trip, including the time it takes to get to and from the bus stop?

Number of valid observations (listwise) = 724.00

| Variable | Mean | Std Dev | Range | Minimum | Maximum | Valid N | Label |
|---|---|---|---|---|---|---|---|
| TRIPTIME | 45.57 | 25.86 | 208.00 | 2.00 | 210.00 | 724 | |

Question 4: How did you pay your fare for this trip?

1. cash
2. token
3. bus pass
4. SMART CARD
5. other

FARETYPE

| | | Valid | Cum | | |
|---|---|---|---|---|---|
| Value Label | Value | Frequency | Percent | Percent | Percent |
| | 1.00 | 518 | 66.1 | 67.2 | 67.2 |
| | 2.00 | 38 | 4.8 | 4.9 | 72.1 |
| | 3.00 | 53 | 6.8 | 6.9 | 79.0 |
| | 4.00 | 148 | 18.9 | 19.2 | 98.2 |
| | 5.00 | 14 | 1.8 | 1.8 | 100.0 |
| | 99.00 | 13 | 1.7 | Missing | |
| | | ---------- | ---------- | ------we-- | |
| | Total | 784 | 100.0 | 100.0 | |

Valid cases 771 Missing cases 13

Question 5: How often do you travel by bus?

1. less than once per week
2. once or twice per week
3. 3 to 5 days per week
4. every day

BUSFREQ

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1.00 | 78 | 9.9 | 10.6 | 10.6 |
| | 2.00 | 79 | 10.1 | 10.7 | 21.3 |
| | 3.00 | 303 | 38.6 | 41.2 | 62.5 |
| | 4.00 | 276 | 35.2 | 37.5 | 100.0 |
| | 99.00 | 48 | 6.1 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 784 | 100.0 | 100.0 | |

Valid cases 736 Missing cases 48

Question 6: What means of travel do you use most often for all the trips you make over a week's time?

1. drive alone
2. drive with passengers
3. ride with others
4. bus or train
5. walk
6. bike
7. other

FREQMODE

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1 .00 | 77 | 9.8 | 10.9 | 10.9 |
| | 2.00 | 44 | 5.6 | 6.2 | 17.1 |
| | 3.00 | 83 | 10.6 | 11.8 | 28.9 |
| | 4.00 | 449 | 57.3 | 63.6 | 92.5 |
| | 5.00 | 36 | 4.6 | 5.1 | 97.6 |
| | 6.00 | 6 | .8 | .8 | 98.4 |
| | 7.00 | 11 | 1.4 | 1.6 | 100.0 |
| | 99.00 | 78 | 9.9 | Missing | |
| | | | ---------- | ——— | |
| | Total | 784 | 100.0 | 100.0 | |

Valid cases 706 Missing cases 78

Question 7: Have you heard of the SMART CARD?

1. Yes
2. No

HEARDSC

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1.00 | 310 | 39.5 | 43.1 | 43.1 |
| | 2.00 | 409 | 52.2 | 56.9 | 100.0 |
| | 99.00 | 65 | 8.3 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 784 | 100.0 | 100.0 | |

Valid cases 719 Missing cases 65

Question 8: Are you aware that you can purchase the SMART CARD to use for trips on this route?

1. yes
2. no

CANBUYSC

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1 .00 | 257 | 82.9 | 87.4 | 87.4 |
| | 2.00 | 37 | 11.9 | 12.6 | 100.0 |
| | 99.00 | 16 | 5.2 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 310 | 100.0 | 100.0 | |

Valid cases 294 Missing cases 16

Question 9: Did you purchase the SMART CARD?

1. yes
2. no

DIDBUYSC

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1.00 | 150 | 58.4 | 59.1 | 59.1 |
| | 2.00 | 104 | 40.5 | 40.9 | 100.0 |
| | 99.00 | 3 | 1.2 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 257 | 100.0 | 100.0 | |

Valid cases 254 Missing cases 3

Why did not you buy the SMART CARD?

1. I do not regularly use the bus
2. The SMART CARD could not be used for my trips
3. I do not know how to buy a SMART CARD
4. I do not want to buy a SMART CARD
5. Other

WHYNOTBY

| Value Label | Value | Frequency | Valid Percent | Cum Percent |
|---|---|---|---|---|
| | 1.00 | 10 | 9.8 | 9.8 |
| | 2.00 | 8 | 7.8 | 17.6 |
| | 3.00 | 36 | 35.3 | 52.9 |
| | 4.00 | 14 | 13.7 | 66.6 |
| | 5.00 | 34 | 33.3 | 100.0 |
| | 99.00 | 5 | Missing | |
| | | ---------- | ---------- | ---------- |
| | Total | 107 | 100.0 | 100.0 |

Question 10: When did you first purchase your SMART CARD?

1. July
2. August
3. September
4. October

WHENBUY

| | | Valid | Cum | | |
|---|---|---|---|---|---|
| Value Label | Value | Frequency | Percent | Percent | Percent |
| | 1.00 | 53 | 35.3 | 36.6 | 36.6 |
| | 2.00 | 46 | 30.7 | 31.7 | 68.3 |
| | 3.00 | 40 | 26.7 | 27.6 | 95.9 |
| | 4.00 | 6 | 4.0 | 4.1 | 100.0 |
| | 99.00 | 5 | 3.3 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 150 | 100.0 | 100.0 | |

Valid cases 145 Missing cases 5

11. How much have you used the SMART CARD since you purchased it?

1. used it many times
2. used it a few times
3. used it only 1 time
4. have not used it at all

USEMUCH

| | | Valid | Cum | | |
|---|---|---|---|---|---|
| Value Label | Value | Frequency | Percent | Percent | Percent |
| | 1.00 | 133 | 88.7 | 93.7 | 93.7 |
| | 2.00 | 6 | 4.0 | 4.2 | 97.9 |
| | 3.00 | 2 | 1.3 | 1.4 | 99.3 |
| | 4.00 | 1 | .7 | .7 | 100.0 |
| | 99.00 | 8 | 5.3 | Missing | |
| | | ——— | | ---------- | |
| | Total | 150 | 100.0 | 100.0 | |

Valid cases 142 Missing cases 8

Question 12: Please answer the following questions about using your SMART CARD

How easy is it to purchase the SMART CARD?

1. easy
2. OK
3. difficult

EASYBUY

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1 .00 | 100 | 66.7 | 70.4 | 70.4 |
| | 2.00 | 30 | 20.0 | 21.1 | 91.5 |
| | 3.00 | 12 | 8.0 | 8.5 | 100.0 |
| | 99.00 | 8 | 5.3 | Missing | |
| | | ---------- | ---------- | -w---w---- | |
| | Total | 150 | 100.0 | 100.0 | |

Valid cases 142 Missing cases 8

How easy is it to use the SMART CARD?

1. easy
2. OK
3. difficult

EASYUSE

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1 .00 | 125 | 83.3 | 89.9 | 89.9 |
| | 2.00 | 13 | 8.7 | 9.4 | 99.3 |
| | 3.00 | 1 | .7 | .7 | 100.0 |
| | 99.00 | 11 | 7.3 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 150 | 100.0 | 100.0 | |

Valid cases 139 Missing cases 11

How easy is it to renew the SMART CARD?

EASYRNEW

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1 .00 | 79 | 52.7 | 62.2 | 62.2 |
| | 2.00 | 33 | 22.0 | 26.0 | 88.2 |
| | 3.00 | 15 | 10.0 | 11.8 | 100.0 |
| | 99.00 | 23 | 15.3 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 150 | 100.0 | 100.0 | |

Valid cases 127 Missing cases 23

Question 13 : Compared to the way you usually paid your bus fare before you had a SMART CARD, would you consider the SMART CARD easier, about the same or harder to use?

1. easier
2. about the same
3. harder

COMPARSC

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1.00 | 123 | 82.0 | 85.4 | 85.4 |
| | 2.00 | 15 | 10.0 | 10.4 | 95.8 |
| | 3.00 | 6 | 4.0 | 4.2 | 100.0 |
| | 99.00 | 6 | 4.0 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 150 | 100.0 | 100.0 | |

Valid cases 144 Missing cases 6

Question 14: During the time you have been using a SMART CARD, have you ever experienced any of the following ?

My card was lost or stolen

1. yes
2. no

SCLOST

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1.00 | 9 | 6.0 | 6.9 | 6.9 |
| | 2.00 | 121 | 80.7 | 93.1 | 100.0 |
| | 99.00 | 20 | 13.3 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 150 | 100.0 | 100.0 | |

Valid cases 130 Missing cases 20

My card was damaged

1. yes
2 no

SCDAMAGD

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1.00 | 9 | 6.0 | 6.9 | 6.9 |
| | 2.00 | 121 | 80.7 | 93.1 | 100.0 |
| | 99.00 | 20 | 13.3 | Missing | |
| | | ---------- | ----m-w--- | _-___----- | |
| | Total | 150 | 100.0 | 100.0 | |

Valid cases 130 Missing cases 20

The card reader on the bus would not accept my card

1. yes
2. no

SCNREAD

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1 .00 | 35 | 23.3 | 27.1 | 27.1 |
| | 2.00 | 94 | 62.7 | 72.9 | 100.0 |
| | 99.00 | 21 | 14.0 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 150 | 100.0 | 100.0 | |

Valid cases 129 Missing cases 21

The bus driver would not accept my card

1. yes
2. no

SCNACCPT

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1.00 | 8 | 5.3 | 6.3 | 6.3 |
| | 2.00 | 119 | 79.3 | 93.7 | 100.0 |
| | 99.00 | 23 | 15.3 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 150 | 100.0 | 100.0 | |

Valid cases 127 Missing cases 23

The card reader deducted more than one trip for one ride

1. yes
2. no

SCMITRIP

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1.00 | 33 | 22.0 | 25.6 | 25.6 |
| | 2.00 | 96 | 64.0 | 74.4 | 100.0 |
| | 99.00 | 21 | 14.0 | Missing | |
| | | ---------- | --m-m----- | _----m---- | |
| | Total | 150 | 100.0 | 100.0 | |

Valid cases 129 Missing cases 21

The bus driver allowed me to ride for free because of problems with my card

1. yes
2. no

SCTFREE

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1 .00 | 45 | 30.0 | 37.5 | 37.5 |
| | 2.00 | 75 | 50.0 | 62.5 | 100.0 |
| | 99.00 | 30 | 20.0 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 150 | 100.0 | 100.0 | |

Valid cases 120 Missing cases 30

Question 15 : Overall, how satisfied are you with the SMARTCARD?

1. very satisfied
2. satisfied
3. not satisfied
4. very unsatisfied

SCSAT

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1.00 | 116 | 77.3 | 81.1 | 81.1 |
| | 2.00 | 26 | 17.3 | 18.2 | 99.3 |
| | 3.00 | 0 | 0 | 0 | 0 |
| | 4.00 | 1 | .7 | .7 | 100.0 |
| | 99.00 | 7 | 4.7 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 150 | 100.0 | 100.0 | |

Valid cases 143 Missing cases 7

Question 16: Are you interested in participating in additional SMARTCARD or other new technology trials

1. yes
2. no

PARTSC

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1 .00 | 129 | 86.0 | 92.1 | 92.1 |
| | 2.00 | 11 | 7.3 | 7.9 | 100.0 |
| | 99.00 | 10 | 6.7 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 150 | 100.0 | 100.0 | |

Valid cases 140 Missing cases 10

Question 17: Please indicate whether you agree or disagree with each of the following statements

Having a personal credit or debit card like SMARTCARD for paying bus fares makes taking the bus easier

1. Agree
2. Disagree

AGREBUS

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1 .00 | 194 | 76.4 | 89.8 | 89.8 |
| | 2.00 | 22 | 8.7 | 10.2 | 100.0 |
| | 99.00 | 38 | 15.0 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 254 | 100.0 | 100.0 | |

Valid cases 216 Missing cases 38

Using a personal credit or debit card like SMARTCARD gives too much information about me to transit agencies

1. Agree
2. Disagree

AGREEINFO

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1.00 | 54 | 21.3 | 25.8 | 25.8 |
| | 2.00 | 155 | 61.0 | 74.2 | 100.0 |
| | 99.00 | 45 | 17.7 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 254 | 100.0 | 100.0 | |

Valid cases 209 Missing cases 45

Cards like SMARTCARD are easy to lose or have stolen

1. Agree
2. Disagree

AGRELOST

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1.00 | 53 | 20.9 | 25.2 | 25.2 |
| | 2.00 | 157 | 61.8 | 74.8 | 100.0 |
| | 99.00 | 44 | 17.3 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 254 | 100.0 | 100.0 | |

Valid cases 210 Missing cases 44

Cards like SMARTCARD make taking the bus safer

1. Agree
2. Disagree

AGRESAFE

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1.00 | 145 | 57.1 | 71.1 | 71.1 |
| | 2.00 | 59 | 23.2 | 28.9 | 100.0 |
| | 99.00 | 50 | 19.7 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 254 | 100.0 | 100.0 | |

Valid cases 204 Missing cases 50

Cards like SMARTCARD are unreliable

1. Agree
2. Disagree

AGRENREL

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1.00 | 30 | 11.8 | 14.9 | 14.9 |
| | 2.00 | 171 | 67.3 | 85.1 | 100.0 |
| | 99.00 | 53 | 20.9 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 254 | 100.0 | 100.0 | |

Valid cases 201 Missing cases 53

Cards like SMARTCARD make it harder for people to avoid paying their fare

1. Agree
2. Disagree

AGREPAY

| | | | | Valid | Cum |
|---|---|---|---|---|---|
| Value Label | Value | Frequency | Percent | Percent | Percent |
| | 1.00 | 105 | 41.3 | 53.3 | 53.3 |
| | 2.00 | 92 | 36.2 | 46.7 | 100.0 |
| | 99.00 | 57 | 22.4 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 254 | 100.0 | 100.0 | |

Valid cases 197 Missing cases 53

Question 18: How old are you?

1. less than 20
2. 20-29
3. 30-39
4. 40-49
5. 50-59
6. 60 or older

AGE

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1 .00 | 105 | 13.4 | 14.9 | 14.9 |
| | 2.00 | 166 | 21.2 | 23.5 | 38.3 |
| | 3.00 | 172 | 21.9 | 24.3 | 62.7 |
| | 4.00 | 140 | 17.9 | 19.8 | 82.5 |
| | 5.00 | 75 | 9.6 | 10.6 | 93.1 |
| | 6.00 | 49 | 6.3 | 6.9 | 100.0 |
| | 99.00 | 77 | 9.8 | Missing | |
| | | ---------- | | | |
| | Total | 784 | 100.0 | 100.0 | |

Valid cases 707 Missing cases 77

Question 19: Including yourself, how many people are there in your household?

Number of valid observations (listwise) = 662.00

| Variable | Mean | Std Dev | Range | Minimum | Maximum | Valid N | Label |
|---|---|---|---|---|---|---|---|
| NHHOLD | 3.35 | 2.11 | 20.00 | 1.00 | 21.00 | 662 | |

Question 20: How many motor vehicles are available to members of your household?

Number of valid observations (listwise) = 650.00

| Variable | Mean | Std Dev | Range | Minimum | Maximum | Valid N | Label |
|---|---|---|---|---|---|---|---|
| NVEH | 1.42 | 1.09 | 6.00 | .oo | 6.00 | 650 | |

Question 2 1: Do you have a driver's licence?

1. yes
2. no

DRIVEL

| Value Label | Value | Frequency | Valid Percent | Cum Percent | Percent |
|---|---|---|---|---|---|
| | 1.00 | 404 | 51.5 | 58.9 | 58.9 |
| | 2.00 | 282 | 36.0 | 41.1 | 100.0 |
| | 99.00 | 98 | 12.4 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 784 | 100.0 | 100.0 | |

Valid cases 686 Missing cases 98

Question 22: Are you employed?

1. yes
2. no

EMPSTAT

| | | Valid | Cum | | |
|---|---|---|---|---|---|
| Value Label | Value | Frequency | Percent | Percent | Percent |
| | 1 .00 | 529 | 67.5 | 76.3 | 76.3 |
| | 2.00 | 164 | 20.9 | 23.7 | 100.0 |
| | 99.00 | 91 | 11.6 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 784 | 100.0 | 100.0 | |

Valid cases 693 Missing cases 91

if yes, full-time or part-time?

1. full-time
2. part-time

EMPTIME

| Value Label | Value | Frequency | Percent | Valid Percent | Cum Percent |
|---|---|---|---|---|---|
| | 1.00 | 328 | 52.9 | 68.0 | 68.0 |
| | 2.00 | 154 | 24.8 | 32.0 | 100.0 |
| | 99.00 | 138 | 22.3 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 620 | 100.0 | 100.0 | |

Valid cases 482 Missing cases 138

Question 24: What is your combined total household income?

1. less than $15,000
2. $15,000 to $25,000
3. $25,000 to $40,000
4. $40,000 to $80,000
5. $80,000 or more

HHINC

| | | Valid | Cum | | |
|---|---|---|---|---|---|
| Value Label | Value | Frequency | Percent | Percent | Percent |
| | 1.00 | 198 | 25.3 | 32.1 | 32.1 |
| | 2.00 | 152 | 19.4 | 24.7 | 56.8 |
| | 3.00 | 113 | 14.4 | 18.3 | 75.2 |
| | 4.00 | 117 | 14.9 | 19.0 | 94.2 |
| | 5.00 | 36 | 4.6 | 5.8 | 100.0 |
| | 99.00 | 168 | 21.4 | Missing | |
| | Total | 784 | 100.0 | 100.0 | |

Valid cases 616 Missing cases 168

Question 25: What is your gender?

1. male
2. female

GENDER

| | | | | Valid | Cum |
|---|---|---|---|---|---|
| Value Label | Value | Frequency | Percent | Percent | Percent |
| | 1.00 | 323 | 41.2 | 46.6 | 46.6 |
| | 2.00 | 370 | 47.2 | 53.4 | 100.0 |
| | 99.00 | 91 | 11.6 | Missing | |
| | | ---------- | ---------- | ---------- | |
| | Total | 784 | 100.0 | 100.0 | |

Valid cases 693 Missing cases 91