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Smart Cards for Transit: Multi-Use Remotely Interrogated Stored-Data Cards for Fare and Toll Payment

U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe
National Transportation Systems Center
Cambridge MA 02142

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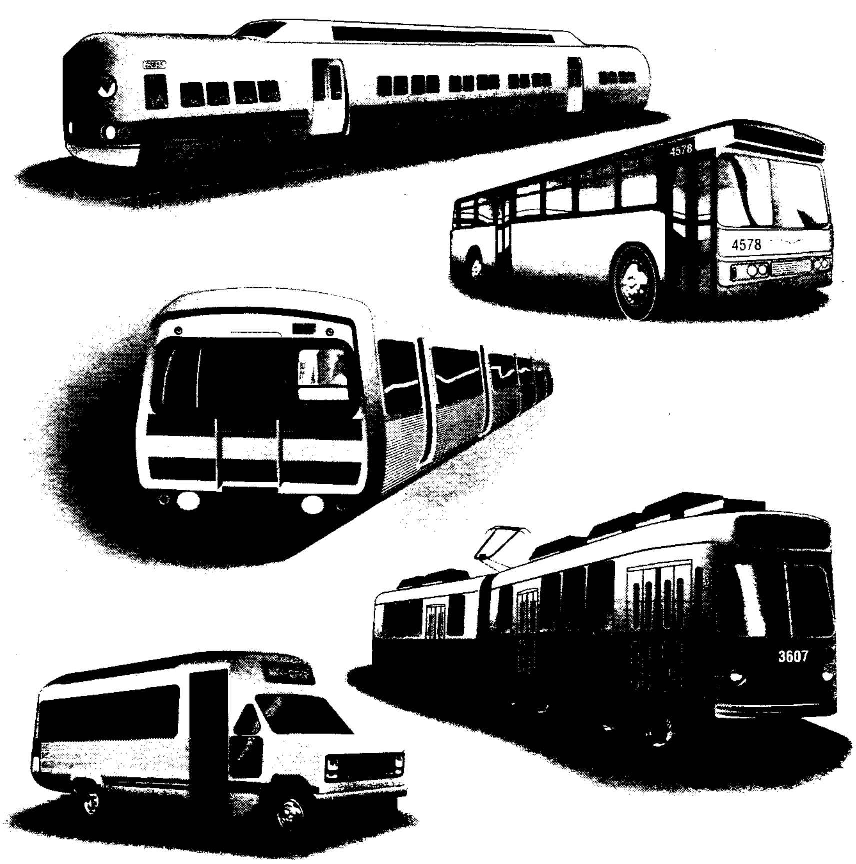
Final Report



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6. AUTHOR(S)
William R. Bushnell*

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Coopers & Lybrand
Federal Consulting Practice
One Main Street
Cambridge, MA 02142

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13. ABSTRACT (Maximum 200 words)

This project developed relevant information on existing and future, stored readable/writable data card technology for fare and toll payment, in pursuit of the objective of developing a plan for a common standard card-based fare payment system that can be used for various public transit modes. Information was developed through analyses of existing automated card technology, examination of current and planned applications in relevant transit modes, and in-person interviews with public transit personnel. Fare and toll applications have different requirements, and the goal of integrating these two applications (person-based and vehicle-based) onto a single card is complicated by differences such as the required read range. For the person-based applications, it appears that short-range (a few cm or inches) RF proximity technology will best satisfy integrated requirements. A key reason for choosing RF proximity technology over magnetic stripe technology was to support the needs of mobility limited riders. For vehicle-based applications, a much longer read range is necessary and it appears that longer range (a few meters or feet) smart transponder RFID technology is the most appropriate. Only a few of the existing card technologies are applicable when matched against critical requirements and performance criteria.

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PREFACE

This technical report provides the results of the MULTIUSE REMOTELY INTERROGATED, STORED-DATA CARDS FOR FARE AND TOLL PAYMENT study. Work was performed under the OMNI Contract No. DTRS-57-89-D-00037, and the IA 3095 TTD during the period of February 1993 to March 1994. For the Volpe Center, the Technical Task Initiator (TTI) was Dr. F. Ross Holmstrom. For Coopers & Lybrand, Robert H. Ropp was the Project Manager. William R. Bushnell of Coopers & Lybrand was the Principal Investigator and primary author of the report. Technical information was provided for this effort by ARINC, Inc., acting as teammates with C&L on the project. The draft of this report was circulated to members of the ITS/APTS Smart Cards/Tags Working Group and other interested parties and their views and suggestions were solicited. Comments from a number of people were received, including extensive commentary from Pete Comps of LTK Engineering Services, Chicago, to whom a special note of thanks is directed. The responsibility for assessing comments and incorporating them into the final version of the report fell to Ross Holmstrom, on whose shoulders rests the responsibility for any further errors or omissions remaining in this document.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	= 2.5 centimeters (cm)
1 foot (ft)	= 30 centimeters (cm)
1 yard (yd)	= 0.9 meter (m)
1 mile (mi)	= 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	= 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	= 28 grams (gm)
1 pound (lb)	= 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	= 5 milliliters (ml)
1 tablespoon (tbsp)	= 15 milliliters (ml)
1 fluid ounce (fl oz)	= 30 milliliters (ml)
1 cup (c)	= 0.24 liter (l)
1 pint (pt)	= 0.47 liter (l)
1 quart (qt)	= 0.96 liter (l)
1 gallon (gal)	= 3.8 liters (l)
1 cubic foot (cu ft, ft^3)	= 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	= 0.04 inch (in)
1 centimeter (cm)	= 0.4 inch (in)
1 meter (m)	= 3.3 feet (ft)
1 meter (m)	= 1.1 yards (yd)
1 kilometer (k)	= 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	= 0.16 square inch (sq in, in^2)
1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	= 1 hectare (he) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	= 0.036 ounce (oz)
1 kilogram (kg)	= 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)	= 1.1 short tons

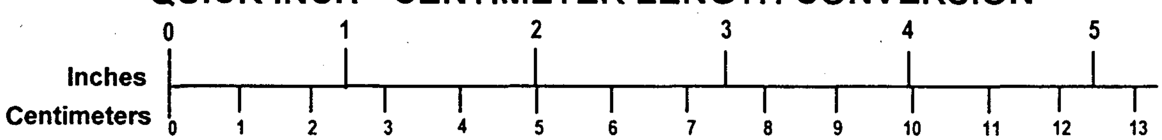
VOLUME (APPROXIMATE)

1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 liter (l)	= 2.1 pints (pt)
1 liter (l)	= 1.06 quarts (qt)
1 liter (l)	= 0.26 gallon (gal)
1 cubic meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)

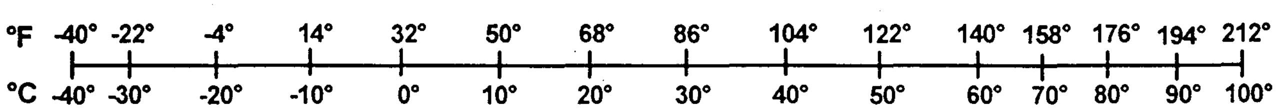
TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



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EXECUTIVE SUMMARY

The purpose of this project is to provide the Federal Transit Administration (FTA) with relevant information on existing, and future, stored readable/writable data card technology for fare and toll payment. This project coincides with the FTA's objective of developing a plan for a common standard card-based fare payment system that can be used for various public transit modes.

Information was developed through analyses of existing automated card technology, examination of current and planned applications in relevant transit modes, and numerous in-person interviews with public transit personnel. The key finding was that fare and toll applications have decidedly different requirements. Moreover, the goal of integrating these two applications (person-based and vehicle-based) onto a single card is complicated by a variety of differences, the most significant being the required read range. For the person-based applications, it appears that remote coupling (RF proximity) technology will best satisfy integrated requirements. A key reason for choosing remote coupling technology over magnetic stripe technology was to support the needs of mobility limited riders. For vehicle-based applications, a much longer read range is necessary and there are several additional user interface features that should be provided. Consequently, for the vehicle-based applications, it appears that the smart transponder (RFID Type III) technology is the most appropriate.

Another important finding was that only a few of the existing card technologies are applicable when matched against critical requirements and performance criteria. The main discriminating factors, including read distance, transaction speed, and read/write capability quickly narrowed the list of practical alternatives.

The ultimate goal of this project was to develop a conceptual design for an automated card that could support fare and toll payment applications. The body of this report presents card design characteristics for person-based and vehicle-based applications as well as application characteristics that must be supported by the ultimate automated card system. The overall investigative process leading to these results included an analysis of available automated card technologies, the definition of relevant transit modes, examination of existing and planned automated card projects, identification of the external factors influencing system implementation, definition of automated card requirements for each transit mode, and the ranking of technology alternatives based on critical requirements. Much of this background work is summarized in the appendices of this report. The work was accomplished over a period of twelve months under the direction of the Volpe National Transportation Systems Center.

1. INTRODUCTION

1.1 Background and Objectives

1.1.1 Background

The Volpe National Transportation Systems Center (Volpe Center) is assisting the Federal Transit Administration (FTA) by helping to investigate opportunities for increasing public utilization of various means of ground transportation. The current focus is on existing and emerging stored readable/writable automated card systems technology for fare and toll payment or other payment applications.

A variety of stored readable/writable card technologies currently exist for fare and toll payment in transportation systems. Examples include magnetic stripe tickets used for fare collection on subway and bus systems, radio frequency identification (RFID) tags designed for electronic toll collection, integrated circuit (IC) contact cards utilized in some integrated European applications, and parking meters using smart cards or electronic keys for fare payment.

1.1.2 Objective

The FTA's objective is to develop a plan for a common standard card-based fare payment system that can be used for a multitude of public transit modes including buses, subways, taxis and toll applications such as tunnels, bridges, and roads. The desired result is increased ease and efficiency for users of multimodal and intermodal transportation systems. Ultimately, it is hoped that such a payment system may have broader applications including credit card purchases, vending machines and telephones.

1.2 Summary of Task Approach

Information contained in this report was developed through investigation of existing and potential automated card technology, examination of existing and planned automated card applications in relevant modes of transportation, and synthesis of transportation agency and user requirements. Many of the findings are based on in-person interviews with transportation agency representatives, card manufacturers, and system integrators, as well as news articles, relevant industry reports, and card technology conference materials.

Figure 1 provides an overview of the project approach by outlining the specific tasks and activities performed during the course of the study. In order to arrive at a conceptual design that was both technically feasible and practical within the constraints of the transportation agency and user environments, it was necessary to identify the functional and performance requirements of the card system, as well as the external factors that could influence system design. Much of the investigative work necessary to develop the conceptual design was performed in Tasks A and B and is summarized in the following paragraphs:

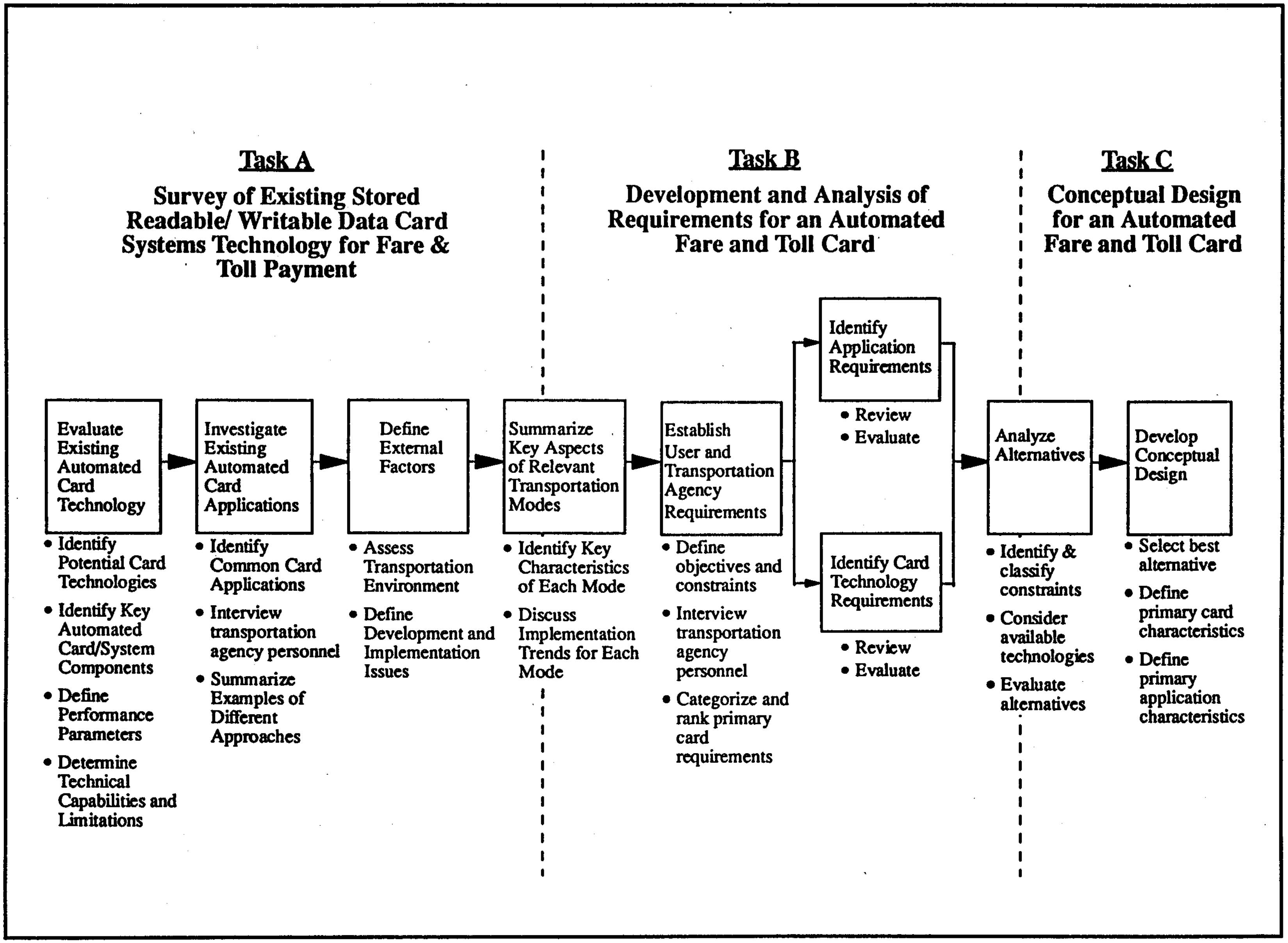

Figure 1. Overview of Study Approach

- Task A: The purpose of this task was to survey existing stored readable/writable card systems technology for fare and toll applications including magnetic stripe, laser/optical, bar-coding, integrated circuit (contact), coupling (RF proximity), and all major categories of long distance RFID. Additionally, a review of existing and planned fare and toll projects was conducted and was ultimately segregated into two major categories. The first category included projects where a fare is generally collected from an individual, such as in bus, subway, taxi, and paratransit systems. The second category involved the collection of a toll from a vehicle, including toll roads, tunnels and bridges, and parking systems. Finally, for purposes of our research we identified numerous external factors that may impact the implementation of an automated fare or toll card in a public transportation environment.

- Task B: The objective of this task was to develop and analyze the actual system requirements for an automated fare and toll card. The initial step was to identify relevant transit agency stakeholders and collect their needs and expectations. Then, the preparation of a baseline of user requirements established by transportation/technical issues and external factors was required. This provided a clear definition of objectives and constraints that set the stage for interviews with transportation agency personnel to identify their unique requirements. We then categorized, prioritized, and ranked primary card requirements, and conducted tradeoff analyses to match the critical application requirements against available card technology alternatives. The results of this analysis provided a logical transition to Task C.

- Task C: The culmination of project work was performed as part of Task C and is presented in the following sections of this report. Section 2.2 includes a description of possible implementation schemes for both person-based and vehicle-based systems. Section 2.3 provides recommended design characteristics for a multimodal fare or toll card. Section 2.4 identifies application characteristics that must be considered in developing an automated card system. Finally, key overall findings and recommendations are presented in Section 3.

1.2.1 Task A Results Summary

Technology

This task identified and provided technical summaries of existing and emerging forms of **automated card technology** (See Appendix A of this report for some examples). Since the area of card technology has still not been clearly defined by industry, there were a variety of ways to classify or distinguish the types of cards that are on the market. For this report, we chose to differentiate card technologies by communication technique, or more specifically the method used to transfer information between the card and a read-write unit. Based on this approach, the following types of card technology have been identified:

1. Magnetic Stripe
2. Integrated Circuit (IC) Contact
3. Radio Frequency Identification (RFID)
4. Close Coupling (Capacitive)
5. Remote Coupling (Inductive)
6. Laser/Optical
7. Bar Code

There are obviously many sub-classifications or variations of these types of cards depending upon: whether or not the card is "smart" (contains a microprocessor); the method used to store and update information; and the use of an on-card power source (active vs. passive). These specific issues, and more, were discussed for each card type in the form of detailed technical summaries. Appendix A contains technical summaries for three of the most pertinent examples that were developed for the Task A report: RFID; IC Contact; and Magnetic Stripe.

Applications

The Task A Preliminary Report also summarized information from an investigation of existing automated card transportation projects. This research was conducted in order to develop an understanding of applications which have concerns related to those of the FTA in designing a multi-use card system for fare and toll payment.

Information was collected through discussions with transit system managers, system integrators, and equipment suppliers, and through review of technical journals and publications. This segment of Task A included a matrix of existing and planned **fare and toll applications** (see Appendix B of this report).

External Factors

A number of **external factors** (see Appendix C this report) had to be carefully considered before the implementation of any multimodal card system applications. For example, in the private sector, introduction of new products and processes is driven by a perceived customer need combined with adequate technical capabilities and a profit motive. Conversely, within the public transportation area, the factors to be considered were in many cases not driven by a profit motive. Rather, initiatives in the public sector begin by identifying and responding to needs that benefit the population at large. However, adequate responses to a perceived need on the part of public institutions are impacted by a multitude of factors as shown in Appendix C.

1.2.2 Task B Results Summary

Relevant Transit Modes

In order to define requirements, consider alternatives, and discuss cost benefit issues, it was first necessary to identify and categorize the **fare and toll application** areas that were the focus of this study (see Appendix B of this report). To that end, fare and toll applications were subsequently divided into vehicle-based and person-based applications. Additionally, the decision was made not to include the multitude of card applications outside the realm of transportation payment such as access control cards, personal identification cards, and health cards. The rationale behind that decision was to focus on functions similar to those found in the fare and toll collections environment with the potential to be more easily integrated onto the card.

Requirements

A representative sampling of major requirements for an automated payment card was obtained from agencies in all relevant modes of ground-based transit. Where possible, examples are used within the descriptions of each requirement to compare and differentiate them based on specific transit agency application needs. Ultimately, the specific requirements were identified for each relevant mode of transit (see Appendix E of this report). Information was collected through telephone and in-person interviews, as well as from published articles and conference presentations.

Before considering the requirements shown in Appendix E, the reader must understand the focus of Task B, as well as the narrow perspective taken in defining and analyzing requirements. In terms of the application focus, the concern was primarily with the **functions relating directly to fare and toll collection**. Other ancillary functions that could be added to the card or that may be performed by a transit agency were not weighted in the discussion of **primary requirements**.

Additionally, the primary requirements only considered the card portion of the overall fare or toll collection system. Any other system concerns past the card-reader interface were listed as other considerations, and were not included in the summary of primary requirements. This narrow focus was helpful in separating card requirements from functions that are performed at the system level. System level functions and external issues, however, will need to be addressed prior to system implementation, and consequently these were discussed briefly in other sections (see Appendix C on External Factors and Section 2.4 Application Characteristics). Various tradeoffs will eventually need to be made between technical card capabilities, external issues, and system design and implementation concerns. In order to simplify the presentation of requirements, the decision was made not to dilute discussion with these issues until a solid grasp of the basic requirements at the card level was attained.

Another important consideration was that requirements were identified based on what functions needed to be performed, not on how these functions or specifications were met. For example, a user interface requirement may be that the user must only bring the card within a few inches of the reader. This does not mean that we should say that the application requires a radio frequency solution. Every attempt was made to avoid describing the requirements in terms of solutions.

Alternatives Analysis

Perhaps, the most significant discussion in Task B pertains to the **comparison of card technology alternatives with the composite of person-based and vehicle-based requirements.** Appendix F of this report presents a comparison matrix that was based on an iterative requirements analysis for each of the relevant transportation applications summarized in Appendix B. The matrix compares the current capabilities of existing card technology alternatives with the critical composite requirements identified in Appendix E. The existing technology alternatives were scored based on whether or not they could satisfy these critical requirements. In some cases, failure to meet a particular requirement, would eliminate a candidate technology. For example, IC Contact Cards were able to meet many of the critical requirements but could not meet the essential read distance and speed requirements. Consequently, the analysis process focused mainly on the rejection of inappropriate technology alternatives rather than on the selection of a particular technology.

Two of the key findings resulting from this process were: (a) there is no available technology which fully meets all of the critical requirements; and (b) the ultimate selection of a technology will require further investigation of the tradeoffs between specific application requirements, equipment costs, and card system capabilities.

Cost/Benefit Issues

Investigation into **cost/benefit issues** (see Appendix D) yielded marginally meaningful information. Very few agencies were examining the benefits gained from expending costs for new equipment, or for advantages obtained by investing in a new technology. Most of this work was accomplished by outside consultants retained to advise the various agencies. Remarkably, very few of the interviewees had compiled sufficient cost data to complete a payback analysis. However, more often than not, they were able to gain inclusion of their respective projects in state budgets.

2. CONCEPTUAL DESIGN FOR AN AUTOMATED FARE AND TOLL CARD

2.1 Assumptions and Constraints

2.1.1 While **overall system issues and external factors** have been considered in preparing the conceptual design, the primary focus of this section is on the design characteristics of the card portion of the system. Design characteristics of other system components such as readers, gate or lane equipment, and computer processing equipment are considered outside the scope of this study.

2.1.2 The **definition of system requirements** was based primarily on fare and toll collection in the relevant transit modes defined in Appendix B. Other potential uses of automated card technology, both within the transit environment or for external applications were considered to be ancillary functions, and were not included in the analysis of requirements, rating of card technology alternatives, or in the development of card design characteristics.

2.1.3 The **rating of card technology alternatives**, and discussion of implementation scenarios presented in this report, was based on the existing capabilities of each technology. As card technology improvements are realized, or new types of card are introduced, the relative card ratings presented in Appendix F may change. Consequently, the feasibility of a particular technical solution may also change.

2.2 Possible Implementation Schemes

A key finding (see 3.1.1, "Fare and Toll Applications Have Significantly Different Requirements") was that there is indeed a logical division of the relevant transportation modes into the two basic categories of person-based and vehicle-based systems. This division was necessary due to significant differences in the critical functional and performance requirements. **Based on the current capabilities** of the most feasible automated card technologies, it was determined that combining all of the relevant transportation modes onto a single card was not practical or cost-effective at this time.

This section of the report will present a summary of each of these two main system types, as well as possible implementation schemes. The possible implementation schemes are provided as examples in order to help clarify the specific parameters discussed in the card design characteristics presented in Section 2.3.

2.2.1 Person-Based Systems

Person-based systems involve the collection of a fare from an individual as they use a transit service including open rail, closed system rail, bus, taxi, and paratransit. Based on the functional and performance requirements identified in Appendix F, the use of a proximity or "touchless" technology, such as remote coupling, appears to be the most suitable approach. While the use of a contact technology, such as magnetic stripe, will support many of the critical requirements, the contactless approach will better support the needs of mobility-limited riders.

2.2.1.1 Key Requirements

The ultimate success of a person-based system is highly dependent on providing a convenient and easy to use card. From the user's perspective, this implies that the card must:

(a) Have a convenient size in order to fit into a wallet or purse;
(b) Be durable enough to withstand bending and be able to resist common forms of external interference;
(c) Be designed to minimize necessary user actions and support simple and easy to follow procedures; and
(d) Be designed to maintain a certain level of reliability bearing in mind possible variations in user actions.

Transit agencies are not only concerned with meeting the key user requirements listed above, but also must ensure the efficiency and effectiveness of overall system operations. This implies that from the transit agency perspective the card must:

(a) Be low cost to support a high level of distribution;
(b) Allow quick passenger throughput at reader stations;
(c) Be a standard size (e.g., ISO) to allow uniformity of reading equipment, both internally and for integration with external agencies and groups; and
(d) Support a high level of performance, particularly in terms of read reliability and information integrity.

2.2.1.2 Implementation Schemes

There are several potential implementation schemes that can satisfy most of the critical person-based requirements. However, the best approach appears to be the use of a read-write prepaid card. Read-write is required to support distance based and peak travel pricing schemes, as well as other special pricing schemes such as modal transfers. The prepaid approach is preferred because it retains the anonymity of the user, and it does not require the transit agency to establish or maintain user accounts.

Figure 2 shows a possible implementation scheme for a distance based prepaid fare card. In this example, the card ID number and balance are read when entering and exiting the system. The ID number is used by the transit agency to confirm that the card is valid and to maintain an audit trail of transactions. The ID number, combined with the existing card balance may also be used to identify possible cases of fraud.

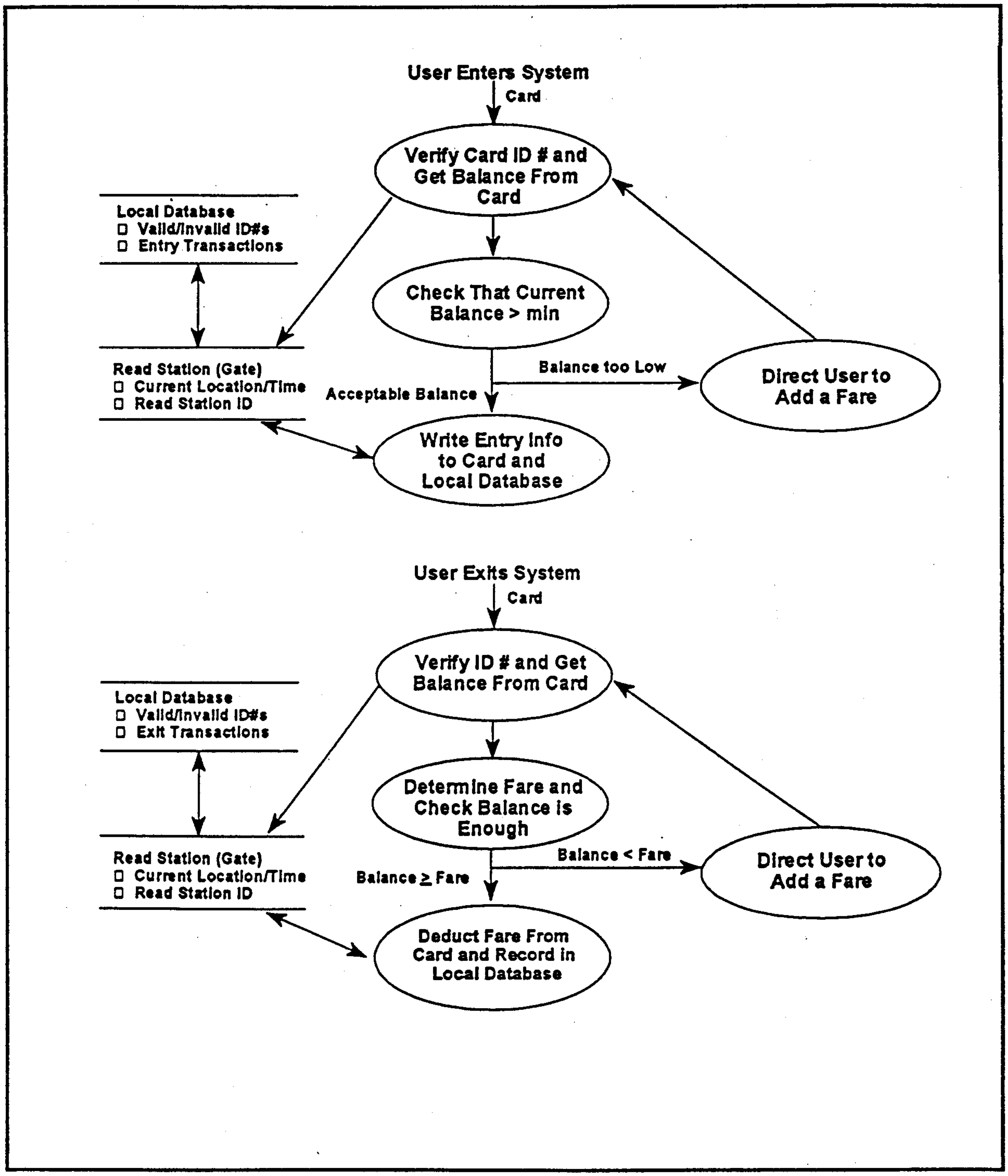

Figure 2. Person-Based System (Prepaid Fare Card)

When entering the system, the entry location, time, and possibly the read station ID are written to the card. Upon exit, the entry information and existing balance are read to calculate the fare, and the remaining balance is written back to the card. Also upon exit, the trip information may either be closed and erased from the card or, depending upon the available memory capacity, it may be retained as part of a transaction history.

Using the preferred decentralized validation and transaction processing approach, information such as valid/invalid ID numbers and the existing fare pricing schedule is maintained in the reader or fare box, or in a local database. While fare calculation and determination of the remaining balance could potentially be performed by the card itself, the recommended approach is to perform these activities at the reader or in the local database. This will keep the cost of the card low, and will prevent the need to update the fare schedule on the card as pricing changes are made by the transit agency. While Figure 2 separates the read-write unit (gate) and the local database into two distinct items, they could easily be combined and likely will be in bus applications.

2.2.2 Vehicle-Based Systems

Vehicle-based systems involve the collection of a fare or toll from a vehicle as it passes through closed toll road entry and exit plazas, barrier toll plazas, or parking gates. Vehicle systems may be: (a) distance-based for closed toll roads with entry and exit plazas; (b) barrier-based for bridge, tunnel, or toll road barriers; or (c) time-based for parking.

Vehicle-based systems are primarily concerned with the type or classification of the vehicle, validation of reference ID number, and collection of the appropriate fare based on vehicle classification and system usage. Based on the requirements identified in Task B, and on the worldwide examples of electronic toll collection and automated parking systems, vehicle tagging has been considered a reasonable way of identifying vehicles and processing vehicle transactions. Since vehicle operators and passengers do not generally need to carry the tag with them, the size of the tag is not as critical as in person-based systems. As a result, a variety of tag designs have been developed by various vendors, most of which differ in size, specific communication method, and primary location on the vehicle.

2.2.2.1 Key Requirements

From a **user's perspective**, the success of a vehicle-based system will depend on whether the tag:

(a) Supports non-stop toll collection;
(b) Minimizes the actions required by the driver in order to maintain safety;
(c) Provides a means of notifying the user of account validity for an approaching plaza;
(d) Can be conveniently obtained and updated;
(e) Does not create a significant theft concern when left unattended in the vehicle;
(f) Allows the user to obtain a receipt for transactions;

(g) Supports a convenient means of determining the remaining balance - if the balance is stored on the card; and
(h) Does not invade the privacy of the driver or passengers.

Toll road authorities additionally require that vehicle-based tags:

(a) Support high speed validation and transaction processing to reduce congestion;
(b) Are low cost to allow a high level of distribution;
(c) Can perform reliable long-distance communications (up to 10 ft or greater);
(d) Are compatible with similar systems maintained by other agencies;
(e) Maintain working effectiveness, including read reliability and information integrity, within typical environmental conditions;
(f) Can be implemented in a configuration that minimizes cross lane reads, multiple reads, and the effects of internal and external interference; and
(g) Can be implemented in a configuration which maintains or improves the existing level of safety, both for drivers and for authority personnel.

Many of the same requirements exist for parking systems. However, the need for high speed validation and transaction processing is not as evident, since the vehicles will likely be moving at lower speeds.

2.2.2.2 Implementation Schemes

Vehicle-based systems can be designed to use tags or transponders which vary significantly in complexity, particularly in terms of processing power and memory utilization. While there are many approaches which are technically feasible, focusing on the most critical system and user requirements should help to narrow the list of appropriate choices. Figure 3 presents a barrier toll road example to highlight the difference between a low-cost read only tag, an intermediate read-write tag, and a smart transponder capable of driver notification and possibly balance display.

The actions performed by a read-only tag can be seen by eliminating all of the steps within the two dotted boxes in Figure 3. In this case the vehicle would enter a tag lane, a reader in the lane would determine if the vehicle had a valid tag, and would store a record of the tag ID along with the toll amount in a local database. A failure signal might be displayed for vehicles without tags or with invalid tags. Additionally, a failed transaction might initiate a video enforcement system (VES) or police notification. While this approach uses low-cost tag technology, its integration with distance based toll road systems requires the toll authority to establish and maintain user credit accounts.

By adding the steps in the lower dotted box, an example of a read-write tag system can be seen. In this case the same validation process is used, but the balance is prepaid and is maintained on the tag. While passing through the tag lane, the reader can determine the current tag balance, deduct the toll amount and write the new balance back to the tag. While this type of technology is slightly more expensive than the read-only tag, this approach could possibly enhance privacy by not requiring the user to maintain an account with the toll authority. However, privacy could only

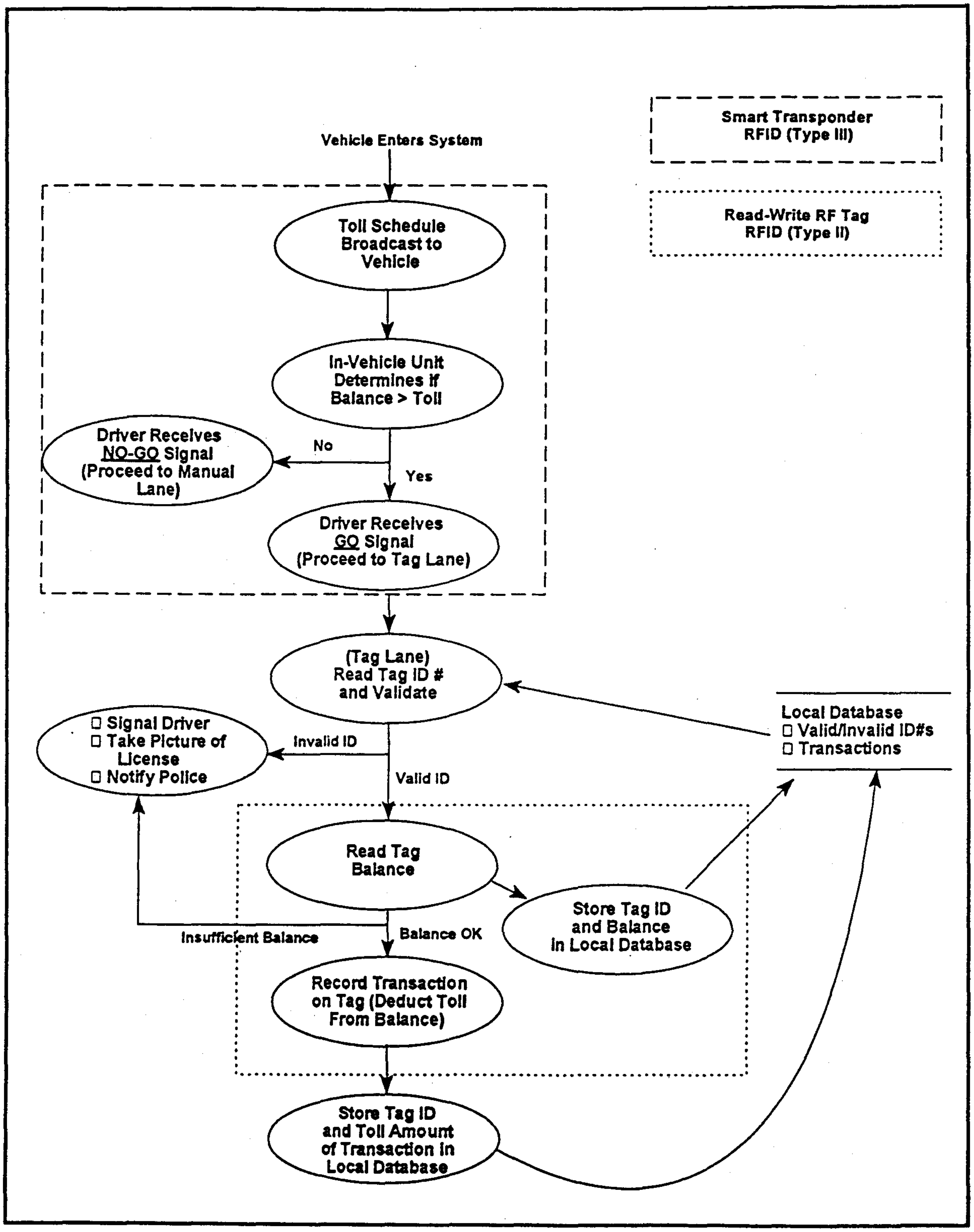

Figure 3. Vehicle-Based System (Barrier Design)

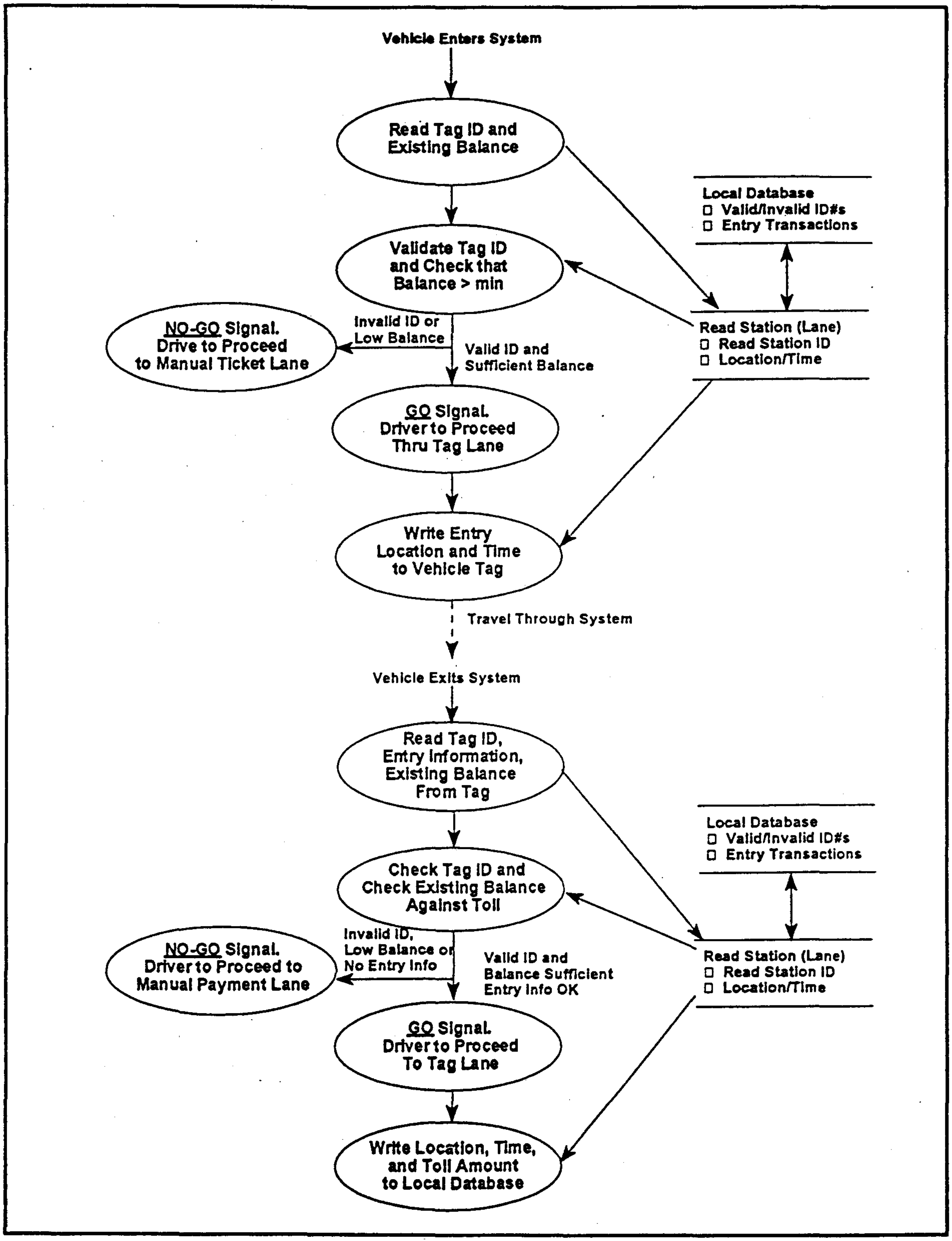

Figure 4. Vehicle-Based System (Closed Toll Road Distance-Based Example)

be guaranteed to the extent that safeguards existed to prevent the recording of transactions with users indicated, or to control access to such recorded information. This type of tag could ultimately be standardized to support integration with other distance based toll road systems, especially where the read-only tag is inadequate.

Finally, by adding the steps in the upper dotted box, some of the additional features of a "smart transponder" are shown. In this case the balance would still be maintained on the tag, but the tag would also have a processing capability along with other features such as an alphanumeric display or a visual and audio signal system. In the Figure 3 example, the additional capabilities include balance calculation and a driver signaling system. By broadcasting the vehicle rates to the tag in advance of the toll plaza, it will be possible to signal the driver in advance that the tag has sufficient funds for the toll transaction, or that there are insufficient funds and the driver should proceed to a manual lane. This will not only cut down on the number of invalid transactions, but it should also increase safety and driver confidence in the automated collection system.

In the first two examples, read-only and read-write, there were still many critical requirements which were not met, especially from the user's perspective. However, in the third example involving the use of a smart transponder, there will likely be a significant tradeoff between tag capability and cost. Although meeting all of the critical requirements should be a goal of transportation authorities, it may not presently be cost-effective to do so based on existing technological capabilities. Toll and parking authorities will need to carefully consider the life cost of adding additional tag features.

Figure 4 provides a second example of a vehicle-based system. In this case, an implementation scheme is provided for a closed toll road where the toll amount is based on distance traveled. This example assumes the use of a smart transponder in order to provide advance user notification of clearance to proceed through an automated lane.

2.3 Card Design Characteristics

This section presents a summary of the recommended design characteristics for a multimodal card to be used for automated fare or toll collection. These characteristics are based on the critical functional and performance requirements identified in Task B. The recommended design characteristics are summarized in Table 1. This information should not be used as a technical specification, since it does not always include exact parameters, and since the requirements for each specific system installation may differ due to unique environmental conditions.

As discussed earlier, it was necessary to cover person-based applications and vehicle-based applications separately due to significant differences in the critical requirements. Where the card characteristics are similar for the person-based and vehicle-based applications, they will be discussed together. In the cases where they are significantly different, they will be discussed separately.

Table 1. Design Recommendation Summary

CHARACTERISTIC	PERSON-BASED	VEHICLE-BASED
Memory Type	• Read-write • ROM/PROM for static fields • EEPROM/SRAM for dynamic fields	• Read-write • ROM/PROM for static fields • EEPROM/SRAM for dynamic fields
Memory Capacity	• 512 to 1024 bits minimum • 1 k-8 kbits for multiple accounts	• 1 k-8 kbits minimum • 8 k-48 kbits with transaction history (1 k-6 kbytes)
Information Integrity	• 99.9999% accuracy rate	• 99.9999% accuracy rate
Read Reliability	• 99.99% accuracy rate	• 99.99% accuracy rate
Transaction Time	• 1 second for overall transaction • 0.05-0.2 seconds comm. cycle	• 1-2 seconds for overall transaction • 0.05-0.3 seconds comm. cycle
Security	• Store static elements in ROM • Tamper resistant	• Store static elements in ROM • Tamper resistant
Durability	• 1-2 year overall life span • 3,000 to 5,000 read-write cycles • ISO/IEC 10536-1 bending and static electricity guidelines	• 2-5 year overall life span • 10,000 to 15,000 read-write cycles • Military Standard 810D durability testing guidelines
Processing Power	• None required	• Microprocessor (for balance calculation, driver notification) • Battery (or external power source)
Read Distance	• 4-20 inch general range	• 5-30 foot general range
Size	• ISO 7816 standard dimensions	• No strict requirements
Physical Features	• Blind notch (for insertion only) • Color coding for unique fare classifications • Provide a way for user to determine remaining balance	• Driver notification (using a combination of signal lights and audio tones) • Key activated balance display

2.3.1 Memory Type

Memory Type refers to the medium that is used to store information on the card. One of the primary concerns is whether to use read-only or read-write memory. There are various ways to store information on a card such as bar coding, magnetic stripe, Wiegand coding, and reflective optical pits. Additionally there is a wide choice of silicon chip memory types including non-volatile forms such as ROM, PROM, Serial EEPROM, Parallel EEPROM, FLASH EEPROM, and volatile forms (which require current or at minimum a voltage) such as Dynamic RAM (DRAM) and Static RAM (SRAM). While SRAMs require a constant voltage source, actual power consumption in this type of application is nil, the voltage is merely used to retain the present memory settings. DRAMs require a constant current to retain their data.

DESIGN CHARACTERISTIC - Based on the need to store and update information, read-write memory is required for both person-based and vehicle-based applications. As for the specific type of memory, the use of silicon chip memory is preferred over magnetic stripe and optical memory since it can be stored inside the card and can be better protected both in terms of card durability and security. Additionally, magnetic stripe and optical memory require close contact with the reading equipment, while silicon chip memory can be accessed remotely with various forms of contactless technology. A combination of ROM or PROM, and EEPROM or SRAM is recommended. ROM or PROM should be used to store the card ID and other static system or application information. EEPROM or SRAM should be used, depending on available power capabilities, to store the modifiable information such as entry/exit location, time, and balance.

2.3.2 Memory Capacity

The amount of memory required to perform critical card functions will depend on the size and number of the specific data items that must be stored on, or added to the card. This must include both the storage area needed for card control functions, and the area available for application data. Generally memory is specified in terms of bits or bytes. Typically 7 bits, representing an alphanumeric character, plus one control bit, equals one byte.

DESIGN CHARACTERISTIC (Person-Based) - A minimum of 512 to 1024 bits will be needed to store most of the critical data fields, including ID number, balance, fare classification type, entry/exit locations and usage restriction codes, as well as the static function control information. More memory will be required if it is necessary to maintain separate accounts, or to maintain a transaction history. In this case 1 k-8 kbits or more will likely be required. Most of the memory will need to be modifiable (EEPROM or SRAM), as there are typically fewer fields that are static and can be placed in ROM.

DESIGN CHARACTERISTIC (Vehicle-Based) - A minimum of 1 k-8 kbits will be needed to store most of the critical data fields, including ID number, balance, toll classification type, entry/exit locations and usage restriction codes, as well as the static function control information. It is expected that for vehicle-based applications, multiple accounts will need to be stored on the tag to accommodate unique driver applications that might be outside the jurisdiction of a local area or metropolitan clearinghouse. Additionally, transaction histories may need to be maintained to allow users to obtain receipts at their convenience. In this case, 8 k-48 kbits (1 k-6 kbytes) may be required.

2.3.3 Information Integrity

Card information integrity is one of the most important aspects of the card, especially from the user's perspective. Specifically, this characteristic involves preventing information stored on the card from being altered unintentionally or corrupted. Information integrity is especially critical when monetary values are stored on the card. Users would be extremely frustrated with the value of a $50 card accidentally being erased, since in some cases there may be no way to prove what balance remains. For instance, magnetic stripe credit cards can be demagnitized by dropping them onto the demagnetizers found on store counters used to demagnetize anti-theft merchandise tags.

DESIGN CHARACTERISTIC - A failure rate of 1 in 1,000,000 or an accuracy rate of 99.9999% has been discussed by some transportation authorities and manufacturers as a goal. However, the integrity of existing card products has not been clearly demonstrated, especially over the complete product life span and in varying environmental conditions. Consequently, it is possible that none of the products currently available can meet this level of performance.

2.3.4 Read Reliability

Read reliability is defined as the accuracy percentage or number of successful reads divided by the total number of read opportunities. Read reliability is an important consideration, since a single missed read can result in lost revenue, user frustration, and reporting discrepancies. Reliability may be most critical in applications where user frustration could occur, since this may ultimately lead to greater losses in revenue as the result of lower ridership. In some systems, multiple reads within the opportunity window are performed to increase the opportunity for a valid read, as well as to verify that the information was read correctly. In other systems, error correcting codes are used to improve read reliability. In specifying this characteristic, however, we are only concerned with the overall accuracy percentage.

DESIGN CHARACTERISTIC - A failure rate of 1 missed read in 10,000, corresponding to an accuracy rate of 99.99%, is being considered by many transportation agencies as an attainable minimum goal. However, it is likely that there is no existing system that actually provides this level of performance when all environmental factors are considered. Some toll road authorities are reporting believable figures in the range of 99.5% to 99.9%. In many cases it is difficult to measure read reliability accurately, since the authority may be unaware of missed reads.

2.3.5 Transaction Time

Transaction time is one of the more difficult design characteristics to clearly define, and for which to establish reasonable performance parameters. The overall transaction time can be thought of as the time is takes a person or a vehicle to pass through a fare gate or toll lane, respectively. A very significant component of this time, is the communication cycle consisting of card reading, validation and fare calculation, and card writing. The objective is to keep read reliability high while minimizing the impact of the communication cycle on the overall transaction time. The optimum would be to allow a person to pass through a fare gate at normal walking speed, or a vehicle to pass through a toll lane at normal highway speed (if this could be done safely).

Recommended values will be presented for both the overall transaction time and the communication cycle time in order to provide a more thorough description of this characteristic. The communication cycle time could vary significantly depending on a number of factors including message length, data transfer rate, validation and fare calculation time, read distance or size of the communication window, traveling speed of the card or tag, and whether or not redundant read-write cycles are used to improve overall read reliability.

DESIGN CHARACTERISTIC (Person-Based) - Many transit agencies are attempting to achieve an overall transaction time of 1 second or less for bus and rail systems, where the large number of transactions could lead to congestion, or affect schedule adherence. Pilot tests of proximity cards have already shown an advantage over both the swipe and mechanical transport type magnetic stripe systems in terms of overall transaction time. Keeping required user actions to a minimum should also help in attaining a reasonably short transaction time. A communication cycle time of 0.05 to 0.2 seconds is recommended. This range is based on the use of a proximity technology with a read distance of 4 inches, and with user pass through at a rate approximating average walking speed (3-4 mph).

DESIGN CHARACTERISTIC (Vehicle-Based) - For vehicle applications, an overall transaction time of 1-2 seconds per vehicle should be acceptable. The exact value will depend on the length of the toll lane and the traveling speed of the vehicle. This range was based on discussions with toll agencies that are suggesting travel speeds of 15-30 mph through the toll plazas. Some barrier systems are identifying vehicles moving at much higher speeds; however, these are generally using read-only tag designs. To stay within the overall transaction time, a communication cycle time of 0.05 - 0.3 seconds will probably be required. As an example, for a vehicle traveling at 30 mph past a read-write unit with a range of 10 feet, the maximum allowable communication cycle time would be 0.22 seconds. Since it may be possible for vehicles to travel through the toll area at speeds of 70-80 mph or higher, the lower communication cycle time of 0.05 seconds may be necessary to discourage speeding to avoid payment.

2.3.6 Security

Card security involves two primary considerations: information access restriction and prevention of card tampering. Information access restriction may be required to ensure that private information is unalterable, except by the approved source, and unreadable to prevent unauthorized viewing or duplication. Cards will also likely require a minimum level of tamper resistance to prevent fraud, by changing a fare classification, or altering the card balance, or fare evasion by intentionally preventing transactions from being written to the card. Other security issues relating to account verification, user identity verification, and additional forms of fare evasion, such as card passback or equipment vandalism, may also need to be addressed at the system level.

DESIGN CHARACTERISTIC - Certain portions of the card memory, specifically the ID number, and fare classification should be unalterable except by the card manufacturer or the card distributor. This can be accomplished by storing these data elements in read-only memory (ROM) or in PROM (write once). For the other required data items, many of which are modifiable, a high level of security is not required. Generally, for fare and toll applications, the protection of modifiable card data will not be as important as in financial applications, since the amount of money on the card will be relatively small in most cases. The cards should be tamper resistant to prevent unauthorized modification of the data, but only to the extent that it is not highly profitable to alter card information. Additionally, audit checks can be performed at the system level to catch modified or duplicate cards, and the card numbers can then be reported to the local readers for confiscation.

2.3.7 Durability

Card durability can be measured by several factors including: (a) typical overall card life span in months or years; (b) card memory life span in term of the number of read-write cycles; (c) card resistance to bending, shock and vibration; and (d) card resistance to other environmental factors such as humidity, water, chemicals, static electricity, electromagnetic fields, and temperature variation.

DESIGN CHARACTERISTIC (Person-Based) - Many of the durability requirements of a transit fare card will be similar to those of the typical credit card. However, the introduction of silicon memory chips to support a contactless read-write capability creates some additional durability concerns. For the general card life span, a range of 1 to 2 years is recommended. A shorter life span will limit the cost-effectiveness of the card, while establishing too long a life span might lead to performance problems or might delay incremental system improvements. Card memory life span (number of read-write cycles) should be significantly longer than the general life span of the card to ensure that the card is replaced before performance problems appear. With this in mind, the card should have a minimum capability of 3,000 to 5,000 read-write cycles. Card durability guidelines have already been specified for some of the common environmental factors. Relevant information on bending and static electricity is presented in Annex A of ISO/IEC 10536-1 (Contactless IC Cards). Additionally, Section 5.14 of ISO 7810 discusses card resistance to chemicals, but may need some modification for contactless cards, where the silicon chip is fully sealed within the card casing.

DESIGN CHARACTERISTIC (Vehicle-Based) - Tags or transponders used in vehicle-based systems have notably different durability characteristics than person-based fare cards. Many of these differences relate to the more complex design and relatively higher cost of the tag or transponder as well as variations in typical environmental conditions. A longer tag life span of 2 to 5 years is recommended to offset the relatively higher equipment costs. The recommended number of read-write cycles is 10,000 to 15,000. This number is larger than the person-based minimum due to the longer tag life span and due to the possibility that roadside readers may activate redundant read-write cycles frequently for verification. Guidelines for the measurement and testing of most tag environmental factors are discussed in Military Standard 810D. One of the more significant environmental concerns is temperature variation, since a tag placed on a dashboard could be exposed to extremely high temperatures. High temperatures may not only affect the tag casing and circuitry but may significantly reduce battery life, an important consideration if power is required.

2.3.8 Processing Power

Processing power refers to the on-card capability to perform complex functions without complete dependence on external system controls. Generally this involves the use of a microprocessor and, in some cases, an on-card power supply. In some applications, on-card processing is required to perform functions which cannot be performed efficiently by other parts of the system.

DESIGN CHARACTERISTIC (Person-Based) - For person-based fare cards, no on-card processing or portable power source is required. All of the vital system functions can be controlled by other parts of the system.

DESIGN CHARACTERISTIC (Vehicle-Based) - There are a variety of feasible alternatives for vehicle-based systems which meet most of the critical requirements. However, in order to meet the requirement for advanced driver notification, the use of a transponder with processing power is recommended. The primary functions that must be performed include balance calculation, and driver notification. A microprocessor will be needed to control these operations. Additionally, a portable power source, such as a battery, may be required if there is no external means of powering the transponder either through a cigarette lighter or other special vehicle connector.

2.3.9 Read Distance

Read distance is specified in terms of the minimum separation between the card and the reader during a transaction. This characteristic is generally based on: (a) limitations of practical proximity between the card and reader; (b) whether the card must be in motion during the transaction; (c) timing considerations for validation, transaction processing, and pass through; and (d) overall requirements for convenience. The most important design decision to be made is whether to use a contact or a contactless technology. While cards using contact methods (e.g., magnetic stripe, and IC contact) are generally less expensive and more widely available, in some cases it may not be practical to perform verification and transaction processing using a contact technology.

DESIGN CHARACTERISTIC (Person-Based) - Most person-based fare application requirements can be satisfied using either a contact or a contactless technology, as long as the gate pass through time meets overall system performance objectives. However, in order to meet the needs of mobility limited riders, contactless technology is required. A range of 4 to 20 inches should be acceptable. A more exact range determination can be made by considering the spacing of the reading gates, the height of the reader, and any other unique fare box design aspects. Readers will need to be carefully adjusted to work within the established range. If the read distance is too long, there could be unintentional reads or multiple reads by adjacent readers.

DESIGN CHARACTERISTIC (Vehicle-Based) - Contactless technology is required for vehicle-based applications where non-stop validation and transaction processing is the most efficient way to perform fare and toll collection. A read distance in the range of 5 to 30 feet may be required depending upon the average traveling speed of the vehicle, the configuration of the reading or message broadcasting equipment, and the positioning of the transponder on the vehicle. For systems using a read distance of over 10 feet, there must be a way of uniquely identifying each vehicle during the reading and writing process. Otherwise, information may be written to the wrong vehicle, or the reading equipment may confuse information received from different vehicles.

2.3.10 Size

Size refers to the physical dimensions of the card. Standardization of card size will be critical in supporting intermodal use of the card through integration of the relevant fare and toll applications. Card size also becomes important when considering possible integration with other external applications, e.g., banking, retail, telephone systems, access control, and personal identification.

DESIGN CHARACTERISTIC (Person-Based) - For person-based applications, the card should adhere to the standard dimensions specified in ISO 7816. From a user's perspective, this will allow convenient storage of the card in the standard wallet or purse. Standardization may also promote the combination of contactless technology, such as RF proximity and infrared, and contact technology (e.g., magnetic stripe, IC contact, and optical) onto a single card.

DESIGN CHARACTERISTIC (Vehicle-Based) - For vehicle-based applications there are no strict size requirements. Generally, it will not be necessary for a person to carry the vehicle transponder with them. Some of the main concerns are that the transponder does not obstruct the driver's view of the road, that it does not limit driver mobility within the vehicle, and that the shape and placement of the transponder does not become a safety hazard in the event of an accident.

2.3.11 Physical Features

This design characteristic will identify any special card features or physical attributes that are needed to meet critical requirements. This will mainly include external or visual items that relate to the card's user interface ranging from a picture or holographic image to an alphanumeric keypad and display.

DESIGN CHARACTERISTIC (Person-Based) - The use of a blind notch for card orientation will be required if the card supports an insertion type of technology such as magnetic stripe. Color coding of cards based on different fare classifications such as student and senior is recommended, although not required, to help transit service providers detect cases of fraud. Additionally, a way of allowing the user to determine the card balance is needed, although it is still not clear how to best provide this capability.

DESIGN CHARACTERISTIC (Vehicle-Based) - Vehicle-based transponders will require a driver notification system. The most appropriate choice appears to be a combination of signal lights and audio tones, to notify the driver with minimal distraction. A key activated balance display is also recommended, although not required, to allow periodic checks of the remaining balance.

2.4 Application Characteristics

Application characteristics include overall system issues that may impact card design, but may not directly specify card features or performance parameters. These characteristics describe the operating constraints and the environmental conditions within which the card is expected to operate. Any specific card technology under consideration must be adaptable to a system configuration that can address these issues.

2.4.1 Safety

Safety issues must be addressed to protect both the system users and the transportation agency employees. Safety concerns may include: (a) establishing general system design and operational guidelines including the optimum placement of automated toll lanes in vehicle-based systems; (b) establishing minimum health or environmental safety levels for operation and use of system equipment; (c) establishing procedures to minimize the opportunity for card theft and limiting the financial advantage of card theft; and (d) providing a minimum level of overall safety at or within transportation facilities.

The use of RFID systems which generate electromagnetic fields (EMF) could potentially pose a safety problem if not implemented properly, especially for the transportation agency employees who work near the readers for extended periods of time. While increasing the reader power output may provide a better transmission range, there are limitations imposed by the FDA and the FCC in order to ensure safety and to limit interference with other communications. Based on IEEE Standard C95.1-1991, the FDA has set a safety limit of 10 milliwatts/cm^2. In addition, the FDA has stated that exposure to this power level should not be maintained for longer than six minute intervals.

An additional safety concern of the vehicle-based systems is the placement of a transponder within the vehicle. The location must be chosen so that it does not impede the driver's vision or actions, and so that it does not become a hazard in the event of an accident.

2.4.2 Convenience

Convenience, especially from the user's perspective, will be critical to establishing initial system acceptance and for maintaining a high level of confidence in system performance. The critical application factors which must be addressed include: (a) establishing logical and easy to follow user procedures; (b) minimizing required user actions; (c) supporting efficient, accessible, and well arranged intermodal transfers; (d) providing readily available and accessible card distribution and balance update locations; (e) establishing payment options that meet a wide range of user preferences; (f) providing the capability to perform common user functions such as determining the remaining balance and obtaining travel receipts; (g) furnishing reliable traveler information;

and (h) providing a more cost-effective and less time consuming alternative to other forms of transportation.

2.4.3 Intermodal Integration

Integration of similar and related transportation modes will be required to ensure a high level of market penetration, and to ensure that a card or transponder used on one system does not conflict with or affect the overall performance of another system.

2.4.4 Special Fares

The automated collection system must support special fare classifications and different fare strategies. For the person-based systems, this will include establishing qualification criteria and special fare rates to groups such as juniors, students, and seniors, as well as other unique groups such as transit employees or police. Additionally, different fare strategies must be supported including time-based strategies for peak-period travel, holidays, or special events, and quantity discount strategies for predefined periods such as daily, weekly, monthly, and yearly. For the vehicle-based systems, charges will be based on the vehicle type classification and many of the same time-based and quantity discount strategies identified for person-based systems.

2.4.5 Infrequent Users

The system should be designed with the goal of providing the same level of service and convenience to all system users, whether they are frequent travelers or commuters, occasional travelers, or one-time users. This implies that either the card must be low cost, or that an alternative collection scheme for infrequent system users must be established.

2.4.6 Card Distribution Infrastructure

An infrastructure must be established for card distribution and other relevant user services. In many cases it will not be cost-effective for a transportation agency to establish a specialized network for card or transponder distribution, travel receipt generation, and stored balance updates. As a result, cards may need to be designed to support distribution and update through existing networks controlled by external organizations, e.g., banks, retail chains, gas stations, and lottery companies.

2.4.7 Revenue Collection and Distribution

Specific payment options and appropriate procedures for revenue collection and distribution must be established by all of the service providers who will accept the intermodal card for payment. This may include providing a variety of payment options to system users such as cash purchase or update of card balance at service locations, credit transfer to the card from a conventional credit card, or account update through other means. For example, account update could be performed, based on card ID number, through the mail or by telephone. Balance updates could then be downloaded to all system read-write units which would add credit to the card the next time the card is used. Finally, once revenue is collected by a particular agency it may be uploaded to a central clearing facility and later distributed based on transaction summaries linking card usage to a specific service provider.

2.4.8 Account Balance Examination

Providing a convenient way for users to examine their account balance will be a critical system requirement. There are a variety of ways this can be accomplished including: (a) automatic display at the read station during each transaction; (b) providing a visible indication on the card of the remaining balance using printing, punching or other methods (person-based only); (c) providing on-card display capability which can be activated by the user (vehicle-based transponders only); and (d) providing special readers similar in appearance to ATM machines at read station sites or in other convenient locations. Additionally, low balance warnings should be given in situations where the balance is not easily obtained or may not be checked regularly by system users. Careful consideration should be given to the method chosen since in some cases users may not want their remaining balance openly displayed, especially when a large amount of money is stored on the card.

2.4.9 Transaction Receipt

Both the person-based and vehicle-based systems must be able to generate transaction receipts as needed by system users. For person-based systems, receipts could be generated as needed at the fare box or through a special request to a driver or attendant. For vehicle-based systems, a travel history could be maintained on the transponder and then downloaded to produce a receipt or travel summary at a later point in time. This would prevent the need for business travelers to stop at a manual lane each time a receipt is required.

2.4.10 Transaction Summary Information

While transportation agencies will typically need to maintain a record of transactions for financial reporting and auditing, there are a variety of other possible uses of this information. Consideration should be given to the specific data fields that are captured during a transaction to allow for subsequent analysis or development of summary reports. Possible uses of transaction summary information include: (a) isolation of equipment problems; (b) identification of trends in ridership and development of traveler profiles; (c) marketing of transportation services based on geographic location and levels of transportation service usage; (d) route or shift planning based on system usage; and (e) identification of possible cases of fraud based on record inconsistencies.

2.4.11 Open System Standards

Adherence to applicable national and international standards will support the interoperability of system components, including cards and readers, and will enhance the fairness of competition among system component suppliers. Additionally, by establishing standard equipment interfaces, fewer problems will likely be encountered during the upgrade or replacement of system components.

3. SUMMARY OF FINDINGS AND RECOMMENDATIONS

3.1 Key Findings

During the course of this study, many important issues, factors, and trends were uncovered. This section will identify some of the more critical items. Most, if not all of these items will have some bearing on the card design characteristics, or will impact overall system implementation and operation.

3.1.1 Fare And Toll Applications Have Significantly Different Requirements

While one of the goals of this study was to attempt to integrate fare and toll applications onto a single card, detailed investigation of the requirements for these applications demonstrated that the functional needs for these two types of systems were significantly different. Through analysis of the requirements in Task B, a clear division was made into person-based and vehicle-based applications.

One of the primary differences between these two types of systems involves the required read range. For the person-based applications, including open rail, closed rail, bus, taxi, and paratransit, it appears that a proximity or "touchless" solution possibly combined with a magnetic stripe capability will best satisfy integrated requirements. For vehicle-based applications, a longer read range is required to allow for non-stop toll collection. Another major difference is in the requirements for card size. In the person-based applications, an ISO standard card appears to be the best approach, while any reasonably sized tag will likely work for the vehicle-based applications since the tag will typically remain in the vehicle rather than be carried in a wallet or purse. Convenience, or ease of use, is also considered to be more critical in the vehicle-based applications where there is a need to limit required actions by the driver due to safety concerns.

Considering the present capabilities of non-contact card technology, it may not be practical to integrate long-range reading with an ISO card. While an option may be to implement a system that allows insertion of an ISO standard card into a dashboard unit used for vehicle to roadside communication, this advantage of this type of system has not been adequately proven in an operational environment. Furthermore, it is not clear what safety issues may arise when a user forgets to insert the card until reaching a toll plaza.

3.1.2 Only A Few Of The Existing Card Technologies Presently Satisfy Most Of The Critical Performance Requirements

In analysis of technology alternatives in Task B, performance requirements were considered to be most critical and were weighted higher than other requirements in developing an overall rating for each technological solution. Consequently, the main discriminating factors included read distance, transaction speed, information integrity, and read reliability. Additionally, identifying the most promising card technologies was more a process of elimination than a process of selection. Many of the available technologies could be eliminated because they failed to satisfy one or more of the most critical requirements. For example, IC Contact Cards scored well overall but failed to meet the critical requirements for read distance, transaction speed, and user convenience.

With the non-contact or "touchless" read distance requirement considered to be one of the most critical, there are only a few acceptable technologies including: the RF Proximity Card; the Type I RF Tag (Read-Only); the Type II RF Tag (Read-Write); and the Type III RF Tag (Smart Transponder). Each of these technologies has the potential to provide a feasible approach, depending on other system design aspects, e.g., credit vs. prepaid account, and centralized vs. decentralized validation and transaction processing. However, as was discussed in Section 2 (Vehicle-Based Systems), the read-only tag will only work in certain designs of a barrier toll system. For a closed toll road system which is distance-based, the read-write tag, and possibly the smart transponder, will likely be required.

For person-based fare applications, the RF proximity card appears to provide the best available option for an integrated fare card. Magnetic stripe cards will also satisfy most critical requirements for the relevant person-based fare applications, except for paratransit riders. Paratransit applications require a non-contact proximity technology to meet the needs of mobility-limited riders (see Section 2.2.1, Person-Based Systems). One possible way to still implement a magnetic stripe system for the majority of system riders would be to use a different type of card, and consequently a different card technology, for paratransit riders. However, this would require that both types of card readers, i.e., magnetic stripe and RF proximity, be installed in all locations.

Regardless of the specific design that is implemented, the above discussion of feasible technology options is based on the existing capabilities of these technologies. The choice of an appropriate technology for each scenario may change in the future as existing technologies are improved or other new technologies emerge which can satisfy the critical functional and performance requirements identified in Task B.

3.1.3 System Design Should Emphasize User Requirements

In order to increase ridership, transit agencies are placing a greater emphasis on identifying and meeting requirements from a user perspective. This includes determining card level specifications for performance, convenience, ease of use, durability, and reliability, as well as identifying user preferences for payment method and system operations. Additionally, transit systems must be able to support unique user groups such as paratransit riders, students, and senior citizens, without sacrificing overall performance for both frequent and infrequent system users.

3.1.4 Existing Telecommunication Capabilities Cannot Adequately Support On-Line Transaction Processing Requirements

The need for a short validation and transaction processing time is considered to be one of the more critical performance requirements identified in this study. Consequently, the ultimate system design must be able to support a transaction time that allows passengers or vehicles to move swiftly through gates or lanes, respectively. While some agencies have considered a centralized approach to ID validation and transaction processing, the existing telecommunications infrastructure will not adequately support this type of system.

The main reason why this approach will not work is due to the collective time it takes to query a central database, allow for a verification check, and receive a response over standard phone lines. An analogy can be made to the wait for an approval code when using a credit card to make a retail purchase. The difference between a validation time of a second or two, and five to ten seconds, becomes quickly apparent when the number of transactions is in the hundreds or thousands. Additionally, the reliance on telecommunication lines also involves the need for uninterrupted service, which is something that even the largest telecommunication companies cannot promise at present.

Eventually, more responsive and reliable telecommunications systems, such as fiber optics systems with redundant links, may be able to support timely on-line transaction processing. This type of capability may still be a few years from being fully adequate or cost-effective. Consequently, system design based on existing technology must perform ID validation and transaction processing at the local reading station.

3.1.5 Establishing The Financial Collection, Reporting, And Distribution Procedures For An Integrated System May Be One Of The Greatest Challenges Facing Transportation Agencies

While existing card technology capabilities and the rationale for using a specific technology approach are two of the main topics of this study, it became evident during discussions with transportation representatives that solving the financial issues associated with developing an integrated system may present a more significant challenge to the agencies. Several agencies indicated that once they had established the financial framework for an integrated system, actual upgrade or replacement of the fare box or toll collection technology would be a relatively simple task.

The financial issue that appears to raise the most concern is the **collection and distribution of shared revenue in an integrated environment**. Since in a fully integrated approach a card may be purchased from any relevant transportation agency, it will be necessary to ensure that the revenue for the card is distributed based on where the card is used. Independent financial clearinghouses are being proposed as a means of tracking revenue collection and distribution.

In some cases where a credit approach is being considered, the transportation agencies are not familiar with handling regular user correspondence or maintaining user accounts. The overall merit of the "credit" approach must be considered carefully, since in some cases cost savings achieved through improvements in operational system efficiency may be lost to the creation of a customer service and account maintenance functional area.

An additional concern is the cost of the card distribution and revenue collection infrastructure. Many transportation agencies, especially in the smaller cities or suburban areas, do not have the financial resources to establish a distribution network that is convenient to system users. Some agencies are currently considering forming partnerships with outside groups, such as credit card or lottery companies, who already have the distribution infrastructure in place, and who are more familiar with distribution and marketing strategies.

3.1.6 Interagency Cooperation Is Necessary, But Difficult To Achieve

The need for interagency cooperation, both internal and external, has become increasingly apparent in the design and implementation of automated card systems. Improvement of traveler convenience and other incentives that make transportation services more desirable to the public (e.g., transfers and pricing) will likely require adoption of an integrated approach by transportation providers. Transit passengers cannot be expected to carry a separate card for each transit service they use. Similarly, attaching multiple tags to a vehicle will not only cost more, it may also lead to conflicts during the reading process.

There are several transportation agency benefits that can be derived from group cooperation including a potential for better market penetration, lower equipment costs from manufacturers, and pooling of infrastructure resources. Unfortunately, reaching agreement on technical design characteristics and revenue collection and sharing procedures has already proven to be a difficult task for some pioneer groups.

3.1.7 The Integrated System Must Be Cost-Effective Over Its Full Life Cycle

The cost of implementing an automated card system is obviously one of the main concerns of transportation service providers. A low-cost technology is certainly preferable, but the technology must be able to support the essential functional requirements of the system. Additionally, the full life cycle cost must be used to assess the feasibility of any particular solution. The maintenance and operational costs of some designs could far outweigh the original equipment costs.

3.1.8 Transportation Agencies Are Risk Averse and Favor Proven Technology

Discussions with transportation agency representatives consistently demonstrated a reluctance to adopt potentially risky technological alternatives. In many cases this was due to limited experimental funding, a bias to continue using existing product or system suppliers, or political pressures which advocated waiting for proven results before initiating upgrade or replacement of existing systems.

As illustrated in Figure 5, choosing a technology that is nearly state of the art can be very costly. The converse situation of continuing to use outdated technology may also have a significant overall cost, due to the labor or time invested in manual processes. As the model demonstrates, the most cost-effective approach will typically involve choosing a recent but proven technology that is between these two extremes.

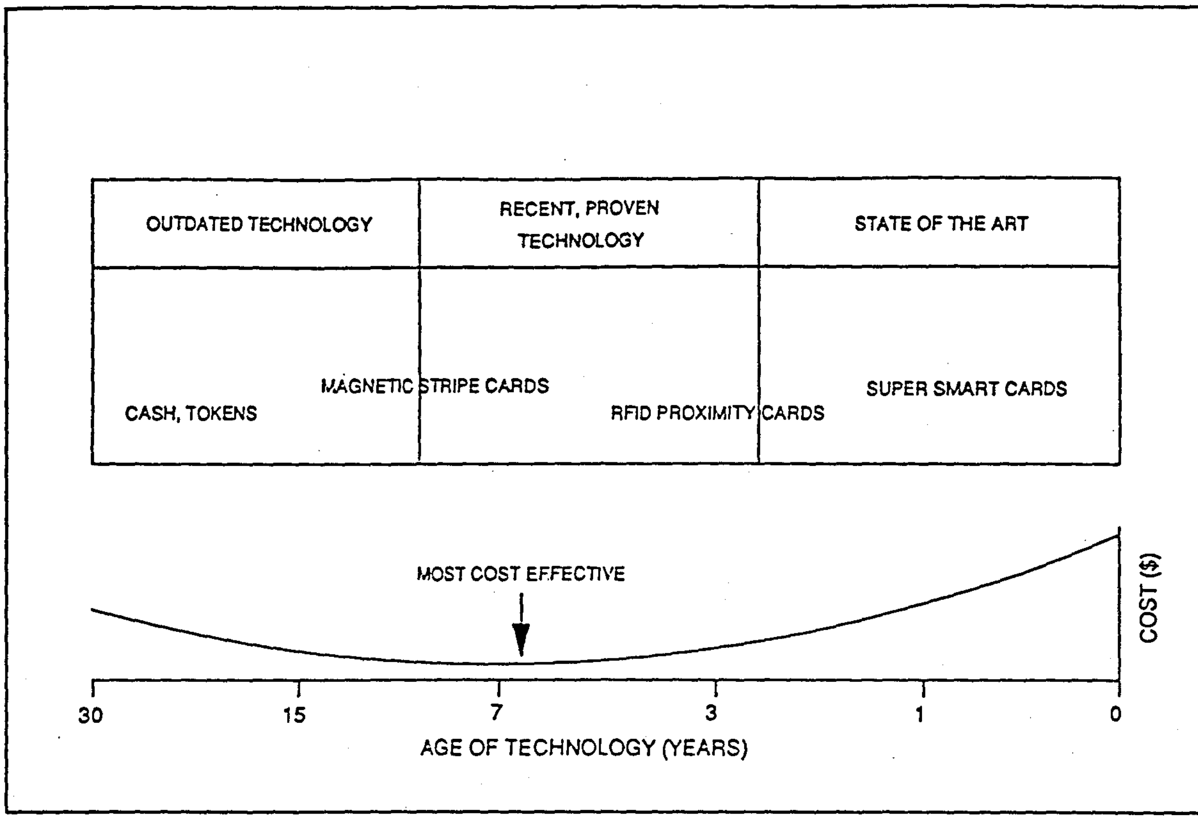

Figure 5. Optimum Technology Model

3.1.9 Standards Are Slow In Developing

Despite significant interest in automated card technology, some types of cards have not fully matured to the point where standards have been established. The large number of potential applications further complicates this problem by increasing the number of groups that are involved in the development of standards. Additionally, vendors of card and reader systems have often proposed their product specifications as standards without careful consideration of transportation agency and end user requirements.

3.1.10 Some External Factors Could Have A Significant Impact On System Design

The system design could be impacted by numerous external factors which may have varying degrees of influence on what constitutes a "feasible" solution. These factors include policy issues, organizational issues, regulations, legal issues, environmental concerns, safety concerns, security concerns, and external interfaces. It will be important to identify these factors and determine their potential impact early on in the system development process in order to prevent the creation of an inappropriate system. A summary and explanation of some of the more common factors can be found in the Task A report and Appendix C of this report.

3.2 Recommended Courses of Action

The following recommendations are provided in order to facilitate the continuation of efforts focused on the development and implementation of automated multimodal fare and toll collection systems. These recommendations are based on recurring needs identified by relevant stakeholders during the course of this study.

3.2.1 Establish a Contact Point for the Latest Information on Automated Card Technology

In order for transportation service providers to be aware of the latest developments, a contact point should be established to collect and disseminate relevant information as it becomes available. This will include maintaining information such as: (a) technical product specifications from relevant manufacturers; (b) summaries of existing and planned automated card applications in relevant transportation areas; (c) technical and policy contact points for interested transportation agencies, product manufacturers, systems integrators, industry forums or committees, and research groups; (d) copies of studies covering system design and implementation issues; (e) applicable standards for various types of equipment; (f) product samples; and (g) results of pilot or operational tests.

The types of information listed above are required by transportation agencies to make reasonable assessments of the type of system design most appropriate to their needs. Many agencies do not have the time or the financial resources to fully investigate the automated card industry, and consequently often depend on vendors for much of this information.

3.2.2 Continue Efforts to Resolve Remaining Design Issues

While this report has provided general recommendations on many of the key design issues, there are still many issues which must be investigated further. Some of the remaining questions include:

- What other applications, e.g., telephone payment, banking, access control, retail purchases, could logically be combined with an integrated transportation card?
- What is the most appropriate combination of technologies for a card that can support other common user needs outside of the relevant transportation applications?
- Should a different type of card technology be used for mobility limited riders in order to allow the more cost-effective magnetic stripe cards to be used for the majority of person-based system users?
- What level of standards are appropriate to help promote fair competition without limiting the technical creativity of manufacturers?
- Once the technical feasibility of a product is proven, can the manufacturers deliver products that are essentially free of defects and that have an acceptably low failure rate?

Additionally, the FTA should continue to explore whether emerging automated card technologies can satisfy the requirements of all the relevant transit modes on a single card.

3.2.3 Conduct Impartial Testing of Available Products

An impartial testing site should be established where transportation agency representatives can see the latest products perform under a variety of environmental conditions. While site specific tests will still need to be performed for each installation, this will familiarize agency representatives with product capabilities and limitations, and will also provide insight on system design considerations.

3.2.4 Establish Product Performance and Interface Standards

Despite significant interest in automated card technology, some types of cards have not fully matured to the point where standards have been established. The large number of potential card applications further complicates this problem, since it increases the number of different groups interested in the development of standards. Additionally, vendors of card and reader systems have often proposed their product specifications as standards without careful consideration of end user requirements.

The development of general equipment interface standards, particularly for cards and readers, as well as specific performance standards for an intermodal transportation system, will be critical to providing a cost-effective solution with the flexibility to support future system upgrades. Transportation agencies will be required to play a more active role in the development of system functional and performance specifications, and must work with card manufacturers to develop products that meet these specifications.

APPENDIX A
AUTOMATED CARD TECHNOLOGY PROFILES

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APPENDIX A - AUTOMATED CARD TECHNOLOGY PROFILES

Introduction

The purpose of these summaries was to provide the background information necessary to make informed decisions on a feasible conceptual design for a multi-use automated card system for fare and toll payment. The intent was not to make decisions on which card technology is superior, but to fairly present a summary of the technical and economical aspects of each technology.

The same outline was followed for each technical summary in order to facilitate comparison of the advantages and disadvantages of each type of card technology with other card technologies as well as with other non-card oriented solutions. For this appendix, the following outlines have been included: A.1 - RFID Card Technology; A.2 - IC Contact Card Technology; and A.3 - Magnetic Stripe Card Technology. Each outline includes the following sections:

1. Functional Introduction

2. Card Performance Characteristics
   - 2.1 Communication
   - 2.2 Memory
   - 2.3 Power
   - 2.4 Security
   - 2.5 Environmental
   - 2.6 Reliability

3. System Operation
   - 3.1 General Description of Components
   - 3.2 Standard Configuration
   - 3.3 Physical Characteristics
   - 3.4 Standard Interfaces

4. Costs
   - 4.1 Initial Equipment
   - 4.2 Infrastructure
   - 4.3 Operational
   - 4.4 Maintenance

5. Future Trends and Considerations
   - 5.1 Anticipated Developments
   - 5.2 Life Span Limitations
   - 5.3 Standards

A.1 RFID Card Technology

A.1.1 Functional Introduction

RFID technology is generally used to support applications where one of the primary requirements is the ability to perform a transaction remotely. By not requiring direct contact, the system can be designed with greater flexibility and can be used in harsh environments where it is not practical to use other types of cards such as optical, barcode, IC contact, or magnetic stripe.

The range of RFID products is extensive. Depending upon the requirements for read distance, transaction speed, mobility, memory capacity, power consumption, and durability, there are a multitude of different vendors with relevant experience and specialized product lines. At a high level, however, there are two distinct categories of RFID products: short range (or proximity), and long range. It is typically necessary to determine which category an application requires before investigating products since the majority of the vendors currently do not make products in both categories.

Short-range or proximity RFID generally involves a range of less than a few feet. Common applications include production control, access control, item routing and sorting. In most of these applications, low-cost RFID technology is used. Low cost implies that there is a minimum amount of electronics (e.g., integrated circuit chips or onboard power), memory capacity, and application flexibility. Most cards in this category are typically used for identification only, leaving most of the processing and recording functions to the reader or to a central control unit.

Long-range RFID is typically in the range of 20 to 50 feet, but may include anything from 10 feet to a couple of miles. Common applications include Automatic Vehicle Identification (AVI), item inventory, and item tracking. Products in this category generally include a mix of low cost and high cost, depending on the amount of processing capability that is incorporated into the card or tag.

A.1.2 Card Performance Characteristics

A.1.2.1 Communication

There are a multitude of variables that must be considered to fully understand which RFID communication method is most appropriate. The ability to accurately, efficiently, and securely communicate between the card and the reader is effected by the communication method (type of signal), modulation scheme (method of data encoding), operating frequency, signal directionality, information transfer rate, sleep cycle delay (if battery powered), and specific capability requirements for traveling speed, multiple card reading, and range.

METHOD

Generally, the choice of a particular communication method depends on range requirements, the need for stationary vs. mobile interrogation, orientation requirements for the card, and expected varieties and levels of interference. Common RFID communication methods are described below.

Reflective Backscatter - This method simply takes the original signal sent by the reader, modifies or modulates it, and then reflects the modified signal back to the reader. In order to ensure that the signal is reflected back to the reader, the card and the reader must be properly aligned. Some systems may also require a metal backing on the card.

Single Frequency (Transmit/Receive) - This method involves using a transmitter and receiver combination on both the card and the reader unit. While in some systems this may require a battery on the tag, the use of a battery will allow the interrogator signal to be sent at a lower power while maintaining the same read distance.

Spread Spectrum (Transmit/Receive) - This method utilizes a communications technique that was originally designed for military systems. One advantage of this technique is that it can reduce the effect of some types of interference. However, this technique currently remains very expensive to implement for typical RFID applications.

MODULATION

Information is encoded on the carrier signal using modulation. Common modulation schemes include the following:

- AM (Amplitude Modulation)
- FM (Frequency Modulation)
- PM (Phase Modulation)
- ASK (Amplitude Shift Keying)
- FSK (Frequency Shift Keying)
- PPM (Pulse Position Modulation)
- PDM (Pulse Duration Modulation)
- PWM (Pulse Width Modulation)

The most prevalent of these schemes for analog communication are AM and FM. AM is considered a much simpler and less expensive method than FM, but FM is generally preferred due to several advantages including immunity to pulse noise (e.g., machines, electric equipment, lightning) and a heightened ability to separate signals based on their strength (which decreases with distance).

Shift keying techniques such as ASK and FSK are used for digital modulation where digital data must be transformed into an analog signal in order to be transported on the carrier frequency.

COMMUNICATIONS FREQUENCY

While specific definitions of communications frequency categories for RF/ID may vary, they are generally described in the three categories identified below. Figure A - 1 (Characteristics of RF Communications Bands) graphically depicts these categories next to electromagnetic spectrum subdivisions as specified by the International Telecommunications Union (ITU), as well as listing the key advantages and disadvantages of each band.

LF, MF, HF < 30 MHz

Typically, the lower frequency electromagnetic range is useful for proximity applications where the existence of non-conductive materials such as plastic, glass, wood, dirt, and grease must be overcome. This range has disadvantages in terms of the speed at which information can be transmitted, the number of reads in a given time interval, and the communication range which can be attained using low power levels.

VHF and Lower UHF 30 MHz to 1 GHz

The VHF and lower UHF range provides the capability to increase read distance and data transmission rate over levels obtainable in the low frequency range. Data transmission rate, typically on the order of several kbps for this frequency range, becomes more critical when there is a significant amount of information that must be stored on a card, or when the card is placed on a moving object. While the data rate and read range are not as great as in the microwave range, the longer wavelength of radio waves makes them less sensitive to atmospheric attenuation.

Microwave Frequency 2 GHz to 40 GHz

This range generally provides the highest data transmission rate (in the hundreds of kbps range), and consequently is more suited to the reading of mobile objects since there may only be a small time window where communication is possible. The ability to improve read range results from the fact that high frequency signals can be focused more accurately into a beam which propagates energy in a single direction rather than diffusing the energy omnidirectionally. Disadvantages of high frequency communication include greater likelihood of interference, spurious reflections, multiple card conflicts, and possible licensing and safety problems. For long-distance communication in this frequency range, many systems also have high power requirements.

For each of the three frequency ranges described above, there are also limitations on the specific frequencies that can be used for low power unlicensed communications. In the U.S., the FCC has specified the available unlicensed bands (see Figure A - 1) as follows: (I) 260-470 Mhz; (II) 902-928 Mhz; and (III) 2400-2484 MHz.

Unfortunately, the bands specified by the FCC do not always coincide with the bands available in other countries. Also, the availability of these bands may change due to reallocation of the spectrum by the FCC based on the high demands currently placed on certain portions of the spectrum, on plans by the European Community to specify 5.8 GHz as the common frequency for

ITU SPECTRUM	FCC	WAVE TYPE	ADVANTAGES	DISADVANTAGES
LF (Low Frequency) 30 - 300 kHz; MF (Med. Frequency) 300 kHz - 3 MHz; HF (High Frequency) 3 - 30 MHz		LOWER FREQUENCY ELECTRO-MAGNETIC < 30 MHz	- LOW POWER REQUIREMENTS - GOOD FOR PENETRATION OF DEBRIS - MULTIPLE TAG CONFLICT UNLIKELY	- VERY LOW DATA RATE - SHORT COMMUNICATION RANGE - ALIGNMENT OF EQUIPMENT CRITICAL - MORE SUSCEPTIBLE TO INTERFERENCE CAUSED BY ELECTRICAL EQUIPMENT
VHF (Very High Freq.) 30 - 300 MHz; UHF (Ultra High Freq.) 300 MHz - 3 GHz		RADIO 30 MHz-1 GHz	- TRANSPARENT TO IONOSPHERE - NOT SENSITIVE TO RAINFALL ATTENUATION - SUITABLE FOR BROADCAST COMMUNICATION	- LOW DATA RATE - EQUIPMENT ALIGNMENT IMPORTANT - SENSITIVE TO MULTIPATH INTERFERENCE (REFLECTION OFF LAND, WATER, OBJECTS)
SHF (Super High Freq.) 3 - 30 GHz		MICROWAVE 2 - 40 GHz	- HIGH DATA RATE - GREATER COMMUNICATION RANGE - SUITABLE FOR POINT-TO-POINT COMMUNICATION	- SENSITIVE TO ATMOSPHERIC ATTENUATION - MAY HAVE HIGH POWER REQUIREMENTS - MICROWAVE OVEN INTERFERENCE

Figure A-1. Characteristics of RF Communication Bands

RF/ID and related applications, and on the anticipated development and use of new technologies such as Personal Communication Services (PCS) and Intelligent Transportation Systems (ITS).

DIRECTIONALITY

Directional capability becomes an important factor when the orientation and location of the card varies within the application. Omnidirectional capability (generally found in the radio frequency range) allows systems to be designed which can read cards regardless of their orientation, and may also allow limited reading even in the presence of metal objects or when there is not a direct line of sight between the card and the antenna. The decision to use an omnidirectional system, however, must consider application requirements and be weighed against the benefits of directional or focused beam systems, since the use of a directional system can mitigate multiple card read problems.

INFORMATION TRANSFER RATE

One of the main advantages of RFID is the ability to communicate with mobile cards, although the ability to complete a transaction will depend on several different constraints, including the traveling speed of the card, the size and shape of the communication window (where the reader is focused), and the time required to power up the card (if necessary). Generally a higher the signal frequency allows a greater system bandwidth, and consequently a faster transmission rate. Rates of interest to applications requiring the identification of fast moving objects (over 20 mph) are typically on the order of several hundred kbps (kilobits/second). The exact rate required will also depend on the amount of information that must be transmitted since a simple ID code can be read relatively quickly, while a complete transaction history will take much longer.

MULTIPLE CARD CONFLICTS

There are several concerns relating to the reading of multiple cards within an RF field. The ability to read multiple cards simultaneously becomes important when using a longer read range and when cards are located close to each other. There are a variety of existing techniques to differentiate between cards, many of which are considered proprietary. System control software is frequently used to differentiate between multiple cards in transaction oriented systems, while item identification and inventory may require more sophisticated hardware for card separation. An additional consideration is the number of reads required to accurately identify all cards within range, since many systems base accuracy projection on a minimum number of read attempts.

STANDARDS AND PROTOCOLS

One of the main issues regarding the development and use of RFID equipment is the present lack of global RFID system standards. The most publicized RF standards concerns are in the area of communication frequencies, but other system standards issues must also be addressed (e.g., dataframe, bit encoding).

While there are a wide variety of applications which might benefit from the use of RFID equipment, the absence of domestic and international communication standards has increased the financial risks involved with procuring RFID equipment characterized by limited communications flexibility. It appears that the European Community may settle on 5.8 GHz as the standard frequency for ETTM (Electronic Toll and Traffic Management) communications. Currently however, many toll systems in Europe use 2.45 GHz, while the majority of existing U.S. toll systems operate in the 915 MHz band (the actual FCC range is 902-928 MHz).

A.1.2.2 Memory

TYPE OF MEMORY

The choice of a particular type of memory can be based on how often stored information needs to be changed, and other specific application requirements for versatility and flexibility. The following types of memory, which are presented in order of increasing complexity, are commonly used in RF/ID systems. As the complexity of the memory increases, there is also an associated increase in die size and consequently in cost.

Non-Volatile Memory (NVM)

ROM - Read Only Memory is generally encoded at the integrated circuit manufacturing plant. Using ROM where possible will help reduce the chip size and prevent unintended loss or modification of key information.

EPROM (Electrically Programmable ROM) - This will allow a single write where the information is "burned in" during assembly, and then it becomes read-only.

SERIAL EEPROM (Electrically Erasable Programmable ROM) - Will allow multiple read-writes. This chip has a standard 8 pin size, is currently available in 5 volt and 3-3.5 volt types, can be directly addressed, and is currently available with capacities up to 16 kbytes.

PARALLEL EEPROM - Also a read-write chip, but is significantly (5 to 6 times) larger than serial EEPROM. This chip has a standard 32 pin size, currently requires 12 volts of power for programming (most EEPROMS on the market require higher voltage for programming than for reading) and can currently provide memory capacities up to 128 kbytes.

FLASH-EEPROM - This type of memory has a read-write capability and is generally used for capacities over 128 kbytes. Unlike the other EEPROM chips, this chip is not selectively addressable, and requires that entire blocks of memory be erased and rewritten in the write process (12 volts of power is required for the write process).

Volatile Memory

DRAM - DRAM chips are the least expensive way to store large amounts of read-write memory and use the densest circuitry. However, DRAM chips require constant current to retain their data. In PCs, DRAM chips are used for main memory.

SRAM - SRAM chips are more expensive than DRAMs and more easily reprogrammed than flash memories. However, while they use virtually no current, they require a constant voltage source to retain their data. In PCs, battery-powered SRAM chips are used to store clock and startup data when line power is turned off.

MEMORY CAPACITY

Currently available memory capacities vary by memory type (e.g., Serial EEPROM-16 kbytes, Parallel EEPROM-1 Mbits). ROM can hold a significant amount of information, but in most card applications there is rarely a need for a large amount of unmodifiable data. Consequently, ROM is typically used for identification and security codes.

Also, chip manufacturers are beginning to mix memory types on the same chip. A chip may include a combination of RAM, ROM, and EEPROM, each performing different functions. Therefore when understanding memory capacity requirements, it is important to only consider storage area that is available for application data, since in some cases a portion of the total available memory is set aside for control functions. It is also important to realize that memory capacities may be specified by suppliers in either bits or bytes, which may cause confusion.

MEMORY INTEGRITY

The chip oriented memory commonly used in RF cards and tags, as with all forms of changeable media, may be subject to a loss of data. This includes all of the chip memories listed above with the exception of ROM, which is encoded and verified by the manufacturer and cannot be altered. Even EPROM memory which can only be written once, and then becomes read-only, may need to be verified to ensure that it retains its original information.

LIFE SPAN

Different memory types have different limitations on the number of read-write transactions that can be performed. For example, EEPROM presently allows approximately 10,000 rewrites before the information integrity becomes uncertain, while FLASH memory may only allow 100 re-writes.

A.1.2.3 Power

A variety of solutions exist for providing on-card power; most solutions involving batteries require some amount of maintenance. Power also relates to the signal strength of the communication transmission. Factors which should receive attention include:

Power Type

There are basically two categories with respect to card power: active and passive. Active cards typically rely on the use of a battery to allow the card to perform a variety of activities including: information processing; memory management; signal amplification; and signal transmission. Passive cards may receive power from the RF signal emitted from the read-write unit. Proximity-type RFID cards typically receive and transmit signals using carrier frequencies in the range of approximately 50 kHz to 200 kHz. Signal transmission uses localized magnetic induction fields created and sensed using loops of conductor, rather than propagating electromagnetic waves. The RF energy received by an RFID card from a nearby transponder can be transformed to DC by an on-card power supply, and used to power card circuitry.

Transmission Power

Transmission power relates to the signal strength required at a certain frequency to accurately transmit information over a specified distance. While increasing the transmission power may provide a better transmission range, there are limitations to acceptable power levels due to human safety (e.g., exposure to electromagnetic fields) and possible interference with other communications. The IEEE C95.1-1991 standard has defined the maximum permissible human exposure in a controlled environment to be 10 milliwatts/cm^2. This IEEE standard includes a provision that exposure to this power level should not be maintained for longer than six minute intervals. The exact level permitted will also depend on the specific frequency used. Additionally, a level of 100 milliwatts/cm^2 has been adopted by the U.S. Army as "intrinsically" safe in the presence of munitions.

Battery Type

There are basically two common types of batteries used in smart card applications. The first is a lithium button-type battery and the second is a nickel-cadmium rechargeable battery. A thin version of the lithium battery is also available, but has not been widely accepted since it does not easily fit into the ISO standard financial cards, and may be damaged as a result of bending.

Battery Life

Lithium batteries generally have an average life of about 5 years. Suppliers typically claim a life span between three and eight years. Battery life may be significantly reduced depending on environmental conditions. In some cases reading and writing to the card will have an impact on battery life. Some systems provide a battery low warning prior to battery failure (typically this is difficult with a lithium battery). This is important, because in some cases an inability to read the card may not be noticed immediately. Also, without knowledge of the remaining battery life, the inclination may be to replace the batteries more frequently than necessary rather than to risk failure. In cases where battery power is used to enhance the communication signal, it may still be possible to read the card once the battery has failed, although range may be reduced.

A.1.2.4 Security

Security concerns in RF data card systems exist and can be addressed at many levels. From a systems point of view, it is useful to consider the potential value of the information maintained on the card and the estimated cost of circumventing security measures. Security is enhanced by keeping the value of the information as small as possible, and raising the cost of subverting system safeguards.

Providing information to authorized users may also make the information more readily accessible to unauthorized users. Therefore, security issues should be addressed at each system level starting at the integrated circuit chip and continuing to the central control unit. For most RF systems, card level security is primarily determined by both chip security and communications signal security.

Chip Security

One of the primary concerns is the method used to store information, since it is this method which generally defines the level of information security that can be attained. There are specific hardware features of a secure microcontroller which can prevent access to stored information. These features can be utilized to ensure that data cannot be selectively modified. Common techniques used to prevent unauthorized access to information include password identification, and data encryption.

Signal Security

Careful consideration should be given to the method used for protecting the RF signal, since it may be possible to duplicate this signal if it is not disguised or encrypted. Illegal frequency detection circuitry can be used to dynamically verify the signal received by both the card and the reader.

A.1.2.5 Environmental

RF cards and other system components must, at a minimum, be able to withstand the environmental conditions expected under normal use. While specific durability requirements will vary depending on the application, the following factors should be considered:

Operating Temperature:

Typical RF card operating ranges are generally within -40°C to +60°C while some cards geared toward production use may be able to withstand much higher temperatures. The difference between operating and storage temperature may also need to be considered depending on the application. The storage temperature range is typically greater than the operating range.

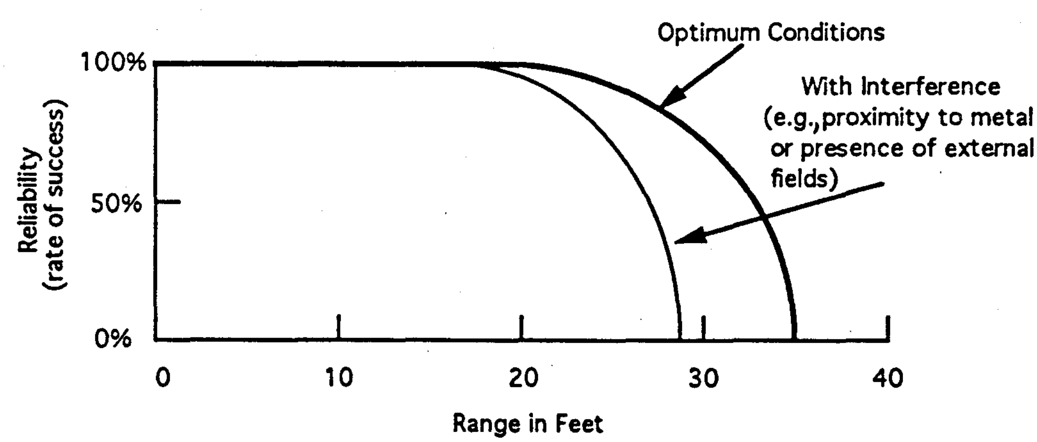
When considering temperature it is useful to realize that temperature extremes, even within allowable ranges, may reduce component life. Battery life may be reduced significantly when exposed to high temperatures.

Environmental Resistance:

There are many environmental elements which may affect the soundness of a card, including exposure to humidity; fresh or salt water; salt mud; icing/freezing rain; sand and dust; mechanical shock; drop shock; and temperature variation. Testing should be performed to determine the potential for component malfunction based on any one or combination of these items. There are specific military standards and procedures relating to the measurement and testing of each of these items (specified by Military Standard 810D). However, military standard compliance might be overkill for devices used in consumer applications.

A.1.2.6 Reliability

RFID equipment suppliers often describe product performance in terms of the maximum possible effectiveness under the most favorable conditions. Ultimately, however, it is necessary to consider more realistic ways of measuring reliability relative to specific application conditions. A useful way to view the reliability of a particular product is to graphically depict how performance is diminished as a result of introducing different types of external influences (see Figure A-2).



Note: Supplier may claim a read range of up to 35 feet. However in order to maintain reliability near 100% this product can only be used at ranges up to 20 feet. Also, in situations where interference exists, reliable read range may be reduced even further.

Figure A-2. RF Communication System Range Reliability

Based on the application, a reliability rate (e.g., 99%, where 99 out of 100 reads are accurate) should be established as a minimum acceptable performance level. Once this is done, tests can be conducted to determine the maximum possible range that will support this reliability rate. Supplier products can then be compared, based on expected forms of interference, to determine which products provide the best range.

A good indicator of reliability is whether or not exactly the same result is repeated under identical conditions. Many products will sample the signal multiple times in order to verify accuracy, and may not include occasional mis-reads in reliability rates. However, variations in results, even within tolerable performance levels, may suggest reason for concern.

A.1.3 System Operation

A.1.3.1 General Description of Components

RFID system components can be arranged in a variety of configurations depending on the specific application, but there are six main component levels which must be addressed: IC Chip; Card; RF Communications; Antenna/RF Module; Reader; and Central Control Unit.

Central Control Unit

Generally, the central control unit performs the functions of coordinating system communications, compiling activity information, and managing the user interface or information display. The specific responsibilities of the central control unit may vary depending upon the intelligence of other system components. Some systems may place more responsibility on the card for validation, and information storage, while other systems may rely primarily on information maintained in the central control unit for processing each transaction.

Reader

The reader performs the functions of converting information into the format used for transmission by the antenna/RF module, and amplifying and interpreting the information that is received by the antenna/RF module. This conversion process involves either combining information with, or separating information from, the format definition and error management bits. In most fixed reader applications, the reader will communicate with the central control unit via a parallel or serial interface. In a completely remote system, a portable hand-held reader may perform the functions of the central control unit including information processing, and information display.

Antenna/RF Module

The antenna/RF module is responsible for transmitting and receiving energy in the radio frequency spectrum. For transmission, the RF module may generate the RF energy using an RF oscillator, amplify it in an RF processor and transmit the energy through the antenna to the card. For reception, the system may use the same antenna, which receives the RF energy and preconditions and amplifies the signal prior to relaying it to the reader.

RF Communications

While there is no hardware associated with the actual communication signal once it has left the antenna, there are a multitude of different communication techniques, each of which has its own advantages and drawbacks. Signal frequency, strength, and type of modulation will impact the effective range of communications, the types of interference that will be encountered, the rate at which information can be transmitted, the directionality of the signal, and the workable orientation of cards and antennas.

Card (Tag/Transponder)

The card (sometimes referred to as tag or transponder) is responsible for receiving the signal emitted by the antenna, modifying the signal, and either reflecting or re-transmitting the signal back to the antenna. RF cards typically consist of at least an antenna/RF module, a memory chip, and other chips and circuits which handle internal functions such as modulation, code generation, system clock functions, and card power. Cards may also include a microprocessor (which provides intelligence and makes the card a true "smart card") and a battery which provides internal power. Obviously, as more complexity and functionality is added to the card, the cost and size of the card increase, limiting practical and cost-effective application.

IC (Integrated Circuit) Chip

IC chips are used to store information and, in some instances, to process information and control card functions. While the IC chips are a significant element of the card, they must be considered separately in order to develop a clear understanding of how they impact overall system capabilities and performance. Presently, the majority of chip suppliers do not get involved in producing cards. They simply sell their products to card manufacturers, who integrate them with other card components. This may change in the future, however, as some chip manufacturers such as Motorola (Scotland) and Micron (Boise, ID) are beginning to create a larger market for their products by developing integrated circuit chips specifically for the smart card market.

A.1.3.2 Standard Configuration

The most common RF system configuration consists of three separate hardware items including the card, the reader, and the central control unit. In this configuration, the reader includes the antenna/RF module.

A variety of portable configurations have also started to emerge. The most popular involves the use of a hand-held reader with its own internal memory and power supply. In some applications (e.g., container tracking), the hand-held reader can be used to display information maintained on the card.

Recently, other forms of contactless card technology (e.g., inductive and capacitive coupling, barcode, magnetic stripe) have been combined with RF technology to form hybrid systems.

AT&T has developed a contactless card which communicates with a reader using inductive and capacitive coupling. For electronic fare collection applications, this is combined with a dashboard reader module (manufactured by Mark IV of Canada) which uses RF to communicate with roadside readers. R&D efforts are underway to develop a low cost RF/barcode tag which can be used for item tracking and routing applications such as airline baggage handling. Combination magnetic stripe and RF chip cards are also beginning to emerge.

A.1.3.3 Physical Characteristics

RF cards range in size from small buttons or pins used for security or item sorting, to hockey puck or cassette size tags which can be attached to containers or vehicles. Typically the smaller RF devices have limited memory capacity and communication range, and are used for low-cost, proximity applications.

On-card processing, large data capacity, and long-range communications require more circuitry, placing limitations on how small the device can be made. Presently, many manufacturers are working to develop a full-featured RF card which is no thicker than an ordinary credit card, but currently there are no products satisfying this constraint.

A.1.3.4 Standard Interfaces

Presently, RF interfaces vary from one supplier to another. Additionally, there are a variety of cable interfaces which are used in RF systems including RS-232, RS-485. Some equipment suppliers have provided tags which can communicate either via RF or through modem ports. In most systems, however, card to reader communication is performed using RF, and reader to central control unit communication is performed using a serial connection. Despite these common configurations, there is still no industry standard communication speed or type of RF interface.

A.1.4 Costs

A.1.4.1 Initial Equipment

Card Cost - Unit cost of the card will depend on a multitude of factors including the information storage type and capacity, on-card processing power, and communication range, to name a few. Moreover, the cost of the card cannot be treated as an independent item. The ratio of cards to readers for the specific application, and the relative cost of these components will help to determine what type of card should be used. Presently, card costs range from about 50 cents for short range identification products, to over $100 for specialized, long-range, read-write smart transponders. Actual cost per card is based on both card features and on the quantity of cards purchased.

Reader Cost - Reader cost will include the total cost of the antenna/RF module and the reader unit. Fixed reader costs typically range from $3,000 to $12,000, with the lower figure representing volumes of several hundred to several thousand units.

Hand-held Reader Cost - The availability and cost of hand-held readers becomes particularly important in applications where unplanned reading is required or where it is not feasible or cost-effective to install fixed readers. Hand-held reader costs typically range from $4,000 to $8,000.

A.1.4.2 Infrastructure

In most cases, cards are distributed directly by the service provider. For example, in most toll applications users must typically pick up devices at a few limited locations. As a result, the distribution costs are relatively low. This may change in the future, however, as many toll agencies will likely use distribution channels which are more convenient to users.

While RF card systems may not necessarily reduce overall system costs associated with information control, auditing, and reporting, they have the potential to increase the accuracy of information.

A.1.4.3 Operational

Some training costs are likely to be incurred as a result of switching to new identification and transaction handling methods. In many cases, however, properly designed and implemented RF systems should lead to reductions in necessary staffing levels and overall operational costs.

A.1.4.4 Maintenance

While initial procurement and operational costs are usually the primary consideration, the maintenance costs should not be overlooked in evaluating the viability of a solution. Maintenance costs have the potential to be many times the cost of the original equipment.

RF cards which are battery powered present special situations which could have significant long-term maintenance costs. In many cases this would require maintaining inventories of replaceable batteries, or spare cards where non-replaceable or non-rechargeable batteries are used (and the entire card is discarded once the battery is out). Variations in battery life due to environmental conditions (e.g., high temperature) would also require periodic checking of remaining battery life.

A.1.5 Future Trends and Considerations

A.1.5.1 Anticipated Developments

Integrated Circuit Chips

The most dramatic developments impacting RFID systems technology in the near future will likely come in the area of IC chip improvements. Integrated circuit chips, according to several chip manufacturers, will continue to get smaller, cost less, and have greater security and versatility. Expected future enhancements include: smaller size; higher memory capacities; faster clock speeds; lower power consumption; more single chip mixed memory (e.g., RAM, ROM, EEPROM); and greater overall IC integration (e.g., RF modules on the same silicon as microprocessor and memory).

Multi-Function Cards

RF cards have historically been used in low-cost, single function applications. This is expected to change as products are increasingly standardized to prevent the need for consumers to maintain separate cards for similar applications. For example, AVI toll systems currently differ between regions or states which is a significant hindrance to the trucking industry where interstate travel is frequent. The long-term trend is toward the development of a multi-functional card that can maintain separate accounts for different collection agencies, as well as support a variety of applications such as toll collection, transit fare systems, and financial transactions.

Multi-Technology Cards

As different automatic identification technologies (e.g., RFID, barcode, magnetic stripe) become accepted for specific applications (as each technology finds its niche), and as cards begin to support multiple functions, there will be a trend to combine multiple technologies on a single card. This will allow the card to take advantage of the most appropriate technology depending on the particular situation.

A.1.5.2 Theoretical Technical Limitations

Reading Distance

The potential reading distance of RF products is limited by a number of factors such as frequency and signal strength. As additional restrictions are placed on signal strength due to safety and interference concerns, advances in reading distance and the rate at which information can be transferred will also be limited.

A.1.5.3 Standards

RFID fare payment card systems use so little RF power that FCC licensing is not required, and a sizeable range of frequencies can be used. In the future if technological advances allow one stored-value RFID card to be used for several applications as long as the correct numbers and codes are stored, standards for frequency and communications protocols will be essential. Protocol standards will need to cover a variety of issues, including modulation type, record structure, error detecting/correcting technique, and encryption.

AVI systems operating at UHF and microwave frequencies will be affected by the reallocation of the frequency spectrum anticipated within the next several years. The reallocation is due to the high demands currently placed on portions of the spectrum, and on emerging technology areas (e.g., cellular communications, IVHS) which will require allocation of special bands. In addition, the European Community is attempting to standardize AVI systems to use a small band in the 5.8 GHz range within the next several years.

A.2 IC Contact Card Technology

A.2.1 Functional Introduction

Cards using electrical surface contacts for communication were the first form of IC cards (cards which contain Integrated Circuit chips) to be introduced. Despite the growing interest in other types of IC cards (e.g., RF cards), they still represent the largest portion of the IC/Smart Card market. These cards have embedded microelectronic circuits which are connected to metallic contact pads on the card surface. The standard card has eight surface contacts (most existing cards actually use only six of these) which perform data communications, supply power to the card, and provide clock timing signals for control functions.

Contact cards may contain a microprocessor making them a true "smart card" or they may simply be memory cards (used as secure information storage devices). The use of a microprocessor allows a higher degree of security to be attained by performing on-card verification and information access control.

Most contact cards also have a magnetic stripe to allow them to be read by a wider variety of equipment. This dual technology approach is necessary in many cases to allow a smooth transition to new reading equipment, rather than mandating the immediate replacement of existing reading equipment, which could have a substantial cost due to the extensive number of magnetic stripe readers that have already been distributed. The magnetic stripe portion of the card, however, cannot maintain as much memory or provide as high a level of security as the microelectronic portion. Consequently, the full functional capability of the card cannot be realized unless the contacts and internal microelectronics are used.

IC contact cards first started to appear in the French telephone industry in 1983. The need for common equipment configurations eventually led to the ISO (International Standards Organization) adoption of standards for card size, I/O format, and on-card positioning of physical contacts in 1987.

The two primary types of IC contact cards are prepaid cards and credit/debit cards. Prepaid cards usually contain a low monetary value which is decremented as it is used. Typical pre-paid card applications include telephone cards and transit cards. Credit/debit cards generally record transactions and tie them to a customer account. Typical credit/debit card applications include bank cards and retail charge cards. A higher transaction value is generally allowed on credit/debit cards which necessitates a greater level of security. In most prepaid card applications it is assumed that the card bearer is the owner of the card, while credit/debit cards almost always require verification of user identity using one or a combination of authentication techniques (e.g., Personal Identification Number or PIN).

A.2.2 Card Performance Characteristics

A.2.2.1 Communication

METHOD

Information is communicated between the card and read-writer through the electrical contacts on the card surface. The card must be physically inserted into a reading device in order to transmit information.

SPEED

Information is typically transmitted between the card and the read-write unit at a speed of 9600 bps.

STANDARDS

Standard communication specifications (including communication modes and protocols) for ISO IC contact cards are defined by ISO 7816 Part III.

A.2.2.2 Memory

IC contact cards typically have memory capacities in the range of 2 - 8 kbytes (or the equivalent of up to 2 standard text pages), but may hold more in the future as chips with higher memory capacities and lower power requirements are already available.

See memory description for RFID cards (Section 1.1.2.2) for detailed descriptions of the various forms of memory chips available and other relevant issues.

A.2.2.3 Power

In most IC contact cards, power is supplied by the reader/writer through card surface contacts. In some cases, batteries may be embedded in the card. According to ISO specifications, IC cards should operate properly at 5 volts +/- 10% and for any frequencies (clock speed) between 1 and 5 Mhz. (Note: While the current standard is 5 volts, there is a trend toward the use of integrated circuit chips which have lower power requirements, e.g., 1.4 or 3.5 volts).

There is generally a concern for what may happen if the card is supplied power that is outside the vendor recommended range. Since card performance outside this range is unpredictable, it may be possible to illegitimately obtain access to restricted information. Therefore, the prevention of operation outside of the normal power ranges is an additional security concern.

A.2.2.4 Security

Common safeguarding measures (available to all types of contact cards and other high memory technologies) listed in increasing measure of security, include: (a) basic identification (no verification); (b) PIN verification (e.g., public key, DES); (c) biometric verification (e.g., fingerprint, retinal scan, voiceprint).

Security in contact cards is limited by the processing capability on the card to perform verification routines, the type of memory that is used in the application, the type of encryption used on the information transmitted, and prevention of physical penetration of internal card electronics and memory modules.

A.2.2.5 Environmental

TEMPERATURE

IC contact cards will typically perform accurately within a temperature range of 0°C to 40°C. Most cards can be stored or exposed to temperatures ranging from -35°C to 80°C without being damaged or losing data. Readers can typically withstand the same storage temperature range but have a more restrictive operating range.

OTHER

Operational relative humidity (non-condensing) ranges for cards are typically between 20% and 90%, while readers will operate between 25% and 85%.

Cards will generally withstand rain and water splashing, while readers will not operate in the rain. In addition, cards should be dry before they are inserted into the reader. Cards will also withstand reasonable levels of dirt, salt spray, and ultraviolet radiation.

A.2.2.6 Reliability

Primary reliability concerns include wearing of the physical contacts, and vandalism of the reading/writing equipment. Once the card is properly inserted into the reader, the accuracy of data transmission is very high and there is little concern about interference which is a common issue in the use of non-contact cards (e.g., coupling, RF).

A.2.3 System Operation

A.2.3.1 General Description of Components

IC contact card systems consist of three primary components: (a) cards; (b) readers; and (c) central control units.

CARDS

There are two basic types of IC contact cards: memory cards, and microprocessor cards. Memory cards typically contain a small amount memory (32-128 bytes) and are used in debit card applications. (Note: This type of memory card should not be confused with the PCMCIA 68-pin card module, also referred to as a "memory card," that has a high memory capacity and is used in computer applications.) Microprocessor cards, which are commonly used in credit/debit applications, typically contain up to 8 kbytes of memory, include an 8-bit microprocessor, and can provide a higher level of security.

READERS

According to McCrindle, read-write units can be categorized into four basic types: (a) intelligent stand-alone units; (b) non-intelligent units; (c) hand-held units; and (d) integral units. Intelligent stand-alone units contain a microprocessor, memory, keyboard, display, and are capable of performing all transaction functions without being connected to a central control unit. Non-intelligent units simply provide an interface to the central control unit, typically through an RS-232 connection. Hand-held units are small battery powered devices normally containing a keyboard and small display. Integral units are non-intelligent units that are part of a larger, more complex device, such as an automatic teller machine (ATM).

CENTRAL CONTROL UNITS

The central control unit performs the functions of coordinating system communications, compiling activity information, and managing the user interface or information display. The central control unit may consist of a local machine coordinating the operation of one or more readers, or may be a remote system connected through a telecommunictions link.

A.2.3.2 Standard Configuration

The standard configuration involves the use of a card, a reader, and a central control unit. The main variable in the configuration is the reader. Depending upon the application, the reader may be any one of the basic types described above. In some remote applications, there may not be a formal communication link between the reader and the central control unit. In this case, transaction records may be recorded on the reader and the card, and summary information will be provided to the central control unit at a later point in time.

A.2.3.3 Physical Characteristics

Physical card size is specified by ISO 7816 Part I (card dimensions are 54mm x 85.6 mm x 0.76 mm). Card weight is generally between 1 and 2 grams. Reader sizes vary depending on which of the types listed above are used. Generally readers are between the size of a radar detector and a shoebox. Readers typically weigh between a few hundred grams and a couple of kilograms.

A.2.3.4 Standard Interfaces

The standard card interface is specified by ISO 7816 Part IV. Most reader to central control unit interfaces involve the use of an RS-232 connection.

A.2.4 Costs

A.2.4.1 Initial Equipment

Cards - Memory cards will generally cost between $1 and $5 when purchased in volume. Microprocessor cards typically cost between $3 and $15 (in volume) depending upon the memory capacity and the level of security that is required.

Readers - Intelligent stand-alone units and hand-held units generally cost $500 to $1,000, while some cost more. Non-intelligent units which can be connected to a PC or central control unit are available for $100 to $200. Integral units to be installed in ATM machines or phone machines are offered by some vendors for as low as $5 to $10 per unit.

Other - An initial licensing fee must be paid to Innovatron, a French company that holds the patents related to smart card technology. While some of the patents will soon expire, Innovatron will negotiate to either receive a large up-front fee or a small per-unit royalty. Some up-front fees have been established at over $100,000.

A.2.4.2 Infrastructure

While initial equipment costs are relatively high, issuing and distribution costs for cards will be substantially less than with magnetic stripe cards since IC contact cards may last up to three times longer.

A.2.4.3 Operational

IC contact cards will have many of the same operational costs as magnetic stripe cards. The primary difference is the potential reduction in fraud due to increased card security. No other significant differences are apparent in personnel (staffing and training) or facility (power, space) operational costs.

A.2.4.4 Maintenance

As with all types of contact or insertion reading equipment, there is a risk of vandalism. This has the potential to lead to significant maintenance costs, especially when readers are used in unsupervised locations.

A.2.5 Future Trends and Considerations

A.2.5.1 Anticipated Developments

Presently the IC contact card market is approximately comprised of 90% memory cards and 10% microprocessor cards. This ratio is expected to change in the future as silicon chip improvements reduce circuit cost and size, and provide more memory capacity. Microprocessor cards will become a larger portion of the overall market as the benefits of higher security and multi-function cards become apparent to industry.

Security improvements are also expected as there is a shift from the single key approach to a multiple key (e.g., public key) approach. Since the multiple key approach requires additional on-card processing power, this will be dependent on silicon improvements. If multiple key security can be provided, financial institutions will take a greater interest in smart card developments, and large scale financial applications will likely follow.

A.2.5.2 Lifespan Limitations

There are two main limitations regarding card life span. The first is the amount of wear that the card can endure on the surface contacts. The second regards the number of write operations that may be performed on non-volatile read-write card memory. Improvements in memory lifespan are expected to continue. Physical electrical contacts are a potential trouble spot in any electrical system. They can become dirty and corroded. Gold plating resists corrosion but adds to cost and tends to wear. European experience appears to be favorable with contact smart cards to date, but the issue of contact performance and durability should be considered by any potential system designer. Non-contact cards avoid this potential problem area.

A.2.5.3 Standards

Physical standards for IC contact cards are reasonably well established by ISO 7816. However, as higher memory capacities are made available, and as cards are used more in multi-purpose applications, standard information formats and memory allocation guidelines will need to be formalized.

A.3 Magnetic Stripe Card Technology

A.3.1 Functional Introduction

Magnetic stripe media provide an inexpensive and flexible means of maintaining modifiable information. A magnetic stripe consists of magnetic material combined with paint or binder that is subjected to a magnetic field before drying. This field aligns the magnetic poles of the magnetic material, and makes it suitable for reading and writing. The magnetic stripe may be stamped or laminated on any flat surface, such as a credit card, a hotel room card-key, or a security identification badge. The information is written on and read from the stripe by a number of types of readers. A reader consists of a magnetic recording head which can read and write the magnetic information on the card. The information on the card consists of binary code. From this low-level data form, a high-level data format such as ISO BCD or ALPHA is used to convert the binary code into alphanumeric characters.

Magnetic stripe cards started to appear in the banking industry in the late 1970s. Once international standards were developed, magnetic stripe cards became an effective way of providing convenient customer service. The use of ATMs allowed the banks to offer new services, and to accommodate the growing number of customers without having to increase staff levels or build expensive facilities.

Today magnetic stripe cards are widely used for banking, retail, telephone systems, access control, airline ticketing, and transit fare collection. In fact, the existing infrastructure of magnetic stripe reading and writing equipment is so extensive that changing to an alternate technology would likely be a very slow and costly process.

A.3.2 Card Performance Characteristics

A.3.2.1 Communication

METHOD

The magnetic stripe and reader communicate via a magnetic field. Reading is performed by swiping the magnetic stripe card through a reader. The reader picks up the changes in polarity on the stripe through the magnetic recording head. For writing, the reader creates a magnetic field that will effectively alter the polarization of a small region on the stripe, and thereby write information on the stripe. Data interchange between the card and the read-write unit typically occurs at speeds of about 12,000 bits per second.

STANDARDS

There are several parameters associated with magnetic stripes such as the physical attributes of the media, location of tracks on the stripe, encoding techniques, decoding techniques, and data format. ISO has two specifications for these parameters (ISO ALPHA and ISO Tracks 1, 2, and 3) but many applications do not adhere to them. This lack of adherence is due to the flexibility of available equipment, as well as a desire to enhance security.

A.3.2.2 Memory

TYPE OF MEMORY

Read-write - When a stripe is exposed to a polarized magnetic field, it will adopt a similar field for a small specific region on the stripe. This process can be repeated for erasing data or storing new data.

MEMORY CAPACITY

The capacity of a specific magnetic stripe is determined by the type of media, the method of writing the data, the number of tracks, and the density of the information on the tracks. The ISO standard card consists of three tracks. Track 1 was originally created for the airline industry and can hold up to 79 alphanumeric characters using a density of 210 bits per inch. Track 2 is used by the banking industry and can hold up to 40 numeric characters using a density of 75 bits per inch. This track is generally encoded before the card is given to the end-user. Track 3 is the area most commonly used for information that changes frequently. This track holds up to 107 numeric characters using a density of 210 bits per inch. Combining the memory capacities of tracks 1, 2, and 3, the ISO standard card can hold up to 226 alphanumeric characters.

However, few if any transit applications of magnetic stripe cards adhere to the ISO standard format. In mass transit read-write magnetic stripe systems currently used in New York, Chicago, and Los Angeles, data is encoded on two tracks, with some redundancy to avoid data loss in the event of physical or magnetic damage. Each track is encoded with the non-ISO density of 120 bits per inch, yielding 720 bits total for the two 3 inch stripes. This total shrinks to approxinmately 300 bits of unique data when overhead and redundancy are included, representing at most 50 ASCII characters if 6-bit ASCII coding is used.

MEMORY INTEGRITY

The magnetic stripe is susceptible to alteration or erasure from other magnetic fields, as well as physical and environmental damage. The need to prevent such damage has led many manufacturers, integrators, and application engineers to develop cards with more resistant magnetic properties. The resistance of the magnetic stripe is typically discussed in terms of **coercivity** (measured in Oersteds), which is defined as the magnetic force required to erase an encoded tape. Generally, low coercivity cards (300 Oersteds) are more easily changed or encoded than high coercivity cards (3000 Oersteds). There are limitations to useful coercivity levels, however, since a stripe with a coercivity above 3000-5000 Oersteds may be difficult for the read-write unit to modify. Additionally, some manufacturers have stated that coercivity may not be the best indicator of stripe performance, and have started to consider more performance oriented measures of **magnetic immunity**.

LIFE SPAN

The life span may vary significantly due to reader quality, material used in the card, and the environment in which the card and the read-write equipment are maintained and operated. In many cases the card will be physically damaged before the magnetic integrity of the stripe becomes a factor. Some manufacturers claim that typical readers will read two million cards and that the typical card can maintain its magnetic integrity through several thousand reads. However, practical experience has shown that most regularly used card will wear out and will need to be replaced after about 1000 reads. Obviously, this number would be significantly lower for thin paper magnetic stripe cards that are easily damaged.

A.3.2.3 Power

There are no on-card power requirements.

A.3.2.4 Security

In spite of millions of magnetic stripe transit fare cards in use today in the U.S., counterfeiting has not yet emerged as a major problem. For transit agencies, living with existing levels of loss appears less costly today than the expense of additional security procedures.

There are numerous ways of violating the security of a magnetic stripe card including counterfeiting, skimming, and buffering. Presently, alteration or manufacture of counterfeit cards is a significant security problem in non-transit areas. However, skimming, or encoding additional data on a card, and buffering which involves the temporary storage and subsequent reloading of original data, can be prevented through measures taken by some available products. For example, some vendors offer products that combine unique security signatures, or signals, with natural variations, or "jitter," when the cards are encoded, to deter counterfeiting or alteration of stored information.

A.3.2.5 Environmental

The best environment for magnetic stripes is a cool, dry, clean area. The typical storage temperatures are -40 to 176 °F (-40 to 80 °C). Typical operating temperatures are 32 to 130 °F (0 to 55 °C). Operational relative humidity is 5% to 95% non-condensing. Magnetic fields may alter or erase information stored on the stripe or may reduce the performance of the stripe. Dirt of any kind that collects on the magnetic stripe may cause substantial wear, or impede the reading or encoding operation of the read-write unit.

A.3.2.6 Reliability

The reader head is designed to be in direct, physical contact with the magnetic stripe. Any dirt, chemicals or grime which interferes with this contact will degrade performance significantly. Studies have shown that common magnetic stripe cards have an read failure rate of 0.06 %.

A.3.3 System Operation

A.3.3.1 General Description of Components

Cards

Magnetic stripe cards are generally ISO standard thickness or thinner. The materials include PVC, polyester, paper, and other similar materials. The weight of the card is determined by the material used, but the choice of card design is usually based on the specific application, the desired average price per card, and the desired minimum lifetime of the card.

A.3.3.2 Standard Configuration

The standard system configuration includes a magnetic stripe card, a read-write unit, and a data analysis platform. These components each come in several types, and there are several thousand different configurations possible. Each application may have a unique configuration.

A.3.3.3 Physical Characteristics

The size and thickness of magnetic stripe cards vary depending on the type of paper or plastic that is used. A wide variety of read-write units are available; their size depends on the intended application. Some read-write units are completely stand-alone and may house data storage equipment for later upload to a central facility. Small read-only units are also available and are relatively inexpensive.

A.3.3.4 Standard Interfaces

Most magnetic stripe cards use variations of the ISO BCD, ISO ALPHA and ISO Tracks 1, 2, and 3 standards. Many applications use slightly different formats for security reasons. The reader to controller interface is quite varied. The most frequent are RS-232 and RS-424.

A.3.4 Costs

A.3.4.1 Initial Equipment

Cards - Magnetic stripe cards are commodity priced. The typical card is purchased in large quantities (thousands) for pennies a card (on average $0.12-0.45).

Readers - The cost for a reader ranges from $200-600 (point-of-sale reader) to several thousand (high quality reader/writer). Read-only readers are also available for approximately $15-250.

Control Units - Control units are available for many applications and can be a personal computer. The costs range from a thousand to several thousand dollars.

A.3.4.2 Infrastructure

The infrastructure cost would include the cost of each reader-writer and control unit, inventory of blank cards, communications between control units and central system, and staffing to install, maintain, and man the control units.

A.3.4.3 Operational

Once the infrastructure is in place, the operational costs might include telecommunications costs, card distribution, customer service, and user account management.

A.3.4.4 Maintenance

While the cost of magnetic stripe cards and readers is inexpensive in comparison to other card technologies, the maintenance costs can be rather substantial. Due to the insert or swipe nature of card reading and the mechanical nature of the read-write units, the systems are often prone to failure. Transport type read-write units can have an especially high maintenance component. Swipe read-write units have fewer mechanical parts, but are still susceptible to wearing and misalignment of the magnetic heads, and vandalism of the slot. Consequently, a significant level of staffing will be required to repair or replace equipment, maintain spare parts, and monitor system usage.

A.3.5 Future Trends and Considerations

A.3.5.1 Anticipated Developments

No significant developments are anticipated, but minor advances may be made in card security as the result of new or enhanced security procedures.

A.3.5.2 Theoretical Technical Limitations

Many aspects of magnetic stripe technology appear to be nearing theoretical or practical limitations. For example, the memory capacity of an ISO standard card is approximately 1 kbits, and although more information could probably be stored on a card, a significantly different configuration would make the card unreadable to an ISO standard reader.

Reasonable advances may still be possible in the area of security, but staying one step ahead of counterfeiting or fraud has not been an easy task for the banking industry over the last few years.

A.3.5.3 Standards

Standards (ISO) already exist for the placement of information on the stripe as well as the formatting methods. Since most applications do not adhere to the specifications exactly (due to the flexibility of the equipment and the desire for increased security), there may be minor changes to the existing standards to reflect this variation in the marketplace.

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APPENDIX B
RELEVANT APPLICATIONS

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APPENDIX B - RELEVANT APPLICATIONS

B.1 Application Development Background

The advent of automated card technology has the potential to dramatically alter both the public usage of transit services and the means by which these services are accessed. While many transit service providers have been aware of this potential for a number of years, only recently have applications started to appear in the transportation sector. This has been due to the lack of standardization of automated card products as well as the cost of conversion from existing fare and toll collection methods. As a result, many agencies are waiting for the market to develop before they invest time and effort in an automated card system.

The **IC/smart card** concept was invented in 1974 by Roland Moreno who founded Innovatron, a French company that still holds patents on IC/smart card technology[1]. The French government played a large role in initiating IC/smart card development by subsidizing efforts in the French banking and telephone industries. Many French companies are still leaders in the industry as a result of this initiative taken by the French government.

B.1.1 Potential Smart Card Benefits

Most early automated card applications involved the use of low-cost magnetic stripe or IC contact cards. One example is the prepaid telephone cards that are not truly "smart" since they do not contain a microprocessor. The only early applications involving more expensive **smart cards** were those that required a high level of security, either for financial applications where there was a potential for a large monetary value to be maintained on the card, or for military applications where it was important to safeguard sensitive information. However, as the price of the more sophisticated cards continues to fall, there is a greater opportunity for transit agencies and the general public to take advantage of some of the more interesting features of these "smarter" cards. Potential benefits include:

(a) Security: One of the main advantages of smart cards is the ability to reduce fraud. Many financial institutions were experiencing significant losses due to counterfeiting and fraud. These losses dropped significantly when smart card systems were introduced.

(b) Flexibility: The ability to re-configure a card once it is in use allows new applications to be added or existing applications to be modified without completely redesigning the system or purchasing new equipment.

(c) Multi-Use Capability: Higher memory capacities and greater flexibility allow cards to be used for more than one application. This should ultimately help to promote integration and standardization of services which may lead to a signification reduction in operating expenses.

(d) Speed: By maintaining most of the application information directly on the card, transaction validation can be performed on location without the need to query a central database which is both time consuming and expensive. Additionally, in existing applications, where it is not possible to access a database, use of a smart card could greatly reduce the potential for fraud.

(e) Ease-of-Use: Substantial improvements in convenience and access to services should become highly evident at the user level. For example, transit riders will not need to worry about having the correct change to pay for transit services.

The majority of forward thinking transit managers are now paying close attention to other pilot system implementations. Realization of many or all of the benefits described above could ultimately help transit agencies to increase ridership levels. However, most agencies will not consider implementing their own system until they are overwhelmingly convinced that the potential advantages of an automated fare collection system can be realized. With this in mind, understanding the reasons behind the successes and failures of the operational and pilot applications identified in this report is critical to the development of an appropriate conceptual design for a multi-use card system for fare and toll payment.

B.1.2 Relevant Transportation Modes

In order to identify and categorize basic agency requirements, relevant transportation modes were identified so that each mode could be investigated separately. This was done to allow the unique requirements of each mode to be determined.

Following an initial definition and analysis of the relevant transit modes, two main categories were identified: **vehicle-based** and **person-based**.

VEHICLE-BASED applications involve the collection of a fare or toll from a vehicle, such as a car, truck, or bus, as it passes through entry and exit ramp toll plazas or barrier toll plazas which are located on the road itself. Vehicle applications may be:

(a) **Distance-based**, as determined by toll road entry and exit;
(b) **Barrier-oriented**, such as bridge, tunnel, or toll road barrier;
(c) **Time-based**, such as parking systems; or
(d) **Combined**, where they consist of some or all of the above.

Vehicle-based applications are generally more concerned with the type or classification of the vehicle, such as car or commercial, and are generally not concerned with the identity of the individual operating the vehicle, or the passengers in the vehicle. For this reason, vehicle tagging has been considered a reasonable way of identifying and classifying vehicles. Additionally, since vehicle operators and passengers do not generally need to carry the tag with them, the size of the tag or card is not as critical as in person-based applications. As a result, a variety of tag designs have been employed by various vendors, most of which differ in size, specific communication method, and primary location on the vehicle.

PERSON-BASED transit applications involve the collection of a fare from an individual as they use a transit service such as a subway, bus, or taxi. Since the person is not expected to be moving at high speeds relative to the reading equipment, proximity and contact type cards become a practical approach to fare collection. Additionally, the size of the card is important, since passengers must carry it with them.

Based on a logical segmentation of fare and toll applications, the following modes were identified:

Vehicle-based:
- Toll Road
- Bridge and Tunnel
- Parking

Person-based:
- Closed Rail
- Open Rail
- Bus
- Paratransit
- Taxi

The following sections provide basic descriptions for each mode and a discussion of high-level requirements. Examples of significant worldwide applications are also provided that briefly cover insights from pilot tests and issues relating to system implementation.

B.2 Toll Road

Toll road automated fare collection systems originated from Automatic Vehicle Identification (AVI) technology. For actual fare collection, however, there is more involved than simply identifying the vehicle. The establishment of toll pricing criteria, payment methods, tag distribution, and user notification systems must also be considered. Additionally, the need to consider integration with other separately operated toll agencies has quickly become a primary concern. Regional interagency cooperative groups and consortiums have formed, realizing the need to integrate their systems for the convenience of users, especially in the areas of commercial trucking, interstate travel, and for commuters in major metropolitan areas. In an effort to promote standardization among vendor products, a few industry cooperative groups have proposed standards for system design and performance. One of the problems, however, is that many of these standards setting cooperative groups are comprised mostly of vendor representatives. The level of transportation agency and end-user interest and participation is still well below what is necessary to develop standards that allow fair competition among all industry vendors.

For the purpose of discussing requirements, toll road payment applications will primarily include the collection of highway tolls based on vehicle classification and distance traveled. While this application category will also include some discussion of barrier systems having locations where all traffic is routed through toll plazas, we will determine requirements for this category based on the entry and exit plazas, where the toll is calculated based on the distance traveled.

Electronic toll payment applications started to appear in 1987-88 both in Europe and in the U.S. There are currently over twenty-five toll road collection agencies worldwide that have implemented, or are close to implementing, contactless tag or card systems. Most of these use RF technology, due to its ability to perform a transaction without requiring a vehicle to stop, and its effectiveness under a wide range of environmental conditions. One of the first U.S. applications appeared on the North Dallas Tollway. This barrier system uses a read-only RFID (Type I) tag to deduct payment from a pre-established account. While approximately 50,000 tags have been issued for this system by the Texas Turnpike Authority[2], a similar system in Oklahoma, known as PIKEPASS, has become the nation's largest with over 200,000 tags in distribution.

Recently, other variations of RF products have started to appear that offer creative ways of satisfying distance-based system requirements. The Illinois State Toll Highway Authority is in the process of implementing a smart transponder system, known as "I-PASS," on the Chicago North-South Tollway[3]. It will employ an in-vehicle read-write transmitter with processing and display capability (RFID Type III). Also, the Transportation Corridor Agencies (TCA) consortium in Orange County, CA, is planning to implement a system combining a close coupling card with an RFID dashboard transponder. The dashboard unit and card combination could have significant advantages over the basic tag/transponder system. A system with this arrangement could be designed to allow separate cards to be used in the same dashboard unit, creating the opportunity to use a different card depending on the situation. For example an anonymous prepaid card could be used for personal travel, or a special corporate card could be used for business travel. However, the feasibility of this approach must be investigated further to determine if there are safety issues related to inserting the card while driving.

The main point of contention in the design of electronic toll payment systems, as in many other modes of transit, involves the level of complexity necessary at the card or tag level of the system. This encompasses all the fiercely contested issues including read-only vs. read-write memory and centralized vs. decentralized transaction processing. It is generally believed that read-write technology is required on distance-based toll systems in order to record the entry and exit points. Moreover, the related issues of user convenience in terms of payment, determining the account balance, updating the balance, and general correspondence with the toll agency, become significant concerns when considering the long-term operation of the system.

B.3 Bridge and Tunnel

Bridge and tunnel toll applications generally involve barrier type systems, and therefore do not usually require entry or exit locations to be recorded. In this type of application, the read-only tag is considered a viable solution when considering requirements only for this or other barrier systems. For integration with other types of toll and transit systems, however, read-only technology may not be sufficient.

Applications of Electronic Toll Collection (ETC) on bridges and tunnels started to appear along with the early barrier toll road systems. One benefit of electronic collection technology for this transportation mode is that it provides a way of increasing the throughput of the plaza without requiring additional collection lanes. This is extremely useful in cases where plaza expansion is not practical. There are now approximately ten operational bridge and tunnel ETC systems worldwide, and another five to ten pilot projects are underway. One of the first applications appeared on the Crescent City Connection Bridge in Louisiana in January, 1989. With over 26,000 tags now in distribution, the electronic system presently accounts for about 25% of the total daily transactions[4]. The New York State Thruway has implemented a read-only tag system, known as EZ-Pass, on the Tappan Zee Bridge. Two projects in England, the Mersey Tunnels (10,000 tags) and the Dartford River Crossing (20,000 tags), are using a read-write in-vehicle unit (IVU)[5]. Additional projects are also underway on the Aberdeen Cross Harbour Tunnels in Hong Kong, and on Sweden's first toll financed bridge in Oestersund. Many other agencies are considering adopting ETC systems. Pilot tests have been conducted in New York by the Port Authority of NY/NJ and MTA Bridges and Tunnels; by MASSPORT in Boston (Tobin Bridge); and in California on the Coronado Bay Toll Bridge and the Golden Gate Bridge.

B.4 Parking

Interest in automated parking payment systems has grown substantially in the past few years. The value of these systems not only comes from the convenience of automated payment, but also from the possible combination with other benefits such as payment based only on the time used, discount opportunities, access control security, and planning and marketing information for agencies providing the service. Increased usage due to user convenience alone may be reason enough for many agencies to adopt an automated system. According to a user survey conducted by the EZ-Pass Interagency Group in the New York metropolitan area[6], parking at area and airport lots was considered to be the most desirable other potential use of an electronic toll card, rating above consumer purchases at gas stations and restaurants.

Parking applications generally require a way of maintaining elapsed time, either through contact with the card reader which will provide starting and ending times, or through the use of an on-card clock. There are many variations on the functional design of parking payment systems. One type of system, which is now being used in Paris, has already led to the distribution of over 100,000 prepaid IC contact cards[7]. The card for this application can be purchased in several denominations; a ticket machine located near the parking spot issues parking tickets in 15 minute increments when the card is inserted. In another type of approach, several communities in France are instituting the Parcoville concept where cars are stored in large circular shelves underground using a mechanical lift[8]. This type of system, which maximizes space and reduces the possibility of theft, is being combined with a prepaid card used for payment and for maintaining the location of the car and time of entry. In England, the use of an in-vehicle unit is being proposed. The unit will be placed on the dashboard of a car in a streetside parking spot, and will have an on-board meter to display time and fare type. Payment will be deducted from a smart card inserted into the unit.

In a particularly interesting multi-function application, the Melbourne Central Shopping Center in Australia has designed a special carpark which discounts the parking rate for motorists who shop in the Center[9]. A special card dispensing machine was developed which automatically provides an IC contact card as a driver enters the parking lot. The card is presented when making purchases at shops within the center. The amount of purchases is recorded on the card, and is later used to discount the parking rate based on the total amount of purchases made. This system not only provides a benefit to shoppers at the Center, but also provides useful planning and marketing information to the Center Management, such as peak and slack shopping times, average stay in the car park, and average dollars spent per vehicle.

Metered parking on-street and in public parking lots is also important. At present, the two principal U.S. manufacturers of parking meters are moving in the direction of more electronics, fewer mechanical moving parts, and cash card compatibility in their products. A new parking meter developed by Duncan Industries of Harrison, Arkansas has a very traditional looking outer shell but is completely electronic in operation. It is used in conjunction with Duncan's "CashKey," a stored value card with electrical contacts, in the shape of a plastic key. The electrical contacts are distributed along the shank of the key. The key can be reloaded with stored value, a task presently performed at an ATM-like station. Locations using this Duncan system include Downers Grove, IL Coral Gables, FL, and Hong Kong. The Duncan CashKey is a specially engineered form of smart card, manufactured by Datakey, Inc. of Burnsville, MN. It contains a microprocessor chip which has built-in EEPROM for data storage.

The other U.S. manufacturer of electronic parking meters, POM of Russelville, Arkansas, makes parking meters that are used with smart cards supplied by GEMPlus. These electrical-contact type smart cards are sold pre-loaded with value in standard denominations. The POM system presently is being used in locations that include New Orleans; Acton, MA; the Washington, DC Metropolitan Area Transit Authority; Malaysia; and four cities in the People's Republic of China.

B.5 Closed System Rail

Closed rail applications include any form of metropolitan or short distance light rail system where passengers must pass through turnstiles or gates when entering and leaving the system. In some cases, transfer stations exist within the system to allow passengers to switch to connecting lines without having to pass through additional turnstiles. For passenger convenience, and to increase throughput capacity of collection turnstiles, many systems use tokens as a means of payment. There are, however, several significant limitations of systems using primarily cash and token sales. By collecting payment upon entry of the system, there is no practical way of implementing flexibile distance-based pricing. As a result, the basic fare rate encourages longer trips and discourages shorter trips. Additionally, it is difficult to change rates based on peak or off-peak usage, or other special pricing criteria. Some long rail transit lines do implement a form of distance-based pricing by requiring additional fare to exit at a far suburban end, or higher fare to enter there.

Some agencies responsible for closed rail systems have already implemented various forms of automated fare collection systems. Most of these involved the use of paper or thin card magnetic stripe tickets. Due to the enormous volume of transactions, and the ability of read-write magnetic stripe technology to handle the most critical system functions, low-cost magnetic stripe technology has been preferred. Some transit authorities such as Boston's and Chicago's, use read-only magnetic stripe passes for both bus and rail, but soon will update to read-write magnetic stripe tickets. Chicago will also soon implement RFID cards for handicapped transit users, and may consider a contractor recommendation of universal adoption of an RF smart card system in the future.

The Washington Metropolitan Area Transportation Authority (WMATA), has implemented one of the more advanced paper magnetic stripe systems. Using a read-write magnetic stripe approach, this system already performs many of the required functions that are also promised by the more expensive smart card approach, including distance-based fares, and varying peak and off-peak fares. The main limitations include high maintenance of the transport mechanism through which the card passes at station turnstiles, maintenance on card distribution machines, a low level of card security, and a small read-write memory capacity. For the D.C. Metro system, however, the monetary value stored on a card is usually small enough, under $30 for standard cards, so that it does not present a major security threat, either from counterfeiting or card theft. Additionally, the system is relatively easy for passengers to use.

The New York City Transit Authority (NYCTA) is in the process of implementing an automated fare collection system using a high coercivity read-write magnetic stripe card[10]. Swipe magnetic stripe technology was selected over the use of a mechanical transport device in order to reduce the possibility of turnstile failure, maintenance costs and the possibility of theft, as the card does not leave the passenger's hand. Extensive testing of card performance and customer acceptance have already been completed. Opening of 69 core stations using the card is expected to occur in 1994, followed by installation in remaining subway stations, with full installation in transit agency buses by 1996. This system is unique in that serious consideration is being given to how the card may be marketed for payment applications external to the functions of the transit authority such as telephones, taxicabs, and school lunch programs.

Some RF systems are now also beginning to appear in rail applications. The London Underground is considering replacement of their magnetic stripe ticket system, which was implemented in 1988, with a proximity RF card[11]. The main reasons for the selection of a proximity card system over the mechanical transport type magnetic stripe system were to improve convenience to passengers with luggage and those with impaired manual dexterity, as well as to provide a higher comfort level for passengers who maintain a large balance on the card (some may be worth over £1000). In addition, since the system has no moving parts, maintenance costs will be substantially reduced. RF technology will also be investigated by WMATA, who recently received a grant from the FTA to conduct a pilot test of an RF card.

The preference for magnetic stripe technology over RF proximity cards, or more full-featured smart cards, still exists as additional magnetic stripe systems are being proposed. The Chicago Transit Authority (CTA) recently awarded a major contract to the Cubic Automated Revenue Collection Group (CARCG) to install a magnetic stripe system on all CTA subways and buses[12]. Many authorities believe that the cost of more powerful smart card technology is still not justified in the closed rail environment. Some believe that the only way to make it cost-effective is to use the same card for other applications. Additionally, since many metropolitan transit authorities are responsible for both systems, there is interest in combining this area with bus systems. However, few agencies have been able to implement a single multimodal automated fare collection card that can adequately support both modes.

B.6 Open System Rail

Open rail applications generally include any surface, commuter, state, or national rail system where a passenger can board and exit freely without passing through turnstiles or gates. Consequently, this system requires that verification of payment be made while on-board. Generally, this means that a conductor must be on board in order to verify the validity of tickets, and to sell tickets, usually with a surcharge, to those passengers who have not purchased them prior to boarding. While some areas in Europe have adopted surface systems which rely on public cooperation, this may lead to a higher level of fare evasion. For example, on a system in Munich, Germany, passengers are required to purchase zone-based tickets in advance and then have them validated by stamping them in a machine located on the train. Tickets are only checked occasionally by special agency personnel that perform spot checks at random. To discourage fare evasion, passengers caught without a validated ticket face a heavy fine that may be 40-50 times the price of a standard ticket.

Most conventional open rail systems with an on-board conductor use thin card or paper tickets. This has been considered a satisfactory approach since in most cases, with the exception of commuter rail and intercity surface rail, passengers only take occasional trips. Some passengers even prefer to keep the ticket as a receipt or souvenir. Many stations already allow tickets to be purchased using automated machines rather than at a customer service counter. Additionally, for open rail applications, the use of magnetic stripe cards, or low-cost smart cards, may not provide a significant advantage over the paper ticket system. Since passengers typically specify their starting and ending destinations in advance, most fare structures are already distance-based. While the smart card approach would make it easier for rail agencies to vary pricing structures and implement special fares, such as for peak, off-peak, or holiday travel, the low level of smart card penetration into the open rail market is not surprising when the full range of issues is considered.

Only within the last few years have improvements in various forms of card technology, along with reduction in card costs, led some agencies to consider further improvement of their ticketing systems. Additionally, some agencies are beginning to recognize that many of the benefits of a smart card approach are only realized when use of the card is combined with other applications.

Many agencies that manage bus and open rail systems allow common fare media to be used on both modes. These are typically monthly passes that are shown to inspectors on the train on demand and are either shown to bus drivers or swiped through a magnetic card reader upon boarding the bus. Although the use of stored value cards on such rail systems has not yet occurred in the U.S., Los Angeles County is testing a common read-write stored value magnetic card for all of the county's bus agencies. The contract has options that may result in the card being used to purchase proof-of-payment receipts from vending machines on rail platforms. The same concept could be extended to a smart card-based stored value fare card.

The Greater Manchester Passenger Transport Executive (GMPTE) recently awarded a contract for the largest contactless card application in the world[13,14]. The contract includes an initial order of 500,000 close coupling RF proximity cards. The cards will eventually be used at 350 rail and Metrolink locations, as well as on the system's 2,700 buses. Following an evaluation of card alternatives, it was determined that a contactless card provided advantages of speed, convenience, and reliability in comparison to magnetic stripe and IC contact cards. In addition, the contactless approach removes many of the mechanical parts of the system which generally have high maintenance costs and are more prone to vandalism. Passengers can buy the cards in one of the transport company's more than 800 sales outlets. At the station, card holders will key in the destination, and place the card on a read-write unit where the fare is deducted. The read-write unit will then write the new balance to the card, and encode the card with all relevant trip information including origin and destination, ticket type, and period of validity. Conductors will use a hand-held control unit to verify ticket information on the train. The system will also allow multi-journey and time-based cards. In this case, as the card is used a display will show the number of trips left, or the last valid date. Success of a major system such at the one at GMPTE may well persuade other agencies to use a similar approach.

B.7 Bus

Bus applications typically involve the collection of fares as passengers board. The rate of passenger boarding and de-boarding is very important to the overall efficiency of the system. Consequently, in most metropolitan transit applications this leads to the establishment of a basic fare rate which is irrespective of the distance traveled.

In the U.S., all transit bus operations are required by Federal mandate to be exact fare only. This rule was implemented for public and driver safety. Presently over 45,000 electronic registering fare boxes are in use nationally, representing approx. 90% of the national transit fleet. These fare boxes collect coins, tokens, bills, and paper tickets, and store them in secure cash boxes that cannot be opened by the driver. Use of such fare boxes has greatly reduced theft and robbery of fare box contents. Time-based passes are also used as a means of providing added convenience to passengers who use the system frequently.

Many bus agencies are looking at ways of improving their systems. Enhancements are desired not only in the fare collection process, but also in other areas such as improving overall passenger convenience, providing traveler information such as expected arrival times of buses, and integration with other transit modes including rail systems and parking. Another advantage of electronic registering fare boxes is that they can track ridership. Each fare can be recorded by bus, route, run, and time of day. With sophisticated data collection and reporting systems, agencies can get periodic reports of system performance.

While most agencies do not now use sophisticated tools for accounting and analysis, newer systems being installed in cities such as Houston, Seattle, and Minneapolis, will use magnetic fare media and thus will allow the agencies to track individual rides and record detailed information about each transaction. Seattle will use its system to implement the largest employer-subsidized transit program to date with an estimated 100,000 participating employees from several hundred employers.

In some cases, the magnetic stripe approach is being used to provide necessary system functions without the need for more expensive smart card technology. The Phoenix Transit System has implemented a fare collection system, known as "Bus Card Plus," which accepts magnetic stripe cards in addition to conventional forms of payment including cash, tokens, and tickets[16]. The agency provides the magnetic stripe cards, which are valid for 2 years, to companies who distribute them to their employees. Since its inception in 1991, use of the system has grown to include over 90 companies and 10,000 employees. Fare transactions are recorded based on the identification number of the card and are downloaded nightly to a central computer for reporting. Companies are billed on a monthly basis. The system offers an advantage over the typical monthly pass in that companies are billed only for the exact number of trips taken, rather than charging a monthly rate which might not be recovered if the card is not used frequently. As a side benefit, the employer will have documentation showing employee transit system usage which can demonstrate compliance with Clean Air Act requirements.

A few agencies are actively considering the use of advanced fare media such as RF proximity cards. The Ann Arbor Transportation Authority (AATA) is receiving a FTA grant to investigate the use of a RF proximity card for a multimodal system that could support both transit bus and parking applications[15]. The project, which includes participation from the City of Ann Arbor and the University of Michigan, has three main objectives. The first is to uncover problem areas in the implementation and use of RF cards, the second is to evaluate the viability of an RF card within the transit industry, and the third is to consider ways to integrate an advanced fare media system with other applications. Other possible applications might include an Automatic Vehicle Location (AVL) system for passenger information, obtaining system usage information to improve parking and transit management, and providing improved services such as an on-card personal security device.

Several other agencies have already adopted proximity RF cards as a means of payment. A pilot project in Ajax, Ontario, which began in 1991, is considered to be one of the first demonstrations of contactless fare media[17]. Over 1,300 domino shaped tags were provided to students who used them to pay for school trips. The pilot was structured to demonstrate the overall effectiveness of contactless technology, as well as the concept of step-down pricing based on frequent use. Plans for a similar pilot system (1,100 tags) were recently announced by Burlington Transport in

Ontario. London Transport has also conducted several tests of contactless cards and has plans to implement an RF system.

There is an effort by some agencies responsible for both bus and rail applications to integrate their fare collections onto a single medium. The NYCTA project mentioned earlier includes the installation of magnetic stripe fare boxes on the system's 3,600 buses by 1996. The recent award to Cubic by the Chicago Transit Authority includes installation on all system buses by 1995. Also, the Greater Manchester project in England includes plans to use an RF proximity card on 2,700 buses.

B.8 Paratransit

Paratransit systems have been implemented by many agencies in order to provide disabled or mobility limited passengers equal access to transit services. In some cases, the use of automated card technology has been a critical aspect of the system design. Since many agencies are facing increasing pressure to provide convenient paratransit services, the use of automated cards for paratransit fare collection is expected to grow significantly. Rather than identifying paratransit requirements for each mode of transit, we will look at the use of a paratransit card for all modes in general. An effort will be made to focus on the special needs of the card user, and to determine what must be done by transit service providers to meet these needs.

One of the more critical requirements of a paratransit card is that it must be easy to use, especially in terms of how it is presented to the reader, since some disabled passengers may find it difficult to get near a reader, or to enter or board a system through conventional gates or barriers. There also needs to be a way of ensuring that the service is available to the people who really need it, while ensuring that it is not used inappropriately by others for fare evasion. This may require that the card store the passenger's ADA certification, and be personalized with a photo identification to prevent unauthorized use.

From the perspective of the transit service provider, there is a need for accurate trip reporting. Accuracy in trip reporting is not only important with revenue collection, but it also makes it easier to form partnerships with other agencies or businesses, who will be more willing to pay for services if they believe that they are being charged fairly. Additionally, since in many cases paratransit services are provided through a contract with a private carrier, agencies are concerned about being over-billed by the private carrier.

Bay Area Rapid Transit (BART) in California has implemented a system that allows disabled riders to activate elevators that access the train station platforms[18]. Using a special RF read-only tag, the elevator is called to the appropriate landing when the tag passes in front of the reader. The tag also activates a digitized voice message which says "elevator coming," that has been installed for the benefit of blind passengers. Using a pressure sensitive floor mat, the elevators are programmed to travel to the opposite level of a station, except for three stop elevators that require a floor button to be pressed. The system, which was implemented for 65 elevators in 34 stations in 1988, now services over 2,000 riders. Since the tag reading boxes are tamper-proof and there are no moving parts, system maintenance costs have been extremely low. One concern, however, is that unauthorized passengers may occasionally be able to enter the system for free by entering the elevators with an authorized user.

In another more recent application, the Northeastern Illinois Regional Transportation Authority (RTA) has implemented a Payment and Control Information System (PCIS) which provides a payment card to over 6,000 mobility-limited riders who regularly use paratransit services in metropolitan Chicago[19]. The project, which started in June 1992, involves approximately 260 paratransit vehicles that are capable of providing 4,000 rides per day. The system uses a contact IC card (with a 16 kbit memory) which is inserted into a portable reader maintained by the driver at pickup and destination locations. The driver keys in an odometer reading prior to inserting the card so that the total trip mileage may be obtained. The portable unit also automatically adds a date and time stamp to each transaction in order to avoid disagreements over arrival times. The portable units are placed in an electronic cradle at night to upload all transaction information, and to download update lists which may identify stolen or lost cards, or may replenish stored value amounts based on recent account payments.

B.9 Taxi

Taxi driving is considered one of the most dangerous occupations in the United States, due in part to the fact that drivers often carry a significant amount of cash. While an automated payment card may have the potential to increase safety for both the driver and the passenger, the cost of installing card equipment, and the acceptance of card payment by passengers still needs to be thoroughly explored. The number of passengers and the overall amount of revenue collected may not presently justify the installation of an expensive reader. Additionally, the use of a credit card may be more appropriate than a debit card initially, until a financial clearinghouse can be established that allows use of the card for other transit modes or applications. Moreover, it is not likely that a passenger would carry a card good only for certain taxi operators, or one that has limited use elsewhere. The use of a credit card, however, would require that transactions be verified through a remote connection to an on-line database in order to safeguard against fraud.

Despite the difficulty in establishing an automated payment system for taxicabs, interest in developing such an application has already received some attention. International Verifact Inc., a leading supplier of secured electronic funds transfer at the point of sale (EFT/POS) technology, recently announced their intention to work with Cellular Payphones Inc. to introduce the first cellular credit card payment system for use in taxicabs[20]. There are plans to test market the system in New York City taxis in a collaborative effort with MasterCard International. Verifact Inc. projects that approximately 15% of U.S. cab fares might be captured by credit card payments, representing about $1 billion of the estimated $7 billion in U.S. fares.

B.10 Matrix of Fare and Toll Applications

Table B-1 identifies some of the many automated card applications that are underway for fare and toll collection. This list, although not complete, is rather large, since there are now a significant number of projects that are in various stages of implementation.

The following columns are included in the matrix:

Location — This column identifies the primary city where the project resides. In some cases, this may be the location of the transit agency or authority, especially when the project covers a large geographical area.

Transit Agency — Name of the agency or authority responsible for project oversight.

Project Name — Name given to the project.

Integrator — The integrator is the organization which oversees technical coordination of the project. Typically this is a contractor working for the transit agency. The integrator is responsible for obtaining equipment from suppliers and ensuring that each system component fits into the overall system design.

Supplier — The suppliers are the manufacturer or distributor of system equipment (in this case we are referring to the card manufacturers).

Type — Refers to the specific card technology used. Technologies listed under this column relate to those identified in other areas of this report and include the following:

RFID	Radio Frequency Identification
Optical	Laser/Optical Cards
Bar Code	Bar Code Labels
Mag Stripe	Magnetic Stripe Cards
IC Contact	Integrate Circuit (IC) Contact Cards
Remote Cpl	Remote Coupling (RF proximity)
Close Cpl	Close Coupling (Capacitive Coupling)

 # Cards — The number of cards in distribution. For planned projects, the anticipated card distribution number will be in *italics*.

****** — This appears in fields of the matrix where information was incomplete or unavailable.

Table B-1. Summary of Fare and Toll Applications

Location	Transit Agency	Project Name	Integrator	Supplier	Type	# Cards
PERSON-BASED APPLICATIONS						
Bus Systems						
Ajax, Ontario	Ajax Transit Authority	Ridekey	Precursor Ltd.	GEC Card Tech. Ltd.	RF Coupling	1,300
Burlington, Ontario	Burlington Transport	Pilot Bus Card System	Precursor Ltd.	Disys Corp.	RF Coupling	1,100
Dublin, Ireland	Dublin Bus	DASH (GAUDI field trial)	GAUDI/DRIVE	Schlumberger	IC Contact	2,000
Helsinki, Finland	Helsinki Metropolitan Area Council	Helsinki Travel Card Trial (Bus 91)	AES Scandanavia	AES Datafare	IC Contact	1,000
Helsinki, Finland	Helsinki Metropolitan Area Council	Helsinki Travel Card Trial (Bus 92)	Buscom	Buscom	RF Coupling	900
Helsinki, Finland	Helsinki City Transport	Helsinki Travel Card	Scanpoint Technology	GEC Card Tech. Ltd.	RF Coupling	20,000
London, England	London Transport	Contactless Card Trial	Buscom	Thorn EMI	RF Coupling	1,000
London, England	London Transport	Contactless Card	AES Scanpoint Ltd.	GEC Card Tech. Ltd.	RF Coupling	40,000
Los Angeles, CA	Culver City Municipal Bus	Metrocard	TBD	TBD	Mag Stripe	TBD
Oslo, Norway	AS Oslo Sporveier	Common Electronic Ticketing	Scanpoint Technology	Scanpoint Technology	RF Coupling	**
Phoenix, AZ	Phoenix Transit System	Bus Card Plus	Phoenix Transit Sys.	Mark IV/Duncan	Mag Stripe	10,000
Closed Rail Systems						
Chicago, IL	Chicago Transit Authority	Automated Fare Collection System	Cubic (CARCG)	**	Mag Stripe	**
London, England	London Underground Ltd.	Touch and Pass (Go-Card)	Westinghouse Cubic	**	RF Coupling	**
Washington, D.C.	Washington Metro Area Transit Auth.	Uniform Fare Technology Demo	Cubkc (CARGC)	**	RF Coupling	4,000
Washington, D.C.	Washington Metro Area Transit Auth.	Metrochek	Cubic (CARCG)	**	Mag Stripe	**
Taxi Systems						
Chicago, IL	O'Hare International Airport	Ground Transit System	**	AT/Comm	RFID (III)	TBD
New York, NY	New York City Cab Companies.	Cellular Payment System	Intl. Verifact Inc.	Cellular Payphones	Mag Stripe	TBD
Paratransit Systems						
Chicago, IL	NE Illinois Regional Trans. Auth. (RTA)	Payment & Control Info System	Applied Sys Institute	**	IC Contact	6,000
Helsinki, Finland	Handicab (Espoo)	Helsinki Travel Card Trial	Setec	**	IC Contact	180
Oakland, CA	Bay Area Rapid Transit	RFID System	Security Specialists	X-cyte	RFID (I)	2,200

Table B-1. Summary of Fare and Toll Applications, continued

Location	Transit Agency	Project Name	Integrator	Supplier	Type	# Cards
Multimodal Fare Systems						
Ann Arbor, MI	Ann Arbor Transportation Authority	Ann Arbor Smart Bus	TBD	TBD	RFID	TBD
Berlin, Germany	Berlin Public Transport Company	Bus/Rail/Taxi/Retail Stores	**	Siemans-Nixdorf	**	**
Biel, Switzerland	Post, Telephone & Telegraph (PTT)	POSTCARD	**	**	RF/Mag Stripe	30,000
Central Point, OR	Rogue Valley Council of Governments	Rogue Valley Mobility Manager	Easy St Software	**	Mag Stripe	**
Hong Kong, HK	Mass Transit Railway Corp. (MTRC)	Common Stored Value Ticket	TBD	TBD	RF Coupling	TBD
Manchester, England	Greater Manchester PTE	GMPTE Contactless Smart Card	AES/Scanpoint Ltd.	GEC Card Tech. Ltd.	RF Coupling	*500,000*
New York, NY	Metropolitan Transportation Authority	Metro Card (Rail, Bus)	Cubic (CARCG)	**	Mag Stripe	*3,500,000*
Oakland, CA	Metropolitan Transpt. Commission (MTC)	TransLink (BART, CCCTA)	Cubic/IBM	**	Mag Stripe	TBD
VEHICLE-BASED APPLICATIONS						
Bridge and Tunnel Systems						
Bristol, England	**	Severn River Crossing	Cofiroute/CSEE Peage	Amtech/Elsydel	RFID (I)	4,000
Charlestown, MA	MASSPORT (Tobin Bridge)	Pilot ETC System	Wilbur Smith/SAIC	Amtech	RFID (I)	300
Grosse Ile, MI	Grosse Ile Bridge Company	ETC and AVI System	**	X-cyte	RFID (I)	3,000
Hong Kong	Cross Harbour Tunnel Company, Ltd.	Aberdeen, Cross Harbour Tunnels	Mitsubishi	Amtech	RFID (I)	1,000
Liverpool, England	**	Mersey Tunnels	CSEE Peage	Combitech	RFID (III)	10,000
London, England	**	Dartford River Crossing	CSEE Peage	Combitech	RFID (III)	20,000
Miami, FL	Metro Dade County DPW	Rickenbacher/Venetian Causeways	Revenue Markets Inc.	Amtech	RFID (I)	*17,500*
New Orleans, LA	Lake Pontchartrain Causeway	Lake Pontchartrain Causeway ETC	**	Amtech	RFID (I)	12,000
New Orleans, LA	Louisiana Dept. of Transportation	Crescent City Connection	Lockheed (Repl. GSI)	Amtech	RFID (I)	26,000
New York, NY	New York State Thruway Auth. (NYSTA)	E-Z Pass (Tappan Zee Bridge)	SAIC	Amtech	RFID (I)	40,000
New York, NY	Port Authority of NY & NJ	Lincoln Tunnel ETC for Buses	SAIC	Amtech	RFID (I)	3,000
New York, NY	Port Authority of NY & NJ	Goethals Bridge Pilot ETC	SAIC	Amtech	RFID (I)	750
New York, NY	Port Authority of NY & NJ	Verazano Narrows Bridge Pilot ETC	SAIC	Amtech	RFID (I)	**
New York, NY	Triborough Bridge & Tunnel Authority	ETTM System Test	SAIC	Amtech	RFID (I)	2,000
Oestersund, Sweden	**	Sweden's 1st Toll Financed Bridge	**	Combitech	RFID (III)	**
Sacramento, CA	State of California DOT	Coronado Bay Toll Bridge Test	SAIC	**	RFID (I)	**
Parking Systems						
Leuwen, Belgium	CERA	Parking Garage Access Control	**	Combitech	RFID-IVU	1,500
Melbourne, Australia	Melbourne Central Shopping Center	**	Eftpos Eng. Pty Ltd.	Akyman/Gemplus	IC Contact	**
New York, NY	Port Authority of NY & NJ	Airport Lot Revenue Control System	NYNEX	Trindel	Mag Stripe	**
Paris, France	City of Paris	Paris Carte	**	Schlumberger	IC Contact	**
Pittsburgh, PA	Greater Pittsburgh International Airport	Parking Control System	**	MARK IV	RFID	**
Shiga, Japan	Kayano (Jinja Shrine)	Parking	**	Combitech	RFID (IVU)	1,000

Table B-1. Summary of Fare and Toll Applications, continued

Location	Transit Agency	Project Name	Integrator	Supplier	Type	# Cards
Toll Road Systems						
Albany, NY	New York State Thruway Authority	E-Z Pass	SAIC	Amtech	RFID (I)	20,000
Atlanta, GA	Georgia Dept. of Transportation	Georgia 400 Extension ETC	Lockheed IMS	Amtech	RFID (I)	25,000
Bay Harbor Islands, FL	BHI Dept. of Public Works	Laser Bar Code Scanner System	Cubic Toll Systems	LazerData	Bar Code	*20,000*
Chicago, IL	Illinois State Toll Highway Authority	I-Pass	SAIC	AT/Comm	RFID (III)	**
Dallas, TX	Texas Turnpike Authority	Dallas North Tollway TollTag Sys.	Cubic CARCO	Amtech	RFID (I)	49,000
Denver, CO	E-470 Public Highway Authority	AVI System	PRC Inc.	X-cyte	RFID (I)	2,748
Frankfort, KY	Kentucky Transportation Cabinet	Toll Road Credit Card Collection	IBM	**	Bar Code	30,000
Houston, TX	Harris County Toll Road Authority	EZ Tag	Cubic Toll Systems	Amtech	RFID (I)	13,400
Oklahoma City, OK	Oklahoma Turnpike Authority	PIKEPASS	**	Amtech	RFID (I)	200,772
Orange County, CA	Transportation Corridor Agencies (TCA)	Toll Collection & Revenue Mgmt Sys	Lockheed/AT&T	AT&T/MARK IV	RFID(III)/CC	TBD
Orlando, FL	Orlando/Orange Co. Expressway Auth.	**	Revenue Markets Inc.	LazerData	Bar Code	**
Orlando, FL	Orlando/Orange Co. Expressway Auth.	Computerized Toll Coll. & TM Sys.	**	MARK IV	RFID (I)	50,000
Richmond, VA	Virginia Dept. of Transportation	FASTOLL (Dulles Toll Road)	Cubic CARCO	AT/Comm	RFID (III)	*20,000*
Wichita, KS	Kansas Turnpike Authority	K-Tag	IBM	**	RFID	*50,000*
Alesund, Norway	Alesund/Giske Bruselskap	Toll Road System	**	Combitech	RFID (III)	4,000
Barcelona, Spain	Autopistas	Barcelona/Acesa Highway ETC	IBM	Amtech/Elsydel	RFID (I)	20,000
Barcelona, Spain	Autopistas	Teletac	**	**	RFID	60,000
France	Societe Marseillaise du Tunnel du Prado	Urban Toll System	CSEE Peage	Gemplus	RFID (III)	20,000
France	Union des Societe d'Autoroutes a Peage	Country Wide Toll Prototype	CSEE Peage/GEA	Combitech	RFID (III)	TBD
Italy	AUTOSTRADE	TELEPASS / VIACARD	**	**	RFID (III)	88,000
Kuala L., Malaysia	Projek Lebuhraya Utara-Selatan BHD	PLUS - Malaysian N-S Expressway	**	**	RFID	**
Lyon, France	AREA (Autoroute Rhone Et Alpes)	Toll Road System	CSEE Peage	Combitech	RFID (III)	8,500
Mexico City, Mexico	CPFISC (CAPUFE)	Toll Road & Bridge ETC	Integra Ingeniera S.A.	Amtech/Elsydel	RFID (I)	5,000
Normandy, France	SAPN (Societe d'Autoroute Paris Norm.)	Toll Road System	CSEE Peage	Combitech	RFID (III)	10,000
Oslo, Norway	**	Oslo Toll Ring	**	Micro Design A/S	RFID (I)	200,000
Salzburg, Austria	OSAG Salzburg	Free-Flow Multilane Toll Collection	GESIG	Combitech	RFID (III)	TBD
Tours, France	Cofiroute	Highway ETC	Cofiroute	Amtech	RFID (I)	5,000
Tromso, Norway	**	Toll Road System	**	Combitech	RFID (III)	2,000
Trondheim, Norway	Trondelag Bomvegselskap	Trondheim Toll Ring	**	Micro Design A/S	RFID (I)	70,000
Ville Franche, France	Societe des Autoroutes Paris Rhin Rhone	SAPRR SVT(Systeme Voies Telep.)	Elsydel S.A.	Amtech	RFID (I)	1,000

B.11 Application Summaries

This section provides more detailed information on a few of the projects listed in Table B-1. The intent is to provide additional insight on specific application concerns, design issues, implementation issues, and operational issues facing transportation agencies[21]. The summaries help to highlight some of the unique requirements that exist in the different transportation modes.

Project summaries are structured according to the following outline, but only provide information for those outline topics where information was available. If there was no information available under a certain topic, the header was omitted. These topics include:

Project Name
Organization
Location
Contact Name
Type of System
System Integrator
Equipment Supplier
Recommendations
References
Purpose of Project
Project Status
Description
Benefits Realized
Performance Issues
External Factors
Future Plans

Summaries have been included for the following projects:

#	Mode	Location	Project Name
1.	Paratransit	Chicago, IL	Payment and Control Information System (PCIS)
2.	Bus	Ann Arbor, MI	Ann Arbor Smart Bus
3.	Multimodal	Central Point, OR	Rogue Valley Mobility Manager
4.	Multimodal	Manchester, England	GMPTE Contactless Smart Card
5.	Toll Road	Dallas, TX	Dallas North Tollway ETTM System

Application Summary 1

Project Name:	Payment and Control Information System (PCIS)
Organization:	Northeastern Illinois Regional Transportation Authority (RTA)
Location:	Chicago, Illinois
Type of System:	IC Contact Card
System Integrator:	Applied Systems Institute (ASI)

Purpose of Project

This project is intended to provide the 17,000 mobility-limited riders of paratransit services in metropolitan Chicago with a more convenient payment system. Specifically, the project has four objectives including: (1) automating rider-carrier transactions; (2) preparing payment, performance and exception reports; (3) certification of cardholder access to paratransit services to reduce fraud and unauthorized use and to maintain accurate billings; and (4) determining the feasibility of using card technology for mainline transit services.

Project Status

Approximately 6,000 cards have been issued to frequent system users. The RTA has decided to expand their database by including ADA certification information (this provides additional information on physical and mental disabilities of riders) to ensure that the paratransit system is used by the people who really need access.

Description

Project implementation, which started in June 1992, involves approximately 260 paratransit vehicles. The existing paratransit system is capable of providing 4,000 rides per day, and is generally booked 24 hours in advance.

Paratransit vehicle drivers carry a 19-ounce portable battery powered unit in a holster which is used to read from and write to the personalized cards. A smart card is used by the driver to initialize the hand-held unit. The driver then enters (via keypad) a vehicle registration number and the odometer reading. Dispatchers communicate to the drivers with two-way radios and direct them to the appropriate pickup points.

At each pickup and destination point, the driver keys in the odometer reading prior to inserting the passenger's card so that the total trip mileage may be obtained. The portable unit also automatically adds a date and time stamp to each transaction in order to avoid disagreements over arrival times. Fare payment can be made using the card or other standard forms of payment (cash, tokens, passes, or transfers).

Following a shift, the driver uses the smart card to log off on the portable unit. The portable unit is placed in an electronic cradle to await polling from the PCIS central system, and to recharge the battery. The PCIS central system contacts the cradles based on a set schedule to upload all transaction information and to download update lists, which may identify stolen or lost cards or replenish stored value amounts based on recent account payments.

IC contact cards are used in this application. Each card has a memory capacity of 16K bits. The RTA and ASI investigated a proximity solution, but decided that the cost of this type of equipment was too high at this point in time.

Benefits Realized

Accurate Third Party Billing - One of the major concerns of the RTA was to receive accurate billing information from third parties. Since there is no current means of verifying trips taken by riders, there is a potential for third party providers to take advantage of the RTA in reporting system usage. By actively maintaining trip information for each rider, and uploading summaries of this trip information, the RTA can verify levels of system usage and better plan system operations.

Performance Issues

Personalization - Since the RTA decided to include photos on rider cards for identification, cards must be used for a reasonably long period of time to warrant the extra costs involved. For this reason, the RTA decided not to provide photo cards to drivers, due to the high turnover rate of this position.

Replacement Policies - The RTA is issuing cards without an initial charge to riders. However, due to the high cost of the cards, policies are being developed regarding replacement cards.

Security - Since the value of transit cards may potentially be very high (over $50), the card must be secure against counterfeiting and the system must have the ability to deactivate "hot" cards before they can be used illegitimately. The system currently performs downloads of "hot" card numbers on a daily basis.

External Factors

Training - Since the responsibilities of drivers have changed as a result of system implementation, initial and ongoing training on system operation is now required. This impacts both system drivers and supervisors who must understand how to change their operational procedures to work with the new system.

Electronic Funds Transfer - Since this application uses prepaid cards and account balances are maintained and updated daily in a central system, there is a possibility that funds could be electronically transferred directly from independent user accounts. This will require that a set of business rules be established between the RTA and participating banking institutions.

Application Summary 2

Project Name: Ann Arbor Smart Bus

Organization: Ann Arbor Transportation Authority (AATA)
Location: Ann Arbor, Michigan

Type of System: RFID Card

Purpose of Project
To provide a multimodal system that could support both transit bus and parking applications. Additionally, the system must make it easy for the customer to use public transit as a mode of transportation. Specifically, the project has three objectives: (1) to uncover problem areas in the implementation and use of RF cards; (2) to evaluate the viability of RF cards within the transit industry; and (3) to look at ways to integrate an advanced fare media system with an AVL system (ridership and operating data - Smart Bus Concept).

Project Status
Currently establishing a test bed for the proximity card. AATA believes that the manufacturer must be closely involved in this activity to succeed.

Description
The AATA is working with the City of Ann Arbor and the University of Michigan on this project. Three possible options are under consideration: (1) a card with a button to activate an alarm at a bus stop or parking lot acting as a personal security device; (2) providing real-time traveler information on the number of vacant spaces in parking lots for traveler information; and (3) better customer usage information to improve parking and transit management.

The initial phase involves a separate $130K effort to develop technical details. Following this phase, the project will receive a $1.5 million capital grant from the FTA for system procurement (acquisition of an advanced fare media system).

Benefits Realized
No benefits have been realized at this stage but a key anticipated benefit involves third party billing. By accurately tracking trips billed, partnerships between commercial organizations (e.g., employee programs) and transit agencies will be made more attractive.

Application Summary 3

Project Name:	Rogue Valley Mobility Manager
Organization:	Rogue Valley Council of Governments
Location:	Central Point, Oregon
Type of System:	Magnetic Stripe Card
System Integrator:	Easy Street Software

Purpose of Project
To demonstrate the feasibility of the Mobility Manager concept for three types of transportation services including taxis, paratransit, and fixed route systems.

Project Status
A supplier of magnetic stripe equipment is currently being selected. The decision to use a magnetic stripe system over a smart card approach was based primarily on cost, especially considering the scale of the project. Additionally, the magnetic stripe approach provided enough memory capacity to maintain both an ID code and financial value. It was determined that the additional memory provided by the smart card approach was not required for this application.

Description
The project consists of three phases. The initial phase is focusing on providing transportation services to the elderly and disabled. The second phase will focus on frequent transit riders in urban and rural environments using existing hardware and available software. The third phase will involve participation by the general public.

The system will use a 2-track magnetic stripe card. One stripe contains the passenger ID information and the other track maintains a financial balance. Paratransit passengers swipe the card through an on-board reader as they enter. The system will then validate their ID code through a modem link to a central computer, a process which takes only a second or two. At this point the system can also roughly determine the location of the transaction. A reader-encoder is used to check not only the ID, but also the existing balance on the card. Once the trip is complete, the card is swiped again, the trip cost is subtracted from the original balance, and the new balance is written back to the card.

Performance Issues
Reader Compatibility - One of the main technical hurdles that had to be overcome in the development of this system was a compatibility issue between the fare box manufacturers and stand-alone readers. These card readers are not completely compatible due to different encryption or encoding schemes used by different manufacturers.

Recommendations

The system integrator for this project, Easy Street Software, recommends focusing on the requirements of service providers and end users. There is a project currently underway in Baltimore which is considering service provider requirements. There should also be more joint consideration of the smart card area with the US Department of Health and Human Services (HHS), since the HHS subsidizes qualified transit services.

Application Summary 4

Project Name:	GMPTE Contactless Smart Card
Organization:	Greater Manchester Passenger Transport Executive
Location:	Manchester, England
Type of System:	Remote Coupling Card (RF Proximity)
System Integrator:	AES/Scanpoint Ltd.

Purpose of Project
To improve on the existing automated ticketing system by upgrading from magnetic strip to a contactless RFID system. This is intended to benefit both the GMPTE and system users by improving system speed, convenience and reliability.

Project Status
The initial purchase will involve 500,000 cards used on Greater Manchester's 2,700 buses, the Metroline and rail stations (this will make it the largest contactless application in the world, and first full scale use in a ticketing application). Project implementation is scheduled for the middle of 1994.

Description
Cards will be used as prepaid tickets. A monetary value will be stored on the card and decremented each time the card is used. The system will involve approximately 2,700 buses, 350 rail and Metrolink locations, and over 800 card sales/reissue locations.

The card has no internal battery, but is powered inductively by the reader. The decision not to use a battery was based on cost and the additional card size that would be required (this would not have allowed the card to comply with ISO 7810 dimensions). Fare deduction is performed using inductive coupling with a frequency ranging from 207 - 390 kHz. Changes in the frequency are the means by which information is carried between the card and the reader.

Successful transmission of information can be performed at a distance of up to 3.5 cm, but it was decided that rather than expecting system users to judge this distance correctly, they would be requested to touch the card to the reader.

Cardholders are required to key in destinations as they board trains (inform drivers on buses), then place the card on the read-write unit to deduct the fare price. The read-write unit encodes the card with all necessary ticket information including ticket type, trip starting and ending locations, and period of validity. On board train conductors can make spot checks of card validity using a hand-held control unit. The typical communication cycle including reading and writing to the card takes approximately 0.3 seconds.

If the card is a special multi-journey or season card, there is no need to enter destinations since the card is already valid. In this case the passenger must simply place the card on the read-write unit.

Performance Issues

Contactless technology was selected due to the advantages of speed, convenience, and reliability in comparison to other alternatives such as magnetic stripe or contact IC/smart cards. Inductive coupling cards can be successfully read at a variety of orientations relative to the reader.

Future Plans

Initially, the cards will be used on Greater Manchester buses, the Metroline, and at rail stations. It is anticipated that additional uses will be established in the future. The flexibility of the card will allow other transportation and financial applications to be added at a later point.

Application Summary 5

Project Name: Dallas North Tollway ETTM System

Organization: Texas Turnpike Authority
Location: 3015 Raleigh Street
Dallas, TX 75219

Type of System: RFID (Type I) Read-Only Tag
System Integrator: IBM

Purpose of Project
The Dallas North Tollway project was initiated in order to increase the throughput of existing toll plazas, due to an increase in traffic and the limited space available to expand the number of toll lanes.

Project Status
The system is currently operational. An initial test project was conducted in early 1989 in 2-3 lanes using primarily employee vehicles. This test system demonstrated the feasibility of full-scale implementation. The project was publicly implemented on August 1, 1989 for 64 lanes distributed over 16 toll plazas on the 25 mile tollway. On November 17, 1990, four "tag only" lanes were implemented due to the high level of system usage. As of January 1993, the system has been conducting on the order of 1.6 million transactions per month. Currently, over 49,000 toll cards are in operation and approximately 45% of all transactions are now conducted with the ETTM system.

Description
The system uses a passive (powerless) 3.5-inch card that is attached using a velcro strip on the inside of the windshield, just a couple inches above the dashboard. This placement is designed to separate the tag from any metal interference that may exist on the car frame or as the result of objects resting on the dashboard. Readers are positioned to handle a range of tag elevations above the roadway (approximately 2-8 feet) to allow for the different sizes and types of vehicles using toll cards.

Readers in the toll lanes send out a steady RF signal toward the tag. The tag receives this signal, alters a portion of it, and reflects it back to the reader. This process is known as modulated backscatter. The reflected signal contains the ID code number stored on the tag, which is used to create an audit listing of all toll transactions.

The system is designed to identify vehicles traveling at up to normal highway speeds (55 mph) but has recorded a vehicle traveling at 92 mph. Typically, vehicles travel through the automated lanes at 15-30 mph.

Benefits Realized

1. While the traffic levels have increased approximately 30% since the system was implemented, use of the ETTM system has enabled the Tollway not only to handle this increase but also to reduce existing traffic backups at the same time. Tag lanes allow vehicles to go through in approximately 2-3 seconds, while exact change lanes take 5.2 seconds and change-made lanes require 12.4 seconds per vehicle. This result has been critically important, especially at some of the inner city toll plazas which cannot be widened to add new lanes.

2. The system reduces the amount of coin collections, which typically require a substantial handling effort on the part of the toll agency.

3. The system has provided more convenience to tag users, who are now able to drive through tag lanes without stopping.

Performance Issues

The system has claimed near 100% accuracy, but toll officials and equipment suppliers admit that it is difficult for them to measure the exact level of performance and therefore they might be unaware of some minor performance issues.

External Factors

Safety - Placement of tag only lanes is seen as an important consideration by toll officials, since the design must avoid accidents resulting from last minute lane changes.

Future Plans

The TTA is considering implementing additional AVI only lanes.

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APPENDIX C
EXTERNAL FACTORS

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APPENDIX C - EXTERNAL FACTORS

For the purpose of our research we identified eleven categories of external factors that may impact the implementation of a multimodal card system for transit fare and toll collection. These categories included:

- Policy Issues
- Financial Reporting Procedures
- Standards
- Regulations
- Legal Issues
- Implementation and Development Issues
- Technical Issues
- Environmental Concerns
- Safety Concerns
- External Interfaces
- Security Concerns.

It was determined that factors in each of these categories will require proper attention since any one factor may impact the implementation of a multimodal card system in a public transportation environment. Moreover, interviews with various transit agencies revealed that each agency had it's own set of external factors that were relevant to their particular project.

C.1 Policy Issues

As noted by Gifford, Horan and Sperling,[1] policy issues include legal liability, the respective roles of public and private institutions, intergovernmental relations, international competitiveness, standardization, and environmental impacts. In addition, we believe that labor unions, organizational structure and behavior, interagency cooperation, and social issues require similar attention.

Consideration of these policy issues can help shape the future direction and utilization of automated data card systems. For example, it is possible that a consolidated, interagency position on this technology could increase not only the cost-effectiveness of the systems, but provide a higher level of consistent service and ease of use to consumers throughout the country. However, developing a consolidated position will entail compromises among the policies of individual agencies, and could potentially alter the direction of the evolution of fare and toll payment applications. While there are many decisions to be made with regard to technology, the more difficult problems will be the coordination of broad policy requirements across the multitude of federal programs and across the various municipalities. Functional responsibility for developing standards for transaction processing, coordinating procurement and contracting authority, and sharing of costs are but a few of the underlying issues that are discussed in this section.

C.1.1 Labor Unions

Process innovations which may impact the work force of any transit agency need to be considered. A number of process improvements have been halted before implementation due to the strong resistance of labor unions associated with the transportation industry. Therefore, it is strongly recommended that any improvements in customer access be viewed in terms of the impact the improvement will have on the current work force. Adequate understanding of the impacts of these regulations must be obtained prior to any multimodal card system implementation. The following articles reveal how labor costs, and associated problems, have caused transit operating expenses to skyrocket.

Robert Behnke[2], in his discussion of APTS applications, points out that declining per capita ridership and declining market share of commuting trips are not the only troubles that have hit the U.S. transit industry. Costs, particularly labor costs, have grown much faster than inflation during the past 25 years. According to Behnke, the average cost of a passenger trip on public transit in the U.S. has risen by 170 % during this period. Moreover, passenger fares now cover little more than a third of the operating cost of transit systems in the United States. The major reason for the rapid cost increase is largely attributable to demographics, i.e., there has been a tremendous shift of jobs and residences to low-density suburban areas. Again, as Behnke states, suburb-to-suburb travel tends to be very costly for U.S. transit agencies since personnel, vehicles, and facilities required for peak commuting hours are often under-utilized at other times.

A recent article in the *Boston Globe*[3], dated June 15, 1993, explained the cost dilemma facing the MBTA and the Carmen's union. It cost the "T" over $90 an hour to deliver one hour of bus service, making that system the second most costly to operate in the United States. Antiquated labor laws mandated by the Massachusetts Legislature make it nearly impossible to negotiate with the 6,400 T workers who are organized in 26 different unions. There is no incentive for the unions to bargain with management. Therefore, to trim costs management and the governor have adopted a strategy of introducing competition in the form of privatization by putting selected routes out for bid.

Thus, issues such as increasing ridership and developing more efficient systems are not the only problems that must be resolved. Rather, as in manufacturing and other manpower intensive industries, the cost of labor and unions will not simply disappear for transit agencies once new technologies are introduced.

C.1.2 Organizational Issues

To understand the complexities present in a multimodal card, one must not begin with the technology but rather with the implications and changes which will result from the multiuse card. The agencies will share databases and communication lines, and present transportation modes as a single source of travel services. Moreover, there will be a continuing struggle between managers and transformational leaders. Managers are dedicated to the maintenance of the existing organization, whereas transformational leaders are committed to its change. Tensions will inevitably arise between doing things right and doing the right things.

Joseph Sussman[4], writing on the challenges facing operations research and management science personnel, makes a very interesting point. He states that academia needs to recognize that the educational requirements facing transportation designers are quite different from the traditional civil engineering technologies of structures, materials, geotechnical engineering and project management. Consequently, the institutions of higher learning and the various DOTs must now be concerned with electronics, information systems, communications and sensors and will need to emphasize the operational aspects of the transportation system as well as construction and maintenance.

Finally, in his paper entitled "Integrating ETTM with Transit Fare Collection and Parking," Ronald Cunningham[5] of Lockheed IMS correctly asserts that in the past highway and transit facilities have been "treated as separate and distinct entities as if each has entirely different user communities. In reality, there is often considerable overlap in these user groups... ." Adding to the confusion, Cunningham notes, are flexible fare payment plans and conflicting schedules between operators or transportation modes.

C.1.3 Interagency Cooperation

Ramifications of interagency cooperation, including sharing information resources and the potential consequences, must be considered. Moreover, complicating the situation, is the fact that each agency has, over the years, developed their own way of doing business, i.e., each agency has its own hardware and software systems for collecting tolls.

How are incompatible systems among transit properties going to be handled? For example, what would happen to a transit agency if it had recently acquired a new financial system and it was not compatible with a system identified by other agencies as being a good network standard? These questions, and many more, indicate that interagency cooperation is required.

Two current examples stand out: first, the New England Electronic Toll and Traffic Management Group which combines the seven New England toll and transportation agencies with MIT, and secondly, the E-Z Pass Interagency Group that includes toll agencies from New York, New Jersey and Pennsylvania. Mr. Charles J. Fausti[6], Chairperson for the E-Z Pass Group Technical Committee, points out that agencies must work together if the multimodal card technology is to be successfully implemented in disparate geographical areas with so many different operating agencies. As Mr. Fausti and his colleagues discovered, there are many non-technical issues that need to be resolved by executive managers from the various agencies prior to the introduction and implementation of new technologies and systems.

C.1.4 Social Issues

Robert Behnke's far reaching article[7] on APTS multimodal applications includes an analysis of the social problems facing transit agencies as they explore the utilization and implementation of new technologies. As Behnke notes, most transportation managers have not recognized the trouble they face with environmentalists, taxpayers and elected officials. Most managers are caught by surprise over the adverse reactions of the media when stories are released indicating that there are social, or public problems with their respective agency. Additionally, Behnke points out that the Americans With Disabilities Act (ADA) will force these agencies to expand public transportation services for those with disabilities.

A most relevant and current example is a story in the July 27, 1993 edition of the *Boston Globe*[8]. The National Spinal Cord Injury Association is attacking the Massachusetts Bay Transportation Authority (MBTA) for its poor performance in providing services for the handicapped on the public transit lines. The Association cites the recent death of a blind person who fell to her death onto the electrified third rail.

However, as noted in other sections of this report, the cost of operating a public transit system requires extensive subsidies paid by the taxpayers. Therefore, addressing shortcomings similar to those identified by the ADA will require increased taxes, cutbacks in conventional transit services, or both. Unfortunately, taxpayers are more critical of continuing declines in the public transit's share of the overall transportation market and most transit agencies' productivity (e.g., passengers per vehicle-hour of service) As a result, the beleaguered taxpayer is less likely to support new public transportation initiatives.

C.2 Financial Reporting Procedures

Financial data must be captured in significant detail to perform complex budgeting, cost accounting and financial analysis. General ledger data repositories typically consist of an extensive number of data entities and attributes. For example, financial transactions associated with toll collections may include the appropriate customer ID, account number, account status, and billing information. Many of these fields are edited in combination with one another. Further, some of the combinations are valid only during certain time periods. Maintaining correct values and valid combinations for each of these data elements is a complex and critical task. Without accurate financial data captured at this level of detail, transit agencies would not be able to perform the cost accounting functions required by the local and federal government.

An approach to standardize financial data among agencies must include:

- Defining the organizational entity that is the "owner" of each data element, the owner of the valid combinations, and the owner of the appropriate "date sensitivity" data;
- Defining the policies and procedures (both automated and manual) that are required to ensure that financial data is complete, accurate, and processed into the general ledger in a timely manner;
- Defining and implementing those technical enhancements that would help reduce the manual time required to maintain the data tables and ensure data integrity and processing efficiency.

C.3 Standards

Even where there is no need for a standard in an application, many transit agencies will require a standard to insure multiple sources, future upward compatibility, and interchangeability; (e.g., inter-operability among cards and reader/writers for geographically dispersed applications). This is an issue discussed earlier that is especially pertinent to interagency groups and agencies with significant investments in existing toll and fare collection systems.

An interesting perspective on standards is provided by Amano, Nishimura, and Tokitsu of Toyota[9], who point out the similarities and differences between required standards for logistics/factory automation systems and ETTM/AVI systems. Various factory automation systems, utilizing unique devices, often provide competitive advantages. Therefore, standardization usually occurs when the technology is fully matured. AVI and ETTM systems, however, require that standardization be accomplished prior to full scale equipment installation to prevent incompatible systems from being placed in operation.

C.4 Regulations

The governmental regulatory environment has grown rapidly during the last few years and has resulted in an increase in scrutiny of all government agencies. A number of mandated financial policies and procedures have been identified as being necessary financial controls for government agencies. The most recent financial directives issued include:

- Financial Managers' Financial Integrity Act (FMFIA)
- CFO Act
- Government Accounting Office (GAO) and Inspector General (IG) Audits

The regulatory agencies responsible for reviewing the corresponding implementation as well as assessing compliance with these requirements include:

- Government Accounting Office (GAO)
- Office of Management and Budget (OMB)
- Department of Transportation Inspector General (DOT/IG) internal reviews

Horan[10], in professional testimony, recommended that Congress establish specific evaluation requirements to ensure that ITS, with its associated technologies, will be developed utilizing performance data obtained through operational field tests. This was in response to GAO findings in 1991 that 38 major reports contained little to no empirical field data on ITS-related technologies, including smart card tests. Rather, conclusions were based on model estimations, simulations, or "desk top" projections.

C.5 Legal Issues

The principal legal issue involves the necessity that privacy restrictions be designed into the multimodal cards. Concerns that cards for fare and toll payment might be tied to one's social security number or bank account may cause consumer reluctance to enter the system and utilize the card technology. Moreover, careful attention must be paid to the accommodation of measures to minimize unauthorized use or manipulation of data parameters.

Linda Spock and Michael Zimmerman[11], in their article on video enforcement, discuss the invasion of privacy associated with electronic toll and fare collection in the State of New York. Initially, the law did not contain sufficient strength to fine drivers on the basis of photographic evidence. At issue was the invasion of privacy that occurs when video images of persons in vehicles are captured. The solution involved a focus on the owner of the vehicle (not necessarily the driver) as the violator, with the legislation applying penalties for toll violations only.

Contractual precautions must be taken by transit agencies to help manage the technical and legal risks inherent in acquiring a technologically advanced multi-use transit card system. However, as noted by Mitchell Ostrer[12], there are distinct advantages for local transit agencies that join forces with other organizations in the procurement of newer smart card products. For example, an agency can share risks and enhance benefits. It can contract to increase its chance of taking over and restoring a system if a supplier defaults. An agency can guard against regulatory changes that could make its system obsolete or inoperable and it can also make sure it does not buy itself a patent infringement lawsuit, instead of a new way of collecting revenue. Several potential contract problems and issues were delineated by Mr. Ostrer including the following:

- Contracting Authority of Interagency Groups. Seven New England toll and transportation agencies, and MIT, have established the "New England Electronic Toll and Traffic Management Group." Certain legal issues needing resolution have been identified: For example, can one agency sub-delegate power, e.g., for procurement, to a joint enterprise? Moreover, does the joint enterprise constitute an interstate compact requiring Congressional consent? An answer to the first question is that state statutory or case law govern whether a local toll agency can delegate its powers to an inter-agency group. As for the second question, a regional arrangement is not likely to need Congressional consent if the states are free to withdraw, or if the federal government retains the power to overrule action of the states..

- Intellectual Property. The basis of an advanced multimodal card system, including its software, is its "intellectual property." A risk averse agency will want to contract for the right to secure access to said property in the event that the product or service provider defaults. Items for negotiation include the scope of the intellectual property, circumstances that could trigger a release, and liability for wrongful release. Agencies must also be mindful that in emerging high tech industries, the validity of key intellectual property rights may not be well-settled.

- Communications Licenses and Emerging Standards. An agency procuring a multimodal card system should seek contractual provisions that would reduce the risks that may result from changes in federal communications regulations and from developing smart card standards. The regulatory climate of the FCC is uncertain as a result of pending changes in spectrum allocation. An agency does not want a system it cannot use because it operates on an electronic frequency no longer available.

- Impact of Federal Funds. The availability of federal dollars may be enticing; however, the financial support does not come without numerous encumbrances. For example, grantees must assure compliance with affirmative action, the Copeland Act, the Davis Bacon Act, and the Contract Work Hours and Safety Standards Act. An agency must also comply with the federal financial management systems, and auditing and record retention requirements. Of course, the federal government will assert claims to intellectual property rights. That may include the right to license others for government purposes and, since the promotion of smart card technology is for a government purpose, that may mean the right to license other toll agencies, an obvious concern for a market driven vendor interested in selling its products to other agencies.

C.6 Implementation and Development Issues

Joseph Sussman[13], writing in *OR/MS Today*, states that the development of ITS, and its subsets, including APTS, will require the implementation and deployment of an infrastructure supported largely by the public sector, and in-vehicle equipment, e.g., the smart card transponder, supported by the private sector. However, the hardware and software in the infrastructure must be compatible with the hardware and software that is acquired in the private sector. Mr. Sussman cites the June 1992 IVHS America "Strategic Plan," in which it was estimated that of the $230 billion to be spent on ITS over the next 20 years in the U.S., about 80% will come from the private sector, with the remaining 20% to be expended by the public sector. This, of course, is the historical opposite of the usual infrastructure development, including the Interstate Highway System which was constructed with public funds.

Discussion with industry experts provides evidence that the possible design of multimodal card systems depends, in large part, upon the extent to which the system conforms with existing commercial off-the-shelf products and standards. This evidence is further illustrated by a discussion of necessary system requirements or parameters as follows.

- Compatibility with existing commercial infrastructure: The commercial infrastructure includes not only the equipment in the system such as the terminals, networks and switches, but the operational aspects as well.

- The number and location of processing entities: The number and location of processing entities determines the routing and switch requirements for financial transactions. Interstate transactions that utilize the services of different processors will require either a gateway switch to provide interstate access or a direct connection between the two processors.

- The diversity and location of accounts: Achieving the benefits of consolidating multiple programs on a single, multimodal card requires either that the program accounts be collocated at a common processor or that specialized software be developed that can switch transactions based upon transaction type.

An even more controversial aspect of a multimodal card system is the technology for electronic road pricing. Although it has been a "technical success" as demonstrated in such diverse areas as Hong Kong, Sweden, and Norway, opposition has been encountered as motorists believe they are being charged with a hidden tax or, because of access to personal financial accounts, there is the threat of an invasion of privacy. Sweden, however, intends to use a form of multimodal cards that will be used to pay congestion metering charges or offer the lower cost option of public transit fees. As noted by Lamont Hempel[14], when vehicles equipped with these cards, which combine ETTM, AVI, and peak-hour road charges, enter congestion-prone areas during peak travel periods, they will be automatically identified and billed a user charge for the privilege of utilizing a resource during a period when it becomes "scarce."

Deborah Gordon[15] has evaluated congestion metering as it relates to environmental impact and has determined that without road pricing there will be more road building, and that the expanded capacity will simply attract more vehicle traffic. She has concluded that the only way to reduce congestion is to charge drivers with less demanding commutes a sufficiently high fee, or surcharge, to keep them off congested routes and make alternatives to the automobile more cost competitive. Such charges would be effective if the revenues were used to provide alternative forms of transportation for those who do not utilize the roads during peak periods. As noted earlier, current applications with congestion metering have been greeted as forms of hidden taxation that could be construed as regressive in nature. Ms Gordon, however, believes that "as long as compensation is provided in the form of significant investments in alternatives to automobile transportation, then road pricing should not be regressive."

C.7 Technical Issues

Technology programs should ensure that there is adequate diversification of research and testing projects so that a range of approaches and goals can be attained. Agencies should ascertain if the technical infrastructure is the best current one to effect and manage the kinds of strategic alliance under consideration. However, the technical issues we are most concerned with are primarily hardware and software applications and communications capabilities.

In addition, transportation planners must recognize that political and economic factors, not technical feasibility, constitute the fundamental constraints in future applications of smart card technology. A transit agency must also assess if the technical approach utilizes their own proprietary capabilities. Moreover, psychological factors and social acceptance might be as important.

The E-Z Pass Technical Committee[16], for example, identified the following criteria and performance parameters which they considered as most critical in developing a multimodal card system:

- Radio frequency interference susceptibility
- Radiated power density
- Vehicle lane positioning and spacing
- Tag/transponder positioning within a vehicle
- Environmental tolerances within various agency constraints
- Multiple types of vehicles
- Tag/card content and encoding techniques
- Open highway capabilities of the system for future purposes, e.g., traffic management
- Interface requirements between card reader and agency's toll registration and financial transaction systems
- FCC licensing requirements

ITS America, and other organizations and writers, tend to segment the ITS technology into four to eight functional areas including: Advanced Public Transportation Systems (APTS); Advanced Rural Transportation Systems (ARTS); Advanced Traveler Information Systems (ATIS); Advanced Traffic Management Systems (ATMS); Advanced Vehicle Control Systems (AVCS); and Commercial Vehicle Operations (CVO). Of the principal categories, Sussman[17] believes that APTS can employ ATMS, ATIS, and AVCS to greatly enhance the accessibility of information to users of public transportation as well as to improve scheduling of public transportation vehicles and the utilization of bus fleets.

This is compatible with the thought that a top-down "big technology" approach, e.g., a complete ITS one, may be inappropriate and unworkable with the various agencies involved. System designers may have difficulty with the market forces that favor the development of specialized, niche-oriented technology, as evidenced by the trend throughout the communications industry.

C.8 Environmental Concerns

Deborah Gordon[18] has assembled an impressive array of statistics that indicate that the transportation system, as it currently exists in the U.S., is responsible for direct and indirect environmental impacts. Direct impacts include emissions from internal combustion engines, while indirect impacts include emissions associated with fuel extraction, refining and distribution, infrastructure construction, and vehicle manufacturing. Moreover, she concludes that vehicle pollution is also directly responsible for extensive environmental deterioration, ranging from damage to agriculture and wildlife to contamination of water by leaking underground fuel-storage tanks and oil spills. In addition, Ms. Gordon identifies the infrastructure required to support transportation as having a substantial impact on people and the environment in that large amounts of irreplaceable land are transformed into roads and parking lots.

The critical problem documented by Ms. Gordon is the insatiable appetite for oil of internal combustion engine vehicles that currently exceeds 13 million barrels of oil a day. We are prisoners of that demand and will soon depend upon the Persian Gulf for at least 50 percent of the oil consumed in the USA. Two other factors contribute to this growing problem: a) traffic congestion, which wastes two billion gallons of gasoline annually; and b) the relative low cost of operating a vehicle in America. Traffic has worsened, according to Ms. Gordon, because there are too many passenger cars and trucks being driven too many miles, with too few people in them, for our roads to handle. Her solution: (1) reduce usage of automobiles and increase the utilization of public transportation, and (2) charge tolls to adequately adjust for the actual cost of public roadways. The end result would have resources being applied to such initiatives as AVI and APTS.

Robert Behnke[19] has examined the applications of various components of ITS and concluded that the integration of APTS with conventional transit systems can reduce traffic congestion, gasoline consumption, air pollution, and mobility problems at a low cost to taxpayers. He also points out that the solution may not be within the public sector's financial realm. As an example, the USDOT/FHWA has estimated that taking only 20 percent of the cars off the road during peak commuting hours would reduce traffic congestion delays by more than 50 percent. However, based on the estimated cost of adding new rail lines or expanded bus services within the suburbs, it would cost approximately $300 billion a year in additional transit subsidies to accomplish this auto-to-transit shift using conventional transit, paratransit and ridesharing modes.

Finally, Mr. Behnke concludes that the United States is losing its war against traffic congestion. The following paragraphs summarize several comments Behnke makes about the inability of our existing transit-paratransit-ridesharing system to reduce the transportation, energy and environmental problems caused by our excessive use of single-occupant automobiles:

- Demographic trends indicate that the population continues to disperse outward from large urban areas into lower density suburban developments. This will definitely hamper efforts to increase use of public transportation.

- Given the low-density dispersion of residences and work places, policy makers need to maintain realistic expectations of what conventional transportation can accomplish in the urban environment. It has long been a fundamental assumption of planners that conventional mass transit would provide the ultimate remedy to the urban transportation problem by reshaping urban form and by modifying consumer behavior. On the contrary, the principle lesson to be learned from the census is that for transit to retain its public, it must better adapt to the changes in urban form and consumer preference that are taking place.

- It is becoming increasingly apparent that major changes are needed in the way public transportation services are financed, structured and delivered. The shift of jobs to the suburbs, the growth in inter-suburban commuting, and the increases in private vehicle ownership all make it more difficult for transit to compete with the private automobile and meet consumer needs.

C.9 Safety Concerns

Electromagnetic radiation of certain frequency ranges and power levels may present hazards to public health. Research into health concerns and compliance with specified safety levels should be part of this effort.

In a recently completed study of the IC smart card and RF communications industry[20], Coopers & Lybrand determined that reader power output could potentially pose a safety problem. By industry definition, reader power output relates to the signal strength required at a certain frequency to accurately transmit information over a specified distance. While increasing the reader power may provide a better transmission range, there are limitations imposed by the FDA and the FCC in order to ensure safety and to limit interference with other communications. Based on IEEE Standard C95.1-1991[21], the FDA has set a safety limit of 10 milliwatts/cm^2. In addition, the FDA has stated that exposure to this power level should not be maintained for longer than six minute intervals. Also, a level of 100 milliwatts/cm^2 has been adopted by the U.S. Army as "intrinsically " safe in the presence of munitions.

When considering power levels, it is also important to determine whether the levels identified by vendors are peak power levels or average power levels. With respect to the card power output, for some active systems the card may have its own transmitter and this may lead to safety concerns as cards will regularly be in close proximity to people. In this case, the same concerns expressed above for readers also apply to cards.

C.10 External Interfaces

Philip and Ji Lee[22] address the issue of integrating new card technology with existing systems and are quick to point out that interchangeability and interoperability are two areas that the smart card industry must address. For interchangeability, the smart card industry will require an application programming interface that provides a neutral open system interface to the card. According to the Lees, for interoperability the systems integrator will need a multiple application controller platform that is both secure and smart, on which the application programming interface can reside and operate independently under a host operating system, thus eliminating the need to develop a specific card interface for each operating system.

Security concerns in multimodal card systems exist and can be addressed at many levels. From a systems point of view, it is useful to consider the potential value of the information maintained on the card and the estimated cost of circumventing security measures. Security is enhanced by keeping the value of the information as small as possible, and raising the cost of circumvention. From a technology point of view, the key is ensuring that all links in the system are strong, since the subversion of security measures is generally performed by attacking the weakest link. Recent discussions with chip manufacturers indicate that they have recognized that their component is the principal element in achieving security in the smart card end product. Moreover, design-for-security applies to the silicon manufacturers of smart card ICs. There is no way to attain security in smart card applications without the initial design occurring at the chip manufacturer level, where elements of the design requirements include memory and access control.

Security is a growing problem in terms of vulnerability to theft and fraud and to accidents of information leakage. However, information must be shared between transit agencies and potentially some financial institutions, but it is difficult to combine access and control. The idea of on-line customer service and delivery is to make access convenient and easy for transportation end-users. Control demands the opposite: restriction and difficulty of access.

Ken Gibson[23] points out that the prevention of fraud is the single greatest reason for selling smart cards to passengers. Pertinent to transit operators is maintaining security of revenue, first as it is collected, and secondly during the operating functions of the transit system. As Gibson points out, conventional tickets have a low security factor because they can be copied or used in ways that enable passengers to circumvent the system. For that reason, the paper card has largely been replaced by magnetic machine readable technology that increases the security factor. The next generation will likely be the multimodal card that is versatile, flexible, and the most secure form of toll and fare technology currently available.

Michael Friedman[24] provides an additional albeit more introspective view of the problems facing the introduction of card systems. Friedman cites the possibility of "Big Brother" tracking movements, and that future card technology will provide counterfeiters with fraudulent means to rob revenue. Friedman believes that privacy and security become intertwined when trying to protect financial transactions at toll and fare facilities, and that the emergence of more sophisticated systems will cause the following questions to resurface:

1. What are the threats to system integrity?
2. What is being protected?
3. How should the transaction be protected?
4. How can we recover lost revenue as a result of a violation?
5. Can the anonymity of customers be maintained?
6. Are legal rights of customers and employees protected?
7. What are the benefits/incentives for customers to utilize the card technology?
8. What are the costs to insure privacy and security?

As Freidman points out, the integrity of the network may be threatened in a variety of ways, for example, when counterfeiters attempt to intercept transmissions in order to create copies of the signals and then play the signals back at future toll crossings. But, as Freidman states, the additional expense to incorporate security in most current applications is difficult to justify, in particular those applications that require low-cost, battery-powered, in-vehicle transponders. Finally, Freidman believes a more effective approach is to "allocate message privacy to the host system, with authentication and network integrity part of the basic link hardware. The host encrypts the message that is transmitted over the air and stored in the transponder."

Ronald Cunningham[25] sums the privacy and security requirements aptly as he notes that multimodal cards will, by design, contain potentially sensitive information about the users and their travels. Therefore, the security mechanisms built into the card (beginning with the chip) must prevent unauthorized access to information directly from the card itself. Also, Behnke concurs with Freidman in that the encryption techniques used in communications between the card, the reader, and the central computer system will ultimately be similar to those currently used in the transfer of information between banks and ATMs as these types of controls typically provide excellent protection of data and assure the privacy of transactions.

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APPENDIX D
COST/BENEFIT ISSUES

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APPENDIX D - COST/BENEFIT ISSUES

D.1 Cost Factors

The costs for equipment could be recouped in time through a variety of fare and toll system improvements including physical plant enhancements, increased collection reliability, reduced costs, increased ridership, and cost-effective automation. Costs could also be retrieved through shared revenue benefits and value-added services attained by marketing a single fare instrument adaptable for use by numerous other transportation agencies. Moreover, smart card technology is regarded as immature, and given that the number of applications is expected to increase, costs for that category could decrease 10 to 20% per year for the next three to five years.

Constituents of the cost data are shown in Figure D-1, "Card Technology Cost Comparison Table." Additional categories vary from application to application, will be site-specific, and involve numerous other organizations including systems integrators, installers and trainers.

a. Equipment. Mel Blackburn[1] describes key factors in card system selection as the cost of system hardware, firmware, and ongoing costs such as maintenance and ancillary costs. However, the cost per smart card, especially in a system with a large number of cardholders, is considerably more than the cost per magnetic stripe card, i.e., \$0.50 - \$150.00 versus \$0.12 - \$0.45 respectively. Even though magnetic stripe is probably the lowest cost option, it has limitations such as capacity to store data and poor security. In addition, transit properties such as WMATA, which use magnetic stripe cards, report very high maintenance costs for turnstiles with their card transport mechanisms.

b. Facilities including host computer. Interviews with ongoing system retrofit projects, including the Tobin Bridge in Boston[2] and the New York City Transit Authority's Automated Fare Collection (AFC) program[3], indicate that the facilities will require many improvements including those listed below:

- Structural enhancements to increase security, prevent fare evasion, and improve passenger or vehicle throughput.

- Power upgrades, usually AC power, are necessary to accommodate the new system including probable lighting improvements.

- Communications between the host computer and the fare or toll equipment, including software, will usually require upgrading. For example, the installation of a fiber optic network will not only be cost-effective, but most likely a necessity at all older sites.

- System electronics, including a central computer, readers, and any on-board vehicle equipment, may need upgrading.

c. Implementation and training. These services are usually provided by the system integrator and/or the card vendor and are negotiated as part of the procurement package. Cost will depend, obviously, on the number of sites and personnel involved.

d. Maintenance and replacement costs. These costs can be incurred in numerous ways, but usually involve either contract service or in-house maintenance personnel. The option lies with the owning agency and often involves negotiations with existing union contracts, particularly if union members are displaced by the new system. However, unless the new system is large enough to support agency maintenance crews, the most fiscally prudent alternative is contractor service.

e. Marketing and distribution of cards. Depending on the status of an existing distribution network, the agency must allocate funds for the sale and distribution of cards. Again, this is a cost that will vary from project to project, and may include the installation of automated vending machines and the utilization of retail outlets to complement current booth sales. Education of the consumer begins long before the system is open to the public and can range from focus groups that assess customer acceptance to public service announcements and distributed printed media.

Table D-1. Card Technology Cost Comparison Table

CATEGORY		COST ($$)		
			Readers	
Family	Type	Card	Read-Only	Read-Write
Mag Stripe		0.12-0.45	15-225	225-600
Optical		0.5-3.00		750-4500
Bar Code		0.01		100-1000
IC Contact	Memory only	0.75-1.50		30
	With CPU	3.75-7.50		75
RFID	Type I R/O	0.50	5000-7000	
	Type II R/W	1.50-3.00		5000-12,000
	Type III Smart	5.00-150		5000-12,000
Coupling		1.00-6.00		5000-12,000

It should be noted that Table D-1 provides the initial cost of card media and not the average cost of media per unit of time (month, year, etc.). Initial cost and cost per year of use will both impact market acceptability, but in slightly different ways. Plastic magnetic cards costing $0.25 used as monthly passes cost a total of $3.00 per year. If a smart card cost $6.00 but lasted two years, annual costs would be the same. Furthermore, the convenience of the smart card, possibly marketed as a "premium" service, might make it possible to get users to underwrite all or part of the media costs.

One other relative cost item is media lifetime. Magnetic media typically have limited shelf life, whereas smart cards powered by external power last forever.

D.2 Potential Benefits

Unfortunately there is no wholly satisfactory method for defining the exact rate of return of a long-lived, capital expenditure. However, most transit agency financial investments are being measured against a discounted cash flow (DCF) rate of return or the internal rate of return (IRR). As a rule, when evaluating capital budgets on the basis of IRR, an investment is considered acceptable when the opportunity cost of capital is *less than* the IRR.

The New York City Transit Authority (NYCTA)[4], for example, has expended significant resources in calculating the IRR for the implementation of their intermodal AFC system. According to the NYCTA, annual cash outlays (costs) are weighed against estimated revenue benefits received from fares and expected improvements such as those listed below:

a. Reduction of fraud. As noted earlier, the security of magnetic stripe card technology is inferior to IC and RFID cards. However, the victim of fraud is usually the user of the card rather than the agency. The agency suffers lost revenue if riders have reason to fear for the security of their funds and decide against utilizing the automated fare and toll application. Additional study are necessary to quantify this cost/benefit factor.

b. Reduction of fare and toll evasion. Fare control improvements are the result of incorporating structural modifications with the new automated card system and electronic turnstiles. Estimates of lost revenue range from 4 to 8 percent. For example the NYCTA field study, completed in 1988, revealed that approximately 5.5 percent, or 60 million passengers, were evading fares. Their cost/benefit analyses indicated that fare control improvements would yield $45 million in annual revenue.

c. Reduction of vandalism. Although vandalism cannot be totally eliminated, design measures can be taken to minimize the damage to the system. For example:

- Strong fascia plates on exposed or vulnerable areas.
- Restricting the media slot opening to just what is required for correct media.
- Internal components should not be visible through the media opening.
- Shutters or deflecting plates can be used to protect internal parts.

d. Increase in throughput rate. According to C.J. Stanford[5] of CardWare Limited, contactless cards are ideal for transit applications as cost analyses indicate that the use of contactless technology is superior to other forms of prepaid cards in two different applications:

- On buses: Increasing the passenger throughput rate[6] by 2% can result in a reduction of the average travel time by 15%. Transit agencies as well as fellow road users benefit from the increase in average speed, particularly in heavily congested traffic. As Stanford points out, this translates to millions of dollars saved in energy costs and an ancillary benefit in reduced pollution caused by motor vehicles.

- On rails: Again, the passenger throughput rates[7] show a reduction in boarding times of 20% with magnetic stripe technology and up to 40% when using contactless cards instead of cash payment. The direct benefit to the agency is less barriers or turnstiles required, thus, a reduction in equipment and maintenance costs.

e. Increase in fare ridership. A single fare card that provides a seamless connection between intermodal applications will encourage increased utilization of fare and toll equipment. The NYCTA and MASSPORT have conducted independent studies that show additional revenues will be generated from merchant fees, revenue float and enhanced marketing opportunities. The NYCTA estimates that annual revenues of $34 million in new fares would result through the development of a universally accepted card.

f. Increase in mean cycles between failure (MCBF). This parameter pertains to the readers, and in the NYCTA example, the new electronic equipment has a MCBF of more than 120,000 cycles versus 30,000 cycles for the current mechanical devices. The benefits include reduced maintenance costs, increased operating efficiency, and higher throughput rates.

g. Pricing strategy opportunity. The tradeoff between "read-only" and "read/write" technology is most evident when determining a pricing strategy. Read-only is simpler and appropriate for a single price, multiple-ride card. However, if a fare policy involving, for example, peak/off-peak or commuter pricing is required, then the read/write card is necessary. The NYCTA is implementing a read/write magnetic stripe card after extensive testing. The Tobin Bridge (Boston) is utilizing read-only initially with the capability to convert to read/write when they change their single fare pricing strategy. The NYCTA studies estimate that its pricing policy will generate an additional $49 million in revenues. Other pricing policies made possible by additional card memory include carefully tailored price incentives for multiple trips per day, park-and-ride incentives, and mode-to-mode transfer incentives (commuter rail to bus to subway).

h. Marketing

- Interagency. Several agencies believe that the first organization that has an automated card system operational in a region will be able to "sell" their experience and information to sister transit agencies. Moreover, vendors and systems integrators may soon discover that the intellectual properties clauses in their contracts will aid the public sector's marketing initiatives.

- Services include sales of statistical information on employee utilization of the automated fare and toll system. For example, the Tobin Bridge management has already received requests for information on vehicle throughput data by several commercial entities.

i. Economies of scale. Utilization of standard smart card memories and microcontrollers, particularly off-the-shelf products, and multiple procurements by consortiums of agencies can generate considerable cost savings. Unfortunately, our interviews indicate that the loosely knit agency associations do consult each other, but act independently when purchases and contracts are developed. Therefore, the opportunity to achieve economies of scale on an intra-state, let alone interstate, basis is not occurring.

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APPENDIX E
CARD REQUIREMENTS

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APPENDIX E - CARD REQUIREMENTS

E.1 Description of Requirements

While there are many issues which must be addressed in the implementation of an automated fare card system, requirements should be considered in their most basic form. Specifically, we are concerned with categories of items such as the essential functions that must be performed, the information that must be maintained in order to carry out a fare transaction, minimum performance goals, and user interface requirements.

Secondary functions that may be possible as a result of implementing new technology, including traffic monitoring and congestion pricing, should be considered ancillary requirements and should not be part of the initial analysis and comparison of essential requirements. It is important to note this distinction, since there is a tendency to discuss the possibilities of new technology while losing sight of the original intention, or primary function, of the system.

Every effort was made to identify, define, and categorize, the more important automated fare card requirements as completely as possible. The specific needs of transit agencies will vary somewhat depending upon the type of service that is provided, interface requirements, and the specific method of implementation. Consequently, this list should not be considered complete or fully representative of card requirements from the viewpoint of any individual agency.

E.2 Primary Card Requirements

Primary card requirements are divided into six major areas: (a) Information Requirements; (b) Processing Requirements; (c) Performance Requirements; (d) User Interface Requirements; (e) Interoperability Requirements; and (f) Security Requirements. For each requirement, levels of criticality are discussed in comparison to each transportation mode. Three levels of criticality are identified in the text and summarized in the matrix which follows. These include:

- ● Critical Requirement
- ○ Minimal Requirement
- × No Requirement

Critical requirements typically describe features or capabilities that are essential to system performance. The inability to meet certain critical requirements might prevent a vital function from being completed, significantly reduce system benefits, or otherwise hamper system operations. **Minimal requirements** might include features or capabilities that are "nice to have" but that are not essential. The minimal requirement category might also be used to specify the middle range of a performance characteristic. Where certain features or capabilities are not needed or are not applicable to system operations, the **no requirement** category will be used. Definitions are provided based on these three levels for each of the primary card requirements that follow.

E.2.1 Information Requirements

Account Identifier(s) - To establish the validity of a card or tag and to charge the correct user, the system must be able to identify the appropriate account. This is normally done with an account number which is stored on the card. The actual number may be the production number of the card or tag which is linked to a particular account. Account identification does not always require that the identity of the individual be known. In fact, cards may be anonymous in some instances. For prepaid, or debit cards, the number can be used by the service agency to determine the balance remaining on the card. For multimode applications, more than one account identifier may be maintained. An account identifier is a **critical requirement** for all applications. More than one identifier may be required if there are multiple agencies involved. A specific amount of memory may be allocated to each application under a unique identifier.

Account Balance(s) - Storing the account balance on the card is not considered a critical requirement for any application, since the system can be designed using a centralized approach to account administration. There is, however, a significant tradeoff between the cost of centralized account administration and on-line processing, and the decentralized approach of storing a monetary value on the card. Considering the difficulty in providing fast and efficient on-line processing, the use of debit or prepaid cards that maintain a balance has been more successful in areas where the telecommunications infrastructure does not adequately support on-line transaction verification. In terms of the way a balance is stored, it can either be stored in the form of currency or units. Some agencies have taken the approach of storing the balance in units, where each transaction may be equal to one or more units. This approach may be more successful where international travel is frequent and different currencies are involved. Maintaining an on-card account balance is considered a **minimal requirement** for all applications, since this may be more desirable from the user's perspective.

Fare Classification Code - A fare classification code is often used to determine the specific rate that is charged. For vehicular applications, the classification is generally determined based on vehicle type or vehicle weight. For person-based applications, the rate classification may be based on age, e.g., junior, standard, senior, or other special criteria such as a student or disabled person. A classification code is considered a **critical requirement** for all applications except taxis where classification discounts are not typically offered. The classification code is necessary to distinguish between special fare categories for people and vehicles. For some person-based applications this can be accomplished using either a specially colored card or by maintaining a classification code on the card which, for example, may be displayed by the reader on a bus as passengers board to alert the driver to a unique situation. Obviously the main concern is to prevent fraud where a discount card is used inappropriately.

Restriction Code(s) - Some agencies may provide special cards which are only valid for certain periods of time, or can only be used between certain locations. In this case, the card may be required to maintain the type and conditions of the restriction. For example, a monthly card may have a date stored beyond which it is no longer valid. Another card might also be issued which is good for a certain number of trips regardless of when they are taken. The validity restriction code is considered a **critical requirement** in parking, closed rail, open rail, bus, and paratransit applications where restrictions are typically enforced. For toll road and bridge/tunnel applications, it is considered a **minimal requirement** because toll agencies generally use a "pay as you go" approach, and there may be a safety concern if drivers are unaware of the restrictions. For taxicab applications there is **no requirement**, since cab companies do not typically restrict usage.

Entry Location - In order to adequately support distance-based pricing in some applications, the entry location must be stored on the card. This is considered a **critical requirement** for toll road, closed rail, bus, and some paratransit applications. For barrier based applications, i.e., bridges and tunnels, entry location is a **minimal requirement** in order to support a transaction history. Entry location is not required for all other applications where the location is: (a) already known, as in parking; (b) cannot efficiently be determined, as in open rail configurations; or (c) can be determined by other means, such as taxis.

Exit Location - Exit location is only needed for systems which are distance based and are required to maintain a transaction history on the card. Exit location is therefore only considered a **minimal requirement** for toll road applications. It is **not required** for other applications.

Entry Time - Entry time is considered critical for parking applications, where the rate is typically time based. It is a minimal requirement for all other applications to allow rate changes based on peak/off-peak usage or other time based criteria. Entry time is not required for taxi applications.

Exit Time - Exit time is not a critical requirement for any applications, but is considered only a **minimal requirement** for parking applications where the card may need to perform an elapsed time calculation. It is **not required** for any other applications.

Transaction Date - A transaction date must only be recorded when the duration of the service extends beyond a 24-hour period, as in long-term parking, or when a transaction history must be maintained. A transaction date is considered a **critical requirement** for parking applications, and a **minimal requirement** for toll road application to record transaction history. It is **not required** in other applications.

Processing Station ID - Recording the Processing Station ID is necessary in some applications to assist in tracking down performance problems associated with a specific fare gate or card read-write box as is currently done on the Washington D.C. Metro. This is a **minimal requirement** for all applications since different gates or read-write units may be used at certain locations in some cases, or problems with vehicle-based read-write units on buses, paratransit vehicles, and taxis may need to be located.

Security Code - The use of a security code may be required in some applications where there is a potential for fraud, such as the unauthorized use of a discount card, or where the financial amount of the transaction is large. A security code may be maintained in the form of a photo, stored as a key or PIN, or stored in the form of a biometric print that can be validated during the transaction. Obviously the more complex techniques such as biometric verification would only be used for transactions requiring high security or very large financial amounts. A security code is seen as a

minimal requirement for all applications where there is a potential for fraud or when a credit card is accepted for payment.

Transaction History - In some applications, an on-card record of transactions is needed in order to produce a receipt at a later time. An on-card transaction history can also be used to resolve any discrepancies in card usage. Obviously, the number of transactions that can be stored will depend on the amount of available memory. Maintaining the history on the card will reduce the collection agency's financial administration costs, while allowing the card user to print trip receipts as desired without requiring the agency to monitor user travel. A transaction history entry, usually in a compressed format, may include a time/date stamp, location of the transaction, and the amount of the transaction. A transaction history is only considered a **minimal requirement** in all vehicle-based applications, where transactions are contactless but the decentralized approach may be used.

E.2.2 Processing Requirements

Time Calculation - Time calculation only becomes an on-card requirement when there is no contact with a reader that performs this function. An on-card clock is necessary to complete the time calculation. This function is only considered a **minimal requirement** for parking applications, since there may be applications where in-vehicle-units replace roadside meters. For all other applications, there is **no requirement** for time calculation.

Distance Calculation - Distance calculation is only necessary when the reader may not be able to perform the calculation. This function is only considered a **minimal requirement** for toll road applications, since in some cases the speed of travel may not allow time for distance calculation by the reader. There is **no requirement** for all other distance-based applications, where the trip distance can be determined by the reader based on the entry point stored on the card.

Account Balance Calculation - Account balance calculation is only required in applications where the decentralized approach is used and the balance is stored on the card, and only in the event that users need to be informed of their balances prior to transactions. For decentralized toll road and bridge/tunnel applications, this is considered to be **critical** since it may be necessary to warn a driver that the card balance is low prior to entering an automated collection lane. This will allow the driver time to proceed to a manual ticketing or payment lane instead. For all other applications there is a **minimal requirement**, since readers should be able to perform the calculation when the card is presented for use.

Balance Display - On-card balance display is only **critical** for decentralized vehicle-based applications, including toll road and bridge/tunnel, where the user must make a decision on whether or not to enter an automated toll lane based on the existing card balance. For all other applications this function does not need to be performed on the card, since the reader should be able to provide this information during the transaction or special readers can be made available to allow users to view the existing balance at their convenience.

Driver Notification - Driver notification is a **critical requirement** for decentralized vehicle-based systems including toll road and bridge/tunnel applications. This requirement involves the use of audio or visual signals to notify a driver that the card is valid for an automated lane transaction. If the card is malfunctioning, invalid, or has an insufficient balance to use an automated lane, a card invalid signal, or the lack of any signal, will indicate that the driver should proceed to a manual ticket or payment lane. This capability is **not required** for any other modes.

E.2.3 Performance Requirements

Read Reliability - Card reliability is essential for all applications since a single missed read can result in lost revenue, user frustration which could lead to future lost revenue, reporting discrepancies, and a variety of other problems. In a general sense, however, user frustration with a system has the potential to lead to greater losses in revenue than the occasional missed fare. For this reason it is important that reliability be considered more critical in those applications where user frustration could occur. This would include closed systems where a missed read at either end could result in a user being overcharged or challenged by an attendant when they were not attempting to evade the fare. A failure rate of 1 read in 10,000, corresponding to a 99.99% accuracy rate, will be considered a critical reliability goal. Note that this rate is based on vendor projections of product performance for toll applications. A formal reliability standard has not yet been established for each application area based on actual transit agency system requirements. A minimal reliability goal will be between 99.9% and 99.99%. A reliability level of less than 99.9% will be equated to the "**no requirement**" category. Considering prevention of user frustration most important, followed by revenue loss, a **critical** reliability requirement exists for toll road, parking, closed rail, bus, paratransit, and taxi applications. The **minimal** range is required for bridge/tunnel and open rail applications where a misread is likely to lead only to revenue loss, or where the operating agency may be willing to overlook an infrequent failure.

Information Integrity - On-card information integrity is perhaps more critical than read reliability, especially when a monetary value is stored on the card. A missed read, as identified above, may simply require that the user present the card again for a correct read, while in an information integrity failure the card may need to be completely re-initialized. Users would be very frustrated with the value of a $50.00 card accidentally being reset to $0, since in some cases there may be no way to determine how much of the value had been used, or to prove the actual starting value. Also, in taxi applications dependence on the card for payment could become a significant problem if the card fails, since it is not likely that the driver would be willing to dismiss the fare without payment. The requirement for information integrity can impact the choice card type and card reader. For instance, the NYCTA has reportedly found that read-write magnetic stripe cards can have stored information corrupted by a faulty swipe through a swipe-type card read-write unit. Information integrity is considered a **critical requirement** for all fare applications. Based on discussions with transit agencies, we have identified a preliminary goal of 1 failure in 1,000,000 or an accuracy rate of 99.9999%.

Transaction Time - The overall transaction time can be defined as the time is takes a person or a vehicle to pass through a fare gate or toll lane, respectively. A very significant component of this time is the communication cycle consisting of card reading, validation and fare calculation, and card writing. The objective is to keep read reliability high while minimizing the impact of the communication cycle on the overall transaction time. The optimum would be to allow a person to pass through a fare gate at normal walking speed, or a vehicle to pass through a toll lane at normal highway speed (if this could be done safely). For example, the Texas Turnpike Authority has estimated that change-made lanes require an overall transaction time of 12.4 seconds per vehicle vs. 5.2 seconds per vehicle for exact-change lanes, while their RFID tag system takes approximately 2-3 seconds per vehicle using a suggested speed of 15-30 mph through the toll plaza. The New York City Transit Authority has estimated that an overall transaction must occur in less than 1 second for their closed rail and bus system. Tests of the London Underground (closed rail) RFID proximity card demonstrated a 17% improvement in flow rate or overall transaction time over the existing magnetic stripe ticket system. AES/Scanpoint has stated that once the driver has keyed the destination into the read-write unit, their contactless system designed for the Greater Manchester Passenger Transport Executive has a communication cycle time of approximately 0.3 seconds for bus operations. The communication cycle time could vary significantly depending on a number of factors including message length, data transfer rate, validation and fare calculation time, read distance or size of the communication window, traveling speed of the card or tag, and whether or not redundant read-write cycles are used to improve overall read reliability.

Transaction time is considered a **critical requirement** where improvement in throughput results in a direct benefit including: toll road, bridge/tunnel, and parking applications where congestion and pollution are reduced; bus applications where road congestion is reduced, and where the length of stops and overall route completion is reduced; and closed rail where passenger congestion at fare gates is reduced, possibly allowing a reduction in the number of gates required. Transaction time is considered a **minimal requirement** in applications where there is a noticeable, but not significant, improvement including: open rail where it may help conductors verify more cards, but will not directly affect train speed, boarding, or user convenience; paratransit where it may speed boarding, but where there may be more time for individual passenger attention; and for taxis where it may speed fare payment, but where a few seconds improvement is not critical.

<u>Read Distance</u> - A certain distance may be necessary between the card and the reader when it is not practical to process a transaction based on physical contact. A distance of 5 inches or greater will be considered a critical requirement, less than 5 inches will be considered a minimal requirement, and direct contact will be equated to no requirement. For toll road and bridge/tunnel applications, a communication range of 5-30 feet or greater is required to efficiently process a transaction without requiring a vehicle to stop. For paratransit applications, the read distance is also a **critical requirement**, since a range of 4-20 inches may be most appropriate for mobility limited passengers that find it difficult to use contact or close contact read-write equipment. For parking, closed rail, and bus applications there is also a **minimal** remote requirement since a proximity or remote coupling system may improve the passenger or vehicle throughput rate. For open rail and taxi applications, contact systems are considered sufficient.

<u>Life Span</u> - Life span involves the number of read-write cycles a card can sustain before the memory integrity becomes questionable. Based on present microchip technology, some vendors

are producing products which have a life span of 100,000 read-write cycles. This will be considered a critical requirement, although agencies still need to specify a life span which is required to meet their needs. A minimal requirement will be considered between 10,000 and 100,000 read-write cycles, and below 10,000 will be equated to no requirement. Since 10,000 read-write cycles is considered adequate for typical card usage, all applications have a **minimal** life span requirement.

E.2.4 User Interface Requirements

Convenience - User convenience is stated as one of the key potential benefits of an automated fare card system. There is usually a significant tradeoff, however, between automation to improve convenience, and the cost of the automation technology. Therefore it is helpful to consider where using automation to improve convenience provides a substantial benefit. For toll road, bridge/tunnel, and parking applications, convenience is considered **critical** since distracting a driver with secondary tasks, e.g., looking for currency, pushing buttons, and adjusting equipment, could have a significant safety impact as drivers enter the toll area. For paratransit applications, user convenience is also **critical**, since in some cases passengers may need to operate equipment in an unmanned location. For all other applications, convenience is important but is considered a **minimal requirement** since users expect that some actions may require responsibility on their part.

Size - From the perspective of the user, size is important when considering that the card may need to be carried by the user. For example it must be able to fit in the standard wallet or purse. Exact size of the card, and whether or not it conforms to ISO standards, will also become important when considering potential use of the card for other transit modes or external applications. Obviously most users would rather carry one card that can be used in ten applications, rather than ten cards that each have a specific purpose. Size is considered a **critical requirement** in closed rail, open rail, bus, paratransit, and taxi applications where the user will likely need to carry it with them. For vehicle-based applications, size is only considered a **minimal requirement** since it may be affixed to or stored in the vehicle.

Durability - Durability is important when the card is exposed to harsh environmental conditions, and when the card must have a long life span for equipment costs to be recovered. For toll road, bridge/tunnel, and parking applications, durability is considered **critical** since in some cases the card or tag may be affixed to the outside of a vehicle, or may be exposed to extreme temperatures. For all other applications, durability is considered a **minimal requirement** where it may be similar to that of a bank card.

E.2.5 Interoperability Requirements

Card/Reader Interface - A standard card/reader interface is considered a critical requirement for all application types. On the one hand, there may be a requirement for a standard card/reader interface to allow for a card developed for one agency to be used by another agency in a similar application. On the other hand, the card may need to support the services of agencies responsible for different types of applications. For example, in toll road and bridge/tunnel applications, some travelers are likely to interact with many different agencies which have similar requirements, and consequently, a standard card/reader interface is considered **critical**. For all other applications, the standard interface is still a **critical requirement**, but may be more difficult to achieve, since a user may require the services of a number of different types of agencies including closed rail, open rail, bus, and taxi, all of which have unique system requirements.

Data Format - Data form relates to how information is arranged on the card. For example, a certain amount of memory may be allocated for each field of information to include account identifier, time stamp, and entry location. Obviously, as more information fields are added to the card, the task of standardizing data format becomes increasingly difficult, especially when many different agencies or service providers are involved. Data format interoperability is considered a **critical requirement** for all applications.

Data Content - Data content relates to standard words, terms, or codes that are used within data fields on a card. As is the case with data format, as the number of content definitions increases the task of standardization becomes more difficult. Data content interoperability is a **critical requirement** for all applications.

Operation Flexibility - Operation flexibility involves the ability of the card to allow minor performance variations in order to satisfy site-specific requirements. For example, in some RF applications, the frequency of communication may need to be altered to work through interference problems. Each specific application will require thorough testing in the actual environment where it is to be used, prior to full implementation. Operation flexibility is considered a **critical requirement** for all applications.

E.2.6 Security Requirements

Account Verification - Account verification is a **critical requirement** in all applications to ensure that the correct user is charged, and that the fare transaction is accurately recorded. Normally, account verification can be ensured by protecting the integrity of the account number on the card, e.g., by storing in ROM, and by protecting alteration during card/reader communication.

User Identity Verification - User identity verification is required in some applications where there is a potential for fraud, or where the financial amount of the transaction is large. User authorization may be verified in a number of ways including use of a photo, a key or PIN (Personal Identification Number), or a biometric technique. Verification is important, and is considered a **minimal requirement** in paratransit applications, where the service is only provided to a select group. For other person-based applications, the importance of verification is also **minimal** and will depend on the type of card that is used or whether the card can be used for a discount fare. For non-contact vehicle-based applications such as toll roads, bridges and tunnels, user verification is still a **minimal requirement**, but is much more difficult to implement.

Information Access Restriction - In some situations it may be necessary to restrict access to certain information on the card. For example, any security codes stored on the card should be unalterable except by an approved source and should be encrypted to prevent unauthorized reading or duplication. This is considered a **critical requirement** in all applications.

Prevention of Card Tampering - Cards should be resistant to tampering to prevent fraud, e.g., by changing a fare classification, or altering the card balance or fare evasion, e.g., by restricting transactions from being written to the card. Prevention of card tampering is a **critical requirement** for all applications.

Table E-1. Person-Based Requirements

Requirement	Closed Rail	Open Rail	Bus	Paratransit	Taxi	Composite
Information Requirements						
- Account Identifier(s)	●	●	●	●	●	●
- Account Balance(s)	○	○	○	○	○	○
- Fare Classification Code	●	●	●	●	×	●
- Restriction Code(s)	●	●	●	●	×	●
- Entry Location	●	×	●	●	×	●
- Exit Location	×	×	×	×	×	×
- Entry Time	○	○	○	●	×	○
- Exit Time	○	×	×	●	×	×
- Transaction Date	●	●	●	●	●	●
- Processing Station ID	○	○	○	○	○	○
- Security Code	○	○	○	○	○	○
- Transaction History	×	×	×	×	×	×
Processing Requirements						
- Time Calculation	×	×	×	×	×	×
- Distance Calculation	×	×	×	×	×	×
- Account Balance Calculation	×	×	×	×	×	×
- Balance Display	×	×	×	×	×	×
Performance Requirements						
- Read Reliability	●	○	●	●	●	●
- Information Integrity	●	●	●	●	●	●
- Transaction Time	●	○	●	○	○	●
- Read Distance	○	×	○	●	×	●
- Life Span	○	○	○	○	○	○
User Interface Requirements						
- Convenience	○	○	○	●	○	●
- Size	●	●	●	●	●	●
- Durability	○	○	○	○	○	○
Interoperability Requirements						
- Card/Reader Interface	●	●	●	●	●	●
- Data Format	●	●	●	●	●	●
- Data Content	●	●	●	●	●	●
- Operation Flexibility	●	●	●	●	●	●
Security Requirements						
- Account Verification	●	●	●	●	●	●
- User Identity Verification	○	○	○	○	○	○
- Information Access Restriction	○	○	○	○	○	○
- Prevention of Card Tampering	●	●	●	●	●	●

Table E-2. Vehicle-Based Requirements

Requirement	Toll Road	Bridge/Tunnel	Parking		Composite	
Information Requirements						
- Account Identifier(s)	●	●	●		●	
- Account Balance(s)	○	○	○		○	
- Fare Classification Code	●	●	●		●	
- Restriction Code(s)	○	○	●		●	
- Entry Location	●	○	×		●	
- Exit Location	○	×	×		○	
- Entry Time	○	○	●		●	
- Exit Time	×	×	○		○	
- Transaction Date	○	×	●		●	
- Processing Station ID	○	○	○		○	
- Security Code	○	○	○		○	
- Transaction History	○	○	○		○	
Processing Requirements						
- Time Calculation	×	×	○		○	
- Distance Calculation	○	×	×		○	
- Account Balance Calculation	●	●	×		●	
- Balance Display	●	●	×		●	
- Driver Notification	●	●	×		●	
Performance Requirements						
- Read Reliability	●	○	●		●	
- Information Integrity	●	●	●		●	
- Transaction Time	●	●	●		●	
- Read Distance	●	●	○		●	
- Life Span		○	○	○		○
User Interface Requirements						
- Convenience	●	●	●		●	
- Size	○	○	○		○	
- Durability	●	●	●		●	
Interoperability Requirements						
- Card/Reader Interface	●	●	●		●	
- Data Format	●	●	●		●	
- Data Content	●	●	●		●	
- Operation Flexibility	●	●	●		●	
Security Requirements						
- Account Verification	●	●	●		●	
- User Identity Verification	○	○	○		○	
- Information Access Restriction	○	○	○		○	
- Prevention of Card Tampering	●	●	●		●	

APPENDIX F
ALTERNATIVES ANALYSIS

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APPENDIX F - ALTERNATIVES ANALYSIS

F.1 Introduction

The analysis of card technology alternatives was divided into two main tasks. The first task consisted of identifying and differentiating relevant types of cards that could potentially be applied to fare and toll applications. The second task involved the ranking of card technologies based on their ability to satisfy critical application requirements.

The ranking process was highly subjective and, consequently, the results that were obtained can only be used to show at a high level whether or not a particular alternative can meet the critical requirements. As technology improvements or changes are introduced, and as application requirements are more clearly defined, the technology ranking may need to be recalculated. Despite this limitation, the ranking and analysis process should provide some valuable insight on which technology alternatives are feasible and on emerging trends in the industry.

F.2 Technology Alternatives

Only a brief description of each alternative will be presented in order to provide a common base line for the technology comparison matrix that will be developed. Much of the investigative work needed to identify technology alternatives was performed in Task A of this study. The reader may want to refer to the technology profiles, presented in Appendix A of this report, for more detailed descriptions. Summary matrices that highlight the features, capabilities, and performance parameters are provided for each alternative following the text description.

F.2.1 Magnetic Stripe Cards

Magnetic stripe cards have already proven to be a low-cost alternative capable of meeting many of the critical fare (person-based) requirements. The magnetic stripe itself may be placed on any flat surface and consequently can be packaged in a variety of formats including credit cards, badges, thin plastic cards, and paper tickets. Performance characteristics for magnetic stripe cards may differ significantly due to variations in format, quality, and environmental conditions. Three main forms of read-write cards have emerged for transit applications, including thin paper tickets, thin plastic swipe cards, and ISO swipe and insert cards. The main advantage of the magnetic stripe technology appears to be cost, while the main drawbacks are low durability (for the most common formats), low read reliability, and the dependence on contact reading. Generally, low durability is the result of exposure to a harsh environment since in many cases the card will be damaged before the magnetic integrity of the stripe becomes a factor.

Table F-1. Magnetic Stripe Card Summary

CHARACTERISTIC	Common	Optimum
Memory Type	• Read-Write (Magnetic Encoding)	• Read-Write (Magnetic Encoding)
Memory Capacity	• 225 to 550 bits (Single Track) at 75 and 210 BPI respectively	• 1 kbits total (ISO Tracks 1,2,3)
Read Reliability	• 95-99% accuracy rate (swipe)	• 99.5% accuracy rate (swipe)
Data Transfer Speed	• 12,000 bits per second	• 12,000 bits per second
Security	• Low - Easy to copy or counterfeit	• Medium - Using watermarks, holomagnetics, jitter, etc.
Durability	• Low life span due to bending, wear • 5-50 read-write cycles (paper) • 100-500 r/w cycles (plastic)	• Medium if ISO or Plastic Card with coated strip • 500-1,000 r/w cycles (plastic)
Processing Power	• None	• None
Read Distance	• None	• None
Size	• ISO standard or thinner	• ISO standard or thinner
Cost	• $0.12 - 0.45	• $0.12 - 0.45

F.2.2 IC Contact Cards

Cards using electrical surface contacts for communication were the first form of IC cards (cards which contain Integrated Circuit chips) to be introduced and still represent the largest portion of the chip card market. The cards have embedded microelectronics which are connected to metallic contact pads on the card's surface. The standard card has eight surface contacts (most existing cards use only six of these) which perform data communications, supply power to the card, and provide clock timing signals for control functions. Contact cards may contain a microprocessor making them a true "smart sard" or they may simply be memory cards (used as secure information storage devices). The two primary types of IC contact cards are prepaid cards and credit/debit cards. Prepaid cards commonly used for telephone and transit applications usually contain a low monetary value which is decremented as it is used. Credit/debit cards, which are commonly used for banking and retail, typically record transactions and tie them to a customer account. A higher transaction value is generally allowed on credit/debit cards which necessitates a greater level of security. The main benefits of IC contact cards are a high memory capacity, a reasonably long overall life span, and a medium to high potential level of security. The main drawbacks are cost, the need for insert contact reading, and the vulnerability of the surface contacts to wearing or exposure damage.

Table F-2. IC Contact Card Summary

CHARACTERISTIC	Common	Optimum
Memory Type	• Read-Write (EEPROM)	• Read-Write (EEPROM)
Memory Capacity	• 2-3 kbytes or 16-25 kbits	• 8 kbytes or 64 kbits (2 pages text)
Read Reliability	• 99.9% accuracy rate	• 99.95% accuracy rate
Data Transfer Speed	• 9,600 bits per second	• 9,600 bits per second
Security	• Medium	• High, with microprocessor
Durability	• Medium life span due to wear • 100-1,000 read-write cycles	• Medium life span due to wear • 1,000-3,000 read-write cycles
Processing Power	• None	• May contain a microprocessor
Read Distance	• None	• None
Size	• ISO standard	• ISO standard
Cost	• $0.75-1.50 (in volume)	• $3.75-7.50 with microprocessor

F.2.3 RFID (Type I) Read-Only

Read-only (Type I) RFID products have been widely available since the early 1980s and were originally used for item and animal identification. In the late 1980s read-only tags were applied to vehicle identification and electronic toll collection on barrier type toll systems. Since read-only memory chips usually contain only an identification number, the technology can be packaged in a variety of formats ranging from button or pin size items to rugged tags used in container tracking or fleet management. The main advantages of read-only RFID are non-contact and in some cases non-line-of-sight identification, the ability to identify moving objects, high durability since the memory chip can be protected, high memory integrity since the memory cannot be modified, potentially low maintenance, and low-cost. The main limitations include the inability to maintain modifiable application specific information (e.g., for distance or time-based pricing), the need for a centralized accounting or tracking system to relate ID numbers to user accounts, and privacy issues as the result of linking system usage to a specific user.

F.2.4 RFID (Type II) Read-Write

Read-write (Type II) RFID products offer many of the same features (including non-contact, non-line-of-sight, and mobile identification) that are supported by read-only (Type I) RFID products. But in addition, read-write technology can also support distance and time-based pricing as well as portable account balance which can enhance user privacy and reduce the dependence on a centralized accounting system. Another advantage of read-write RFID is that currently available memory chips have a reasonably high memory capacity, when compared to most other types of automated cards. Read-write RFID cards can be designed to run on power extracted from the interrogating RF signal or from an internal battery. While the use of a battery can help to obtain a longer read distance or reduce the reader power requirement, the maintenance and environmental concerns resulting from battery use may be significant.

Table F-3. RFID (Type I and II) Summary

CHARACTERISTIC	Read-Only (Type I)	Read-Write (Type II)
Memory Type	• Read Only (ROM, EPROM)	• Read-Write (EEPROM, SRAM)
Memory Capacity	• Typically 64-256 bits	• 2 kbytes - 8 kbytes
Read Reliability	• 99.9% accuracy rate	• 99.9% accuracy rate
Data Transfer Speed	• 8 k-500 kbits per second	• 8 k-500 kbits per second
Security	• Medium	• Medium
Durability	• High life span potential • Potentially unlimited read cycles	• High life span potential • 10,000-100,000 read-write cycles
Processing Power	• None	• Typically contain a battery
Read Distance	• 0-40 feet	• 0-250 feet
Size	• Varies based on application	• Varies based on application
Cost	• $.50-5 (depending on casing)	• $3-8 (with battery)

F.2.5 RFID (Type III) Smart Transponder

The RFID smart transponder provides all the basic capabilities of read-write RFID and can also incorporate many additional specialized features. As the term "smart transponder" implies, RFID (Type III) includes a microprocessor which can be used to locally control a variety of processes. Not only can the microprocessor be used to enhance read distance, memory management, and security, but it can also support features such as an alphanumeric display or a visual or audio signal system. Most existing smart transponders on the market used for ETTM resemble the common radar detector in size and provide an account balance display and driver notification signal. The main disadvantages of this type of technology are that it requires a local power source, and that the per unit cost is typically much higher than other forms of RFID technology. There may be a significant tradeoff, however, between the per unit cost and the reduction of cost and processing power required by other portions of the system.

Table F-4. RFID (Type III) Summary

CHARACTERISTIC	Common	Optimum
Memory Type	• Read-Write (EEPROM, RAM)	• Read-Write (EEPROM, RAM)
Memory Capacity	• Typically 3 k-8 kbytes	• 16 kbytes
Read Reliability	• 99.9% accuracy rate	• 99.9% accuracy rate
Data Transfer Speed	• 8 k-500 kbits per second	• 8 k-500 kbits per second
Security	• Medium	• High
Durability	• Medium life span potential • 10,000-100,000 read-write cycles	• High life span potential • 1,000,000 read-write cycles
Processing Power	• Microprocessor Controlled	• Microprocessor Controlled
Read Distance	• 0-500 feet	• 1.5 miles
Size	• Varies based on application	• Varies based on application
Cost	• $20-50 (in volume)	• $20-50 (in volume)

F.2.6 Close Coupling Cards

Both close coupling and remote coupling cards are forms of RFID technology, although they demonstrate considerable differences in performance and common implementation schemes when compared to RFID (Types I, II, and III) described previously. The read distance of close coupling cards is limited by the use of capacitive coupling. Capacitive coupling involves using a pair of conductors in the read-write unit, and a similar pair of conductors below the surface of the card. When a voltage is placed across the conductors, a charge separation creates an electric field which can extend beyond the surface of the read-write unit and induce a charge separation between the conductors in the card. The main advantages of this method include a contactless read-write capability, medium to high durability, and no on-card power requirement since coupling can be used both for data communications and to power the card. The main disadvantages are that the read range is very short (typically less than 3 mm) and that the card must be very precisely aligned with the read-write unit. Additionally, close coupling cards are typically read through insert type readers limiting their practical use in time critical applications.

F.2.7 Remote Coupling Cards

Remote coupling cards are based on inductive coupling which is less restrictive than capacitive coupling in terms of the read distance and the alignment between the card and the read-write unit. The inductive coupling method involves the use of two coils. The first coil performs the primary role of creating an alternating magnetic field which induces a current in the secondary coil when the coils are brought close together. Based on current industry capabilities, the maximum read-write communication range is approximately 3-4 inches. Beyond this range, card reading may still be possible using inductive coupling, but the current induced on the card may not be sufficient to perform memory management functions without a battery. The main advantages of remote coupling cards are touchless read-write communication, user convenience, no on-card power requirement, and low per unit cost for the capability provided. The main disadvantage is the limited distance at which read-write communication can be performed.

Table F-5. Close and Remote Coupling Card Summary

CHARACTERISTIC	Close Coupling	Remote Coupling
Memory Type	• Read-Write (EEPROM, EPROM)	• Read-Write (EEPROM, EPROM)
Memory Capacity	• Typically 3 k-8 k bytes	• Typically 1 k-8 kbytes
Read Reliability	• 99.9% accuracy rate	• 99.9% accuracy rate
Data Transfer Speed	• 2.4 k-300 kbits per second	• 8 k-100 kbits per second
Security	• Medium	• Medium
Durability	• Medium life span potential • 10,000-100,000 read-write cycles	• Medium life span potential • 10,000-100,000 read-write cycles
Processing Power	• None	• None
Read Distance	• 0-3 mm	• 0-100 mm (0-4 in.)
Size	• ISO Standard Dimensions	• ISO Standard Dimensions
Cost	• $.50-3 (in volume)	• $.50-3 (in volume)

F.2.8 Laser/Optical Cards

Laser cards use similar technology to that found in Compact Disc (CD) systems. The card medium is written to with a laser that burns pits into the card representing 1s or 0s. A similar laser, usually with a different wavelength, is used to read pits on the card. The value of the bit is determined by the strength of the reflected light. The main advantage of this technology is its ability to store large amounts of information (2-6 Megabytes) on a device the size of a standard credit card. The main disadvantages include the fact that rewritable cards are not widely available yet, existing cards require insertion into the read-write unit and consequently are not suitable to a time critical transit environment, and that the cost of the read-write units are expensive in comparison to other automated card technologies.

Table F-6. Laser/Optical Card Summary

CHARACTERISTIC	Common	Optimum
Memory Type	• WriteOnce-ReadMany (WORM)	• WriteOnce-ReadMany (WORM)
Memory Capacity	• 2-4 Megabytes	• 6 Megabytes
Read Reliability	• 99.99% accuracy rate	• 99.999% accuracy rate
Data Transfer Speed	• 150-200 kbits per second	• 150-200 kbits per second
Security	• Low-Medium	• Medium (if encrypted)
Durability	• Low-Medium card life span • 1 Write, Unlimited Reads	• Medium card life span • 1 Write, Unlimited Reads
Processing Power	• None	• None
Read Distance	• Contactless (but insert required)	• Contactless (but insert required)
Size	• ISO Standard Dimensions	• ISO Standard Dimensions
Cost	• $.50-3 (in volume)	• $.50-3 (in volume)

F.2.9 Bar Code Labeling

Bar code technology provides an inexpensive means of labeling items. Labels consist of a series of parallel lines and spaces that represent coded information. The bar code information is read by a light beam that is reflected off the tag and received by the reader. There are no size standards for labels or tags, although a number of coding standards exist. The main advantages of this technology are low-cost, adaptability to a variety of sizes, and contactless reading. The main disadvantages include the inability to modify information stored on the label once it is created, low read reliability due to potential interference, low durability, and low security.

Table F-7. Bar Code Labeling Summary

CHARACTERISTIC	Common	Optimum
Memory Type	• Pattern Encoding	• Pattern Encoding
Memory Capacity	• 64-100 bits	• 64-100 bits
Read Reliability	• 90-95% accuracy rate	• 99% accuracy rate
Data Transfer Speed	• Unknown (not critical)	• Unknown (not critical)
Security	• Low	• Low-Medium (with encryption)
Durability	• Low (Susceptible to Damage) • Unlimited Reads (undamaged)	• Low (Susceptible to Damage) • Unlimited Reads (undamaged)
Processing Power	• None	• None
Read Distance	• 0-2 feet	• 0-10 feet
Size	• Adaptable	• Adaptable
Cost	• $.12-.45 (in volume)	• $.12-.45 (in volume)

F.3 Alternative Rating Based on Critical Requirements

This section presents matrices comparing the critical fare and toll requirements with the technology alternatives outlined in Section 2. Section 3.1 presents a comparison matrix for person-based requirements, while a vehicle-based requirements comparison is presented in Section 3.2.

The rating matrices include checks (✓) in each field where the technology alternative satisfies the critical requirement. The most difficult part of the analysis process was establishing the criteria for eliminating the technologies which could not support the most critical application requirements. In each matrix an (**x**) has been placed below the alternatives which failed to meet an essential application requirement. Alternatives with an (**x**) are not presently considered to be practical candidates meeting application requirements based on current technology.

F.3.1 Alternative Rating For Person-Based Requirements

Primary disqualifiers which eliminated technologies as practical alternatives for person-based fare applications included:

1. Transaction Speed
2. Read-Write Capability
3. Size

Based on discussions with transit representatives and industry experts, these three requirements were considered to be essential for person-based applications, and the inability of a technology to satisfy them would make it impractical to implement this technology.

The three technologies passing this initial qualification level included magnetic stripe, RFID (Type II), and remote coupling cards. Of these, the RFID (Type II) and RF remote coupling cards appear to satisfy more of the critical requirements. The main advantage of the RF cards is their ability to read and write at a distance. Consequently, they provide a higher level of convenience to system users, as well as satisfying the need for easy access to the read-write units for mobility limited passengers. The reader may wish to refer to Appendix E of this report to review the definition of the critical requirements.

Table F-8: Person-Based Rating Matrix

Technology / Requirement	Mag Stripe	IC Con-tact	RFID Type I R/O	RFID Type II R/W	RFID Type III Smart	Close Cou-pling	Remote Cou-pling	Laser/ Optical	Bar Code
Account Identifier	✓	✓	✓	✓	✓	✓	✓	✓	✓
Fare Classification Code	✓	✓	✓	✓	✓	✓	✓	✓	✓
Restriction Code	✓	✓	✓	✓	✓	✓	✓	✓	✓
Entry Location	✓	✓		✓	✓	✓	✓	✓	
Read Reliability		✓	✓	✓	✓	✓	✓	✓	
Information Integrity	✓		✓					✓	
Transaction Time	✓		✓	✓	✓		✓		✓
Read Distance			✓	✓	✓		✓		✓
Convenience	✓		✓	✓	✓		✓		✓
Size	✓	✓	✓	✓		✓	✓	✓	✓
Account Verification	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tamper Prevention	✓	✓	✓	✓	✓	✓	✓	✓	
Total Ranking Score	**9**	**8**	**9**	**10**	**9**	**8**	**10**	**8**	**8**
		x	x		x	x		x	x

F.3.2 Alternative Rating For Vehicle-Based Requirements

For vehicle-based applications, the primary disqualifiers which eliminated technologies as practical alternatives included:

1. Read Distance
2. Transaction Speed
3. Read-Write Capability

Only two alternatives, the RFID (Type II) read-write tag and the RFID (Type III) smart transponder, passed this initial qualification level. Of these, the smart transponder satisfies more of the critical requirements. The smart transponder has an advantage over the read-write tag in performing special functions such as balance calculation, balance display, and driver notification.

Table F-9. Vehicle-Based Rating Matrix

Technology Requirement	Mag Stripe	IC Con-tact	RFID Type I R/O	RFID Type II R/W	RFID Type III Smart	Close Cou-pling	Remote Cou-pling	Laser/ Optical	Bar Code
Account Identifier	✓	✓	✓	✓	✓	✓	✓	✓	✓
Fare Classification Code	✓	✓	✓	✓	✓	✓	✓	✓	✓
Restriction Code	✓	✓	✓	✓	✓	✓	✓	✓	✓
Entry Location	✓	✓		✓	✓	✓	✓	✓	
Entry Time	✓	✓		✓	✓	✓	✓	✓	
Transaction Date	✓	✓		✓	✓	✓	✓	✓	
Balance Calculation		✓			✓	✓	✓		
Balance Display					✓				
Driver Notification					✓				
Read Reliability		✓	✓	✓	✓	✓	✓	✓	
Information Integrity	✓		✓					✓	
Transaction Time			✓	✓	✓				✓
Read Distance			✓	✓	✓				✓
Convenience			✓	✓	✓				✓
Durability		✓	✓	✓	✓	✓	✓	✓	
Account Verification	✓	✓	✓	✓	✓	✓	✓	✓	✓
Tamper Prevention		✓	✓	✓	✓	✓	✓	✓	
Total Ranking Score	**7**	**11**	**9**	**12**	**15**	**10**	**10**	**10**	**7**
	x	x	x			x	x	x	x

APPENDIX G - AGENCY CONTACTS

G.1 Agency Interviews Conducted

During the course of the study, several agencies were asked to meet with the study investigators to discuss issues relevant to automated card system implementation. The following agencies were kind enough to make time to meet with the investigators and provide insight on automated fare and toll system card requirements, design issues, implementation issues, and external factors:

- Massachusetts Bay Transportation Authority (MBTA)
- Massachusetts Highway Department (Central Artery/Tunnel)
- Massachusetts Turnpike Authority (MASSPIKE)
- MASSPORT (Logan International Airport)
- MASSPORT (Tobin Bridge)
- Metropolitan Transportation Authority Card Company (MTACC), New York
- New York City Transit Authority (NYCTA)
- Texas Turnpike Authority (TTA)
- Triborough Bridge and Tunnel Authority (TBTA)
- Washington Metropolitan Area Transit Authority (WMATA)

We wish to thank these agencies for their cooperation. Please note that although input from these agencies was factored into this report, the agencies were not given the opportunity to review the preliminary results and, consequently, they may not be in full agreement with the findings of this study.

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