Information Technologies in the Context of Tren Urbano

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May 30, 1995

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I. Executive Summary

Intelligent Transportation Systems (ITS) is viewed as communication and information in support of transportation. Hence, deployment of ITS in the San Juan Metropolitan Area (SJMA) implies expediting information flows that can enhance operations of the transportation system. As such, ITS can benefit both the operators and the users of the transportation services.

The construction of the Tren Urbano will provide many of the necessary conditions to implement ITS applications. This report attempts to analyze the major links between ITS and Tren Urbano. ITS contributions to the SJMA in the context of the current and planned transportation system include improving the utilization of the capacity, enhancement of intermodalism and seamless transfers, overall increased system reliability, safety improvements and a positive effect on the public's perception of public transportation. Therefore, ITS applications are considered as supportive of Tren Urbano, rather than competing against it. On one hand, there is applications such as vehicle identification systems and advanced fare payment media, that can directly enhance the performance of public transportation and enable greater intermodal integration. On the other hand, there is applications such as electronic toll collection, that improve vehicular flows on the current road network. Deployment of these applications agree with the stated objective of improving the entire transportation system of the SJMA. Hence, ITS can become a successful system's integrator and therefore can assist in gathering support for Tren Urbano. This dynamic relationship of ITS with the existing stakeholder's of the transportation system is depicted graphically in Figure I, on page iii.

ITS consists of multiple technologies that can apply to individual vehicles, the roadside and the traveler, thereby improving information flows and decision-making processes. The current report analyses several core elements of ITS that can be implemented in a metropolitan region. The elements included in the study are Transit Management Systems, Electronic Toll Collection Systems and Smartcards as Fare Payment Media. Since most of the core elements are interrelated, other elements were also indirectly addressed. These elements of the core group were selected based upon the added functionality they can provide to the transportation system, and particularly for public transportation in the SJMA. Figure II in the next page depicts the core elements and their relation with users.

Early deployment of these applications may be bound by the need for a system architecture. Ideally, the architecture should develop in accordance with the fundamental goals of ITS and having the National ITS Architecture as a frame of reference. This architecture should be modular enough to facilitate future enhancements while guaranteeing system interoperability. Also, the architecture should explicitly establish the tradeoff between functionality and cost, as well as market penetration sensitivity.

A Strategic Plan for ITS Deployment in the SJMA is currently being developed by private consultants for the ACT under and FHWA Grant. The Plan is a first step in the successful deployment of ITS applications. Reduction of inter- and intra-institutional barriers and frictions is highlighted. The Strategic Plan should address the fundamental question of institutional and societal readiness in the adoption of these new information processes.

The methodology used in studying these applications is to concentrate on each technology and its effects on the transportation system. The benefits and costs of each system are analyzed in a quantitative and qualitative manner, drawing from the experience of worldwide case studies included. Analysis of the need for implementation of the application in the SJMA is then performed, emphasizing three main aspects:

- potential barriers and risks
- existing needs and possible benefits accrued
- interaction with Tren Urbano and other current and planned transportation investments

As a result of the analysis, a recommendation about the implementation of each technology is made. In the long run, a traffic management system anchored on the successful development of electronic toll collection systems, and some public transportation and traveler information systems initiatives, is feasible. The early development of these anchors may prove to be critical not only to the development of ITS but to the political success of its proponents, and ultimately, its adoption by users.

Figure I

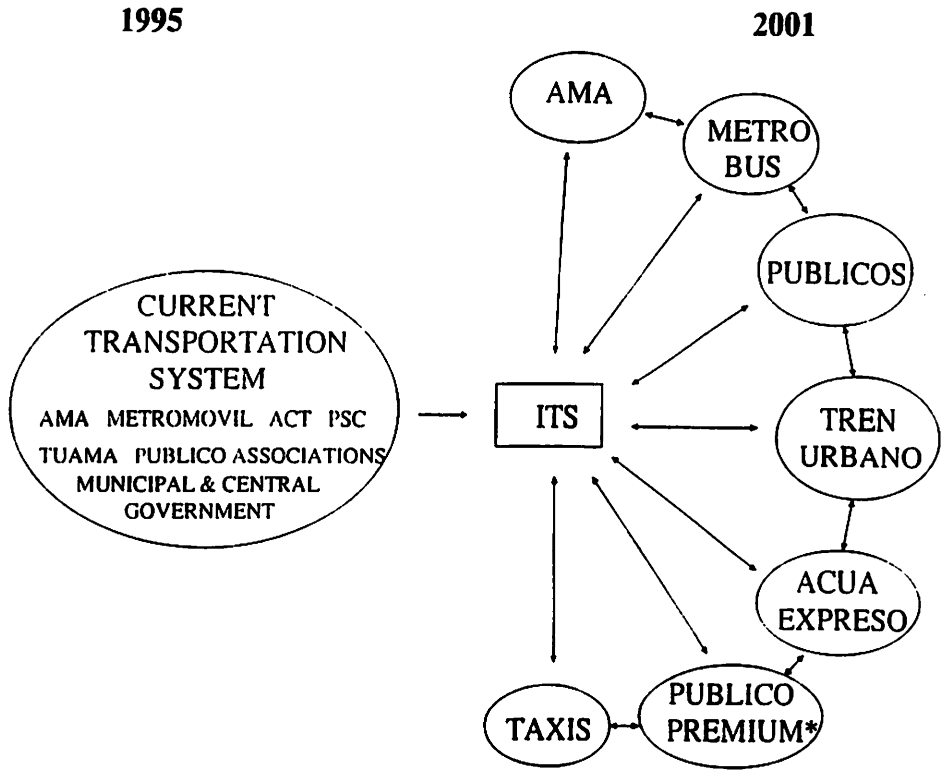
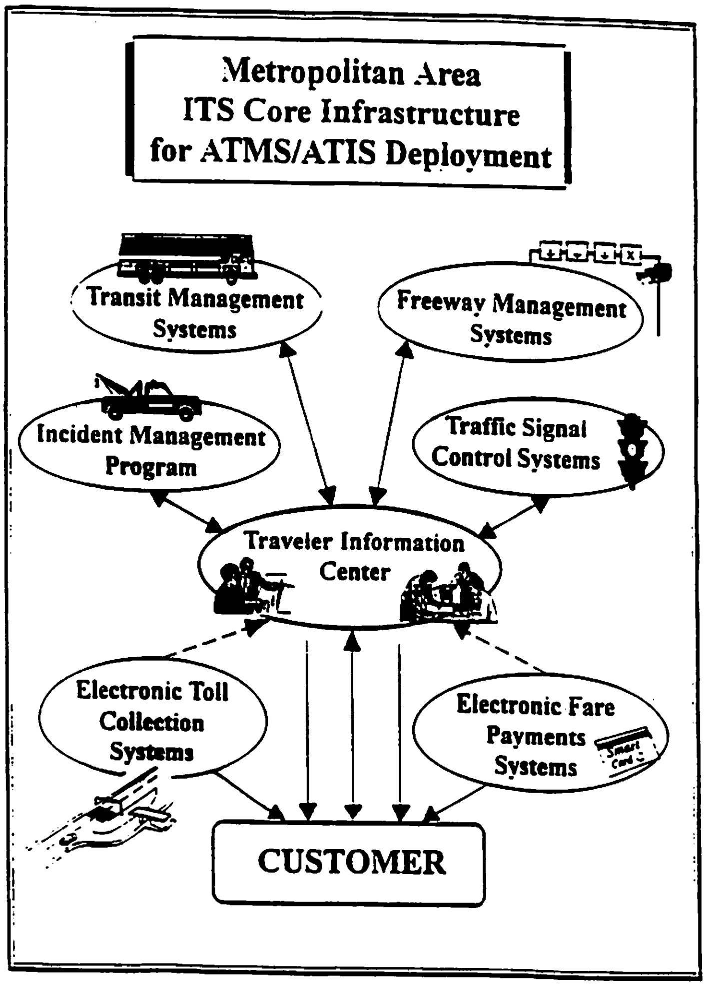


Figure II



Smart cards

The proposed changes to the transportation system of the SJMA brought by Tren Urbano generate two decision-making scenarios for fare payments and structure: policy and technology. Policy decisions include the structure and level of the fares. It is recommended that fare policies should be integrated for both AMA and Tren Urbano to allow for better intermodal transfers and to convey a solid image of the system to the public. This suggests that the structure should be developed with the customer in mind, even though fare levels may differ. The structure should also have both rail and bus services as a common basis, resulting in the maximum allowable integration and ease of use.

The technology-related decisions include the fare collection strategy, the level of automation and the type of equipment needed. Given that fare integration is recommended, a natural step is therefore to further suggest technological integration between the motor bus system and Tren Urbano. New fare collection media provides the following benefits:

- Fare evasion decreases
- Variable pricing is enabled
- High quality data about riders is collected at low cost
- Although increase in maintenance and personnel training is foreseen, long term reduction in costs is expected, particularly from fare collection labor costs

Smartcards are a specific type of technology recently developed that can be implemented for fare collection, electronic toll collection, bank account information and handling of personal information among other applications. The cards contains a chip embedded into its thin structure hence improving security in transactions. The card also has large memory capacity (up to 2MB) to store information. After comparing the benefits and costs of a smartcard with a magnetic card, and analyzing their current implementations, it is recommended that magnetic cards be used as the common technology for fare collection. Magnetic cards offer most of the benefits of smartcards in addition to the following:

- Have a proven track record of satisfactory performance in multiple transit agencies
- Have low implementation costs compared to smartcards

Advanced fare payment media may face institutional barriers that arise from the need of sharing common goals and ensuring strategies to achieve them. In terms of smartcards, stronger public-private partnerships are needed, and several regulatory constraints need to be addressed. In the long run, information capacity, issues of security and the development of multiple applications will popularize smartcards. However, magnetic card equipment can be retrofitted to read smartcards without a significant investment.

Electronic Toll Collection

Electronic Toll Collection (ETC), the collection of tolls without having to stop the vehicle at the toll booth, can be the first ITS success story for Puerto Rico. There is a need for reduction of traffic delays at the toll plazas in the SJMA. Electronic Toll Collection provides benefits by decreasing delay times per person and reducing vehicle emissions. Therefore, a rigorous deployment plan should develop specific measures of effectiveness to monitor the relative success of the program. In addition, the current political will can serve as a catalyst for the deployment of electronic toll collection. The system has to be anchored in regional, if not national, architecture standards that will provide future technological enhancements and service options. Radio frequency or microwave systems are recommended for implementation, largely because they offer the best operating performance and a good platform for further services.

There are risks associated with ETC deployment, such as the enforcement of the toll. However, the system cannot have gated exits at each booth, as the T. Moscoso

Bridge, because the benefits of an ETC system can become nonexistent. The success effectively depends on market penetration, measured as the number of ETC users, which in turn may depend on the real benefits the system offers. There is a clear potential for an island-wide initiative, not limited to the SJMA. Market penetration should be ensured through an adequate planning process that includes market research and engineering studies. Consecutive bottlenecks after the toll plazas on certain highways should be studied rigorously to obtain a better picture of potential critical points if the flow at the plazas is expedited.

Different operating arrangements and payment toll methods are analyzed. It is suggested that the toll levels should not change due to the development of ETC. Furthermore, it is suggested that a monthly flat fee toll structure be used as additional incentive (besides the delay savings) for públicos only, in order to increase their efficiency, productivity and supply of service.

Automated Vehicle Location and Public Transportation

Automatic Vehicle Location (AVL) is a system that determines the location of a vehicle and communicates the information to a decision agent that acts upon it. This information is valuable to transit services because it can be used to improve operating performance. A vehicle location system has two uses: off and on-line.

On-line uses consist of a decision agent, such as a supervisor or driver, providing different control strategies(e.g., short turning, holding) to maximize adherence to the operating plan. Off-line uses are limited to the provision of information for monitoring the service and evaluating its performance, such as running time and schedule adherence information. Potential benefits of an AVL system include:

- Improved public perception of mass transit
- Increased efficiency, reliability and overall system performance
- Improved data quality and decreasing collection costs
- Potential for implementing real-time passenger information systems

However, there are also some costs and potential risks:

- Increase in operating costs due to maintenance of the equipment
- Organizational discontent due to system complexity
- Unreliable or bad quality equipment

AMA

To determine the potential need for real-time control, four routes were chosen for analysis of variance in running times. Significant variances were found for every route, suggesting the need for control strategies. However, given the current circumstances, significant improvements in running time variability can be achieved without real-time control, that is, without deploying expensive AVL technology. Several phases were recommended, agreeing with AMA's Strategic Improvement Plan developed by Multisystems Inc..

Phase I, the critical Phase in the deployment process, consists of redesign of the data collection effort, reassignment of supervision and monitoring posts, and movement towards incorporating most of the organizational constraints in the planning and scheduling tasks and abiding by them. The overall objective is to develop a reasonable operating plan that takes into account most endogenous and exogenous factors. This Plan agrees with the proposed network restructuring effort currently undertaken.

Phase II consists of evaluating Phase I and proceeding with testing automated data collection techniques if the results of Phase I are satisfactory. Once the organization has proved that it can effectively change, an AVL system can start to improve both the on-line control strategies and the off-line analysis. The envisioned trunk routes with low headways can benefit significantly from such a system. Then, **Phase III** could consist of the selection and deployment of a technology chosen from those tested.

Metrobus

In terms of Metrobus, the short term contractual relationship with the ACT does not favor long term investments. In addition, their current performance measures are considerably better than AMA's. There are fewer incentives, then, to improve operations through capital outlays by either the ACT or Metrobus directly. Performance was also analyzed for Metrobus; it is concluded that dispatching at the Capetillo and Covadonga terminals needs to be improved to reduce variability in the service.

However, there are some limitations to any possible real time control strategies that can be implemented. Due to the limited right of way along the contraflow lanes, it is impossible to have a bus passing another one in a leap-frogging type of scheme. In addition, having the AMA buses on the lane also imposes some additional constraints to the operation of the system. As a result of the analysis, no AVL system is needed for Metrobus operations. Rather, supervisory improvements in the dispatching terminus and along the way can help maintain the necessary headway.

Automatic Vehicle Identification and Signal Priority for Public Transportation

Signal priority strategies consist of expediting a vehicle through an intersection without experiencing delays caused by traffic lights. The expediting is enabled by a system composed of detectors, a communication link and a signal controller. There are several possible strategies for signal priority:

- Phase Extension or Extended Green
- Early Start
- Special Phase or Red Interruption
- Suppressed Phase

Both early start and phase extension are candidates for implementation in the SJMA. The benefits accrued by signal priority schemes are decreased trip times, a possible reduction in fleetsize requirements, improved productivity, decreased fuel consumption and better headway and schedule adherence. All these translate into a better level of service for the passenger, who may experience less waiting times and better distributed loads on the buses.

Metrobus

Ridecheck information gathered at the end of 1993 was used in the analysis. The results showed that most of the traffic light delays in the Northbound direction were caused in the first third of the route. It was not surprising therefore to find that headways effectively deteriorate the most along this segment.

A signal priority system implemented in only five intersections would decrease running times approximately two and a half minutes, which corresponds to almost 6 percent of the current Northbound running time. Given the low headway during peak hours, this may imply savings of up to one vehicle. Cross street effects were not significant. However, the MIST system that synchronizes lights and changes cycles by time of day has been recently installed by Farradyne Systems along Muñoz Rivera and Ponce de León. This implementation hinders the possibilities of signal priority in the corridor.

AMA

AMA's current routes tend to have very low frequencies and high running times. Decreasing running times would only modestly benefit existing riders and would have little or no effect on fleetsize requirements or operating costs. On the contrary, costs of implementation and operations may probably outweigh significantly the few benefits accrued.

Under the route redesign process, the three trunk routes having ten minute headways are possible candidates for signal priority. Furthermore, signal priority systems can be critical to accessing the new transit centers to be operational in October 1995. These centers are located in activity nuclei and therefore have significant vehicle flow and controlled intersections.

As a result of the analysis, the following suggestions are made:
Creation of a task force once the transit centers are operational, having ACT, AMA, Metrobus and público representatives to discuss alternative locations for test priority intersections. The task force should have the specific duty of arranging the test

procedures. Collaboration of the FHWA regional office may be necessary.
Inductive loops or the proprietary detectors developed by the ACT should be used in the tests, unless accurate GPS systems are implemented at AMA's vehicles. In that case, the additional investment for system compatibility is justified.

The task force will develop and use measures of effectiveness to assess the impact of the system on the stakeholders (i.e., pedestrians, private vehicle driver's and each individual agency or association). If considered necessary, the task force will also develop an RFP having system interoperability and general architecture concerns in mind.

Any analysis of signal priority implementation should be done at the most disaggregate level, almost intersection by intersection. Benefits and costs are directly linked to passenger demand for public transport and vehicular and pedestrian flow at each particular intersection.

Passenger Information Systems

Passenger information systems convey information regarding the transportation system to (potential) users. The information can be delivered to the trip origin (i.e., home or office), to a stop or terminal, or in-vehicle. Traditional information services have offered information on highways and their traffic congestion levels. Only until recently new technologies have enabled the provision of multimodal information. In public transportation, information systems provide benefits such as improving trip planning, easing modal transfers, reducing passenger anxiety at stops or terminals, allowing passengers to use their wait time productively and raising the public's awareness about public transportation.

Due to the current state of passenger information systems in the SJMA, the analysis and short-term recommendations focused on static information. Static information does not change over short periods of time and therefore does not reflect the actual field conditions. Static information can be used to provide a better level of service to current users as well as to promote the service in current markets that do not use public transportation. Long term recommendations include creating a real time passenger information system linked to a potential AVL system.

Short-Term Recommendations

The use of information kiosks as part of passenger information systems can become a key tool in improving the negative perception locals have about public transportation. Kiosks may provide static information about schedules on main routes, a calendar of events and updates on the development of Tren Urbano. These kiosks do not have to be interconnected and can function independently. Their implementation is not costly and will require one full time person for the maintenance of the machines and the update of the information. Furthermore, the services may be contracted with a local supplier.

Depending on the location of the kiosks, they can provide access to both users and non-users of public transportation. It is suggested that not more than four kiosks be located in two or three major transit centers, and in two or three major trip origins or destinations, such as Plaza de Las Americas, or work centers as Centro Médico and Centro Judicial. If both users and non-users perceive improvements in public transportation, Tren Urbano's success will be more likely.

AMA and Metrobus

Passenger information systems, static or in real time, may become the bridge between the agency and its customers. It is recommended that AMA should start publishing the operating timetables and schedules as soon as possible. The first step in developing successful information systems is to provide static information at critical points, such as the soon to be realized transit centers, as well as in the major trip generators such as Old San Juan and the University of Puerto Rico. This information is also provided by the few kiosks implemented. Providing this information to the public is subject to improvements in the service, or else the results may be counterproductive.

Long-term Recommendations

Given the implementation of an AVL system, information about arrival times and bus location should be relayed to both transit centers and Tren Urbano Stations. AMA can also develop a simple and inexpensive telephone system providing static information. For Metrobus operations, it is considered that real time information for passengers is not necessary, as long as it maintains reliable service and exhibits adequate dispatch control and monitoring of running times.

Tren Urbano will also have some degree of in-vehicle passenger information systems to comply with the ADA. Terminal and in-vehicle information may include: vehicle location, stop, transfer and connections, delays, routes and schedule changes and emergency information. The intermodal character of this information should be highlighted.

Proposed New Service

Part of Tren Urbano's possible success is being focused on the reduction of traffic congestion. To achieve that end, the new transportation system can be developed so as to generate significant mode shift in the regular peak hours. Therefore, the proposed new service, that may be called "Público Premium" or "Público Ejecutivo", targets a segment of the population that may shift mode given adequate incentives.

Currently, the segment composed of young executives, recent college graduates, secretaries, middle managers and the like, is not being served by public transportation and has to resort to private auto driving at a significant expense for them and for the transportation system. Likewise, the service targets current público riders that are willing to pay a premium for reliability and a higher quality of service.

The concept relies heavily on the existing público scheme, drawing from the positive attributes and minimizing the current negative characteristics. It is also developed in recognition of the importance of providing public transportation to a market that is currently not served, as well as to provide future access to Tren Urbano. The operations of this new service can be enhanced and expedited by the use of information technologies. These technologies can also play a fundamental role in linking the Público Premium with Tren Urbano.

II. Introduction

Significant transportation investments are currently developing for the San Juan Metropolitan Area (SJMA). Among the investments is the construction of Tren Urbano and the development of a Strategic Plan for the Deployment of Intelligent Transportation Systems (ITS) in the SJMA by a group of private consultants contracted by the Autoridad de Carreteras y Transportación (ACT) under an Early Deployment Plan Grant given by FHWA. This report attempts to analyze the major links between Tren Urbano and the deployment of ITS on the Island. The underlying motivation of the current report is the role of ITS as a possible expediter of flows for the entire transportation system. The role assigned to ITS agrees with the publicly enunciated goals of Tren Urbano of improving mobility and reducing traffic congestion in the metropolitan area.

More fundamentally, attention is called to perceiving ITS as an intermodal technology that can allow seamless transfers among the various modes. Hence, ITS is seen as system conveying communication and information that can improve efficiency and productivity in the production and consumption of transportation services.

The methodology used in studying these applications is to concentrate on studying each technology and its effects on the transportation system. The benefits and costs of each system are analyzed in a quantitative and qualitative manner, drawing from the experience of worldwide case studies included. Analysis of the need for the implementation of the application in the SJMA is then performed, emphasizing three main aspects:

- potential barriers and risks
- existing needs and possible benefits accrued
- interaction with Tren Urbano and other current and planned transportation investments

The document is intended as a guide for Puerto Rico's transportation agencies, administrators and students thinking about the role and potential of Intelligent Transportation Systems on the Island. The study may become a starting point when considering the implementation of a specific technology. It may also serve as an initial reference for the development of the Strategic Plan for ITS in the Island.

Rather than an exhaustive analysis of an individual technology, this study presents a broad array of possibilities considering Puerto Rico's needs and current situation. It provides an initial assessment of the likelihood of deployment based on the analysis of the benefits and costs of each application in the context of Tren Urbano. Specific suggestions are made about phasing the implementation process to minimize risks. An evolutionary, rather than revolutionary, approach is recommended as a policy to ensure adequate market penetration and user acceptance. Finally, deployment of the applications is prioritized according to the added functionality that they may bring to the SJMA and to the way users may value that functionality.

III. Potential for Deployment of ITS Initiatives in the San Juan Metropolitan Area

Analysis of the unique conditions of the San Juan Metropolitan Area (SJMA) can convey the core elements of ITS that may be deployed. There are two particular circumstances that may govern which applications may be ultimately implemented: The Strategic Plan for ITS Deployment in San Juan and the possible construction of Tren Urbano. The interaction between these two undertakings is of particular interest. Therefore, Tren Urbano and the other major transportation investments currently being implemented in the SJMA should develop a dynamic relationship with the contractors developing the Strategic Plan to maximize the benefits from each individual project.

A. The Strategic Deployment Plan for ITS for the San Juan Metropolitan Area

The Commonwealth of Puerto Rico was selected as a recipient of an ITS Early Deployment Grant from the Federal Highway Administration. The Plan is to study the implementation of several ITS technologies throughout the San Juan Metropolitan Area to reduce automobile congestion and improve safety while simultaneously enhancing every transportation mode (1). The total cost of the project was estimated at $ 500,000, with a participation of 80 percent of federal funds.

A request for proposals (RFP) was issued during the summer of 1994 by the Department of Transportation and Public Works (DTPW) and the Puerto Rico Highway and Transportation Authority (PRHTA). The RFP established the general and breadth of the Strategic Plan.

The specific objectives of the Plan can be summarized as follows:

- Evaluation of current and planned transportation plans, identifying strengths and weaknesses, as well as the main stakeholders involved in the process.
- Organization of the stakeholders group to guide and endorse ITS implementation.

- Definition of a User Service Plan and develop measures of effectiveness for the possible application deployments.
- Determination of the technological requirements to provide the services and evaluate them against feasible alternatives.
- Development of a preliminary system architecture

The result of this dynamic process is the Strategic Plan for Deployment of ITS in the San Juan Area. The report should also provide alternatives for different terms, namely, short-term (0-4 years), medium-term (5-10 years) and long-term (10-20 years). The RFP highlights the need for the development of adequate services that should enhance the future multimodal character of the SJMA. The need for those service is heightened by the deployment of Tren Urbano. In addition, the identification of stakeholders implicitly calls for the input of the parties that can benefit from the wide array of ITS applications. Tren Urbano, and the current actors of the SJMA transportation system are called upon to actively participate in this process.

The goal of the project is consistent with the goals of the major highway transportation investments in Puerto Rico. Particularly, it refers to the development of systems that "effectively reduce congestion by optimizing performance of the existing transportation infrastructure". Furthermore, the objective is consonant with Tren Urbano's publicly enunciated goals of reducing congestion and increasing mobility.

The Strategic Plan's objective of developing a preliminary system architecture for Puerto Rico should be followed closely. Arguments in favor of a regional independent architecture, an exclusively local architecture, or an architecture compatible with the National architecture being developed can be made. A regional architecture provides faster implementation of applications that need immediate attention, such as Electronic Toll Collection (ETC). Likewise, the current existence of some ITS applications in the Island, such as ETC in the T. Moscoso Bridge, may need the rapid establishment of regional standards to develop fully and maximize benefits. However, such a system would resemble a specific application architecture rather than a multipurpose and more desirable platform-based architecture.

Ideally, the architecture for the SJMA applications should develop in accordance with the fundamental goals of ITS and having the National architecture as a frame of reference. This architecture would be modular enough to facilitate future enhancements while guaranteeing system interoperability. Also, the architecture should explicitly establish the tradeoff between functionality and cost, as well as market penetration sensitivity. The market penetration sensitivity is essential to attract enough vendors to bid for the provision of the services and applications and, in the long term, to become the pioneer showcase of ITS for the Latin America and the Caribbean Region.

Unfortunately, there is no explicit mention in the objectives of the Strategic Plan of the development of a rigorous assessment of institutional issues that may expedite or hinder the implementation of certain applications. Several field operational tests have proved that successful ITS implementations require substantial intra and inter-institutional efforts. Plans evaluating the necessary reduction of barriers and frictions need to be developed. These plans should address the fundamental question of institutional and societal readiness in the adoption of these new information processes. Therefore, it may seem that the Strategic Plan currently envisioned is more oriented towards the analysis of deploying certain technologies rather than on the functionality they provide and the needs they fulfill within the societal context.

As a result of the RFP two proposals were received. A team of the PRHTA and the FHWA evaluated them and selected the proposal presented by a group composed by Parsons, Farradyne Systems and CMA (a local company) among others. The negotiations of the contract are expected to be finalized by the summer of 1995, when the study is expected to start. A committee formed by the Department of Public Works and the Puerto Rico Highway and Transportation Authority will be in charge of reviewing the progress in the Strategic Plan. They will also be in charge of providing information and feedback to each of the deliverables of the group preparing the Strategic Plan.

B. Information Technologies and the Tren Urbano Project

The construction of Tren Urbano opens a window of opportunity for the deployment of modern technologies in the transportation system of the SJMA. ITS applications are considered as supportive of Tren Urbano, rather than competing against it. They can possibly enhance the level of service of the transportation system and can improve the perception of public's perception of mass transit.

A group of ITS applications can be viewed as having a direct relationship with Tren Urbano (TU) and can influence the performance of the transit system. This category comprises initiatives that are not very costly to implement and that may enhance the passenger level of service from a system's perspective. These applications include vehicle identification, vehicle location, traveler information systems, and the use of smartcards. All these alternatives are related to public transportation and their intermodal character with respect to Tren Urbano should be highlighted. The relationship of ITS with the public transportation system is shown graphically on Table 3.1. Some ITS applications can serve as effective facilitators of the new and improved transportation system of the SJMA. Also, notice how ITS can become an element of integration among modes and among their respective operating agencies.

The main hurdle for the implementation of these technologies is financial and institutional, and lies within each regulating agency (and its corresponding operator, if different from each other). For example, the Metropolitan Bus Authority (AMA) has needs that are more fundamental than implementing a bus signal priority system. In other words, the marginal benefit of investing a limited amount of money in signal priority is less than the marginal benefit of hiring extraboard operators for the vehicles (due to the dramatic deficit in vehicle operators). The imminent construction of TU will focus the attention on basic concerns of the existing system, such as having adequate and efficient work force sizes at the same time that will open spaces for other technological developments that may further enhance the level of service. Thus, TU becomes a catalyst for these initiatives and may generate the momentum necessary for their implementation, rather than being a barrier or a competitor.

There are other ITS applications that are not directly related to Tren Urbano's performance. These alternatives deal with traffic management measures such as electronic toll collection, ramp metering and dynamic traffic information. These possibilities enhance the level of service of automobiles, and consequently may attract, or at least retain, many of the riders that may be close to making a mode shift with the new train system. Nevertheless, this apparent contradiction is non-existent. Both Tren Urbano and these traffic management system measures are furthering the stated objective of enhancing the service provided by all the transportation system. Further, this may also provide an explanation for the high investment in the maintenance and expansion of the highway and street network in the SJMA. A conscious trade-off between maximizing the number of Tren Urbano riders and providing an acceptable level of service for all transportation modes is being made.

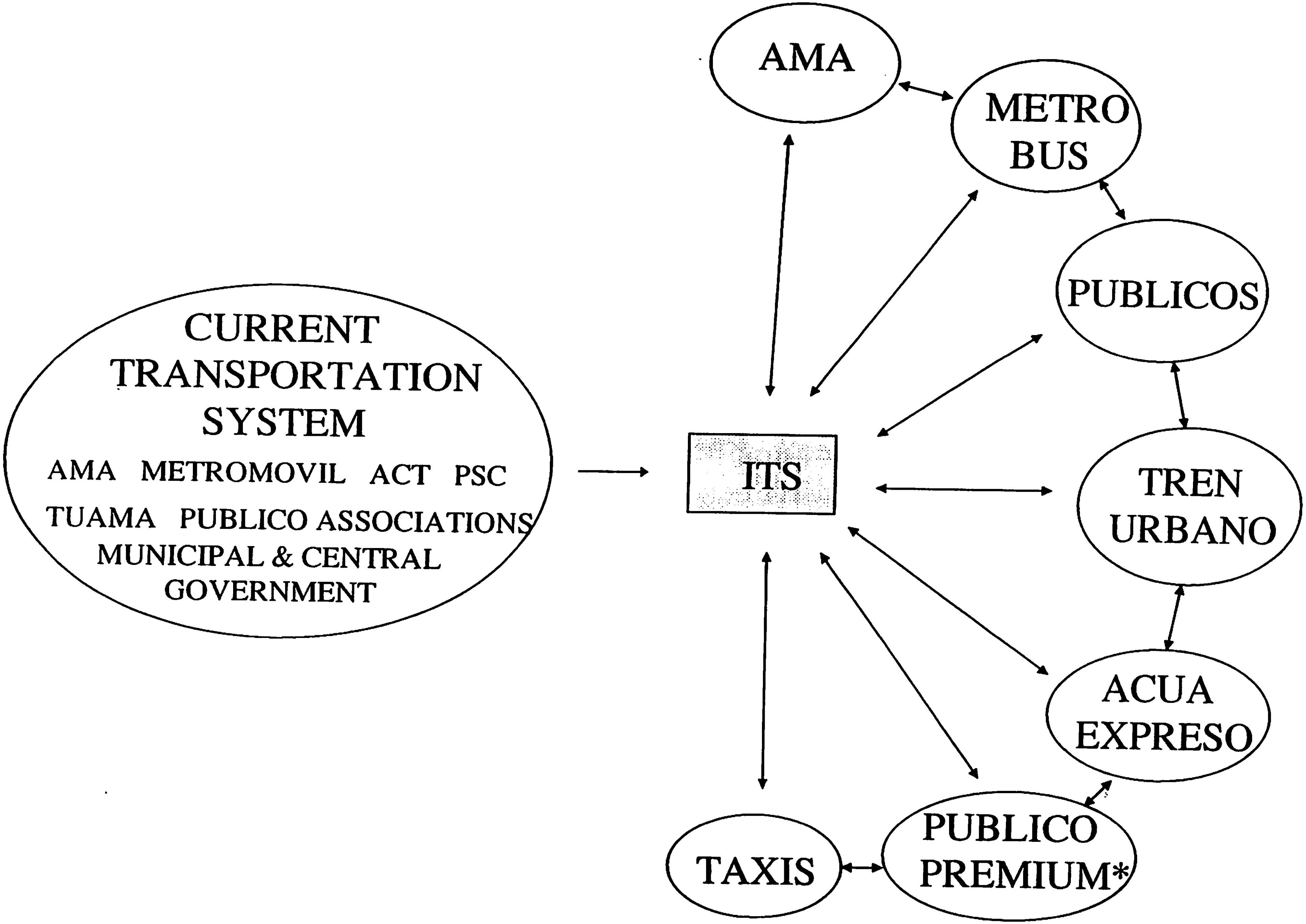
There are as well some other concerns that apply generally to all the applications within the ITS program. Human resources are a constraint to the parallel development of ITS and TU. Unfortunately, San Juan, as many other metropolitan areas, does not have an extensive pool of experts in the transportation field. It is quite natural to expect that most of the local expertise will be drawn towards TU and to current PRHTA projects. The involvement of locals in the development of ITS is an essential step in the completion of the technology transfer process. Therefore, rather than suffering from shortage of qualified personnel, certain ITS applications may be positioned within Tren Urbano, developing a symbiotic relationship.

A similar relationship may develop through the current levels of congestion. The vehicular congestion experienced by commuters may become an agent creating synergy between ITS and TU. There is the political will to come up with alternatives to congestion, if not for solutions to it. The timing is adequate to propose some ITS alternatives that may enhance TU's performance and the overall level of service. The tradeoff between investing now or later in time is captured in the political will to come up with viable solutions.

Finally, institutional and regulatory changes are required for both TU and ITS implementation. It is naive to conceive dynamic institutions and laws that renew themselves upon every challenge. Often institutions resist change, and therefore, efforts should be combined to promote the transformation needed. In this case, for both TU and ITS, acceptable roles and responsibilities should be adopted by the institutions in question, according to the new reality. For example, for a successful implementation of both TU and ITS the current bidding practices are unsatisfactory. Negotiated bids are necessary to enhance the end-product that the user will experience, while providing the agency with enough flexibility to achieve good supervisory work.

In summary, the construction of the TU will provide many of the necessary conditions to implement several ITS applications. Contributions of ITS in the context of the current and planned transportation system include improving the utilization of the capacity, enhancement of intermodalism and seamless transfers, overall increased system reliability, safety improvements and possibly a positive effect on the public's perception on the different transportation modes. On the long run, a traffic management system anchored on the successful development of electronic toll collection systems, and some public transportation and traveler information systems initiatives, is feasible. The early development of these anchors may prove to be critical not only to the development of ITS but to the political success of its proponents, and ultimately, to the attraction of users.

1995 **TABLE 3.1** **2001**



IV. Scope of Work

A metropolitan area the size of San Juan can deploy various ITS applications in response to the current transportation system's conditions. A core group of applications for any metropolitan area has been defined by FHWA to advance the implementation process nationwide (2). As shown in Figure 4.1 at the end of this Chapter, there are seven categories guiding the possibilities of ITS deployment. These categories serve as a long-term deployment roadmap for the region. An evolutionary approach is recommended, allowing for a predicted market stabilization and empowering new stakeholders to get involved in the deployment process at any time.

The current report focuses directly on Transit Management Systems, Electronic Toll Collection Systems and Fare Payment Systems. Since most of the core elements are interrelated, Traveler Information and Traffic Control Systems were also indirectly addressed. These elements of the core group were selected based upon the added functionality they can provide to the transportation system, and particularly for public transportation in the SJMA.

Notice in Figure 4.1 how several of the applications studied are tightly connected with the user of the system, namely, the customer. This is in response to the identified need of improving the negative perception the local San Juan residents have of public transportation. A continuing negative perception can be damaging for Tren Urbano's success, whereas ITS applications can possibly assist in improving them.

This improvement can be achieved simultaneously in two ways:

1. Improving the operations of a public transport agency, which then translates into reliable and improved service and customer satisfaction.
2. Having applications that appeal directly to the user and that may be highly valued, such as information systems enhancing seamless transfers.

In light of the traditional categorization introduced by the Strategic Plan for IVHS in the United States the current analysis comprises Advanced Public Transportation Systems as a central focus and other elements of Traveler Information Systems and

Advanced Traffic Management Systems. The scope of the report is shown graphically in Figure 4.2. The shaded boxes comprise the applications directly analyzed, whereas the white boxes on top are the categories defined in the US Strategic Plan.

On the long run, both vehicle location and vehicle identification technologies will provide the possibility for the development of a traffic management center where modal information is centralized and then disseminated to the users needing it. The notion of the center as the core of applications of ITS is shown in Figure 4.1. However, deployment of such a center is enabled if early ITS applications prove successful in achieving their goals.

Figure 4.1

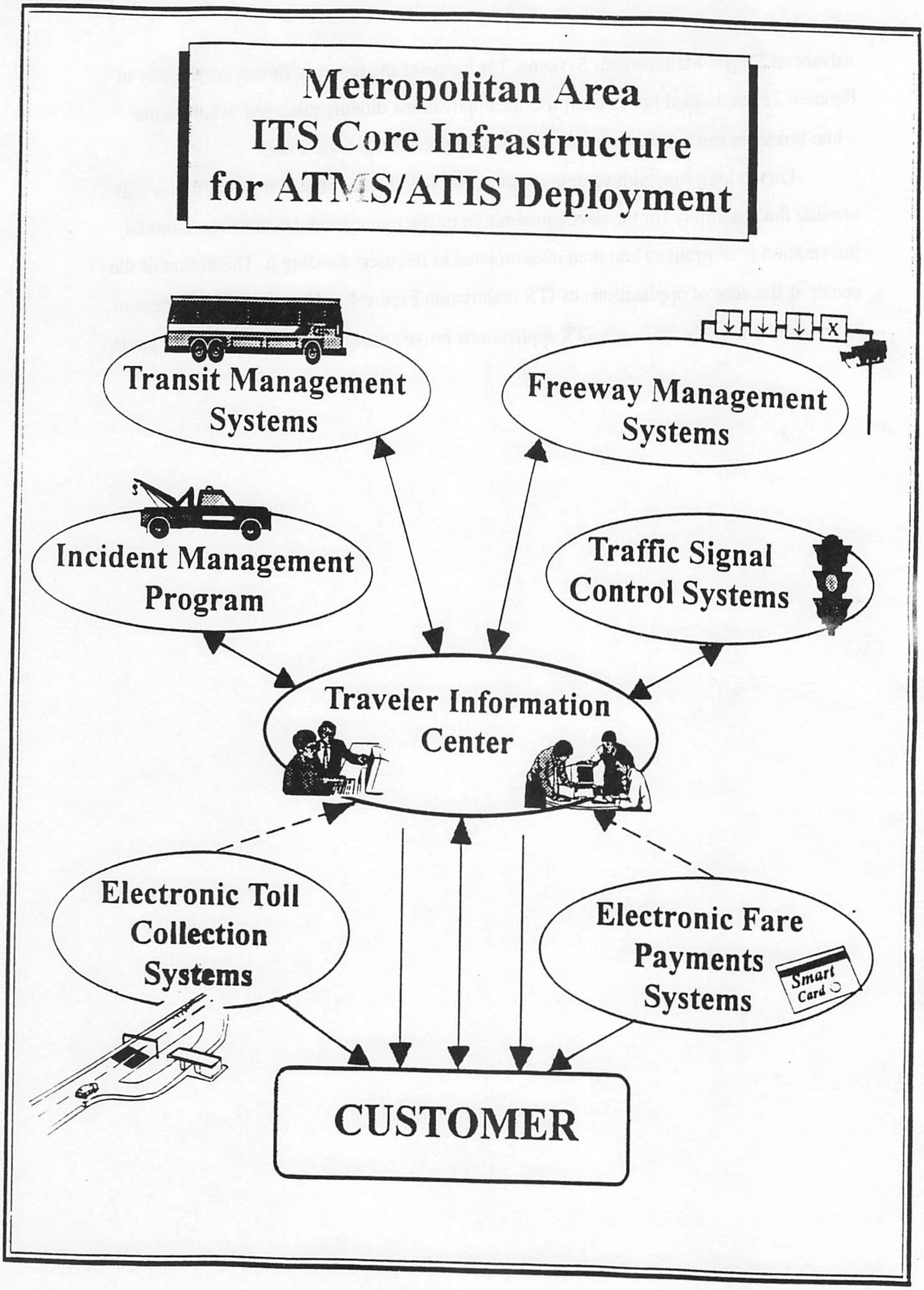
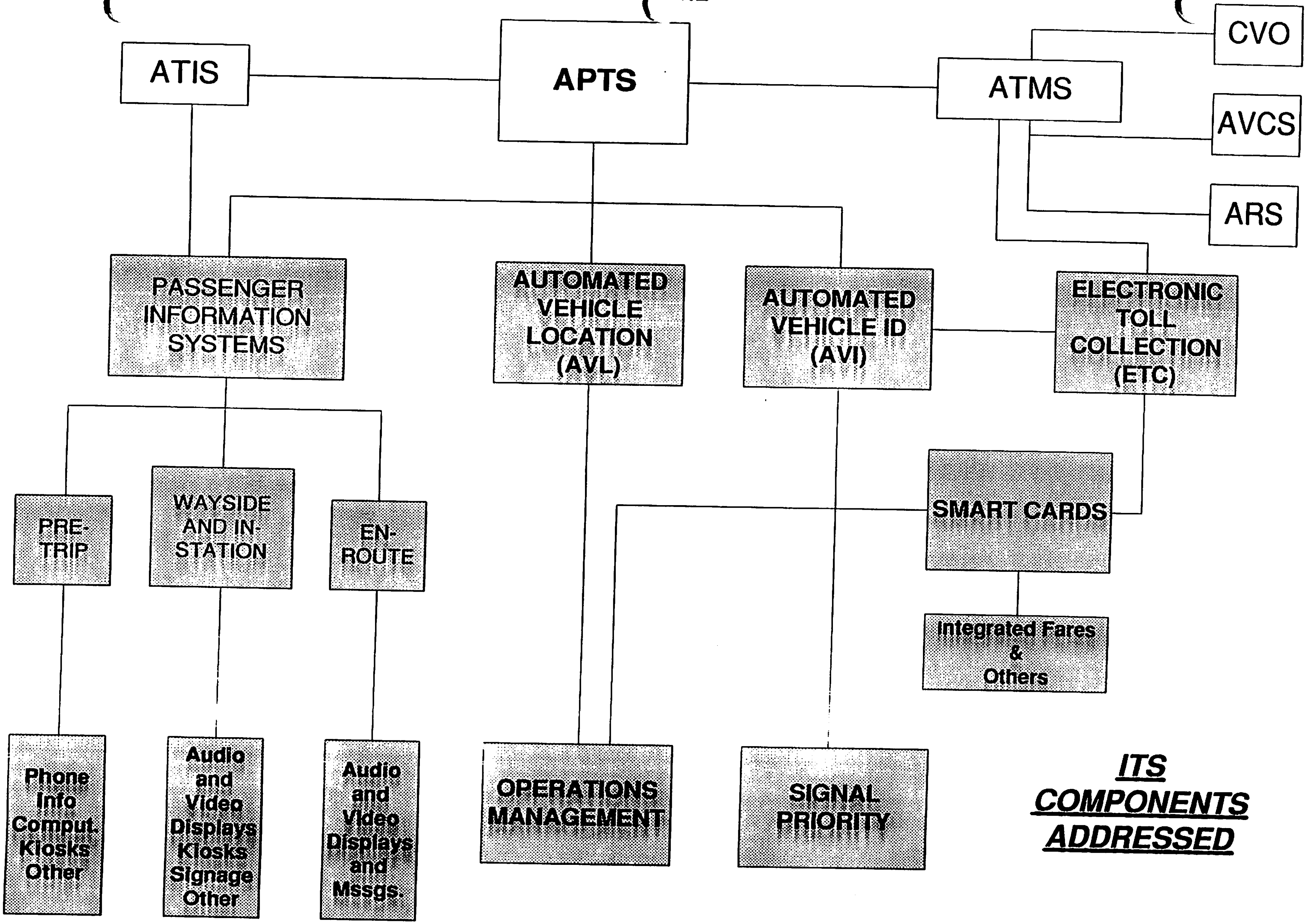

Metropolitan Area
ITS Core Infrastructure
for ATMS/ATIS Deployment
Transit Management Systems
Freeway Management Systems
X
Incident Management Program
Traffic Signal Control Systems
Traveler Information Center
Electronic Toll Collection Systems
Electronic Fare Payments Systems
Smart Card
CUSTOMER

FIGURE 4.2



ATIS
APTS
ATMS
CVO
AVCS
ARS
PASSENGER INFORMATION SYSTEMS
AUTOMATED VEHICLE LOCATION (AVL)
AUTOMATED VEHICLE ID (AVI)
ELECTRONIC TOLL COLLECTION (ETC)
SMART CARDS
Integrated Fares & Others
PRE-TRIP
WAYSIDE AND IN-STATION
EN-ROUTE
Phone Info Comput. Kiosks Other
Audio and Video Displays Kiosks Signage Other
Audio and Video Displays and Mssgs.
OPERATIONS MANAGEMENT
SIGNAL PRIORITY
ITS COMPONENTS ADDRESSED

V. Smart Cards

Smart cards is a fairly new technology that may prove to be very useful in diverse segments of society, including transportation. Powerful public-private partnerships can benefit from the strong image of such a high technology implementation at the same time that proven operating benefits are achieved. Versatility in their implementation possibilities and added security are their main operating feature.

A. Definition of Smartcards

Smart cards were developed around 1970 in Japan, and rediscovered in 1974 in France. They are plastic cards that perform instructions and store information better than traditional magnetic cards. There are two types of smart cards, wired-logic cards and "true" smartcards. The former is a card with fixed instructions that are repeated constantly. Most calling cards in Europe, for example, store an amount of cash that was prepaid by the user. Then, the cards are instructed to debit a pre-specified amount of money after a certain time of phone conversation, until the balance is depleted. Updating the balance only takes one operation which is fixed into the circuitry of the cards. Wired-logic cards are useful for low value transactions where the level of security and complexity of transaction are small.

"True" smart cards, or just smart cards, is the generic term for a collection of cards generally having an integrated circuit embedded into its thin structure, converting the card into a small portable computer. The card's size is the same as a regular credit card, and it is generally made of rugged plastic composites. Having a chip enables the card to have the same three components any computer system has, random access memory, also called volatile memory, read only memory and space for data storage (also called nonvolatile memory).

The operating system is stored in the read only memory (ROM). Nobody besides the operator and designer of an application can alter this part of the memory. Once a card reaches a customer, he or she cannot modify it. When a transaction is starting, the chip refers to its operating system which controls every single operation it makes. The chip is in charge of executing and verifying all the instructions. It enables or restricts access to certain types of information depending on the type of transaction.

Random access memory (RAM) is activated after the operating system is read. Information about the specific transaction is loaded into RAM, such as the name of the person, types of possible transactions, and the like. Random Access Memory could be seen as a scratch pad. When the transaction ends, everything in the scratch pad is transferred to the nonvolatile memory (e.g., new balances after withdrawing money) and the RAM becomes inactive.

Nonvolatile memory is analogous to a hard drive in a computer system. Information about the card, the user and all the applications available is stored there. When a transaction type has been identified, the chip looks for the files in the directories of the nonvolatile memory corresponding to the application. When found, they are retrieved to RAM, as well as the user data and the pertinent data encryption system (if any). Figure 5.1 at the end of the chapter depicts the typical layout of a smart card with a processor and how does the information gets stored and moved around with the machine of a generic application.

As shown in Figure 5.1, the way data gets transferred from the smartcard to a machine of any application and vice versa, can vary depending on the smartcard. There are three interfacing possibilities with the application machines, which defines the three main types of smart cards in the market today: contact cards, proximity cards, and contactless cards.

Initially, smart cards were developed with the chip on the surface; hence, direct contact between the card and the machine was needed. Since the data interchange is substantial, the card needs to be taken from the user's hands and mechanically manipulated in the machine to increase the robustness of the reading device of the system. This is a widely known limitation of contact cards that substantially increase the transaction time in some applications such as fare collection in transportation systems.

New developments in the field brought proximity and contactless cards. Both cards have the ability to read and write information. Proximity cards have to be placed within a specific distance from the reader, generally around 2 inches. They are powered by lithium battery cells that should last well over 10 years (3). These cards are constantly transmitting at a low radio frequency (RF) which is not strong enough to require FCC licensing or to violate ASHO standards. Data validation happens within the card, therefore saving significant on site hardware deployment.

Contactless cards do not emit signals constantly; as the card detects the adjacency of a reading machine the card powers itself. The source of power is an inductive coil that enables the beginning of the contactless communication. The data transfer rates remain unchanged in contactless cards. Additionally, the new processor of these contactless cards is more efficient and provides the data encryption procedure in a slightly different fashion (4). The card has to be inserted in a reading unit, also called transceiver, but the transfer of data is effectively contactless. The transceiver may be connected directly to the machine running the application or it may transmit the information through radio frequency waves. This type of smart card seems particularly powerful when there is a significant (physical) distance between the transceiver and the application system (e.g., electronic toll collection), as well as when highly reliable and secure operations are needed.

The contactless equipment is less subject to vandalism and misuse, since there is no opening through which foreign objects could be introduced. However, there is a tradeoff to the increased security of the equipment; RF or microwave (MW) contactless card systems cost more than the equipment of regular contact smart cards (4).

B. Recent Progress and Outlook

Cards having a processor can also vary in the degree of sophistication. A joint venture to develop improved smartcards specifically tailored for financial applications between Toshiba Corporation and VISA International has resulted in a super smart card, which includes a very small keyboard and a liquid crystal display (5). The processor in the super smart card decreases significantly the chances of fraud, and enables multiple implementations with the same card. Roughly speaking, each application would have a subdirectory under a root directory. Access to each subdirectory is conditioned upon several encryption methods and on the type of transaction being held.

The outlook of smart cards is better understood if its potential competitors and similar technologies are mentioned. Magnetic cards are the most widely used type of plastic and paper cards. They include most of the credit card, bank (e.g., Automated Teller Machine Cards) and transportation applications available in the US They were also developed in the 1970's, and are based on the recording of small iron oxide particles on the stripe. A magnetic card consists of three magnetic tracks in which specific information is written. The maximum information a magnetic card can hold is 250 alphanumeric characters.

Optical cards were developed more recently, because of the high technology needed in their development and use. Canon has popularized optical cards in Japan, although they are not as popular elsewhere. Optical cards, also called laser cards, consist of very thin layers of special materials whose surface is precisely melted by the heat of a laser or other light emitting diode. Therefore, an optical card is a Write Once Read Many times (WORM) application. The main advantage of an optical card is its enormous capacity. An optical card can store up to 2.86 Megabytes of information[1]. Similarly, optical cards are very sensitive to scratches and extreme temperatures. The devices handling optical card are very precise, and therefore, very costly.

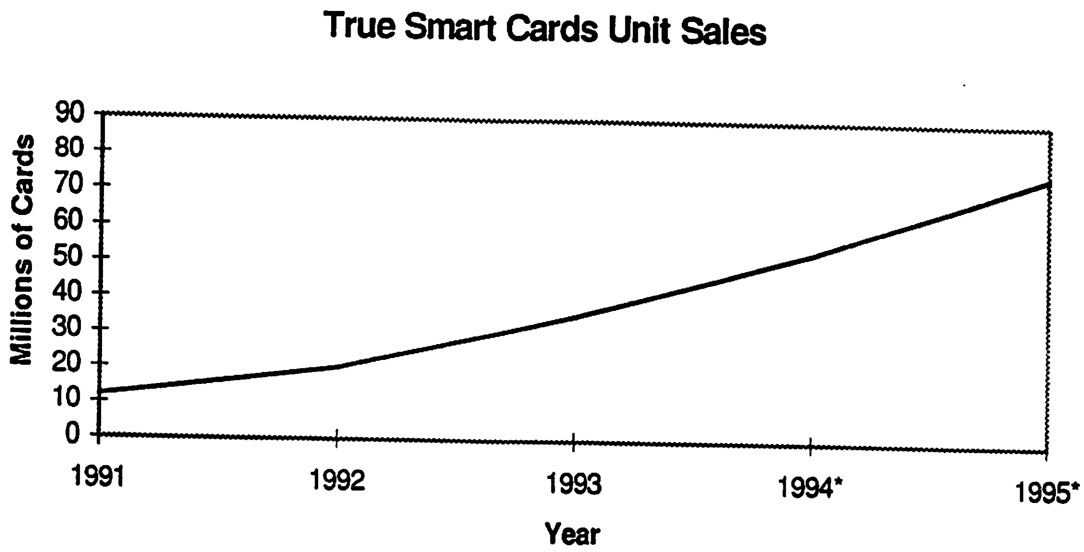
Optical cards have become widely used in the medical field. Each patient carries the medical history in the card, including X-rays and past medical exams. The fact that each patient carries medical data around has raised several concerns regarding privacy. Therefore, optical cards may be used to store only medical insurance related information for everybody and the medical history is only stored in the card of patients with serious health problems.

Both magnetic and optical cards have no data security controls within themselves. Data is encrypted by the machine of the application and then passed to the card. The data leaves the card encrypted and is deciphered in the machine. This provides a fundamental difference with smartcards. Since the smart card's processors control the type of data and its flow, the encrypting algorithms are found within the card. Then, machines do not have to rely on encryption algorithms but rather leave that task to the cards. This is important to the complexity of operations. Generally, magnetic cards work on a wide area network. The data is read, passed to a central computer who deciphers it and validates the user. With smart cards, there is no need for on-line operations. Both the machine and the card record the operation. The information of the machine is then downloaded every week or so, and used to examine any discrepancies that might arise with the card user. This is particularly interesting for deployment of financial applications where the telephone system is not very reliable or widely available.

After analyzing the differences between smart cards, magnetic cards and optical cards it is reasonable to expect that the use of smart cards will consistently grow over the next decade,

[1] Given that there is data enciphering; if no enciphering algorithm is provided, the capacity increase to 4 MB per card.

particularly because of its value in financial applications. A measure of how smart cards have been penetrating the market might be the number of cards sold per year. The next graph suggests how sales (in units sold) have been growing over the last five years worldwide.



Source: Update from (5)

The data for 1994 and 1995 are forecasts based on the 40 percent annual growth registered in previous years. In dollar terms, yearly sales will reach $1 billion by 1996 (6). The data of the graph accounts for true smart cards (i.e., with processor), and not the telephone wired-logic cards, which have sales figures more than five times the figures presented above.

The registered 40 percent growth in smartcard sales is expected to increase over the next decade for various reasons.

- Per unit costs will consistently decrease due to improvements in technology and increased competitiveness in the industry.
- Fraud with traditional magnetic cards will continue to increase. The chip embedded in smart cards provide different levels of security according to the transaction, making it very attractive for financial institutions.
- Centralized verification and processing are now deemed as costly and inefficient characteristics of operations. Off-line operations enabled by smart cards will significantly reduce those operating costs.

- Proliferation of magnetic cards and personal identification numbers (PINs) for individual applications becomes burdensome for consumers. Smart cards integrate diverse applications into a single card. Each application owns a directory in the non-volatile memory with the appropriate information.
- Overhead related to traditional operations (e.g., health insurance claims) can be reduced by implementing this technology. The development of electronic communication equipment and information technology has reduced the paperwork and delay of communications in various productive sectors of society. Smart cards improve the efficiency of processing claims and managing and collecting information.
- Development of an architecture for Intelligent Transportation Systems will encourage private entrepreneurs to develop new applications, as well as the interoperability between systems.

The development of new technologies will very possibly enhance the performance of end uses of smartcards. Magnetic cards by themselves are probably deemed to disappear gradually in some implementations where data security is a must. However, the current widespread deployment of magnetic cards and their readers cannot be regarded as unimportant. It is possible that a super-card integrating magnetic and optical or smart cards be developed in the near future.

Optical cards have a very specific segment of the market to target; namely, applications requiring high data storage capacity and accurateness. Complexity and costs in the operation of optical cards reduce their effectiveness. Therefore, laser cards were not considered as real alternatives to smart cards in the applications analyzed hereafter.

C. Development of Standards

The initial architecture developed in France when smartcards where first developed was taken as a de facto standard in the industry. The International Standards Organization (ISO) promulgated some basic standards regarding card architecture that are being updated once every two years. However, until a few years ago there were still some commercial applications using the French standard. It was proven that the location of the chip in the French standard was subject to electromagnetic interference. The ISO standards also provide room for the installation of a magnetic stripe, therefore enhancing the robustness of the cards and increasing the availability of new applications. The standardized parts of a smart card are:

- size of card, chip location, RAM, ROM and non-volatile memory functions
- protocols used in data transfer
- type of physical interaction between a card and a machine hosting an application

There is some freedom on the location of the magnetic stripe, as well as other minor issues. It is important to realize that the existence of standards will permit the interoperability of cards. Unfortunately, the architecture of the reading/writing machines is not standardized, and therefore cards currently do not work on machines developed by other companies. Additionally, many manufacturers hold proprietary information on many security methods (such as algorithms), hindering further the integration effort.

D. Current Applications of Smartcards

Uses of magnetic cards can be broadly categorized as financial and non-financial. Financial implementations are the most subject to fraudulent uses. Zoreda and Otón (5) classify fraud with magnetic cards in *theft, counterfeit, buffering* and *skimming*. All except *theft* are specific to magnetic cards and can be avoided by using smart cards. Magnetic card fraud is growing very rapidly. Between 1989 and 1990, fraud increased by 100 percent in the UK (6). However, France experienced a decrease in fraud of 5% in 1991 (transactions increased by 15 percent); it coincides with the first major smart card deployment effort there.

Consequently, an immediate application of smart cards is financial transactions. Cards can perform debit and credit card functions simultaneously, as well as provide updated information on portfolio investments and other financial applications. It also alleviates the burden of the extensive networks (e.g., ATMs and the like) and provides for local validation rather than having a centralized system.

Another major application is the health care industry . Several insurance companies in Germany have used smartcards to store important data of medical conditions of the card owner.

Similarly, much of the paperwork related to claims could be eliminated by electronically linking the medical offices with the insurance companies and by providing the patients with the cards.

Transference of social and economic benefits in an electronic fashion could also be carried out by a smart card (7). Federal benefits distributed to qualifying people could be administered more efficiently for both the user and the government, while saving significant amounts of dollars by reducing paperwork and increasing efficiency. Each qualified user would have an account in their smart card which will be credited every time the transaction is made.

Several applications have been implemented in the US. The *Peanut Commodity Card* was implemented in 1987 by the Department of Agriculture to reduce the paperwork and track producer's sales of peanuts against the assigned quotas. Approximately 200,000 cards are used. Initial calculations show that the costs of the program was completed recovered by 1990, and that by 1996 net savings of $14 million from the program were anticipated. An entire county near Dayton, Ohio has developed a smart card application to carry foodstamp values in it. The card is accepted at 93 food retailers. The program has been so successful that an RFP was issued to expand the program to the whole state.

Some of these application may raise concerns about privacy and civil liberties. They may well be a step further in the direction of having a personal identification card for each individual, conveying his or her general information, which is openly debatable. However it cannot be argued that economic benefits are achieved by using electronic media.

Other transactions that have been called "low-value", referring explicitly to the amount of cash involved are also possible smart card implementations. For example, cards can be used in transportation, to pay for the fares and enable an integrated billing system. The user may perceive one system, which in reality is composed of several parts. Similarly, cards can be used to buy from vending machines or to provide (or deny) physical access to certain places or to information, in universities or hospitals. Interestingly enough, smartcards provide room for a magnetic band, therefore enhancing its robustness in low cost transactions.

Additionally, specially powered microwave smart cards can prove to be very effective in the operation of electronic toll and traffic management systems. Because this initiative tends to have its own momentum it will be analyzed thoroughly in the next Chapter of the report.

E. Smart Cards as Fare Payment Media for Transportation

Realizing that transit agencies have decision making frameworks that vary, different possibilities are briefly discussed. Generally, these agencies operate under very constrained budgets which becomes a primary decision factor, and therefore costs associated for deployment of smart card systems and magnetic card systems are compared in the next section. Then, a brief discussion regarding operating costs and the benefits accrued by implementing smart cards is introduced. In the latter part of the analysis, major smart card implementation sites worldwide are mentioned, emphasizing on institutional problems in the deployment, as well as in the scope and timing of the effort.

A transit property may have well established goals and objectives. The provision of the service should reflect the effort of achieving the defined goals. Such a policy driven agency would relate the fare technology possibilities with the structure and level of the fare. These should agree with the goals and objectives specified.

Other properties may be truly technology driven and develops fare structures around the advantages of a specific technology. Finally, other agencies may be service-driven. In this case, an agency is introducing a new service and both policy objectives and fare technologies and structures need to be developed from scratch.

With due consideration given to the possible decision frameworks, and recognizing the financial constraints of agencies, costs associated with implementation are presented hereafter.

1. Costs Associated with Deployment

a. *Capital Costs*

The following table shows the approximate costs of deploying smart cards, magnetic cards and optical cards, granted that there is no retrofitting of existing equipment involved (i.e., everything is installed from scratch). The costs in the table are divided into the card costs and the equipment to operate the cards. It is relevant to mention that magnetic card readers can be personal computers (PC) or point-of-sale (POS). The difference between the two is the use of the third track in the magnetic band. The third track is generally available for use by card issuers, or to convey other useful information, although it is not necessary to complete a transaction. PC magnetic card readers tend to be related to non-monetary transactions, and are often encountered daily at libraries, video rental stores and the like. POS readers are used in transit fare collection, and financial transactions. The costs presented can be generalized for any other application without any significant loss of validity.

As it is shown, the cost of smart cards is substantially more than the cost of magnetic cards. Super smart cards costs depict the very high research and development costs and the current low market penetration. From a marketing perspective, it is quite hard to sell a smart card based solely on the provision of a service, such as transportation or health care. However, since smartcards can handle multiple applications, a public-private initiative can cover most of the

Type of Card	Unit Price (US Dollars)	Reader/Writer Price and Type (US Dollars)
Magnetic Stripe	0.15-0.60	150-600 (PC) 300-1,000 (POS) 10,000 ATMS
Optical Card	4.0-8.0	800-3,000
Smart Cards		
Wired-Logic	0.5-5	100-200 (PC)
Contact	3.0-15	300-800 (POS)
Contactless	5.0-20.0	500-900
Super Smart	20.0-50.0	N/A

Data Updated from (5)

costs of acquiring the cards. Furthermore, since the capital outlays for equipment decrease when using smart cards (at least $200, see with previous table), one can imagine a transfer of funds from budgeted capital costs of equipment to capital costs of cards. Even if the past consideration is not acceptable, many credit card users pay annual fees that nominally exceed the costs depicted in the table for smartcards. Since operating costs also decrease with smart cards (e.g., fewer calls by ATMS in financial applications), those funds can also assist in the financing of the smart cards venture. An additional issue to explore is the cost of retrofitting current magnetic machines for the use of smartcards.

The implementation of smartcards has no major political costs or barriers. It may be seen as a luxury good that may increase the final price a user would pay for the service. Nevertheless, the benefits in terms of improved image outweigh any minor political cost. Yet, if a public agency is to partially subsidize smartcards, several equity issues may be raised depending on the segment of the market being targeted by the new product. In fact, a field operational test in Delaware had to prove to the Securities and Exchange Commission that the smart cards being promoted by a local banking institution were going to be available to the whole population, not only to the customers of the bank (8).

b. Operating Costs

Unfortunately, there is no documentation widely available about the costs of operating smart card systems. Deployment efforts have been rather limited, as evidenced in the description of the implementation sites. Operating costs without including maintenance costs tend to be less than of the traditional fare collection methods. The tradeoff between both systems occurs in the fixed and variable cost portions. Traditional methods are labor intensive, while smart card and magnetic fare collection methods tend to be capital intensive (e.g., equipment), and the marginal cost of an additional user in the system (up to a saturation point) is low. However, Cubic Automated Revenue Service, one of the big players in fare collection, claims that a 20 percent return on investment (ROI) can be reached over the life cycle of the product (3).

2. Benefits Associated with Deployment

Benefits associated with deploying smart cards can be analyzed from the user and the operator perspectives. The user experiences a change in transaction times, depending on the original and he new fare collection system. If proximity cards are used, transaction times would invariably decrease, because proximity cards achieve the lowest times, around 0.2 s (9). Additionally, if a card is reported lost or stolen, the system is re-programmed to disable the old card and a new card with the previous balance is issued to the person. Magnetic cards can also achieve this, however the option of having the feature developed has never been exercised by any agency in the US. Experience has demonstrated that some frequent and most infrequent riders are reluctant to purchase monthly passes because loss of the card will go uncompensated (10). This concern would be addressed by deploying smart cards. Finally, the ease of use is also a benefit that can attract more customers. Proximity cards, the most widely used smart card for fare collection, can be read by the machine if it is placed close enough to the reader, even inside a wallet or small purse.

The operating agency accrues most of the significant benefits. In terms of operations, data will be collected at significantly lower costs. Additionally, more data will be collected on issues where agencies traditionally (mainly because of cost) do not have any information, such as passenger miles per fare category. The question of the ability of an agency to handle and use efficiently such large volume of data is still unanswered. Getting into the train system without paying will also be harder; therefore fare evasion will decrease significantly. Enforcement of fare payment has proved to be critical for the economic health of the subway operating agency in Buenos Aires, Argentina.

In addition, the savings from labor and capital costs are also considerable. The Massachusetts Bay Transportation Authority has estimated saving of between 4 and 10 percent by having advanced technologies in fare collection. This translates into saving between $2 and $5 million dollars.

Financially, if the agency uses a stored-value card, which is the general tendency in agencies worldwide, the up-front cash will also represent significant interest revenues. Some sense of added safety is generated when transit operators limit themselves to operating the vehicle, rather than managing the fare collection, performing ride counts and driving the vehicle. In a few words, the image of the agency can certainly improve with the use of smartcards.

Early results of the Gardenia experiment in California involving a small fleet of buses indicate operating costs of US $10,000 and quantifiable benefits of $40,000 for the first year *without* including capital costs of deployment (9). A detail of the benefits follows.

Type of Revenue	**US $**
Increased Revenue	25,000
Sec 15 data gathering savings	5,000
Advertising & other	10,000

The deployment in Manchester, UK explained in full in the next section, required a £ 10 million investment and is yielding annual benefits of £ 1.6 million, through data collection costs and fraud reduction (11).

3. Implementation Sites in the United States

Smart cards are being implemented in transportation on a worldwide basis as a way of integrating the payment of different modes, and therefore, enhancing the transportation level of service. Experiments have been developed in Europe for some time, and in the last two years in the United States. Some cities, including New York[2], Los Angeles and Chicago, have decided not to install smart cards but to install magnetic card fare collection systems. Their rationale is based on the fact that the continuous and rapid development of this industry yields a very high risk that they are unable to support. Yet, their systems have been designed so that retrofitting to smart card technology is fairly simple and economic.

Currently, there are five projects related to smart cards being sponsored by the Federal Transit Administration (FTA), and one project that has developed independently. The five projects are taking place in Wilmington, DE, Ann Arbor, MI, Los Angeles, CA, Chattanooga, TN and Washington DC (14). The latter project is the only true smart card multimodal project. This report focuses on the experience in the deployment in the United States and mentions the relevant deployment initiatives in Europe.

United States

Wilmington, DE

The Delaware Department of Transportation was selected as an ITS field operational test site for smart cards. This case is worth mentioning because it depicts the clear objectives of a deployment process of this nature. Yet, the project has not moved from a late 1993 stall state because of new developments in technology and rapid changes in smartcards. Unfortunately, the agency was committed to the process but not to the technology, and this led to the current delay (12). Smart card readers will be deployed in the 128 urban bus fleet of the Transportation Authority, The objectives of the project are multipurpose. Naturally, smart cards will serve as fare instruments and would provide the data collection benefits mentioned above. Yet, it is also interesting to mention that the project has also widely involved the private sector. Private

[2] New York City transit authority is interested in the RF proximity cards. Focus groups were conducted at the beginning of the current year. The results indicate that people liked proximity cards over magnetic cards. Similarly, it was informally established that the transaction time with a proximity card decreased to 0.2 seconds per transaction (1).

interesting to mention that the project has also widely involved the private sector. Private companies sponsor the cards to their employees as a part of the employer's trip reduction program. The cards would also serve as payment media in the cafeterias of employers, and as means to provide access to different building locations and information sources (e.g., databases).

Ann Arbor, MI

The Ann Arbor Transportation Authority (AATA) was selected as a test site for a wide array of ITS technology implementations. Smart cards is among the technologies being tested, as well as control systems, adaptive signal controls, computer-aided dispatching and electronic farebox systems (13). The plans include the deployment of smart card readers in a fleet of 60 buses. This process was also stalled at the end of 1993, but in late 1994 a new request for proposals was issued and a selection will be made soon.

The system consists of cards that will serve as prepaid and credit cards, and will work on the bus system as well as on the main parking garages near bus stations. This is designed to enhance mode transfer, and, since Ann Arbor is fairly small, it also becomes a way of integrating the commute and attracting casual bus riders. The current technology chosen by the AATA is the proximity card using RF (14).

Los Angeles, CA

The Los Angeles experiment also involves the California Transportation Department (Caltrans) and Echelon Industries. They will be testing up to 25 vehicles equipped to receive two different types of smartcards, operating in distinct environments and providing different types of services. This experiment will also be developed in several minor cities such as Gardenia and Torrence (13). Up to now almost seven hundred RF proximity cards produced by Racom have been distributed among the users. The operational test will also evaluate Gemplus IC Cards (contact cards) and will report on their main operational differences from an agency's perspective.

Washington DC

WMATA has demonstrated with Cubic Automated Revenue Collection Group of San Diego, CA the installation of proximity card readers and writers for the Metrorail and Metrobus systems, and having the capacity of serving for parking lots. The scope of the project includes

5,000 passengers, fourteen Metrorail mezzanines, twenty-one buses and fifteen parking lanes at five WMATA's parking properties (15). The type of card being implemented is the same one as the AATA, an RF proximity card. The test project will be completed by May of 1995 (16). Readers are placed at both entry and exits of buses, thereby providing for the possibility of continuing with the variable fare structure that has prevailed at WMATA. They are also accessible to physically challenged individuals in both the train and the bus system. This demonstration has been christened as the true multimodal demonstration of smart cards (13).

Chattanooga, TN

The Chattanooga Area Transportation Authority (CARTA) is using smartcards in conjunction with a congestion relief effort in the Central Business District of the city. Public shuttles have been made available at certain sites (called "auto intercepts") where automotive traffic will be restricted (16). The cards would be operational in both the transit vehicles and in the park and ride facilities being implemented. A proposal has been formally selected and negotiations on the details are being conducted nowadays.

The independent effort is being done at the Bay Area Rapid Transit System (BART) to provide RF proximity cards to handicapped individuals. The smart card calls the elevator and provides information to the operator on the person requiring help in accessing the system. Smart cards where contemplated as payment fare media for all the users, but a decision was made favoring the use of prepaid magnetic cards.

4. Worldwide Sites

European Community Integrated Efforts

The European Community (EC) has joined efforts in consolidating the implementation of technology in the transportation system. A three year effort called DRIVE I was started in 1989. Among the different technologies, the system evaluated smartcards in Electronic Toll Collection (ETC), an issue that will be studied elsewhere in this report. Yet, the DRIVE I project funded two interesting evaluations on the use of smart cards in public transportation: SMART and

BARTOC. The SMART program studied smart cards in the urban transport scenario. BARTOC further investigated possible uses of smart cards for public purposes other than transportation. The study included the possible integration with recreational facilities (e.g., swimming pools and parks) as well as public libraries and car parking and as seasonal public transportation passes. The main conclusion of these studies is that the lack of interagency coordination significantly hindered the market acceptance (penetration) of smart cards (5). Similarly, the diversity of smart card technologies led to the increased efforts of standardization that are now evidenced in the industry.

The DRIVE I initiative was reauthorized and became DRIVE II, including two non-EC countries: Sweden and Norway. Under DRIVE II several projects related to smart cards are being implemented. Cities under evaluation include Trondheim, Marseille, Dublin and Bologna among others. The scope of implementation is ample, including deployment of up to 100,000 IC cards in Dublin (5).

Australia

The initiative of smart cards in Australia includes not only transportation alternatives, such as bus, rail and ferry systems, but also other food services and convenience store services. A prepaid card in set amounts will be distributed to consumers with the support of fast food chains such as McDonald's and Kentucky Fried Chicken.

England

The largest application in Europe is taking place in Manchester, UK. It is not an EC sponsored project, yet it has been the largest deployment effort worldwide (13). One million contactless GEE value-stored cards have been ordered and distributed in the Greater Manchester Area, to serve 3000 buses, 25 light rail stations and 105 British Rail stations in the region. The system began in 1994 with the full participation of newspaper outlets, post offices and convenience stores in the service area (17). Potentially, more than 800 agents will be able to add funds, as well as electronic kiosks and the like.

Netherlands

During 1992, the Netherlands Railways conducted a feasibility study for the use of smart cards. The objective of the project was to determine if paper tickets could be replaced by multimodal and multiple application smartcards. The card envisioned would also allow for better revenue allocation and passenger and trip statistics. Specification for the system were finalized in 1994. The recommendations include the development country-wide standards in order to achieve adequate market penetration and further developments in applications.

An important issue raised by several of the US and European deployment projects is the need for a clear vision of the implementation environment. Is it worth to have a single agency administering a multiple mode (or single mode) smart card, or is it better to have a centralized clearinghouse that administers the process? Experience has shown that a single agency handling a single type of payment (e.g., fares) is adequate. When the types of payments enabled by the card involves cross institutional clearing efforts, the best solution is to bring a centralized independent clearinghouse. There is no clear evidence on a solution to the agency that may administer different types of card payments made within the agency (e.g., bus fare, train fare and vending machines at stations). Definite results on the ongoing deployment test sites are not readily available. A framework for evaluation has been developed by the Volpe Center in conjunction with the Federal Transit Administration that will serve as a convergence point for the future evaluation possibilities.

Similarly, it is important to recognize that the transportation industry has accepted proximity cards as the dominating fare collection alternative within smart cards. Contact cards have to be removed from the user by mechanical means and read within the machine, and contactless cards have to be placed inside a transponder. Both situations prove to be inefficient in low cost transactions, as well as in transactions in which its speed of completion is relevant (e.g., fare collection), and therefore have been generally avoided by the agencies, except few success stories, such as WMATA's. Finally, it is too early in the development of smart cards to think about a truly multimodal smart card. Smart cards for both toll collection and transit fare collection operate under different characteristics making it hard to integrate both tasks in the same medium simultaneously[3].

[3] For additional information on this differentiation see Coopers & Lybrand, IC/Smart Card and RF Communications Industry Study, Final Report, prepared for the Volpe National Center, March 5, 1993.

F. Deployment in the San Juan Metropolitan Area (SJMA)

1. Proposed Implementation Options

The proposed changes to the transportation system of the SJMA brought by Tren Urbano generate an adequate scenario for the implementation of smart cards. The possible deployment alternatives described hereafter are categorized by fare collection and information scenarios, and subsequently broken up into the specific modes.

The advent of Tren Urbano require decision making about the new service being provided. It is recommended that fare policies should be integrated for both AMA and Tren Urbano. This does not imply that the fare levels be the same for both modes; it suggests that the structure and levels should be developed with the customer in mind. This means the maximum allowable integration and ease of use.

The technology related decisions studied hereafter include the fare collection strategy, the level of automation and the type of equipment needed. The new service may cause positive fare collection technology changes in other modes; therefore technological integration is also an issue discussed.

Although smart cards can potentially be deployed in all transportation modes in the San Juan Area, this is not likely to happen, nor is it recommended. Smart cards are justified when the volume of the transactions is large and keeping track of the revenues is hard. Similarly, it would also be justified when transaction times are large enough to cause significant delays to considerable amounts of people. Therefore, smart cards used for transport fare collection are not recommended for implementation in públicos and taxis. Públicos cannot manage the deployment costs, and the benefits accrued from smart card payments are not clear in their specific case. Both taxis and inter-municipal públicos carry people that are not from the SJMA, hence the use of smart cards is also limited from the user perspective. Finally, diverse institutional problems could be generated between the Public Service Commission and the Transportation Authority if cards were used for públicos as well as for the train system. A centralized clearinghouse and the related overhead would be needed to deal with the different agencies involved.

The Tren Urbano (TU) case is quite different. Current plans in the procurement process call for the contracting party to design the fare collection system, although input from the local authorities should be left open at all times. Smart cards as well as magnetic cards offer the possibility of having a variable fare structure in terms of time of day and distance of trip. However, current tests show that the use of smart cards is clearly justified when other applications (besides fare payment) are developed for the smart card technology.

The Metropolitan Bus Authority (MBA or AMA) and the Metrobus represent viable scenarios for the deployment of smart cards. One could envision and ideal multimodal card that can take the user from the train to the bus system in a seamless fashion. Yet, since there are multiple stops in each route, it is impossible due to costs and security reasons to have smart cards sold at the stops. This limits the availability of cards to Tren Urbano terminals and other transit centers.

The question of who should pay for an eventual smart card also limits the scope of the deployment. If the user pays for the card, then the regular user would be favored while occasional users will be penalized. The cost of one round trip of an occasional user (e.g., a tourist) can increase by two or three fold if the cost of the card is included in the price paid. Whereas a regular user would amortize the cost over subsequent trips. An alternative deployment involving Banco Popular was analyzed, based on the fact that the Bank has been actively involved in promoting the development of TU. Initially, Banco Popular would develop the cards that could also be used in the transportation system. Yet, several issues hinder this public-private initiative. First, the prevailing smart card technology in fare collection is proximity cards, which is unsuitable for financial applications that need more security in the transaction. Second, even if Banco Popular agrees to put a magnetic band to its IC card to be used in the transportation system, the SEC requires that the card be available to bank and non-bank users. This may be economically unfeasible for the bank.

Based on the experience of the deployment sites worldwide, it is recommended that both the bus and the train system accept prepaid or stored-value magnetic cards at all times, and not smart cards. Currently, magnetic cards accrue almost the same benefits as smart cards, at a lower overall cost and risk for an agency.

Magnetic Cards

- Collect almost the same quality of data as smartcards

- Have service (transaction) times similar to smartcards
- Are also a good fare evasion deterrent
- Can also be used as a integrated fare media
- Enables variable pricing structures too
- Are inexpensive and have a proven track record of satisfactory performance

However,

- They do not have convey such a strong image for the agency as smart cards do
- Value in a lost card generally goes uncompensated
- Deployment is limited to a strong agency/institution designing and operating the system, as opposed to being a multiple application integrator, such as smart cards
- There is limited data capacity
- It is not as convenient as proximity cards (particularly for the elderly and the disabled)

Nevertheless, developments in the smart card market should be closely monitored in the next three years to account for any significant breakthrough in developing applications or in overcoming barriers (legal, market, institutional and the like). The magnetic card system should be deployed taking into account the high likelihood of having to retrofit the equipment in the future to accept smart cards.

Cash and smart card options can be an interesting step towards a future smart card driven market. Providing these payment methods in the future will not be too costly and may significantly enhance the level of service of regular users. It would also provide valuable information about the regular users of the system.

As a parallel service to fare payment in the future, information and other premium services could be provided to the holder of a smart card. This information may be available for non-smart card users as well; however, the transaction time (e.g., typing, choosing among options and the like) would be much greater. A specific service is proposed, composed of information kiosks and a link between the kiosks and certain públicos, which is described as follows.

Proposed New Service

Part of Tren Urbano's possible success is being focused on the reduction of traffic congestion. To achieve that end, the system should be developed so as to generate significant mode shifts in the regular peak hours. Therefore, the proposed new service targets a segment of the population that may shift mode given adequate incentives. Currently, this segment of the market is not being served by public transportation and has to resort to private auto driving at a significant expense for them and for the transportation system. The segment mentioned is composed of young executives, recent graduates, secretaries, middle managers and the like. It can also target current público riders that are willing to pay a premium for reliability and a higher quality of service. The concept relies heavily on the existing público scheme, drawing from the positive attributes and minimizing the current negative characteristics.

Recognizing the informal character of the públicos, it may be very unlikely to organize their operations into pre-determined schedules and a defined coverage area. Therefore, a new service of públicos has been envisioned, called perhaps Público Premium or Público Ejecutivo (literally, Executive Público). The quality of the service would be higher than of the regular públicos, and the price would be increased accordingly. The públicos providing this new service would be committed to certain standards of span of service and area coverage.

The service is planned in two Phases. During the first phase, Público Premium is an express service connecting the multiple nuclei of the SJMA. The market towards Old San Juan during the morning peak and outbound in the afternoon is particularly important for the proposed service. The second Phase starts when Tren Urbano opens to the public. Information technologies will enable reservations of públicos from distant Tren Urbano Stations. The transition between both Phases will be done by introducing the demand responsive service during the morning peaks before Tren Urbano opens.

During the second Phase, the service would also cost more than the regular público fare, but will provide a much better level of service. It consists on the users getting to the TU station and accessing a kiosk. The kiosk will convey multiple information that will be described elsewhere in this report. Among the options, the user can reserve a seat of a público serving the area where the person wants to go. The person can input the information by typing it on a keyboard or touching a quadrant in a map of a monitor, or by bringing their proximity smart card within the range of the reader. The smart card will contain basic information about frequent destinations of the person. The alternative of having access to the service only by having smartcards only is feasible if individuals tamper with the kiosks and start to reserve unwanted rides (although market penetration may be noticeably affected). Another alternative is to have the service paid at the moment when the reservation is made. A matching algorithm couples a person with a público and the parking space where the público is at the terminal.

Before continuing, several operational issues about the públicos need to be clarified. The vehicles providing the Público Premium Service will be equipped with a tag (AVI) that is read or detected once the vehicle is in the queue for a parking space and when the vehicle is parked awaiting for passengers to board in the público terminal. This means that several spaces of the público terminal should be dedicated to Público Premium vehicles. A central computer updates the information and performs the matches. The público driver knows how many people have reserved a ride, and will wait for them. The match is finished when the customer arrives to the terminal with the printout of the reservation, hands it to the público operator and boards the vehicle. The service could initially be provided during peak hours only, and extended if granted by demand.

The completion of the other leg of the trip for a regular commuter, that is, getting from their place of origin to the station is dependent upon how the regular público and bus system is reorganized with TU. It is feasible to have the Público Premium service working as a door-to-station demand responsive service, using efficient matching algorithms. Yet, there are several exogenous variables that have not been defined already, such as the existence of "kiss and ride" facilities or "park and ride facilities".

The advantages of using smart cards in this context are manifold. Initially, it could be the only way to access the ridematching system. Additionally, it provides a further sense of security very valued in San Juan, since the card and the computer system know who was riding on what vehicle. It also serves as a means to monitor the service quality of the públicos providing this service, and provides an added sense of reliability and safety to the users of the system.

The proposed initiative could be financed in several ways. Initially, TU may cover most of the infrastructure costs in terminals, such as the deployment of the kiosks and their connection to a control center. The deployment of tags and readers for the públicos could also be included in the TU package, although another alternative is proposed. The públicos have not been getting operating funds under section 9. The vehicle miles traveled of this service were not recorded until recently, and therefore funding of this sort was unavailable. By recording and reporting the VMTs to the federal government, the públicos become eligible for additional funding, which last year amounted to US $ 10 million.

2. Constituencies Involved and Institutional Issues

The previous scenario will be directly linked to the entity that will be supervising and regulating the Publico's service. The question about the involvement of the Public Service Commission in the públicos is still unanswered. There are factors in favor and against its involvement. In any case, the agency in charge would be directly involved in deploying the proposed service.

Similarly, the público associations should be directly involved in the development of this proposal. Providers of the service would be drawn from the regular público drivers that want to commit to a tighter schedule and more monitoring in exchange for some additional revenue. AMA and Metrobus would also be involved in the process, since they want to be sure that none of their passengers would be diverted to this new service.

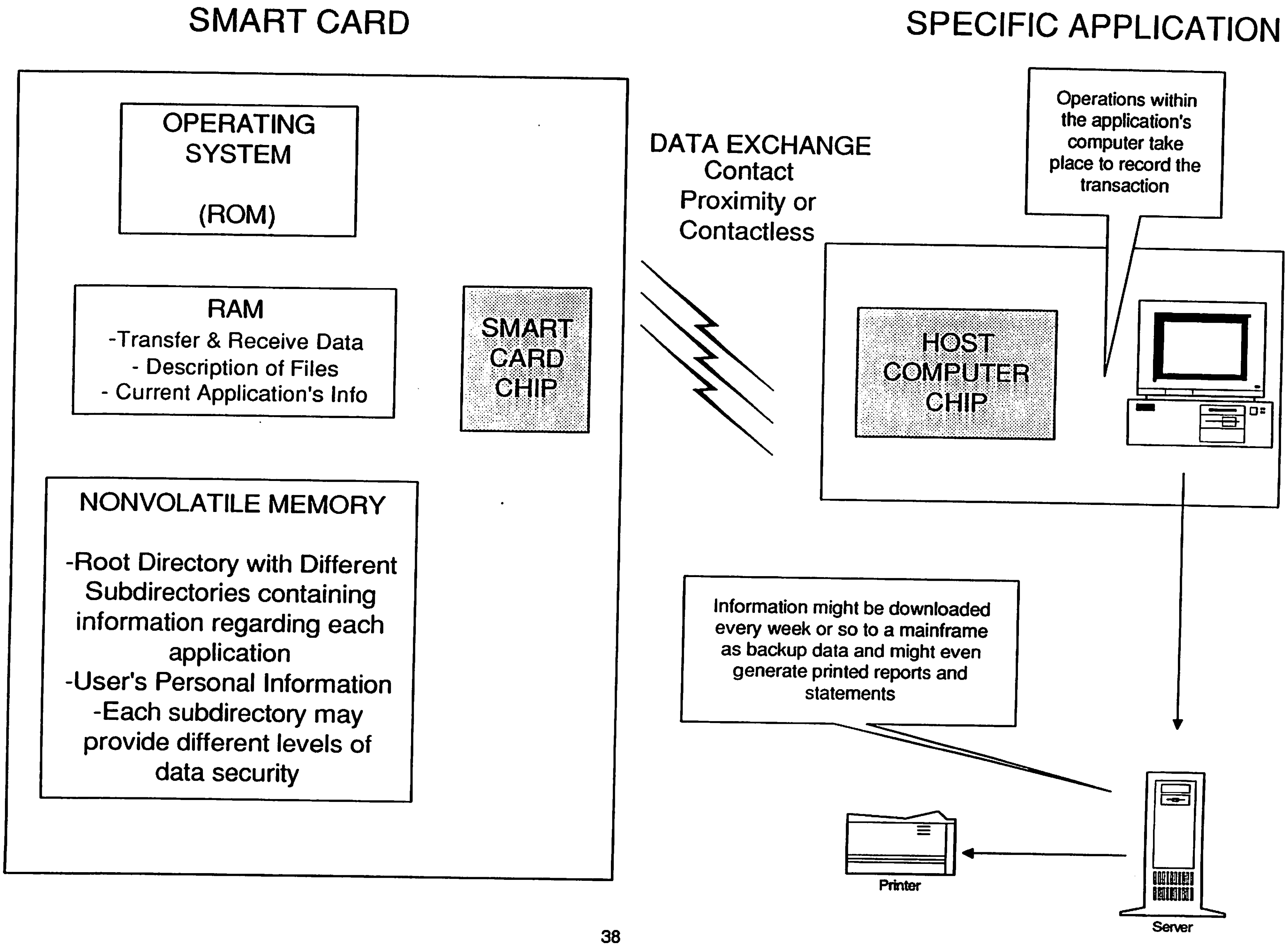
If the rides are prepaid by the user when the reservation is made, some complex institutional issues may arise, because the funds are being received and initially administered by the TU agency (probably a subsystem of Passenger Information Systems that manages the kiosks). Therefore, a mechanism financially linking TU and the Público Premium is necessary to transfer the funds and validate the claims of the público drivers in terms of the number of passengers carried. Although simple in paper, this task is very demanding because of institutional issues involved.

The political will behind this kind of service is fundamental for its successful deployment. As mentioned previously, TU serves as a catalyst to enhance the transportation system. The proven commitment of public authorities to improve the system in SJMA is an indicator of the relevance new proposal and services could have in the Island.

Finally, the users have the ultimate word on the deployment of the service. An adequate market research process before the arrangement is deployed can yield initial predictions on the proposal's success. Potentially, the level of service of this proposal may increase the mode shift from automobiles to TU necessary to alleviate some congestion. Therefore, congestion alleviation is another of the benefits achieved with the proposal.

Further research in this area may concentrate on developing guidelines for a sound fare policy structure given the institutional constraints in Puerto Rico. Another possibility may include the analysis as well as the structuring of the contact with the Tren Urbano operator regarding fare technologies and policies. From a marketing perspective, analysis of the user's reactions to the introduction of advanced payment methods may be an additional possibility. Also, all of these studies may include the analyzing the possible effects on ridership and mode choice.

FIGURE 5.1


SMART CARD
SPECIFIC APPLICATION
OPERATING SYSTEM
(ROM)
RAM
-Transfer & Receive Data
- Description of Files
- Current Application's Info
NONVOLATILE MEMORY
-Root Directory with Different Subdirectories containing information regarding each application
-User's Personal Information
-Each subdirectory may provide different levels of data security
SMART CARD CHIP
DATA EXCHANGE
Contact
Proximity or
Contactless
Operations within the application's computer take place to record the transaction
HOST COMPUTER CHIP
Information might be downloaded every week or so to a mainframe as backup data and might even generate printed reports and statements
Printer
Server

VI. Automatic Vehicle Location (AVL) and Automatic Vehicle Identification Systems (AVI)

A. Definition

AUTOMATIC VEHICLE IDENTIFICATION (AVI)

Automatic Vehicle Identification (AVI) refers to technologies that enable the electronic recognition and communication with vehicles in motion without any direct contact between the vehicle and the roadside equipment. The basic components of all AVI technologies are an on board unit (OBU) containing the vehicle identification data, a roadside transmitting/receiving unit to signal the vehicle and receive information, and processing equipment on the vehicle or at the roadside to manage the information. The following is a description of the current technologies used in AVI for motor vehicles. It is recognized the rail (passenger and freight) systems utilize different technologies appropriate for their operations. However, those applications are beyond the scope of this study.

Optical and Infrared Systems

Infrared systems use infrared frequencies to read information stored in the vehicle, such as the vehicle identification number (VIN). The most reliable type of infrared systems is bar code reading technology. In this system a laser beam is used to scan the bar code pattern on a plastic sticker located on the windshield of the vehicle. The speed of the data transmission is about 2.5 milliseconds (18). The bar code consists of a series of stripes of varying widths and colors which correspond to the VIN of a particular vehicle. The vehicle information is then used for different applications. The range of speed for dependable readings is from 20 to 45 mph at distances from 7 to 10 feet (18). Various levels of accuracy have been recorded, from 95% to 99.5 % where the optimal reading conditions at 30mph at a distance of 7.5 ft (18). This number can decrease significantly due to several conditions such as rain, snow, dirt accumulation and misalignment of the sticker.

Radio Frequency/Microwave Systems

The roadside equipment for radio frequency-based systems (RF) is a transceiver with one to three different antennas depending on the configuration of the system. The antennas identify vehicles approaching, as well as send and receive information from a "tag" mounted on the windshield or dashboard of the vehicle. The tag is the vehicle's OBU. It consists of a signal receiver and/or transmitter depending on the sophistication of the card, a power supply and a memory unit. RF systems utilize frequencies in the 500 to 3000 MHz range and microwave systems 30-1000 GHz (19). RF-based AVI systems tend to be very reliable under severe weather conditions because the transmission range is small and therefore the data is not easily corruptible. However, in more general terms RF systems over long range applications tend to be vulnerable to atmospheric and local geographical conditions, as well as to the number of relays of the information that may add unwanted interference to the communication . Accurate readings have been obtained at maximum distances of 250ft at high speeds (18) with most manufacturers claiming accuracy rates between 99.95% and 99.99% (19). Although, in practice, and depending on the system, the rates of accuracy reported are closer to 93% to 98% (19).

Microwaves consist of waves transmitted at high frequencies, thereby being more reliable, but entailing higher capital and maintenance costs. Microwaves transmit over smaller areas than RF signals because its signal breaks in the atmosphere rather than bouncing. Also, higher frequency waves need almost direct line-of-sight to achieve adequate performance and reach the desired target (20). The size of the antenna(s) and the polling also vary by using microwaves. Antenna sizes decrease and the polling, also known as number of interrogations per unit of time, tend to increase.

Currently, there are three types of RF/microwave tags. Type I is a read-only tag carrying information that can only be read by the roadside units. The configuration of Type I transponders is electronically simple and therefore the least expensive in the market. Type II tags have read-write capabilities. They carry the same information as Type I tags but have wired-logic circuitry in which the roadside equipment can add time-date stamps as well as other information relevant to the particular transaction.

The energy supply of transponders can also be divided into three groups, active, semi-active and passive. An active tag has its own power supply and it is always available for interrogation by the roadside transceivers. It generates the signal that is transmitted to the roadside antenna on its own. Because the rate at which these tags transmit and receive information is quite high, redundancy in the exchange process is allowable; hence higher reliability is ensured.

Semi-active tags, in contrast, are only activated when they are interrogated, although they may also have their own source of power. The rate of transmission of information is not as high as active cards but lower energy consumption is offered. Passive tags usually have no power supply; they collect power from roadside reader when they receive the interrogating signals. This interrogation technique has been popularly called "modulated backscatter". The interrogator sends a demodulated radio frequency which is modulated and returned by the tag. The new modulated signal is received by the roadside equipment and decoded to carry out the appropriate action.

Surface Acoustical Wave

Surface acoustical wave is a type of transponder systems where the vehicle's OBU contains a lithium crystal with etched metal caps that contain the car's VIN (19). The equipment at the toll station sends out acoustical waves that operate in a similar range to Radio and Microwave signals. The crystal reflects the wave sending back time-delayed signals. These signals are decoded by the roadside equipment and the transaction is made in a similar way as with RF and MW systems. This system is also relatively inexpensive because it contains few electronic parts and it can be tuned to accommodate varying frequency settings. However, the reliability of surface acoustic waves at high speeds or big distances is not satisfactory.

Global Positioning Systems (GPS)

In GPS systems the vehicle identification and data collection is done via pre existing satellite technology. Global Positioning Systems use at least three satellites provided by the U.S. Department of Defense. A mathematical procedure called trilateration is developed to locate the vehicle. Each vehicle has an on-board unit that receives the signal from each satellite in the 1-2GHz band and corrects it for the different times of reception (21). Using satellite technology eliminates the need for roadside equipment and therefore, reducing capital, maintenance and operation costs. The system works by having the vehicle's OBU make the toll fare calculations using geographical information provided by the satellite. However, accuracy and reliability are a major concern. Early results have shown accuracy of between 50 and 100 meters. Therefore, the system is not suitable for site specific applications; rather, it can be appropriate for zone and cordon-based toll applications.

In order to communicate with the satellite, GPS requires the vehicle to have an exterior antenna. The OBU itself is more complicated than the tag system used in RF-MW systems because location calculations are done on board. In addition, there needs to be a link between the vehicle and the roadside where the balance of the account is transferred on a periodic basis.

A number of issues need to be addressed with a GPS system. Three of the 24 satellites will be lost by the end of 1996; the Department of Defense has announced it will replace them, but spending cuts in Washington are hindering that possibility. Questions regarding the availability are relevant. The military have decided to deploy selective availability in their satellites, meaning that the satellites are not available 100 percent of the time for every vehicle, but on certain specific instants per a given unit of time (22). Furthermore, the system is also using scrambled signals to discourage its unauthorized and inappropriate use.

AUTOMATIC VEHICLE MONITORING AND LOCATION

Automatic Vehicle Monitoring refers to a variety of functions concerning individual vehicles and their management. AVL systems provide vehicle location thereby enabling schedule adherence monitoring, route guidance, vehicle monitoring, information on load characteristics and the like. Although the current analysis focuses on vehicle location systems, its integration with other functions and systems of a vehicle is quite necessary and will be evidenced along the document. The overall purpose of vehicle location systems is to improve vehicle performance and control and therefore increase the service reliability and the satisfaction of the user.

Automatic Vehicle Location (AVL) technologies, a subset of automatic vehicle monitoring, can be used to monitor the location of a vehicle over a given period of time or a specific geographical range. There are innumerable military applications of these technologies that are now being converted for civilian use. Quite possibly, the field that has benefited the most from this conversion is transportation. Nowadays, hazardous material movements in and around cities, static and dynamic route guidance, vehicle probing to infer congestion levels and fleet management are part of the main applications of vehicle location systems. In the context of the current research, the main concern is fleet management by a public entity, be it an emergency dispatching center or a local transit agency, as well as a broader and general approach to creating an integrated traffic management center where individual modal information converges and is then disseminated.

Primarily, an AVL system is composed of a method for determining the position of a vehicle and a processor that is capable of storing and analyzing the information provided by time and location. Information processing can be done on the vehicle or at a facility outside the system. For example, current route guidance systems use in-vehicle computing capabilities to determine the exact location and provide the necessary results. Transit agencies, on the contrary, tend to receive the location information on a central control unit where all the data processing takes place and judgment is used to instruct the driver on any pertinent actions to take. Therefore, these agencies need a means of communicating between the vehicle and the control center or dispatcher on real time to maximize the benefits of an AVL system. Most transit and emergency dispatch properties do own two way radio systems in which the operator and the dispatcher can interact adequately. Nevertheless, it is possible to have decentralized decision making processes that empower drivers to make decisions regarding their performance. This decentralization process is enabled by providing the vehicle location information on a screen display in the driver's cabin.

Following a categorization done by the Federal Transit Administration (23) and furthered by Lam (24), vehicle location technologies can be studied according to where and how the location process occurs: in-vehicle, identification-based or radio-based.

Vehicle Based Technologies

Vehicle-based technologies were the first type of technologies deployed for vehicle location. An odometer, for example, monitors the axle rotation of the vehicle to measure the distance traveled. For more accuracy, transit vehicles have two or more odometers providing different observations that can yield and adjusted general measure, therefore increasing accuracy. The odometer reading may be complemented with a timer elapsing the time between readings. Afterwards, the times and distances traveled by the vehicle can be analyzed.

Odometer technologies are not very accurate and a fairly detailed knowledge of the route of the vehicle is needed. Any unscheduled deviation will yield inaccurate measurements. Although the system is very inexpensive to deploy, the inaccuracy is unacceptable for the transit industry standard's (24).

Another example of vehicle-based technology is deduced reckoning. Dead reckoning, as it is popularly known, is based on compasses varying in degree of sophistication that are deployed inside the vehicle. They serve as a complement to other locating technologies, such as an odometer. Relative to a starting location, the compass helps calculate the new location of the vehicle. Naturally, errors accrued using dead reckoning accumulate over time. However, general accuracy improves to more acceptable levels (24). Accuracy of between 1 and 3 percent of the total distance traveled has been achieved by AVL deployments using dead-reckoning (25).

Identification Based Systems

Identification-based systems use the AVI technology described in the first part of this Chapter. Each vehicle has a transceiver that reads the tags mounted on utility poles. When the tag is read the vehicle relays the tag information and some additional information (e.g., odometer reading) to the central unit where the vehicle's movements across the system are calculated and monitored. This is also known as "passive identification" (24). The location of the transceiver and the tag can also be reversed. That is, the vehicle can have the tag on its side or windshield and the post has the transceiver. Information is also relayed then to the control center mainly through landlines that provide an economical alternative to crowded radio bands and expensive cellular bands. The main limitation of this system is the physical constraint of having to use signposts to hold the tag or the transceiver, as well as the discrete monitoring of the vehicles, as opposed to continuous monitoring. In addition, the vehicles being monitored should use the same route always. Any deviation from the scheduled route leads to insufficient data.

Radio Frequency Based Systems

Systems based on radio frequencies vary in sophistication and costs. Global Positioning Systems (GPS) use at least three satellites provided by the U.S. Department of Defense. A mathematical procedure called trilateration is developed to locate the vehicle. Each vehicle has an on-board unit that receives the signal from each satellite in the 1-2GHz band and corrects it for the different times of reception. Accuracy and reliability are a concern for GPS systems. Early results have shown accuracy of between 50 and 100 meters. Questions regarding the frequency vehicles should be detected, also called polling, and possible congestion effects in the airwaves are being addressed. The military has decided to deploy selective availability in their satellites, meaning that the satellites are not available 100 percent of the time for every vehicle, but on certain specific instants per a given unit of time (22). Furthermore, the system is also using scrambled signals to discourage its unauthorized and inappropriate use.

To improve accuracy, differential GPS, or DGPS, is being developed by the research community. DGPS uses a stationary point of known location that also receives the signals from the satellites. By doing this, the necessary corrections are made to the measurements. DGPS improves accuracy to 5 to 10 meters.

Both GPS and DGPS are fairly new technologies that are probably going to improve in the future. In the specific urban scenario, two additional problems are germane to satellite systems: urban geography and radio frequency availability. Major urban centers worldwide have high-rise buildings, highway underpasses and tunnels. These objects can "hide" the vehicle from the satellite and communication is lost partially. Also, the limited number of radio frequencies available in some cities has also restricted the polling strategy. Some transit agencies have decided to use "exception reporting" which means that a vehicle reports only when it is behind schedule. Otherwise, it is assumed that the vehicle is on schedule (22).

Another system based on radio frequency technology is the Long Range Aid to Navigation (LORAN-C) system. Instead of using satellites, the LORAN-C system uses land-based antennas. It uses low frequency[1] waves to gain good coverage. However, LORAN-C systems are highly susceptible to electromagnetic interference as well as the urban geography. For example, it has been established that the inside lights used in most transit buses considerably affect systems using LORAL-C technology, as well as high voltage electric wires.

Naturally, these technologies can be combined with each other to achieve improved and acceptable levels of accuracy. For example, the signpost/odometer mix is the most common AVL application found in transit agencies. Similarly, GPS and sophisticated gyroscopes are gaining significant market share in police departments, emergency vehicle dispatch centers and paratransit operations. AVL can also be integrated with other existing technologies such as automatic passenger counters (APC) and electronic fareboxes. Although possible, integration of these technologies is not an easy task. However, from a monitoring and planning perspective, integration of these systems seems inevitable because the information provided by them can be strategically complemented with each other.

There is heterogeneity not only in the way a vehicle is located, but also in the manipulation and transfer of the information from the vehicle to a control center, if needed. Wireless technologies are concerned with wave saturation due to more applications developing in a limited bandwidth and the related increased cost. In addition, most transit agencies have channels dedicated to voice communications that implies a

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[1] Low frequency waves proved good coverage but are easily corruptible. High frequency waves - microwaves- are directed toward specific ranges but are very robust in integrity.

significant underutilization of the capacity of the frequency. Polling was mentioned before as a strategy of transit agencies to utilize scarce frequencies more efficiently.

Communication by land lines is not affected by the atmosphere or by the electromagnetic fields commonly encountered. Furthermore, it is the most reliable communication media in terms of data integrity (24). The main disadvantage is the lack of flexibility and mobility it has, since it is fixed to the infrastructure.. However it can be used in the fixed portions of the system such as poles and signposts or stations.

Radio frequencies are the most popular media for wireless communications. The frequency at which a transmitter must operate determines if it is regulated by the FCC or not. Generally, lower frequencies are not subject to FCC licensing, as is the case with proximity smart cards. The most popular type of transmission of AVL has been through modulated frequency (FM). It is vulnerable to atmospheric and local geographical conditions, as well as to the number of relays and processes involved that add unwanted interference to the communication. The FCC has constrained the transmission rate in the 40 to 512Mhz range to 3600 bits per second, therefore limiting the polling strategy, whereas frequencies above 512 MHz can transmit at higher speeds (24). A temporary solution has been the appearance of digital radios, where the wave is converted into binary format thus reducing the effects of interference.

Microwaves consist of waves transmitted at high frequencies, thereby being more reliable, but entailing higher costs. Microwaves transmit over smaller areas than RF signals because its signal breaks in the atmosphere rather than bouncing. Also, higher frequency waves need almost direct line-of-sight to achieve adequate performance and reach the desired target (20). The size of the antenna and the polling frequency also vary using microwaves. Antenna sizes decrease and polling frequencies increase with the use of microwaves.

Cellular technologies are now widely available in the main metropolitan areas of the United States. The bandwidth is divided into small cells, therefore noticeably increasing the capacity of the frequency. Several packs of information are carried in the same bandwidth by adjacent cells (24). When a vehicle leaves the area covered by the low powered antenna, the system seamlessly transfers the user to a cell controlled by another antenna. Cellular systems have been now fully tested to carry data without major concern for its integrity. The major drawback for a transit agency is the considerable cost associated with its use.

Another aspect of the potential deployment of AVL systems is the need for adequate human resources that may support the deployment of the system. Innovative techniques need not only upper management commitment but an adequate cascading of the will and the concepts to every level of the organization.

In summary, the processes and equipment needed for deploying and AVL system are (after [24]):

- Location System (AVL)
- Communication Systems
- Vehicle Maintenance System
- Central Computer For Both Real and Non-Real Time Calculations and Simulations.
- Dispatcher and Driver training

Optional systems that can be integrated with additional gains are:

- Driver and Dispatcher Interface and Systems

Related to Transit Operations:

- Automatic Passenger Counter
- Passenger Information Systems
- Additional Software that Can Assist In Planning and Scheduling

B. Recent Progress and Outlook

AUTOMATIC VEHICLE IDENTIFICATION (AVI)

Recently there has been considerable development of a third type of microwave tag, called a type III or "smart transponder". The type III system integrates smart card technology to vehicle identification. In such a system, the tag is a small reader with a removable smartcard that can be used on other applications. The reader device is about the size of a radar detector or a calculator and is mounted on the dashboard of the car. The device includes a signal receiver/transmitter, power supply, and the card reading unit. It can also include an LCD display and connecting port for other electronic devices, creating a modular platform that can be upgraded easily. Figure 6.1 shows the electronic components of a smart card reader

There are many advantages to using smart card technology for ETC. The sophisticated technology offers separate file systems that can allow multiple toll levels. Furthermore, the smartcard can be utilized in multiple non-transportation related applications. In addition, the card in the reader belongs to the driver, not the vehicle. Hence, this distinction could help authorities in the enforcement of traffic violations. Also, since the transactions occur in the vehicle's own OBU rather that at the toll station the transaction is completed at a faster speed. Finally, the capability to re-program the card reader reduces the risk of obsolesce for the equipment that helps make the equipment more cost efficient.

It is also important to mention new developments in the implementation of modulated backscatter transceiver technology. The backscatter method can be used as the method of transmission to the roadside antenna regardless of the type of tag selected. It offers several advantages over fixed frequency systems. For example, there is a reduction of noise interference possibilities. The roadside equipment that is used in this method is set up to verify the signal received from the vehicle and to compare it to the signal originally sent. Therefore, data integrity is well preserved with modulated backscatter.

An interesting development in AVI in the near future is the establishment of standards in the US. These standards will determine where the direction of the market and the participating vendors. In addition, the results of a National Architecture will have significant effects on vehicle identification systems. Modular, high-tech applications, such as the type III tags, will hopefully be in position to develop further and bring more convenience and benefits to the user and the system.

AUTOMATIC VEHICLE LOCATION (AVL)

There are several trends that will continue over the next decade related to automatic vehicle location. Developments in the way the vehicle is located and how the data is transmitted are envisioned. In location technologies, it is believed that Global Positioning Systems will settle as the dominant force as more vendors enter the market and new systems that improve accuracy are developed. New locating technologies will continue to emerge and will pose as competitors to existing technologies, while older systems will become accuracy supplements of the new systems[2].

The use of dedicated frequencies to voice-only transmissions will tend to disappear. Major cities and municipalities under financial distress will recognize the revenue potential of auctioning certain airwave frequencies that are currently underutilized. Therefore, AVL systems developed in a modular fashion will permit future adaptation to new frequency requirements.

The agencies that have deployed vehicle location systems will realize the need for supplementing their real-time capabilities with improved off-line analysis. As a result of this policy, agencies will tend to integrate passenger counters, electronic fareboxes, vehicle monitoring and vehicle location in a system providing the data analysis capability needed for planning and scheduling. Improvement of the operating plans will be likely as a result of the additional information provided by the whole system. Furthermore, AVL's role of positive integrator of transit with traffic management centers and information systems will be heightened as these initiatives are pursued after an architecture is defined and after ISTEA is reconsidered by Congress in 1997.

[2] An example of such development is the Radio Determination Satellite Service (RDSS) which consists of a variant of GPS. A satellite sends an interrogation to the vehicle which responds. The response is captured by (at least) two other satellites and then sent to directly to a control center where the location is calculated.

C. Standards Development

AUTOMATIC VEHICLE IDENTIFICATION

As AVI systems become more prevalent the need for standardization of technologies becomes an issue. The goal of standardization is to make AVI systems compatible or at least interoperable, and in a broader framework, to integrate ITS applications by a common thread. Lack of industry standards can hurt the development of technologies geared towards intermodalism.

ITS AMERICA is working on developing standards for vehicle identification applications in the United States. Table 6.2. illustrates the technical specifications of various vehicle identification vendors. Also, the European standards from the Vehicle Information and Transactions Aid (VITA) program are outlined and compared with the ITS Draft recommended standards. In terms of the frequencies utilized, US vendor's systems tend to stay close to the 900 to 930 MHz range allocated for industrial scientific and experimental use (19), while the Europeans have chosen to work with microwaves, using the 5.8GHz frequency. ITS Draft standards are not suggested yet, since a decision of the FCC on the allocated frequency is expected soon.

Vendors tend to provide higher data rates for transactions than what it is required. However, the data for vendors was drawn from trade brochures. Therefore, adequate tests are required to verify the accuracy of the numbers reported. The ITS Draft from the Standards Committee recommends 550 Kpbs compared to European standards of 250 Kpbs.

In terms of communication methods for uplinks (the signal from the vehicle to the toll station) most vendors use passive-backscatter methods. Both ITS AMERICA and VITA standards offer the flexibility of both active and passive methods. The main differences between the standards in Europe and the current specifications of vendors are the way the backscatter tags are identified. VITA requires Differential Phase-Shift Key (DPSK), meaning that the tag returns the signal to the transceiver on a different phase. Most vendors in US and Europe provide Frequency Shift Key (FSK) as a method of identifying a backscatter tag. In this case, the frequency and not the phase is shifted by the tag. The ultimate word on the standards will be given in the regulatory realm. Systems that have already deployed AVI-based applications should pay close attention to these developments.

AUTOMATIC VEHICLE LOCATION

Automatic Vehicle Location technologies have also developed without specific standards guiding the innovation process. In terms of data handling and processing within a computing network, AVL technologies are obviously subject to the computer industry standards. However, in terms of the pure technology, most of the issues regarding AVI also apply to AVL. The definition of a system architecture for the United Stated will be the first step to setting adequate standards. The Federal Communications Commission is working closely with vehicle identification and location systems vendors to come up with those standards based on the architecture developed and on the market developments elsewhere in the world.

D. Current Transportation Applications

1. Electronic Toll Collection

Electronic Toll Collection (ETC) is the ability to conduct toll transactions without "physical" contact between the driver and the toll station. All of the various AVI technologies explained above are currently available for ETC. RF/ Microwave technologies are the most prevalent in the marketplace.

a. Transaction Process Description and Specification.

Toll systems can be arranged in two different ways: open and closed systems. In an open system all vehicles under the same classification (i.e., two, three, four or five axles) pay the same toll level regardless of their point of entry or departure from the road. A closed toll system is where the toll level is dependent on the distance between the entry and exit gates. A type II transponder is needed for the implementation of closed toll systems. Type II tags allow the toll gate equipment to write such data as time, date, and toll gate ID in the tag's memory. The new account balance can also be written into the tag after the transaction is processed at the exit gate (26). Because type II tags have this ability, they are the tags used when the method of payment is a debit card.

Besides the fact that type II tags can be used in open and closed systems, there are two other main advantages. First, there is greater speed in the payment transaction, because of higher data rates and because the balance information is immediately accessible to the system. There is also the possibility of greater driver privacy when a debit card payment method is used. The transaction with a type II card may not require any personal information to be read from the card besides the account balances.

b. Cost Associated With Deployment

Deployment of ETC systems can offer significant reductions in construction, maintenance and operating costs. However there are many factors that determine the magnitude of these savings, as shown in Table 6.4. The equipment costs of both AVI dedicated and express AVI lanes is under one third of the costs for manual or automatic gates. However, most toll plazas are set up as a combination of manual and automatic lanes. Hence, the cost of these combined lanes is closer to *seven* times the cost of AVI-only lanes. In contrast, the cost of lanes with combination AVI and manual or AVI and automatic are slightly higher than manual or automatic only. This indicates that combining AVI with other payment methods does not increase capital costs significantly and therefore it may be desirable to include as few lanes for manual toll collecting as a possibility. However, this analysis disregards the implications of such a scheme on operating costs.

It is in terms of operating and maintenance costs the advantage of AVI is most apparent. These costs for manual lanes are about 33 times greater than AVI dedicated and express lanes. The costs of any lanes containing manual capabilities are all in the high range mainly due to labor costs. Automatic lanes and combinations of automatic and AVI lanes offer more manageable costs.

In practice, the need for some manual lanes should not be completely avoided. Although ideally the most cost effective setup would be AVI-only lanes, not every driver will be wanting or able to use AVI technology. Depending on the size of the toll plaza, the best approach may be to reduce manual-only or manual combination lanes to a minimum and make the rest of the lanes either automatic, AVI-only, or a combination of the two. In practice this is very hard to accomplish since fare evasion is a significant constraint. There needs to be some overlap of automatic and AVI lanes in order to make the toll plaza more flexible in responding to traffic needs by switching the dedication of the lanes depending on particular circumstances.

c. Qualitative Benefits and Deployment Considerations

The benefits of ETC can be summarized as follows (after [18,19,26,27])

- Convenience to the driver. ETC offers each driver a reduction in travel time as well as new payment options for toll charges which may be more convenient.

- Congestion relief. ETC could offer relief of traffic congestion by reducing transaction times. This benefit is not only good for each individual driver (as noted above), but to society as a whole. Each individual being expedited by an ETC system is also reducing delays he or she was imposing before on other drivers. Hence, the marginal benefits of ETC are greater than the ones perceived by each driver. In average terms (i.e., the perception of each vehicle operator) there is cost savings by reductions in travel time, fuel consumption and vehicle wear and tear. Therefore, in order to move towards a social economic optimum, there should be lanes dedicated exclusively to AVI, enabling nonstop payments and congestion mitigation.

- Environmental benefits are also accrued in the form of reductions of harmful vehicle emissions. Vehicles release heavy pollutants when they are not traveling at semi-constant speeds (27).

- The technology used by ETC may enable the development of other ITS advanced applications. When the use of this technology is combined with other applications, such as dynamic route guidance (with a Type III transponder), more reliable travel information can be provided to the commuter. This information may also assist highway and transportation authorities in determining the congestion state in the field, and agrees with the possibility of having a centralized traffic information center.

- Since the vehicle does not stop at the booth, added security for the driver may be provided, particularly in unsafe urban areas or isolated rural areas.

- As noted previously, ETC systems can significantly reduce the operating costs at toll plazas.

- From the point of view of the consumer, ETC can become an integral part of a multimodal transportation system. As new technologies develop, ETC will become a single part in a coherent ITS program. Consumers will be able to enjoy the convenience of

ETC as part of a comprehensive, user friendly , system that is interoperable and offers different degrees of sophistication.

Legal issues

The two most cited legal issues in the literature are user privacy and the enforcement of fines for toll violations. The issue of privacy is related to the possible uses and misuses of the information obtained from the car's OBU. It has as much to do with the legal implications of actual misuse, as with finding ways to alleviate the public's perception of the risk they are entailing by using this technology. Most vehicle's OBUs contain personal information about the driver that may be known by the system at the time of a transaction, depending on the design of the application. Most people agree that the possibility of using tags to reduce and gauge traffic congestion is a benefit to the public, but driver anonymity has to be maintained. The question is, how can this information be purged from the toll collection processors once the transaction has been accepted.

There are ways to protect the driver that need to be considered when choosing an ETC system. Systems using a prepaid balance can eliminate the need to transmit unnecessary personal information. In general, several of the case studies showed that privacy was not a major concern for the user's of an ETC system. Furthermore, it could be argued that privacy is not a concern only of ETC, but pertains to a whole range of other applications including communications, credit card purchases and the like, and should be dealt with in that realm.

The other major legal concern is the management of toll violations. Most ETC systems respond to toll violations by taking video images of the delinquent vehicle and using the vehicle's license plate to identify the responsible party. However, this only identifies the car owner but not the actual driver. Unfortunately, in many states, traffic violation tickets can only be issued to the driver of a vehicle and not to its owner. Therefore, new approaches, such as regulatory reform, to solving this problem need to be addressed in specific studies assessing deployment options.

Implementation issues

There are many issues to take into account when choosing between the available technologies. The issues of accuracy and reliability go hand in hand. The reliability of the toll system is mainly dependent on the accuracy of the communication between the vehicle and the roadside equipment. There is little worry about the data processing aspect of the toll transaction because it is generally conducted by standard computer systems. This is the main reason why, in spite of the attractiveness of their low costs, optical systems are not a good alternative. The accuracy of the reading suffers greatly under poor weather conditions.

RF/ Microwave systems have proven to be accurate under severe weather conditions, great distances and high speeds. There are some problems with interference from electronic devices and metal canopies, but these concerns can be addressed in the field by reorienting antennas and arranging the components in a different fashion. It is because of the high level of accuracy and reliability that RF/ Microwave systems are the most common systems and the basis for standardization efforts.

Another set of concerns deals with the "user friendliness" of the chosen technology. Following are a set of questions that may be asked from the consumer's point of view.

- Is the system complicated to use?
- Are different tags required for different highways?
- Can the same tag be used for other applications (e.g. parking, transit, banking)?
- What is the cost of the equipment for the consumer?
- Will it really help save time?
- How convenient are the methods of payment?
- Will driver privacy be compromised because of electronic identification?

There are different billing alternatives for an ETC system. The two main approaches are pre-payment and post-payment. Pre-payment seems to be the most widely deployed option overall, and can be arranged in different ways. The user can set up an account with the agency in charge of toll collection just for this purpose. The user keeps a positive balance on the account by cash, credit card or check payment. This method can be used regardless of the type of tag, since all tags have the ability to carry an account number. At the time of the transaction, the toll computer would use that account number to access the account and make the appropriate deduction.

With the use of Type II tags, pre-payment can also be as simple as using a fixed balance debit card similar to the prepaid telephone cards. In these tags, the account balance is read from the card and the new balance is written in the card's memory after the transaction takes place. However, a potential problem with pre-payment is that the user would need to keep separate balances, either in accounts or cards, for each road system he or she uses. This drawback is eliminated with the use of type III tags in which multiple applications are seamlessly enabled.

With post-payment, the user would only pay for the actual use of toll roads rather than having a debit account balance. The possibility of delinquency for post-payment is much greater because the driver could default on the payment, unless credit and checking accounts are used. This topic is discussed in detail in the San Juan application.

There are other issues that are specifically relevant to the implementation of a particular site. The most important is the problem of lane dedication. In order to help ETC to fulfill its potential of reducing congestion, it is imperative that the physical structure of toll plazas be designed to take full advantage of its features. Another design consideration is the number of lanes before and after the toll gates. Toll plazas tend to have several lanes. A situation where the number of lanes is significantly reduced after passing the collection gate may create a bottleneck effect if flows are large. This problem may also defeat the purpose of ETC because any time saved in the toll transaction is lost again in the congestion at the bottleneck.

Finally, adequate signeage is also essential in making sure that drivers take full advantage of ETC. This issue is closely related to the user friendliness of the system. Signs are important specially if the system includes a mixture of ETC-dedicated and combined lanes which may vary according to the time of day. Signeage is also crucial if there are price variations such as special rates for ETC users or if congestion pricing is implemented.

d. United States Deployment Sites

More than twenty of the approximately 55 toll agencies in the United States have deployed some form of ETTM. Ten other agencies are seriously considering its implementation (29). There are more than 500,000 tags being used for electronic toll collection in the U.S. only .The following review of several deployments scenarios includes radio frequency, microwave, bar code and GPS type of systems. As explained previously, radio frequency and microwave systems are more suitable for future ETC applications than bar code systems. However, it seemed appropriate to include bar code systems because they have been deployed with some degree of success in several agencies in the United States. Tables 6.5 and 6.6 at the end of the chapter summarize the RF systems information in the U.S..

Bar Code Systems

Information on the deployment of bar code systems is very limited because the number of sites is small and decreasing in size. For example, the Nassau County Bridge Authority has considered retrofitting their system to a different technology. The Delaware River Port Authority serves as an example of successful bar code technology deployment. It owns and operates four bridges on the Philadelphia metropolitan area. The technology is being provided by Lazerdata, which estimates that AVI patronage on all of the four bridges accounts for almost 30 percent of the traffic (19).

Some bridges in Florida, such as the Sanibel Causeway & Cape Coral Bridge and Broad Causeway also use bar code readers in a single direction. Speeds of vehicles approaching the booths are low, around 6 and 7 mph, so that the system can operate within the given specifications.

GPS-Based Systems

The ROBIN toll collection system has been deployed at a very small scale in Spain and France. However, the German Federal Ministry of Transportation (Bundesministerium für Verkehr, or BMV) is currently testing several ETC technologies, including ROBIN. Thirty vehicles have been equipped with the on-board units and the software necessary to correct the variance in location given by GPS systems. The trials are testing multilane free-flow systems, with variable weather and traffic conditions on a highway between Bonn and Cologne, and will be running until May of 1995 (30). Due to the nature of GPS locating systems ROBIN may not be succesfully deployed as a road-specific toll collection system in dense networks, such as the downtown area of large cities. However, ROBIN enables zone tolling, instead of road-specific tolling. Zone tolling is one of the congestion pricing strategies that charges a fee to automobiles for gaining access to congested areas of a city.

The BMV has also issued several prerequisites that should be guiding requirements for future ETC deployment. The guidelines are summarized as follows (30).

- Flow of vehicles should be uninterrupted
- The system should be fully upgradable and adaptable to new technologies.
- Transactions should be seamless to patrons, and easy to follow in monthly reports.
- Costs should be kept low for users and taxpayers
- Privacy protection is imperative

Other issues not included in the recommendations of the BMV but also deemed important are:

- Interoperability of systems for a given area of coverage is necessary
- Ease of system operation and management. This would enable smoother interagency cooperation efforts.

Radio Frequency and Microwave Systems

Harris County Toll Roads, Texas

Harris County operates 135 toll lanes, 69 of which were upgraded in 1992 to provide electronic toll collection (31). The system has 5 plazas interfacing with a central host computer where transactions take place and where the data is concentrated and analyzed. The agency has distributed about 30,000 RF tags accounting for 10 percent of the traffic volume (29). The tags are also being used as probes in a traffic monitoring and traveler information test in the Houston metropolitan area. Therefore, tags used in ETC can also aid in attaining ISTEA requirements, such as the development of traffic congestion and traffic management systems.

Oklahoma Turnpike Authority

The Oklahoma Turnpike Authority integrated electronic toll collection to four new and six existing turnpikes, totaling more than 478 miles (19). The products have been very popular among both truck and automobile drivers. The configuration of the system permit PIKEPASS users, as the system is known, to pay tolls electronically at speeds reaching 65 mph. Patrons not using PIKEPASS have to exit the main road to a parallel road where an attendant at a toll booth services them. More than 230,000 RF tags have been distributed, accounting for 36 percent of the daily traffic in the Oklahoma Turnpike System (29).

California Foothills Corridor

The foothills corridor is a three mile road extension that originally used AT&T's contactless smartcard with a fixed transponder in the front windshield of the vehicle. The smartcard could be removed from the transponder and could potentially be used to pay for parking, public telephones, public transportation and be used in vending machines. Approximately 30 percent of daily toll collections were made electronically. Surveys showed that the public was generally satisfied with the service. However, criticism concentrated on the bulkiness of the transponder (32). The AT&T system -tag and transponder- was leased to each customer at $10 per month.

In September of 1994, after confirming that no additional applications that justified the monthly fee were developed, administrators decided to switch from AT&T to MFS

Network Technologies, a subsidiary of Texas Instruments. The reasoning behind the decision was that the system was performing as a type I tag system. A type I tag system has less capital and operating costs, and no leasing fees will be charged to customers. Only between 4,000 and 6,000 smartcards were being used at once time. Merchants argued that it is very hard to tailor applications for such a small customer base.

Similarly, the Foothills corridor administrators wanted to comply with new specifications formulated by Caltrans earlier in 1994. The California Department of Transportation has also awarded several contracts including all nine toll bridges in the State to MFS Netwotk Technologies (29). Therefore, the Foothills decision was also motivated by the integration possibilities of having the same vendor and technology statewide.

New York State Thruway

The New York State Thruway is a member of the EZ-Pass group, an interagency group from New Jersey, New York and Pennsylvania. Initially the Thruway used AMTECH's RF tags, accounting for approximately 45 percent of daily traffic (29). However, strategic planning within the EZ- Pass group led to an unexpected change in technology. Mark IV, a contactless-smartcard based technology is replacing the 70,000 tags in the system. The EZ-Pass group is another interesting example of how agencies can team together to provide regional, and why not national standards, overcoming institutional frictions and barriers.

Florida Turnpike

Florida submitted a request for proposals to develop their SUNPASS system early in 1994. Officials wanted to deploy electronic toll collection in several of their more than 50 toll plazas. The Florida Turnpike extends over 300 miles, having more than 500 toll lanes (31). Currently, portions of the system have ticket-based operations, while others have fully attended booths and automatic coin collectors. Toll collection management and auditing has been fully automated; retrofitting for ETC will cause only minor disruptions.

However, by November of 1994 officials withdrew the RFP awaiting a decision of the FCC regarding the communication standards (33). Specifications for Florida's System call for a frequency of 2.45 GHz, while the FCC wants a 5.8 GHz standard and most U.S. vendors have developed their products for the 920-928 MHz band. Several vendors including Amtech Corp., Delco Corp., Intellitag Products, Mark IV, AT/Comm Inc., MFS Network technologies, Hughes Transportation and Motorola Inc., sent a letter to FCC's chairman Reed Hunt asking him to assign the 900-928 MHz band to ETC (34). Yet, FCC argues that some unlicensed products such as microwave ovens and cordless telephones use frequencies very close to the 900 MHz, severely affecting ETC operations. No final decision has been taken at the time of this writing.

The previous discussion illustrates the volatility of the ETC market. There is a significant need for an architecture and the consequent development of standards. Agencies evaluating ETC potential in their domain should be aware of the functional specifications of the desired system, as well as the market limitations and risks of not having a guiding standard. Nonetheless, there are ways to safeguard an agency from these risks, such as leasing the equipment from the vendor rather than buying it. Although at the end a higher price may be paid, risk aversion of state agencies may suggest leasing as a better possibility.

Dallas North Tollway

The Texas Turnpike Authority has reported that the ETC system deployed accounts for the equivalent of two additional lanes of traffic during peak periods (35). 71,000 type I tags are circulating, accounting for 38 percent of daily transactions, but over 50 percent during peak commuting hours. The system uses AMTECH's RF technology, and has been deployed since September 1989.

e. International Deployment Sites

Electronic toll collection has gained significant momentum in the international arena. There are numerous deployment projects in almost every continent. Several of those projects constituting representative examples of deployment options and specifications criteria are presented hereafter.

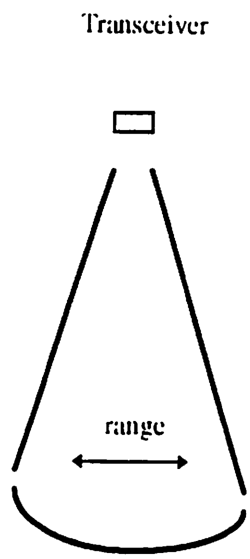
Sydney Harbour Bridge, Australia

A group of three adjacent toll booths were selected in 1994 as a pilot project for the deployment of ETC systems in Australia. The bridge collects tolls 24 hours a day from approximately 106,000 vehicles on only one direction (35). Previous to the ETC experiment, two lanes were manual toll collection booths with ushers, and four where served by automatic coin collector machines. It was required that the new system work in parallel with the existing system, therefore initially providing mixed use of AVI and non-AVI traffic on the chosen lanes. Additionally, a violation enforcement system consisting of cameras and a computer interface was provided by the new system. Before, there were no exit gates at the automatic machines or any other enforcement mechanism to reduce fare evasion.

Three principal specifications of the request for proposal were:

- Response rate from tag data has to be less tan 40 msecs.
- A monitoring feature used to determine the quality of the readings to determine future adjustments should be implemented.
- Adequate detection zones or ranges for various vehicle types.

The ETC system uses radio frequency modulated backscatter techniques at 921 MHz as the primary technology, using a type I tag. Although the tags successfully read at the 20 mph specification speed for the bridge, much higher speeds could be achieved with this system. The first two specifications where achieved without great concern. For the third specification, initial trials showed that the physical existence of booths and a the metallic canopy over the booths caused interference and increased the variability of the reading range for the tags. More predictable results would be obtained if no structures or metalwork caused reflection (35). For larger vehicles, tags were mounted on the bottom end of the windshield as opposed to one of the upper corners because the reading range decreases as the transceiver get closer to the tag (see next Figure), thus, the specification was also attained.



Buenos Aires, Argentina

Most of the highways leading to Buenos Aires are choked with traffic. A 15 mile commute would normally take more than one hour. Following the privatization wave, the government of Argentina has granted a concession agreement to Coviares S.A., a consortium of the largest construction firms in Argentina, to design, build and operate new highways in the area.

Coviaries is building a toll road on a 16 mile portion of the La Plata to Buenos-Aires highway (36).The system being built includes 46 lanes on three tolls plazas, including several AVI lanes. The type II contactless smartcards being deployed can be potentially linked with variable message signs along the route. Similarly, the smartcards can be used in other applications such as transit and parking payment media.

France

On May, 1992, 8 lanes on the Satolas-Chenes highway were converted to an electronic toll collection system. The open system is integrated with automatic coin machines, using a SAAB/PREMID type II card on the 5.8 GHz frequency. By June of 1993, there were 1,500 frequent users and an overall error rate of 5 per 100,000 transactions, which complies with the actual requirement of less than 10 per 100,000 transactions (37).

The identity of the tag is read once it enters the reading range. The information is compared with a blacklist and then posted back to the card to enable follow-up in case of any misreadings. The system deployed is open and takes advantage of a type II card (read-write).

In April 1993 the St-Quentin-Villefontaine-Isle D'abeau Est highway installed a closed system to manage and operate 12 lanes of electronic toll collection. Currently the system issues monthly passes to subscriptors that can go through the lanes unlimited number of times. However, by June 1995 an account debiting function will be operating. The present level of tag users is around 8,000.

In July 1994, SAAB-Combitech will deploy 35,000 tags in replacement of magnetic cards used for toll payment in the Lyon, Albertville and Grenoble area. The system will be installed in all toll plazas, accounting for approximately 115 AVI lanes on a various numbers of autoroutes (A41, A43, A48, A49 and A430) (37).

ADEPT Project

As mentioned in the smart card section of the report, the European Community has appropriated research funds for ADEPT, under the DRIVE-Advanced Transport Telemmatics initiative. Automatic Debiting and Electronic Payment for Transport (ADEPT) has applied a longer range perspective to its analysis of electronic toll collection systems, no different from the EZ-Pass group in the United States. General ETC applications worldwide concentrate on reading the tag and centrally debiting the account. Nevertheless, ADEPT has recognized the possibility of integration of fare payment media for transport and other applications, as well as the need for information.

ADEPT has developed a modular approach that enables the user to have equipment of the appropriate degree of sophistication for the desired applications. It could be a simple ETC tag, or it may potentially convey parking and traffic information. The

ADEPT initiative focuses on beacons with microwave links (MW) as opposed to the popular RF communication links. The MW link provides the means for reading at higher speeds (up to 90 mph) than the regular RF link (38).

Naturally, the ADEPT proposal is being tested in different deployment scenarios in Göteborg (Sweden), Cambridge (UK), Thessaloniki (Greece) and Lisbon (Portugal). The Lisbon initiative will include parking payment strategies and en-route reservations of parking spaces. The deployment in Cambridge is a demonstration of congestion pricing. A pre-defined cordon of the city is surrounded by microwave beams that turn the vehicle's equipment on and off if the auto is entering or leaving the area, respectively. After a certain period of time, if the vehicle has not left the area a fee is charged. The underlying principle is that if a vehicle encounters congestion, it is also contributing to it, imposing costs to other vehicles too (38).

According to Blythe and Hills, members of the Operations Research Group in charge of the ADEPT project, the main problems encountered in the deployment of their initiative are enforcement, operational and legal issues involving integrated payment. As in most ITS proposals, the technology has been developed but institutional and the human factors hinder their deployment.

Milan, Italy

The TELEPASS system developed by Autostrade has been deployed in the north of Milan. TELEPASS serves both as an open and closed system. It uses sensors to classify the vehicles as the approach the toll plaza, and uses photographs of the plates of violating vehicles to enforce toll payment. Currently, about 15,000 daily transactions , or 20% of the total number of transactions, are registered by the TELEPASS system (29).

f. Implementation in the San Juan Metropolitan Area

Electronic toll collection is one of the early successes of new technologies applied to transportation. Success stories are not limited to the United States; Europe, Asia and Latin America have achieved good results with similar deployments. Given the local political will and the financial means, ETC becomes a prime candidate in the effort to increase mobility and improve the overall level of service of the transportation system.

Therefore, it is judicious to study the possible application of ETC in the San Juan context. The motivation is heightened by the fact that there are two major highways within the metropolitan area with significant traffic congestion at the toll plazas during peak hours.

The José de Diego Expressway (PR-22) coming from the West is experiencing the highest levels of congestion, particularly during peak periods. Two toll plazas on PR-22 are located within the San Juan Metropolitan Area. The Luis A. Ferré Highway (PR-52) coming from the South has two stations on the outskirts of the SJMA. Naturally, these two highways are potential candidates for ETC implementation. However, given the importance of market penetration for the success of ETC, it is suggested that the implementation should go far beyond the metropolitan area. It should only include all the toll plazas in the SJMA and other existing and planned tolled facilities in the Island, such as the new PR-53 on the Eastern side and the planned PR-66 which will increase accesability to the core of the SJMA . These highways are (or will be) tolled facilities. Hence, the user can perceive ETC as an expeditor of flows, as opposed to a technology that introduces more taxes on every highway that previously perceived as "free". Besides, the political costs of tolling a previous "free" facility are extremley high. Therefore, a broad deployment beyond the core metropolitan area is reasonable. Additionally, the costs associated with developing the system are leveraged among more toll plazas; hence, economies of scale may be reached.

Toll facilities in Puerto Rico have changed significantly during the last two years. Fares were collected automatically by coin machines and manually at attended booths. Before 1993, fare evasion was a critical problem because there was no reliable toll enforcement mechanism. As a result, exit gates at each toll booth were installed, increasing the service time per transaction. Therefore, the continued growth in auto ownership and trip-making, added to the increase in service times generated significant delays at the plazas.

Acting upon the increasing delays, ushers were hired to service every automatic booth to expedite the transaction process. The scheme effectively decreased congestion, proving the hypothesis that drivers did not have the fare ready when they approached the coin machine. Having a person standing next to the machine served as an instrument to decrease the service times. Nevertheless, backups of more than one mile are continuously reported during the peak hours at some of the plazas.

In addition, video surveillance to control fare evasion was implemented at selected sites. Unfortunately, the enforcement has been limited due to legal and institutonal constraints. However, evasion was reduced signficantly by the joint implementation of the gates and the video monitoring system.

The San José Lagoon crossing is also tolled. The recently constructed T. Moscoso bridge shortens travel times to and from the airport. It is located in the core of the metropolitan area. No congestion effects are currently being experienced on the toll plazas accessing bridge. The bridge has provided electronic toll collection using type I tags supplied by Amtech. Until recently, cash, credit card, ATM cards and AVI were operational in the same lane and exit gates at each booth controlled the vehicle flow. Therefore, transaction times did not decrease and no environmental benefits were realized by having the ETC system.

Nowadays, there is a dedicated lane for AVI and credit card operations with a gated exit. Hence, the benefits are still unrealized. The private operator of the bridge purchased the tags and require a $40 security deposit when they are installed in the user's car. A unique feature of this AVI deployment is that the tags do not have stored cash values. The user provides his or her bank checking account number and a major credit card and the operator is in charge of debiting the card or withdrawing from the bank account every two or four weeks depending on the option chosen by the user. Privacy has not been an issue in this program, even though the toll collecting firm has access to important financial information of the users.

If electronic toll collection is deployed without exit gates, most of the potential benefits can be realized. Reduction in transaction times achieved by enabling the vehicles to be charged without stopping at the toll booth can ease the congestion problem at the plazas. Also, improvements in both vehicle wear and tear and environmental benefits may be expected.

Deployment of ETC does not imply a necessary reduction in congestion and traffic delays at the toll plazas, or anywhere for that matter. Particularly, the toll plazas in the metropolitan area may be subject to decreases in congestion that will be generated elsewhere. If the system has consecutive bottlenecks, removing the first one will only increase the problems in the second bottleneck.

PR-52 Northbound does not seem to have the consecutive bottleneck problem because the Caguas Norte toll station is almost 20 miles away from the core of the SJMA. Also, the actual level of 38,000 daily transactions in the SJMA direction indicate substantial but not critical flows. Then, flows through the Caguas Norte toll plaza would tend to disperse towards the multiple nuclei North (Río Piedras-Old San Juan), West (Bayamón) and East (Carolina) using different routes.

On the contrary, the De Diego Expressway inbound does seem to have a problem with consecutive bottlenecks. The Buchanan toll plaza is located within Bayamón, at the heart of the SJMA, having flows of around 40,000 vehicles per day. The expressway merges with PR-52 less than three miles downstream and becomes a necessary route to access other nuclei of the city. Furthermore, when the two highways merge they become the only access and egress means to and from Old San Juan and Santurce. Therefore, it is argued that delays at the Buchanan toll plaza should be kept at a suboptimal level so that no major congestion effects downstream or any backspill to the local street network be generated. This does not mean that the current level of congestion is adequate. Further research can use observed OD flows and test the hypothesis presented here.

Potential reductions in congestion are also dependent on the market penetration of the system. It is assumed that no increase in the number of lanes per toll plaza is being considered. Therefore, one lane of regular service is sacrificed for one lane having ETC. As a rule of thumb, an ETC can service about twice as many cars per unit of time as a congested toll plaza, such as the ones found in the SJMA. This assumption is consistent with the information provided by the ACT with respect to cars serviced during the peak hour. At Buchanan, for example, around 570 car per lane per hour are serviced. This implies a service time of 6.3 seconds per car. It is safe to assume therefore that ETC can achieve a total service time of about 3 seconds per vehicle per lane. Hence, giving up a regular lane for an AVI lane would mean, in terms of service time, gaining an additional lane.

However, the gain of an additional lane is subject to the market penetration of the system. As an extreme example, suppose a regular lane is given up for a ETC lane that no one uses. Then, the net effect of having ETC meant that a lane was lost. By the same token, 100 percent penetration would yield an upperbound in the reduction of delays.

There are two segments of the population for which ETC will become very attractive: current drivers and public transport users and drivers. Current drivers using the highways with ETC will use the system if the cost of having is outweighed by the value of the time saved. Hence, it is more likely that people with higher incomes (i.e., higher value of time) will make use of ETC. Also, drivers using other routes may be attracted to the highway with ETC, inducing additional demand and congestion.

Taxi cabs and público users will benefit as long as the owner of the vehicle arranges for the use of the tag. This is very likely since a reduction in trip times will imply more trips per day, and hence, more revenue. Also, the Public Service Commission or the públicos themselves can arrange for Section 9 funds to be used in subsidizing the acquisition of the tags. The individual user of a público also benefits from the reduced travel times. However, the real benefit is achieved by aggregating the time savings from all the users of a público. Therefore, delays at toll plazas should not be measured on a vehicle basis but on person basis.

According to the different arrangements that can be made to distribute the tags, it is recommended that the agency in charge of operations purchase the tags from a vendor. The ETC market is stabilizing in the US as the national ITS architecture develops further and as the FCC decides upon the bandwidth to be used. Leasing is a viable option when the market is unstable and capital investments may be risky.

However, the agency's decision to purchase the tags should be contextualized. The technology and the architecture to be deployed have to agree with the intent expressed in the ITS Strategic Plan for Deployment in the San Juan Metropolitan Area. A toll collection system that can be easily upgradeable to other user services depending on the customer's wants and needs is a valuable asset. Even if the Moscoso Bridge toll collection system is considered incompatible with the architecture developed by the Strategic Plan, new developments should strengthen compatibility with the Plan.

Tags can be provided at no cost, leased or sold to customers. It is recommended that the agency provides the tags at no addtional cost. This may ensure additional market penetration. Administrative overhead generated by the management of the system can be paid in part by the net revenue generated by the ETC system. Developing a revenue allocation procedure is recommended as soon as the operating agency expands (or is created) to include ETC operations. ETC tends to generate net revenues which need to be allocated within the agency or transferred to other agencies. Net revenues generated by public agencies that are not carefully accounted for may hinder efficiency and productivity.

It is also meaningful to consider the billing alternatives for an ETC system. Thus far, U.S. and European implementations have heavily concentrated on automated debiting of accounts. Given that most of the cards in the market are type I, this system would still be relying heavily on centralized operations. Type II cards can provide improved operating efficiencies. However, there are other billing alternatives that are useful to consider. Cities in parenthesis have implemented the billing option in question.

- Drawing weekly or monthly from checking or credit card accounts according to use (T. Moscoso Bridge)
- End of month payment
- Monthly flat fee (Villefontaine, France)
- Price differentiation with automatic, fully attended and mixed lanes (U.S., Hong Kong)
- Variable pricing strategies between toll plazas. Two-for-one within a given time frame (Trondheim, Norway).

It is recommended that the agency contracts the billing and collecting operations to an outside party. This eases the revenue allocation procedure and solves regulatory concerns about a state agency being a revenue collector from banks and credit card companies. Under the proposed scheme, the individual operator would function in a similar way as the Moscoso Bridge. There is no declining balance, and the credit card company would be in charge of settling the accounts with individuals. Nevertheless, requiring a credit card and/or a bank account may raise some equity and legal questions. Therefore, a third alternative is to request a considerable amount of non-reimbursable cash up-front that is deposited into a bank account linked to the individual. This scheme is not only innovative, but also customer friendly and effective.

Public transportation vehicles, such as públicos, may utilize a flat fee system. Since público routes are (in theory) regulated, a monthly fee becomes an incentive to provide more trips, given the existence of adequate demand. This agrees with the objective of increasing in mobility and the level of service of the transportation system.

The benefits of ETC in Puerto Rico can be measured by the decrease in delay times per person and improvements in vehicle emmissions. Therefore, a rigorous deployment plan should develop specific measures of effectiveness to monitor the relative success of the program. In addition, the current political will should serve as a catalyst for the deployment of electronic toll collection. The system should be anchored in regional, if not national, architecture standards that will provide future technological enhancements and service options.

However, there are some risks associated with a succesful ETC deployment. The success effectively depends on market penetration which in turn may depend on the real benefits accrued. Therefore, consecutive bottlenecks on certain highways should be studied rigurously to obtain a better picture of the potential critical points. Finally, several institutional arrangements and payment methods are discussed to enhance the efficiency of the system. Arrangements to provide incentives for public transportation, such as charging a flat fee, are also discussed.

2. Public Transportation

a. Applications

Automatic Vehicle Location Systems provide information needed to make decisions at different levels of management. The information provided by the system can be used on real-time or it can be stored for later analysis. Ideally, both strategies should be used because both processes yield information that is useful for different purposes within the transportation organization.

The information gathered by an AVL system (on real-time or not) relates to four different categories (24). The first and foremost category is the vehicle location itself. Knowing where the vehicle is, implies information about schedule adherence and headway adherence. The second category is the condition of the vehicle. Vehicle monitoring equipment yields information about the engine systems, ensuring safety and reliability of the service provided. AVL information can also provide information about road conditions, as the third category. Accidents, emergency situations and weather-related emergency can be detected with the AVL system. Finally, the fourth category is related to passenger monitoring and information. Passenger counters can provide information about vehicle loads, boardings and alightings. When combined with the AVL, the information gets to the detail of passenger boardings and alightings per stop, and average passenger wait and vehicle dwell times.

This information is valuable because transit services are inherently unreliable. Variable passenger demand, changing passenger loads, individual operator characteristics and poor supervisory control yields an unreliable service that is both inconvenient to the user and to the transit agency. Having the information readily available decreases the time of implementing a control strategy.

However, simply providing the information to the driver or a supervisor is not enough. Generally, transit agencies have relied on rules of thumb to make decisions. These rules of thumb are based on judgmental decisions that are sometimes inconsistent, based on inadequate information and slow in response. By providing the data, and enabling a software system that may assist in the analysis of the current situation, a supervisor can make better decisions.

The on-line uses of an AVL system are valuable in that they report on the actual conditions of operations. By knowing the conditions the supervisor can provide solutions so that operations will resemble the original operating plan. When the operating plan and schedule are not well developed, real time control strategies lose most of their value and become off-line data gatherers for developing an adequate plan of operations. This suboptimal use of AVL system is possibly generated by earmarked funds for investment in specific technologies, rather than having flexibility in investing in programs that yield the highest incremental benefits for the agency.

As a result of the unreliability of the service, a supervisor can provide different control strategies to try to minimize it. The following real and semi-real time control strategies may be implemented[1].

- Short Turning
- Expressing and Deadheading
- Holding Vehicles - Adjusting Recovery Times at Either Terminus
- Inserting Reserve Vehicles

Finally, real time information about vehicle location can be relayed to passengers in a simple, yet friendly interface. Passenger at stations and at the way-side may be informed about the next vehicle arriving to the stop and the expected time of arrival. It has been widely hypothesized that passengers value knowing their expected wait time over just knowing the vehicle location (40). However, there is no conclusive evidence of how ridership is affected by the provision of this information. Also, incidents in the field and significant delays can also be relayed to an information center. Trip makers would potentially access that information center during the trip planning stages. Hence, accurate information on real time provided by the AVL can assist the user in making an informed

[1] A good description of the control strategies is found in Wilson, Macchi, Fellows and Deckof, Improving Service on the MBTA Green Line Through Better Operations Control. Transportation Research Record 1361.

decision about mode or route choice. This aspect of AVL will be treated in detail in the Passenger Information Systems part of this report.

Off-line uses of AVL are beginning to be explored in the transit community. A study by the Canadian Urban Transportation Association has found that systems that are most successful in using the off-line capabilities of an AVL system had previous strong information systems developed in conjunction with the location system (41). Off-line uses can be categorized by two activities generated from the data:

- Service Design, Operations Planning and Evaluation
- Administrative Information

Service planning activities are related to evaluating and designing services. The planning component is involved with more macroscopic activities about the route, while a second scheduling activity is related to detailed information such as running times and load information. However, both are gathered together in the same category because the information requirements of both processes are very closely related. This information relates to headways, schedule adherence, cycle times, recovery times, speed profiles and boardings and alightings. Therefore, useful performance indicators of the system can be derived from the AVL system without major complications. Further integration with fareboxes can refine the quality of the information to transfer fare types and the like. There is also external information that is helpful on a long-term range, such as demographics, land use patterns, latent demands, origin-destination flows, economic development and similar data, that is critical to the planner's duty.

Performance indicators and other relevant data are very important byproducts of having an AVL system. Management is also concerned with costs, maintenance and overall productivity of the service being provided. Information about payroll, absenteeism, trip cancellations, accidents and other incidents, AVL accuracy and utilization, effectiveness of control strategies and the like, may be particularl valuable. Current transit agencies have mechanisms to record most, if not all, of the above information. However, mainstreaming the information can result in significant work-hours reduction and higher quality of data. According to a Canadian Urban Transportation Association (CUTA) study, few properties are utilizing the data to develop an adequate off-line analysis (41). Fully utilizing AVL technologies becomes a problem of information system design with all its complexities, rather than a transportation and location system issue. Nevertheless, understanding fully the potential of AVL and how it can assist an agency is critical to the decision of deployment.

b. Costs of Deployment According to Technologies

Numerous deployments of vehicle location systems using the signpost-odometer combination and the dead reckoning technique are found worldwide. New technologies, such as GPS, are only starting to be deployed in some agencies. Table 6.7 summarizes the total cost of deploying AVL systems in selected public transport agencies in North America. Efforts were made into finding the cost figures for medium size agencies (with fleetsize between 100 and 300 vehicles) because it would be most useful for studying the San Juan case. Nonetheless, the only data available for GPS systems only corresponded to larger size agencies and are therefore included in the Table.

The functionality and technology of each system presented in Table 6.7 is different, therefore explaining some of the variance in the cost figures per vehicle. For example, the system implemented in Hull, Quebec, provides for real time information on any vehicle's expected arrival time to particular station that can be retrieved by dialing a given telephone number. Another example of particular interest to this research is provided by Tri-Met in Portland, Oregon. The system deployed by Tri-Met took advantage of an existing voice radio network and built the AVL features around it. The location system has been installed in about 15 percent of their fleet (42).

The size of the fleet getting the vehicle location system is also an important determinant of the average cost per vehicle. To understand why the fleet size is relevant, total costs will be further divided into capital costs, development costs and annual operating costs (24).

Capital costs are associated with expenditures for hardware and software for the control center(s), the vehicles and the fixed infrastructure in the field.[2] The control center and the fixed infrastructure account for 2 to 25 percent of total costs and do not vary significantly with the size of the deployment effort (in terms of vehicles). Obviously, the number of vehicles is the proxy variable measuring the extent of deployment. Therefore, an agency having many vehicles (e.g., 600) equipped with a location system is amortizing its control center and infrastructure costs over more vehicles than an agency installing the system in, for example, 100 vehicles. Consequently, variance in the average cost per vehicle is further explained by the size of the fleet getting the system. There is, however, a limit to the number of vehicles a system can support. Additional vehicles after that limit would require significant investments in a new or extended control center, as well as new software and the allocation of more capacity in the airwaves.

Development costs are the expenditures of testing the technologies the agency is interested in, gathering all the pertinent information and developing adequate prototypes. It is safe to assume that a part of the development costs will be waived as more agencies deploy their systems and accumulate information on reliability and performance that may be readily shared with other agencies. However, there are some development costs that cannot be underestimated such as the preparation of the requests for information (RFI) and requests for proposals (RFP) as well as the costs of gathering the information from other agencies. Lam estimates that development costs amount to between 25 and 40 percent of the total costs (24). Table 6.8 summarizes estimated vehicle expenses and the possible non-vehicle costs of deploying different technological mixes.

Annual costs of operating the system are directly related to the number of vehicles having the locating possibilities and to a fix portion caused by the maintenance requirements of the control center. These costs are also included in the first year of operations setup and will continue over the life of the system.

Several financial arrangements could be designed to fit an agency's need. Most transit agencies do not have all the money up front to invest in the system. Therefore, it is

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[2] Multiple or single control centers are needed depending on the system architecture. A decentralized system needs several control rooms with a limited range of action, whereas a centralized system needs a control center with total control.

reasonable to assume that the agency will want to amortize the investment over several years, perhaps five or ten. Amortization of the costs means deferring some payments until the money is made available. Naturally, there is a cost associated with this deferral: the time value of money. Therefore, an agency would also have to pay interest rates and bear the risk (some) of inflation over the coming years.

An alternative option for the agency is to lease the equipment from a vendor. Leasing is an attractive alternative because the agency is paying small amounts of money on a monthly basis, relative to a lump sum investment when the equipment is bought. In addition, the agency is avoiding the market risk of committing to a technology in a highly volatile market. However, the truth is that the agency is passing on the market risk to the vendor. Also, after the lease is over the agency owns nothing, whereas in the case of buying the equipment, the technology becomes an asset to the agency. Therefore, the real cost of leasing tends to be greater than buying the AVL technology.

Finally, an agency might consider phasing the deployment of technologies. Implementing the technology by phases allows for time to fine tune the system and to develop insights about the next phases. Correspondingly, some of the benefits are also postponed until the system is fully deployed.

c. Benefits

Potential benefits accrued by deploying AVL can also be categorized according to the effects of the information in the agency. The data that is used on real time for control and management accrues benefits subject to the tactical intervention of the control agent. Immediate responses to operational problems have long term effects on passenger's perception of the system's reliability. In addition, strategic vehicle parts such as the engine, tires and fuel consumption would be monitored and a detailed log of their maintenance can potentially yield better reliability. However, it is germane to mention that some costs may effectively increase due to the improved monitoring of AVL. Road calls and vehicle maintenance costs are likely to increase, as well as the AVL maintenance expenditure. Yet, these expenses are related to the improvement in service and should be treated as such.

Off-line operations permit the adjustment of schedules due to changes in market conditions, reduced data collection costs and better route monitoring. Better estimates of dwell and running times will be reflected on improved efficiencies by having fewer vehicles on the road in peak periods and providing less vehicle miles, or by increasing supply of the service with the same fleet size. Data collection costs would also tend to decrease because the AVL system would replace point and even ride checkers. The magnitude of the decrease depends on the integration of the AVL system with APC. Nevertheless, some information such as schedule adherence and running times is directly available from a simple non-integrated AVL system.

Passengers will also experience the improved reliability and schedule adherence. The magnitude of these improvements is also dependent on how accurate the AVL system is and on management practices. Even passenger loadings and faster responses to incidents heighten the positive perception in passengers. It is not clear, however, if this has a real impact on market demand. London Transport did not find significant ridership differences between a system with AVL and a control group. Furthermore, LT based its stated preference data in the surveys to forecast a 12 percent increase in demand that was never realized (24).

Finally, the community also benefits from the AVL system. Drivers have the possibility of having two way communications on real time, therefore being capable of reporting community related incidents. The feature of having the operators also as town watchers increases community support for the AVL system.

d. North American Implementation Sites

Automated vehicle location systems are popular among transit agencies worldwide. A broad array of examples exists in the current literature. The following summary consists of several implementation efforts in North America that are relevant to the purpose of the current research. Financial, technical and human factors are presented in the analysis, as well as the key elements contributing to the success or failure of a deployment effort.

Toronto, Canada

During the 1970's the Toronto Transit Commission (TTC) studied several critical factors for their operations in the decades ahead. The need for real time information and control was among the top issues raised in the analysis. Consequently, TTC decided to deploy a vehicle location system that it called Communication Information System (CIS). Service monitoring, supervision and inspection were the main objectives of the system. Drivers should be able to communicate promptly with the control center, and the center should be able to provide the drivers with instructions to correct any upcoming problems.

The system deployed consists of a singpost-odometer combination, which corresponded to the best technology available at the time. Ten antennas were located in the Toronto metropolitan area, providing adequate coverage and even some overlap to ensure reliability. Twenty-five channels were provided by the government, although with some technological help TTC converted them into 45 channels (24). A cellular backup system was also installed should the voice and data channels fail. Software for the CIS was developed in-house, at a cost that proved to be almost two and a half times greater than what was originally budgeted (24).

Deployment of the system was phased, allowing for evaluation and correction after each phase was completed. This methodology ensured reliability and integrity of the system in the future when all the features were fully deployed. By 1991 all the 2300 vehicles of TTC were operational with the system in place. However, not everything went well for Toronto. A system that would automatically produce executive reports went awry in the mid 1980's after significant money was invested in its development. Similarly, passenger information systems were also planned but never realized due to unexpected expenditures in other aspects of CIS.

Studies evaluating the potential benefits of implementing CIS for Toronto were made in the late 1980's. It was calculated that systemwide capital and operating savings could reach the $6 million per year. Also, projections showed that increased supervision was a natural benefit gained for the system. Hiring employees to provide the new level of supervision would cost $ 1 million per year.

Proven benefits over the last few years include a 17 percent decrease in user complaints due to punctuality. Complaints due to transfer disputes also decreased by 50 percent. In addition, average monthly emergency requests by the bus operators increased 100 percent. Interestingly enough, only 44 percent of all the reports had to do with incidents involving TTC directly (23). Therefore, the community policing function of the driver and the enabling real time system proved to have real benefits for the community.

Toronto's case can be classified as a success story of AVL deployment. However, being the first agency to effectively deploy locating technology in a widespread fashion was also an expensive feat. TTC's strong management commitment to the system and adequate cascading of the ideas and concerns through the organization were key to its success. The process of communicating the vision was aided by the fact that TTC aimed at developing its real time capabilities because a good supervisory and planning system was already in place.

Kansas City, Missouri

The Kansas City Area Transportation Authority (KCATA) integrated its planners and schedulers into the deployment process of the AVL system. They actively participated in the planning and testing of the different technologies that also followed Toronto's phased approach. As a result of their involvement, the technology got a larger acceptance within the organization.

KCATA has been using the signpost-odometer technique. It was deployed on all of its vehicles, a total of 241 including 24 small shuttles. According to Bob Sellars, AVL Project Chief for KCATA, their system uses 3 channels (43). The first two channels are used for voice and data communications respectively, while the last channel is used for emergencies and backup.

In 1992, KCATA was facing budget cuts and analyzed the possibility of increasing vehicle headways or eliminating some routes. However, planners analyzed the wealth of information provided by its newly installed AVL system and found that the scheduled running times could be reduced without affecting service. As a result, the number of buses needed for the peak period and the base period (buses operating the entire day) decreased and service was a not cut (44).

Total annual operating savings attributable to the AVL system amounted to $ 400,000. Further, the capital cost of replacing the vehicles that were discontinued and would have otherwise been replaced was $ 1.5 million. Mr. Sellars argues that the AVL system was paid by the end of the second year. Nevertheless, there have been new development since the last two years. Due to inadequate sealing of the signpost unit, its lithium batteries became wet and damaged the whole units. Nowadays only 30 percent of the signposts are functioning and their automated data collection efforts are stalled. The agency is relocating some of the signposts and acquiring and reinstalling new technologies.

KCATA's experience is valuable because it shows how committed the agency is to making AVL work. Early benefits accrued were good enough to overcome the technical difficulties encountered. Similarly, the example also highlights the importance of having adequate testing procedures. Had the units gone wrong one year before, most of the investment would have been lost.

The process also shows how the regular planning activities at KCATA where not well developed, possibly due to the lack of adequate or reliable data. When the AVL provided enough information, off-line analysis yield the savings. Hence, the benefits accrued in this case are not related directly to what the AVL should be, but rather, on a by-product resulting from lack of good planning processes.

Ottawa Carleton Transportation Commission (OC Transpo)

In the 1970's OC Transpo began thinking about innovating and improving the service provided by deploying information technologies. The main focus of the agency was not only to improve day to day operations by having information on real time, but also to refine their planning and scheduling functions. The systems envisioned for the improvements were developed in an incremental fashion, using Toronto's phasing approach.

Several stand alone systems were developed, including a passenger information system and an automatic passenger counter using infrared beams.[3] The stand alone systems were concerned with the data collection program, scheduling and information dissemination. However, as the systems evolved, a need for their integrator became necessary. At the same time, increased information was also needed to improve data on the performance of the system. A vehicle location system provided most of the functions required by the agency and also gave additional information that could become valuable in the near future.

The vehicle location system used by OC Transpo uses the same technology as TTC's, but employed in a slightly different fashion. Instead of having the vehicles equipped with transceivers and tags on the signposts, OC Transpo has tags on the buses and transceivers on the signposts The main reason for this decision was financial. Data suggest that operation and maintenance costs of a system as Toronto's is significantly greater than OC Transpo's system. However, also because of financial concerns, the number of tag readers were only deployed at 25 strategic locations. To increase the accuracy of the readings a satellite positioning system was also implemented in the vehicles. The GPS system reports every 60 percent of the scheduled headway time to the control center. Therefore, if the headway in a route is 12 minutes, the system would report the position of the vehicles every 7.2 minutes (45). The position given by the GPS system is also corrected with dead reckoning systems.

The implementation of the system was done by having a dedicated "Project Manager" who overviewed the operations and phasing of the deployment. Mr. Van der Kloot, the Project Manager for OC Transpo, suggests that there is more control over the out-of-house work performed by consultants with the existing organizational arrangement.

All the information is relayed to a single control center, in accordance to the very centralized nature that has always characterized OC Transpo, where the real time operating decisions were taken (24).The software interface between the data and the supervisor is in charge of filtering the information and prioritizing the display of the

[3] Developed by Teleride Sage

information of the vehicles that are behind schedule. This scheme is significantly different from Toronto's where the supervisor uses judgment in deciding which vehicle has priority.

The system has been operational with more than 800 vehicles, therefore completing Phase II. Lam reports some general cost figures for the control center and the development and field costs. Control center related expenditures amounted to CAN $2.5 million, and costs for the field infrastructure and development where around CAN $ 2 million. Phase II included software and hardware updates. Phase IV involved the production phase of the interface with the existing information system. Phase VI is planned for next year and it will potentially integrate the last subsystem: automated passenger counters.

Integration of the subsystems has not been an easy task, perhaps because of the lack of compatibility and overlapping functions among subsystems. Currently, information is being integrated manually. Data is extracted from each subsystem and fed into a relational data base (RDT) where it is brought together and synthesized. These unexpected difficulties have also delayed the furthering of the project, leaving it behind schedule. However, both operators and managers feel that the system has contributed positively to their performance and to the image of the agency.

A current development at OC Transpo involves the agency's reluctance to change their current practices. Institutional readiness is a concern that has to be furthered studied when deploying any kind of technological innovation in an agency. Planners and schedulers have repeatedly expressed their discontent with the system because they argue it is too complex and they do not have the necessary skills to operate it properly (45). These agencies have been working under a constant 10 to 15 year time frame. Technological innovations reduce that time frame while generating internal tensions and high organizational discontent.

Milwaukee, WI

The Milwaukee County Transit System has deployed differential GPS systems (DGPS) in all of its 540 vehicles. As shown in Table 6.7, the total cost of the system was

$8.5 million, which includes a control center with computer aided dispatching, radio systems and the frequency allocation, as well as the location technology in each vehicle.

Deployment of the system was also divided into test and implementation phases corresponding to Phase I and II respectively. Phase I was completed in April of 1994, and Phase II was completed on January of 1995. A new Phase has been added to the process, which consists on fine-tuning the software and the report generation features of the system.

The interesting feature about this deployment is that it was developed by a mix of private companies that is dominated by Westinghouse, now called Transportation Management Solutions. These companies are still in charge of most of the data collection analysis, including all of the schedule adherence features. Although schedule makers had significant previous training with scheduling and run-cutting software, they have expressed discontent with the system citing its complexity. With the assistance of these companies, the agency had more time to reaccomodate and adjust to the changes brought about by the system.

e. Deployment in the San Juan Area

Automated vehicle location technologies can be implemented in firms managing commercial vehicle operations and in public transportation. The current deployment analysis will focus on public transportation opportunities for AVL. The study will describe current vehicle location (if any) and communications technologies and will propose and justify several implementation scenarios that should be analyzed in further studies.

Metropolitan Bus Authority

The Metropolitan Bus Authority, or AMA, as it is known for its Spanish acronym, has a total fleet of approximately 250 buses operating on fixed routes with mixed rights of way. About 159 buses are running daily during most of the time periods of the day through the heavily congested streets and arterials of the San Juan Metropolitan Area.

Currently, there is an odometer based location technology supplemented by voice reports given by a vehicle's operator. Generally, there are no supervisors on the field monitoring the vehicle's and operator's performance, although there are too many supervisors monitoring the end terminals (46). The scheduling and planning functions are understaffed and no consideration is given to operator availability when developing these tasks. Therefore, scheduled services are unmet because the number of operators available is insufficient. Additionally, it is expected that several operators will be retiring during the 95-96 fiscal year, heightening the need for aggressive hiring programs. Most, if not all, of the short and long term operating decisions tend to be centralized at AMA's administrative offices.

According to Eng. Edgar Rodríguez, the radio system uses a UHF band of approximately 7 dedicated channels that were licensed by the FCC exclusively for AMA. Of those channels, one is capable of transmitting data and the other six are voice-only channels. The system was developed by Teleride Sage and is based on Motorola radios that are now obsolete. A new RFP will be issued during the second half of 1995 to update the communications system.

Certain vehicle features such as speed, odometer readings and key engine information are also automatically transmitted to the control center. Following the centralized character of AMA, several antennas have been deployed along the metropolitan region to receive the signal and relay it via microwaves to AMA offices. Map 1 in Appendix 1 shows the location of the antennas along the San Juan Area, namely in Bayamón, Carolina, Capetillo and the Central Offices. Map 2 shows the current AMA routes distributed along the San Juan Metropolitan Area and the location of the antennas. The system is mainly used for monitoring fuel consumption and engine performance. The odometer readings received are matched against the time and are supplemented by the speed information to track the approximate location of the vehicle. In addition, a panic button is available to the operator. Once the button is activated it has preemption over any other communication requests. Also, the control center can interrogate the operator orally through the voice channel to request information about any suspected anomaly in the system.

There has been interest in updating the system by deploying Global Positioning technologies in all the fleet because the accuracy and flexibility of the odometer system is not adequate for AMA's needs. The quoted prices by some vendors reached the $15,000 per vehicle. Although no details were provided about the system, these prices seem high because the frequencies and the radio are already operational, and only some modifications to the control center at the Central Offices would be necessary.

From a broader framework, the need for real-time operations monitoring and control for AMA should be studied. There are several factors that contribute to the unreliability of the service provided by AMA [4]. Endogenous causes correspond to factors within AMA that contribute to the unreliability, such as insufficient number of operators, absenteeism, inadequate vehicle maintenance leading to breakdowns during and before service is being provided and the like. These factors can be minimized by establishing a strategic improvement plan as proposed by Multisystems (see footnote 6). Also, the way routes are currently designed in terms of running times and how circuitous they are, increases the unreliability. Exogenous factors that affect reliability include traffic congestion, road construction and maintenance, inclement weather, traffic light malfunctioning, accidents, variable demand for the service and others. These exogenous factors can be minimized by the use of operation and control strategies, on real time and off-line. Off-line operations are justified when the causes are predictable and systematic (e.g., developing certain thresholds of levels traffic congestion) and involve significant work by the planners and schedulers. Real time information is used for both real and non-real time decisions, but involves as mentioned, a higher level of investment.

A simple analysis of five routes arbitrarily chosen from the San Francisco garage can show the need for operation monitoring and control at AMA. Table 6.9 shows the different average running times (without recovery times) for weekdays and both Saturday and Sunday. The data was collected in October 1993. Both route # 8 and route # 19 depart from Rio Piedras and end at Stop 18, but follow different paths. They are also part of a restructuring plan for several AMA routes that may come into effect as early as October of 1995. Both routes are proposed to have 20 minute headways and will be part

[4] For more information see, AMA Performance review and Startegic Improvement Plan, a study done by Multisystems Inc. for the Commonwealth of Puerto Rico and the Department of Transportation and Public Works, January 1994.

of the broader project that includes several trunk routes and the establishment of transit centers.

As shown, on each route the average running time varies significantly between weekdays, Saturdays and Sundays. Possible causes of the variation described previously lead to the conclusion that some vehicle dispatching and en-route control and monitoring are needed. However, given that headways tend to be very large on AMA routes, real time control would have little or no effect on vehicle requirements for the route and passenger perception of the system would remain unchanged. As they are currently, these routes would be better served by having field supervision and off-line data analysis for adequate scheduling and planning.

As a result of the previous considerations, a phased plan of planning and operations is proposed. The success of the plan relies heavily on management commitment to the plan and by the availability of funds.

Phase I, the critical Phase in the deployment process, consists of the redesign of the data collection effort, reassignment of supervision and monitoring posts, and the movement towards incorporating most of the organizational constraints in the planning and scheduling tasks and abiding by them. This Phase is embedded in the AMA route and operations restructuring process recently proposed. Extraboard operators and adequate vehicle maintenance are the first step to improve current conditions. The overall objective is to develop a reasonable operating plan that takes into account most endogenous and exogenous factors. At the same time, contingency plans are developed for all the foreseeable events that may come up on real-time. The current radio system would serve as a strategic asset in developing this rudimentary control system that tries to follow the operating plan as close as possible. The time frame of this phase is about 3 years.

Phase II will consist of assessing the success of Phase I and testing automated data collection techniques. Once the organization has proved that it can effectively change, an AVL system can start to improve both the on-line control strategies and the off-line analysis. Then, Phase III could consist of the selection and deployment of a technology chosen from those tested. Considerations about real-time and off-line analysis should be made, taking into account the agency's needs and goals at that moment. This phase requires a more mature planning process, and therefore would have a time frame of 2 to 3 years after completion of Phase I.

Metrobus

Metromovil ACL Inc. runs one bus route under a contract with the Puerto Rico Highway and Transportation Authority (PRHTA). The route's termini are at Old San Juan (Covadonga) in the North and at the Capetillo terminal (Río Piedras) in the South. The buses run through contraflow lanes on one-way arterials with quasi-exclusive right of way on most of the trip. Some vehicles turning from perpendicular streets, as well as vehicles pulling out from private properties have to cross the Metrobus lane to get into the arterial. Additionally, some parts of the right of way are also used by about thirty AMA vehicles

Metrobus crosses through the financial district of Puerto Rico as well as through other commercial, residential and university areas through its 7.5 mile route. There are exactly 35 stops heading northbound and 40 stops heading southbound. Metrobus has characterized for having high ridership and a low 5-minute headway since it started operating. The current fare charged to patrons is a flat US $ 0.50, independent of time of day or distance, which is twice as much as AMA's fare.

In terms of communications and control, Metromovil uses 2 radio channels that are rented to *Mobile and Portable* a local company that has been assigned to the 157 Khz frequency. The first channel is used for voice communications with the bus operators, and the second channel is used for supervision. Communication through this channel is not limited to Metrobus; rather, people tuning to that frequency can eavesdrop any conversations and instructions. According to the engineering department at Metromovil, and even though the radios currently used have been at work for several decades, there are no plans to replace them.

Due to the limited allocation of funds that Metromovil receives, it is not easy to invest in communications equipment. Furthermore, based on the short term contractual relationship with the ACT, long term investments may very well not be the priority of

Metromovil. In addition, their current performance measures are considerably better than AMA's. There are fewer incentives, then, to improve operations through capital outlays.

There is no real-time control or monitoring along the routes except the supervisory tasks at either terminus where the headways are somewhat evened out. No information about the location of a vehicle is provided unless it enters into an emergency and uses the voice channel or when it arrives to a terminus. As with AMA, the need for off-line information analysis on the performance of the route is needed. This would be a valuable input to the planners and schedulers at Metromovil who can adjust and correct the schedules and timetables to improve operations and the level of service.

Analysis of headway variations along the Metrobus route over a time period of the day can yield some useful insights on the need for a vehicle location system. Since the route has a high frequency, the concern is not only to maintain schedule adherence because it is assumed that patrons arrive at the stops irrespective of the scheduled bus arrival. Rather, control should focus more on preventing bunching or unstable situations that could increase headway variations.

According to data obtained by Chang (47), in the southbound direction (Covadonga-Capetillo) and for all the time periods, headways deteriorate substantially after Stop 18. Even larger disparities between the headways are found in the northbound direction as the Covadonga terminus nears. Problems at the dispatching terminus, especially during the peak periods are also highlighted by Chang's conclusions.

These headway variations along the Metromovil route can be caused by constraints imposed by the traffic signal system (e.g., red lights), incidents along the right of way, disturbances generated by AMA vehicles, driver effects and vehicle dwell times. As buses are delayed or ahead of schedule, the boardings per stop, and therefore the loads, are correspondingly heavier or lighter. This generates an unstable situation that will tend to deteriorate unless corrective action is taken. For example, in 1994 the average load per vehicle on the morning peak was over 40 passengers for almost half of the 7.5 mile route. This would mean that standees will generate some congestion inside the vehicle that would negatively affect the dwell time. This is not be a problem if headways were maintained all along the route. However, due to the stochasticity of the causes of headway variation previously noted, constant headways is virtually impossible to achieve. Correspondingly, as the boardings and alightings over that distance increase, so is the departures from the scheduled headway. Information about the deterioration of the headway given by a vehicle location system can provide the system with useful information and would very likely yield significant savings in terms of vehicles needed to operate the route.

A vehicle location system would then serve the twofold purpose of providing off-line information, hence reducing data collection costs, and giving on-line information useful for real-time control strategies. Since the ACT may potentially provide the funds for such an investment, it would make sense to coordinate the efforts with AMA to reduce development costs. In addition, the same system would be installed for both operators, thereby reducing total overall costs, since some of the right of way is shared by both agencies. Differentiation between the two operations would be provided by means of different radio frequencies for data and voice operations and transmissions.

Finally, there are some limitations to the possible control strategies that can be implemented. Due to the limited right of way along the contraflow lanes, it is impossible to have a bus passing another one in a leap-frogging type of scheme. In addition, having the AMA buses on the lane also imposes some additional constraints to the operations of the system.

3. Vehicle Signal Priority

Both Automatic Vehicle Identification (AVI) and Automatic Vehicle Location (AVL) can be used to control the cycles of traffic lights at intersections. By providing signal priority an emergency or public transportation vehicle can be expedited through traffic without experiencing the delays caused by red traffic lights. Generally, the term *traffic signal preemption* is used for emergency vehicles, and *traffic signal priority* is used for public transportation vehicles. Both terms will be used interchangeably in the current document, without regard to the type of vehicle moving through the intersection.

AVI for signal priority is deployed much in the same way as described in electronic toll collection and vehicle location systems using signposts. The signposts are deployed at some distance of the intersection in order to detect the vehicle and start the prioritization process. When utilizing continuing location systems such as differential GPS, the control is done in a centralized fashion. The system detects that a vehicle is approaching an intersection and provides the adequate signal priority.

a. Priority Schemes

Signal priority systems can be organized with two strategies in mind, passive and active priority. Active systems function in real time, whereas passive systems use a predefined criteria that is not influenced by the presence of a high occupancy vehicle (HOV). Active priority can be further subdivided into unconditional and conditional signal treatments (48).

Passive Priority Systems

This strategy does not recognize the presence of a high occupancy vehicle in the intersection. It consists of predetermined timing plans that fit the local conditions of the junction. Such plans include the adjustment of the cycle length, area wide timing phases and regulating the flow of vehicles through an intersection. All of these strategies can have both positive and negative effects on individual vehicles but are generally set so as to maximize their total throughput.

Conflicting objectives are found when applying passive priority systems for public transportation. On a typical arterial, traffic signals may be synchronized so as to provide a green wave for private automobiles moving along the arterial. However, buses and light rail vehicles operating in mixed rights of way have to stop between signals to let passengers board and alight. Therefore, the phasing of the traffic light system may be inadequate for public transport vehicles. Figure 6.10 provides a time-space diagram of the situation described previously (49). Using car equivalents for buses can provide an intuitive solution for adjusting area timing plans for public transportation (48). However, this solution does not take into account the queue of private vehicles at the light because the signals are phased for busses speed. In addition, stop spacing and the dwell time at stops between lights is not taken into account in the general car equivalency solution, unless they are incorporated into the conversion factor, which is seldom done.

Active Priority Systems

Active priority have electronic equipment that detects the vehicle and start a predefined prioritization scheme. The system detects the vehicle several hundred feet away from the light and calculates both the arrival time and the phase of the light under a normal cycle operation. Depending on the forecast of the state of the light, one or more of the following strategies is used (1,2):

- Phase Extension or Extended Green. A green light is extended until a limited value is reached when the cycle restarts normally.
- Early Start. A red light is truncated in order to provide a green light for the high occupancy vehicle (HOV).
- Special Phase or Red Interruption. A green light is inserted into the normal cycles of the system. Emergency vehicles using signal priority generally activate a special phase system, where they get a green unconditional of the flows and the state of the light.

- Suppressed Phase: When an arterial has low flows, the green cycle can be suppressed (i.e., skipped) to provide for more than a twice as long green cycle on the arterial with significant flow.[1]

Most transit properties with signal priority have implemented the extended green and early start strategies. In addition, there may be a compensating strategy in which there is a limit to the number of consecutive priorities provided to HOVs. Also, after priority is granted, the non-priority movements get additional green time that is distributed along two or three cycles. Hence, the vehicle delay generated by the strategy is allocated fairly on both arterials.

The compensation possibility introduces the concept of unconditional and conditional priority. Unconditional priority is granted to emergency vehicles. However, it proves to be disruptive to the traffic flows if applied consistently, and may also generate safety problems with pedestrians. It may ultimately even be prohibited by law, as in the State of Washington before 1994 (50).[2] As mentioned in the compensating strategy, priority can be given subject to a set of constraints determined by both the specific characteristics of the system and the objective of having signal priority. If signal priority is developed to increase transit attractiveness without regard to other modes, unconditional strategies may be appropriate. However, this is seldom the case, and therefore conditional strategies are dominant in worldwide deployment examples.

Conditional priority can depend upon one or more of the following factors:

- Transit vehicle's schedule adherence
- Current traffic conditions
- Length of the vehicle queue on non-bus street
- The point of the signal cycle in which the vehicle is detected

[1] It is more than twice as long as the original green phase because one yellow light is saved for the street with significant flow.

[2] For example, until 1993 the State Washington prohibited the use of signal priority devices for buses (56).

There are some other possibilities for providing signal priority, depending on the physical layout of the street in question. For example, queue jumping is a popular strategy that uses the right-turn only lane as an additional HOV lane so that the vehicles can skip the queue and get in front. Operation of such a system requires a minor delay in the red light time for vehicles on the same street as the bus, or a shorter green light time for vehicles on the cross-street. Alternatively, queue jumping can be operated with special phasing settings so that all other flows are interrupted and the vehicle can proceed without delay. Also, the queue jump strategy can only be deployed on street junctions where the bus stop stations occur before the light (also known as near-side stations) to minimize delays imposed on the vehicles behind the bus.

Finally, some considerations should be made about the characteristics of the site selected for deployment. Several issues in the selection criteria are summarized as follows (51):

- Transit delay at intersection
- Degree of saturation of the street and cross-street
- Transit service on cross street
- Nearside and far-side stops (i.e., stops before or after the intersection)
- Pedestrian crossings and access to stops
- Signal timing flexibility
- Similar cycle lengths on main approaches
- Queue storage capacity on cross street
- Similar geometry on all approaches

b. Costs of Deployment and Operations

The equipment used for signal priority systems is composed of the identification system, a communication link and a controller at the traffic light. The most commonly deployed system worldwide uses signposts with tag readers or loop sensors. Loop sensor reliability is subject to weather and pavement conditions, whereas signpost AVI have a much higher reliability but their performance depends heavily on their physical location.

The cost figures for signpost-odometer systems are shown in Table 6.8, introduced in the previous vehicle location/vehicle identification section. By sharing signposts and transceivers for both AVL and AVI applications, significant capital can be saved. The need for modularity and a common standard, at least on a regional basis, is evidenced again. Otherwise, the costs of non-integrated deployment effort would approach the figures presented hereafter.

The other major capital cost is the modification needed to the logic governing the controller and the changes in the controller unit. Unfortunately, these incremental costs are very hard to estimate as they are not easily released by vendors. Nevertheless, cost figures of a completely *new* set of controllers, the software and the tags can be found from pilot projects developed in the United States. Table 6.11 summarizes the costs for new equipment installed in Portland, Oregon during 1994.

Finally, there are other costs of the system related to its development. For example, it is likely that some bus stops may need to be relocated to maximize efficient flows.[3] In addition, the whole deployment effort should be planned and managed by qualified individuals. Experience has proved that these costs are between 20 and 30 percent of the total system costs (52).

c. Benefits

The major benefits provided by signal priority , as perceived by the user, can be categorized as direct or indirect. The major direct benefit experienced as soon as the system is in place is the decrease in trip time. Longer routes experiencing significant traffic delays at intersections are likely to have the best time savings of a signal priority scheme. However, unless the time reduction is dramatic, which is seldom the case, no significant mode shift is expected due to time savings. Hence, long routes with significant traffic signal delays are prime candidates for signal priority implementation. Several attempts

[3] Much care should be put into this relocation, taking into account the possible negative (positive) effects the new site may have on existing and potential passengers.

have been made to analyze the change in ridership due to the decrease in travel times using elasticity values for travel time.[4]

The indirect benefits to the user accrue from the effects the decrease in running time has on bus operations. Decrease in running time on high frequency routes may reduce the fleetsize requirements and indicate an improved productivity in the operations of the current system. Also, accelerations and breakings are reduced, therefore decreasing fuel consumption and wear and tear (53). These reductions in operating and capital costs imply that the same level of service is provided at a lower cost, or possibly a better level of service can be achieved with the budget expenditures previous to the signal priority system.

The variation of running times will also decrease, and also the headway and schedule adherence variations. Hence, the user will experience less changes in wait time at the stop, which means that a better level service is being provided. Improvements in the reliability of the service are useful for both the passenger and the operator. For example, the likelihood of buses to form pairs or bunches is decreased by having traffic signal priority. This translates into more even loads per vehicle and a more comfortable ride.

The public's perception of an operating agency can also improve if the agency uses the implementation of signal priority systems as an element to promote its service. However this promotion should be made with care because the expectations of the user may be too high and this may create disappointment which will be counterproductive for the agency.

The effects of non-bus traffic on both the bus-street and the cross street need to be taken into account. The number of private automobiles benefiting from signal priority, given an extended green case, is the arrival rate multiplied by the extension time. This should be contrasted with the delay in the cross street. All the vehicles on the queue in the cross street and the arriving vehicles to the queue will be delayed by the priority system. However, the previous analysis can be somewhat misleading. The flow of vehicles through

[4] See Khasnabis, Reddy and Hoda. "Evaluation of the Operating Cost Consequences of Signal Preemption as and IVHS Strategy", Transportation Research Record 1390.

the intersection should not be the focus of the analysis. Rather, the flow of people is what matters.

Hence, a very simplified analysis of the break-even point between a single bus having priority and the affected vehicles on the cross street only taking time into account could be made. Assuming a load of 40 passengers, and a 1.3 car occupancy rate, one would deploy the system if less than thirty vehicles are delayed over the time it takes the bus to move and the cross street vehicles to receive a green signal.

Another cost (disbenefit) that may be attributed to the system is the pedestrian delay. Delay generated by a priority strategy system for pedestrians crossing a particular street, for example, was quantified in a study in the U.K. It was determined that under a particular signal strategy for the city of Swansea, each pedestrian would have to wait one additional second to cross the street (54). Although this seems small, the importance of including the effect on pedestrians in the evaluation is highlighted.

d. Worldwide Development Sites

Bochum, Germany (55)

A planning and valuating process for decreasing transit running times by increasing operating speeds is presented below. Several measures of effectiveness were used to conclude that signal priority was the best strategy to follow.

Figures of auto ownership growth and a forecasted decline in the population painted a bleak picture for public transportation in Bochum. Therefore, an overall effort to revitalize existing transit properties started in the late 1970's. The project focused on increasing the speed of public transportation vehicles using non-exclusive rights of way. Funds for the project were provided by the Ministry for Research and Technology, as a part of an integral study for improvement of public transportation.

The locations studied were chosen based on the following criteria:

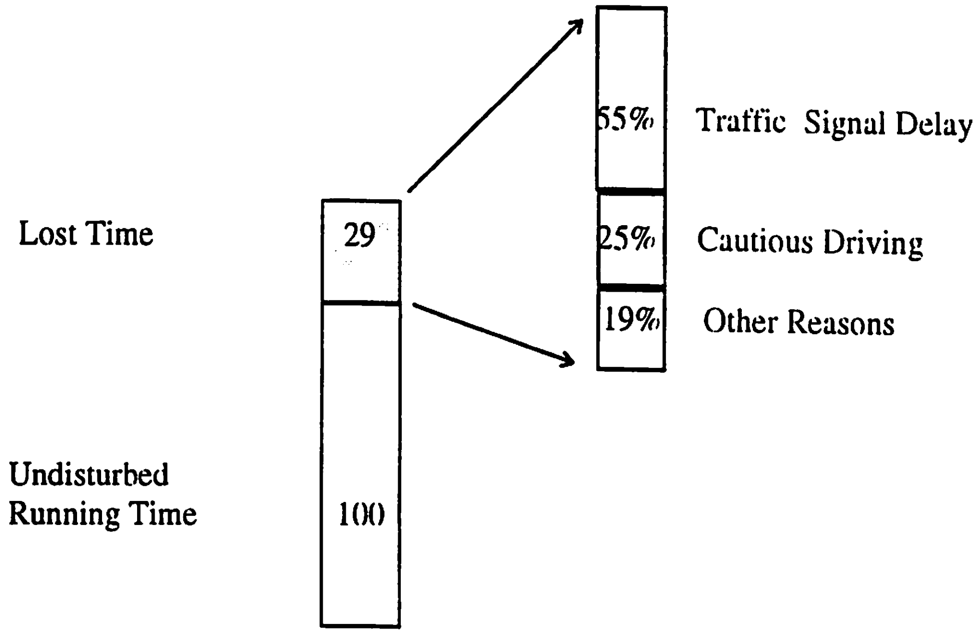
- They provide a link between activity nuclei
- They connect each nucleus with the surrounding communities

- High frequency service is being provided

The bus and light rail operations on the Bochum-Gelsenkirchener section, comprising 11 routes, were chosen for the study. Initial observations shown on the next page proved the intuitive idea that traffic signal delay was significant. Undisturbed running time is the time taken to complete a vehicle run accounting only for boardings and alightings and the vehicle's moving time.

After realizing the significant improvements that could be realized, the schemes to increase the average speeds were developed. Three major possibilities were studied:

- Prohibiting left-turns
- Reducing the number of lanes available for private traffic
- Using signal priority strategies



These strategies were evaluated against a cost effectiveness measure that took into account the major groups affected by such a measure. The effectiveness measure was deterministic in nature, providing weights to the extent of the benefits realized by each party (e.g., transit passenger, private driver, pedestrian). The weights given , however, were discussed and agreed upon with the community.

This case provides a good example of an analysis, planning and evaluating strategy for improving public transport operations through signal priority. The underlying objective of the first phase of the project was to set a common standard whereby cities, analysts and private firms knew the problem and acted accordingly to solve it, given a known data set and well studied system characteristics. The way possible options for increasing speeds are valuated may vary and should not be subject to determinist mathematical formulae. On the contrary, it is suggested that the analysis of possible options be done at the most disaggregate level, almost intersection by intersection because benefits and costs are directly linked to passenger demand for public transport and the vehicular flow at the intersection.

Portland, Oregon (56).

The city of Portland, Oregon and the public transportation operating agency, Tri-Met, have deployed two technologies and different priority strategies over a 2 mile stretch of the Powell Boulevard. This Boulevard is a major 5 lane arterial carrying between 40,000 and 50,000 vehicles per day, with four main junction points over the given distance. A summary of the technologies deployed as well as the costs are shown in Table 6.11. The RF tags were mounted on existing utility poles 400 to 600 ft from the intersection, thereby reducing the implementation costs. The inductive loops were located on the curb lane for each direction. The project consisted in equipping 75 buses corresponding to the route covering the street segment in question.

The three strategies tested are green extension, red truncation and queue jumping. The first two strategies were deployed at three intersections simultaneously, that is, if a vehicle is approaching the intersection and there is a green light it will be conveniently extended, if the light is red, it will be truncated to provide a green light for the bus-street. The third strategy, queue jump, was implemented at the fourth intersection. In this specific application the vehicle on a queue proceeds through the right-turn only lane and positions itself in front of the queue, waiting for the normal cycle to give a green light to cross the intersection.

Data was collected to assess the impact of these strategies on changes in buses running times over the Boulevard segment, total vehicle delay and person delay at each intersection. Bus travel times decreased an average of 6.4 percent in the peak period in the peak direction, whereas no change was found on the total vehicle delay at the intersections. The total person delay changes at the intersections remained constant over the peak periods of observation, and slightly increased on the off-peak.

There is no conclusive evidence about the different strategies and the technologies used because the experiment involved deployment of all the variables at once. Nevertheless, it was observed that the queue jump light was not synchronized adequately and generated more congestion on Powell Boulevard.

The RF technology proved to be more complex in designing and maintaining. It also had some operational problems that were to be fixed by the manufacturer. The loop detectors performed as expected and will be considered for future installations in the Portland area.

Stuttgart, Germany (57)

The Stuttgarter StraBenbahnen AG (SSB) is in charge of the operation of approximately 450 vehicles having over 850 stops over the network. Among the functions of SSB is the selection of light rail routes and their intersection with cross automobile streets. The analysis was performed by gathering the running time data and identifying the intersections causing the most delay.

There are three active priority strategies in place for the light rail system. The first strategy is the extended green time, which provided a 50 percent reduction in the delay of the transit vehicle. The second strategy is the early start constrained to a maximum red time for the non crossing street vehicles. Finally, the third strategy in place is the full preferential or unconditional treatment where the vehicle gets a green light independent of the state of the traffic signal cycle. Priority is generally given before the vehicle arrives to the intersection and detecting technologies include both inductive loops and infrared beacons.

The interesting aspect of this implementation is that the project objective is not to achieve a social optimum where individuals in private vehicles are delayed the least time possible and the transit system passengers are expedited in the best way. Rather, the approach is to increase the attractiveness of public transportation, given an upper limit of delay for road users.

Bremerton, Washington (58).

Bremerton is currently using a traffic signal priority system in which each bus is equipped with an optical strobe of light that is read by the traffic controller which decides on the status of the light. Two signal strategies are in place at Bremerton, one for public transport vehicles and one for emergency vehicles. Emergency vehicles get every type of preemption possible, from extended green to suppressed phase. For public transportation vehicles, however, the system has some conditional requirements.

First, the traffic signals fall back into its original synchronized state within 30 seconds of the interruption. Second, the time allowed for pedestrian crossings is never shortened, and third, all directions must be serviced before attempting to give priority to a new public transport vehicle.

A study was made to assess the impact of the signal priority strategy on both buses and on private vehicle traffic (56). A reduction of an average of 10 percent in travel times was achieved when implementing the priority scheme. The routes originally had a round trip running time of about 50 minutes. This means that frequent service (i.e., five minute headways) on the peak period would need one less vehicle. The study of the delays generated in the intersection were not conclusive; some intersections experienced increased delays whereas other experienced decreases. Unfortunately the study did not evaluate the changes in person delay at the intersection.

This case was included because researchers gathered some interesting anecdotal evidence on the driver's perception and use of the signal priority system. Many driver's were not aware of what to do and how to notice if an emergency vehicle approached the intersection. The level of attention paid by each driver to the process of gaining priority varied significantly. These concerns were deemed as detrimental to the safety of everybody at the intersection. There were also some operational concerns about the reliability of the optical system used. Inaccurate readings occurred mostly when there were significant physical constraints in the placement of the light detectors.

However, drivers seemed enthusiastic about the system, mentioning that it reduced their level of stress in adhering to the schedule and that its operation did not impose a significant workload. In addition, the Fire Department and the Police Department were very pleased with the priority system. The first step for breaking institutional frictions and barriers was a achieved when all the agencies agreed on the objective of improving the service they provided to the public. Priority signaling was seen as vehicle to attain the goal. The installation and use of the signal is evidence that the integration effort was successful and that future programs may gain from this agency coherence.

e. Deployment in the San Juan Metropolitan Area

Signal priority systems can be deployed in SJMA for both emergency vehicles and public transportation vehicles. This report will focus only on the potential benefits that may accrue in public transportation applications. The incremental costs of adding more vehicles (e.g., emergency) to the priority signaling scheme will only consist of the vehicle costs, granted the same intersections are used. There is, however a limit to the number of times an intersection can handle priority requests before generating adverse delays on the cross street. Therefore, a central agency, such as the ACT, should handle all the requests regarding technologies providing priority for specific vehicles.

Metrobus

Implementation of a signal priority system for Metrobus can be analyzed in light of the information of the route and on running times obtained for the first quarter of 1994. The Northbound route has 40 stops and 32 traffic signals. The major sources of delay other than passenger dwell times are red traffic signals, stopped cross traffic and having an

AMA bus ahead, as shown in Figure 6.12. Potential improvements by deploying signal priority systems can influence running times and/or headway variations along the route.

An idealized analysis of a signal priority strategy aimed only at reducing running times on the Northbound route was made. The results are presented on Table 6.13. The traffic lights providing the greatest delay were sorted in descending order. Hence, it is assumed that providing priority at intersections with the most delay would generate the most benefits to transit vehicles. Most of the delays caused by traffic lights on the Northbound direction are generated in the first third of the route. It does not come as a surprise thus that most of the headway deterioration on this route happens precisely on this segment of the route, as evidenced by the data gathered. Therefore, a high correlation between traffic light delay and headway deterioration is suggested and should be studied further. Nevertheless, boardings also happen to be high on this first segment of the route and would also explain part of the variation in headways.

As shown in Figure 6.13, running time would decrease an average of 2 minutes and a half by providing bus signal priority in five critical intersections. The graph does not reflect the fact that on the peak periods the running time decrease is close to three minutes. Under the five minute headway arrangement, this may mean that close to one vehicle may be saved by having signal priority. This analysis does not include the benefits of having less variations in headways and therefore a more even load distributed among vehicles.

The cross street effects were not deemed as significant because there are no major arterials crossing Fernández Juncos or Ponce de León. Pedestrian delays were not calculated given the limited information.

It has been determined that a passive signal system covering 62 intersections along Munoz Rivera and Ponce de León, the Metrobus route, has been installed since October 1994. The MIST system , Management Information Systems for Traffic, is supplied by Farradyne Systems. The lights are synchronized for private vehicle use, varying by time of day. Therefore, the feasibility of signal priority for the Metrobus corridor is further reduced.

As with AVL and other AVI systems it is very unlikely that Metrobus is willing to invest in its deployment. The vehicles used for the Metrobus operations are provided by the ACT; hence, part of the benefits accrue directly to the ACT. Therefore, it is suggested that the ACT should take initiative in implementing the system. Signal priority systems may become a means to improve the image of public transportation in San Juan. A stand alone development for Metrobus is very unlikely due to the political and financial constraints of the Island. However, a broader implementation plan may provide some economies of scale in the operations and maintenance while improving the generalized image of public transport.

Metropolitan Bus Authority

The current route redesign process being developed provides an interesting background for the analysis of bus signal priority systems. Current routes tend to have very low frequencies and high running times. Decreasing running times would only benefit existing riders and would have no effect on fleetsize requirements or operating costs. On the contrary, costs of implementation and operations may probably outweigh significantly the few benefits accrued.

Under the new scheme, the three trunk routes having ten minute headways are possible candidates for signal priority. The two routes from Bayamón to Río Piedras pass through several active centers with signalized intersections, such as Centro Médico and Hato Rey. Part of the success of Tren Urbano rests on the success of these first trunk routes. Furthermore, signal priority systems can be critical to accessing the new transit centers to be operational in October 1995. These centers are located in activity nuclei and therefore have significant vehicle flow and controlled intersections.

Recognizing the budgetary constraints of the ACT, the following recommendations for signal priority implementation should be considered. The scope has been limited to the current Metrobus route, the proposed trunk routes and the access to the transit centers.

- A coordinated effort between AMA, ACT and Metrobus is required. Furthermore, if some of the transit centers will also serve as público stops, the input of the público associations is greatly needed. This effort can be successful predominantly in Bayamón where drivers have organized in a more systematic way.

- Passive signal priority is an alternative that costs significantly less and may provide some benefits to public transport. Essentially, a passive system consists of phasing the light cycles so that the bus moves through a continuous green pattern or "wave". Passive systems cannot change on real time, but can be pre-set to vary according to the time of day. Nevertheless, passive systems tend to be objected by private auto drivers because the inconvenience of accelerating and breaking at every intersection. Furthermore, congestion and environmental problems may increase due to this strategy.

A careful study of the implementation at *selected* sites is needed before proceeding with the actual implementation process.

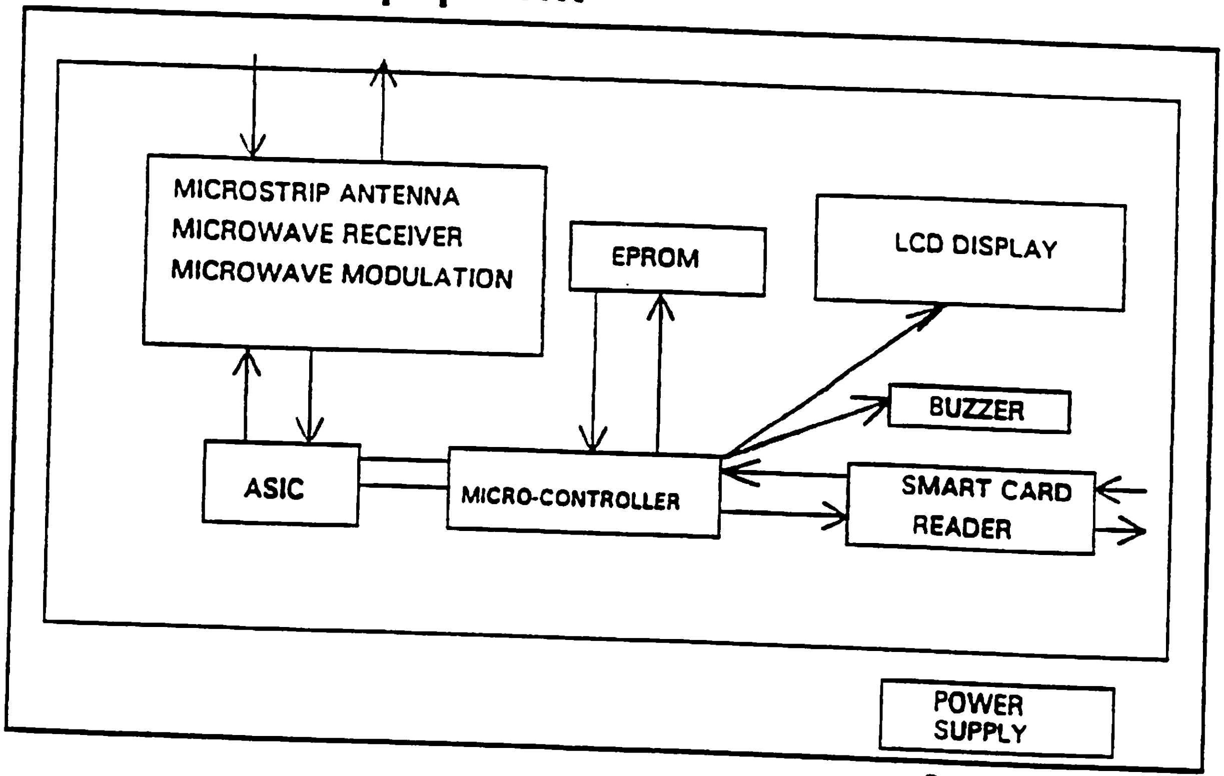
- Signal priority tests could be conducted using inductive loop detectors or the class of detectors that has been developed exclusively by the ACT. Tests could be done on one of the proposed trunk routes and on the Metrobus route. If significant gains are attained at low costs, a wider development may be considered. However, if AMA is planning on deploying a fully equipped vehicle locating system, inductive loops will not be needed and a technology compatible with the AVL system is recommended, even though this may mean a slight increase in costs.

  The tests should be set so that an evaluation team can assess the impact of the system in a technical fashion. The input of agency employees, including bus operators and traffic light managers, would be needed to appraise the human and institutional factors of such development.

- The previous trial phase will also serve as a first step for possible implementation when Tren Urbano is fully operational. Based on the goals currently defined, access to Tren Urbano stations will play a critical role in its success. Signal priority systems may readily improve flows to and from stations therefore making the mode transfer less cumbersome (i.e., seamless).

The previous considerations are deemed as necessary conditions for a comprehensive bus signal priority system that balances both costs and benefits. Additional site-specific conditions, such as the geography and the effects on pedestrians, need to be taken into account.

Figure 6.1
A Schematic Diagram of the In-Vehicle Equipment



Sources: (26) and (28)

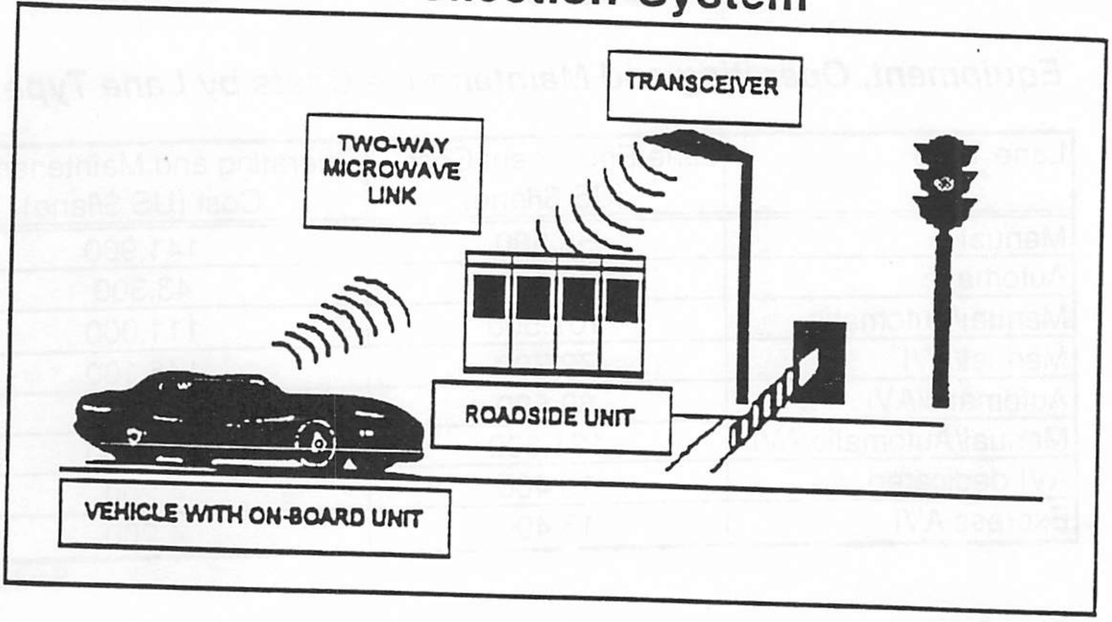
TABLE 6.2

Vendor's Data and US/European Recommmended Standards & Protocols

	ITS Draft 2.0	Vita Version II	Intellitag	Amtech	March IV	SAAB Comb.
Frequency Location	902-928 MHZ 2.45 GHz, 5.8GhZ	5.8GHZ	902-928 MHZ	850-950MHZ 2.4-2.5 GHZ	902-928 MHZ	5.8 GHZ
Data Rates	550 Kbps	250 Kbps	300-600 Kbps	N/A	550 Kbps	250 Kbps
Min. Capture Rate	>99.95%	N/A	N/A	>99.9999%	N/A	99.99999%
Error Rate	<0.00001%	N/A	N/A	1E-07	N/A	1E-07
RF Charact.						
Modulation (downlink)	ASK (Manchester)	ASK (Manch)	ASK (Manch)	ASK	ASK (Manch)	ASK (Manchr)
Modulation (uplink) Active	ASK (Manchester)	DPSK			ASK (Manch)	
Backscatter	AM Subcarrier or FSK modulated @ 600-1200 KHZ	DPSK DPSK	FSK Modulated	FSK		FSK
Power Density	<20 μw/cm²	N/A	N/A	N/A	N/A	N/A
Protocol						
Data	HLDLC, TDMA, binary	HLDLC	HLDLC, TDMA binary	N/A	TDMA, binary	HDLC, binary
Error Correcting	CRC-CCIT, Luhn Code, ID Check	CRC-CCIT	CRC-CCIT, Luhn Code, ID Check	N/A	CRC-CCIT	N/A

Sources: (26) and (28)

Figure 6.3
Electronic Toll Collection System



Source: (26)

TABLE 6.4

Equipment, Operating and Maintenance Costs by Lane Type

Lane Type	Lane Equipment Cost (US $/lane)	Operating and Maintenance Cost (US $/lane)
Manual	58,500	141,900
Automatic	58,000	43,300
Manual/Automatic	107,500	111,000
Manual/AVI	72,700	146,100
Automatic/AVI	69,500	47,500
Manual/Automatic/AVI	121,300	115,200
AVI dedicated	15,400	4,200
Express AVI	15,400	4,200

Source:(19)

TABLE 6.5

Selected Results of RF and MW Based ETC Deployment

Agency and Facility System Under Operation	Lanes	ETC System Vendor	Date of Initation	Approx. # of Tags Distrib.
Harris Co. Toll Road Texas Turnpike Authority	69 mixed	AMTECH	Oct-92	30,000
Greater New Orleans Expressway Commission	N/A	AMTECH	1990	16,000
Crescent City Connection Louisiana Department of Transportation and Development	3 dedicated 9 mixed	AMTECH	N/A	25,000
E-470 Public Highway Authority Colorado	4 dedicated 2 mixed	X-CYTE	Jul-91	1,850
Orlando-Orange Co. Expressway Florida	N/A	MARK IV	N/A	12,000
Oklahoma Turnpike Authority Oklahoma	56 dedicated 17 mxed	AMTECH	N/A	230,000
Dallas North Tollway Texas Transportation Authority	4 dedicated 59 mixed	AMTECH	Sep-89	71,000
New York State Thruway NYS Thruway Authority	N/A	MARK IV	Aug-93	70,000

Sources: (19), (29), (32)

TABLE 6.6

Selected Results of Future ETC Deployment

Agency and Facility Projected System Under Operation	ETC System Vendor
Illinois State Highway Authority	AT/Comm
SR 91, Orange Co. California	MFS Network Tech.
Dulles Toll Road Virginia Dept. of Transportation	CUBIC
Kentucky Turnpike Kentucky Turnpike Authority	AMTECH
Maine Turnpike Authority Maine	AT/Comm
E-Z Pass Group CT,NJ, NY. PA	MARK IV
California Dept. of Transport. California	MFS Network Tech.
Kansas Turnpike Authority Kansas	AMTECH

Sources: (19) (29) and (39)

TABLE 6.7

North American AVL Deployment Sites[a]

City/State-Province	$ (Millions)	Technology Deployed[b]	Frequency[c]	# of vehicles[d]	Cost per vehicle
Ft. Lauderdale, FL	2.3	S-O	2/1	192	$12,000
Halifax, NS	1.0	S-O	1/1	168	$6,000
Hamilton, Ont	6.0	DR	3/1	284	$21,200
Kansas City, MO	2.1	S-O	1/2	240	$8,750
Norfolk, VA	2.0	S-O		151	$13,245
Tampa, FL	1.6	S-O	3/1	162	$9,876
Denver, CO	10.4	GPS	?/2	833	$12,500
Hull, QUE	2.6	S-O		145	$17,900
Portland, OR	5.3	GPS-DR		740	$7,200
Milwaukee, WI	8.5	DGPS		540	$15,740

a Source: (22), (23) and 43

b **S-O:** Signpost - Odometer; **DR:** Dead-reckoning; **GPS:** Global Positioning Systems; **DGPS:** Differential GPS

c Number of frequencies dedicated presented in the *a/b format.* a stands for number of voice channels and *b* of data chanbels.

d All the agencies in the table equipped all their vehicles with the AVL technology.

TABLE 6.8

Vehicle and Non-Vehicle Costs of Different Technologies

Location System	Costs (US Dollars)	
	In-vehicle	Additional Costs
Dead Reckoning	1500-3000	comm system + Software
Signpost	1600-3500	700-1000/signpost + comm system + software
GPS System	700-1000	comm system + control center
Loran-C	700-1500	comm system + Software+ 200,000-300,000 of ctrl ctr

Source: (24)
Note: all figures in US Dollars

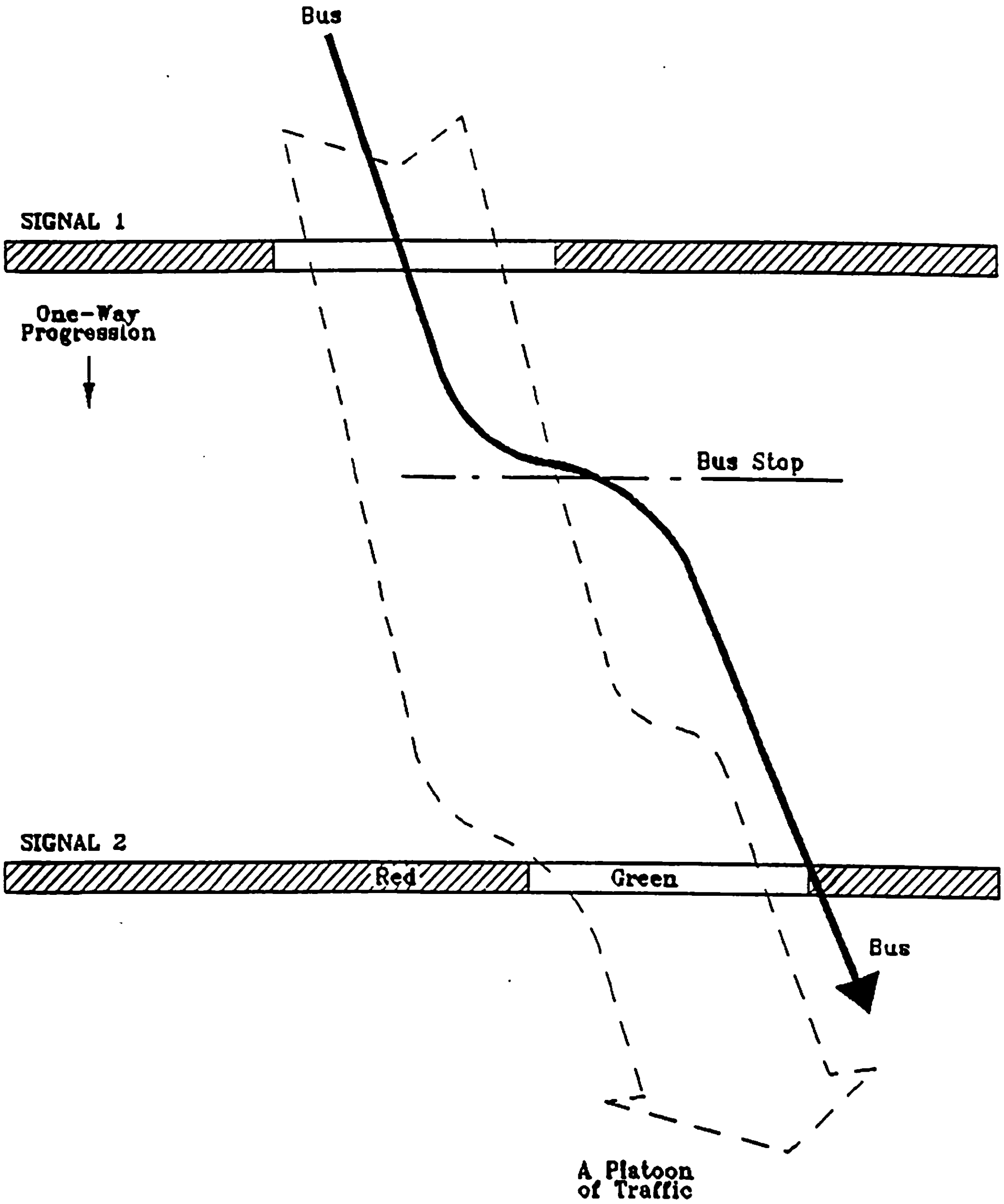
TABLE 6.9

Running Times for Selected Routes -San Francisco Garage- Oct 1993

Route	Running Time	Day
Route 8	1:11 0:59 0:57	Weekday Saturday Sunday
Route 19	1:11 1:12 1:05	Weekday Saturday Sunday
Route 31	1:02 0:39 0:36	Weekday Saturday Sunday
Route 42	1:34 1:19 1:12	Weekday Saturday Sunday
Route 60	1:20 1:07 0:58	Weekday Saturday Sunday

Note: Running Times DO NOT include recovery times
Source: (46)

Figure 6.10



Source (49)

Table 6.11
Implementation Costs for Powell Blvd, Portland OR

Vendor	Vehicle Cost Information		Wayside Cost per Intersection
	Technology & Description	Cost/Bus	
TOTE	RF tags read by devices on the wayside. Includes controller interface and logging reader data	$40	(hardware) $29,000 (labor) $2,000
LoopComm	Special transmitter on bus sends signal read by loop embedded in the pavement	$75	(hardware) $15,000 (labor) $3,500

Source (56)

Figure 6.12: Metrobus Time Spent per Trip (Nbound)

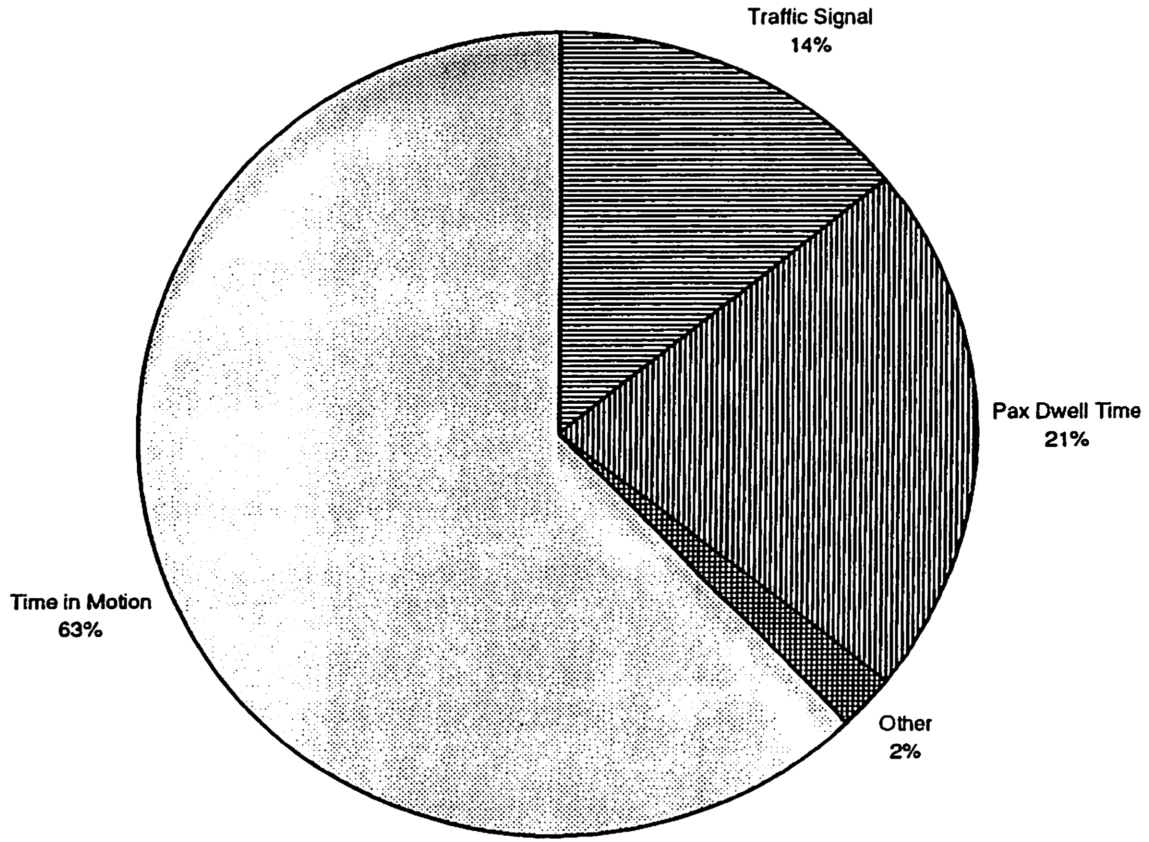
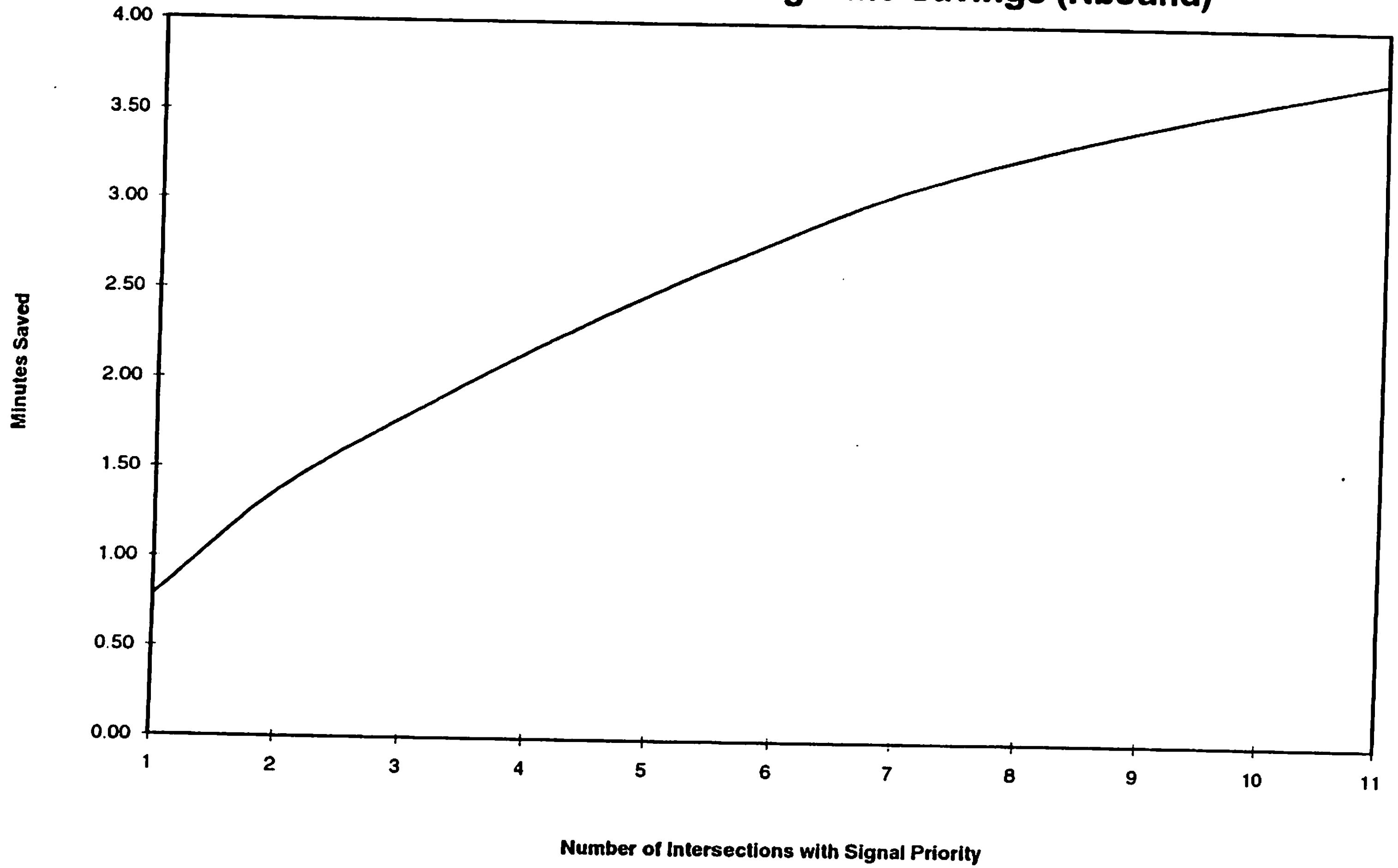


Figure 6.13: METROBUS Running Time Savings (Nbound)



VII. Passenger Information Systems

A. Definition

Passenger information systems convey information regarding the transportation service to (potential) users. They can be deployed as a response to the fundamental causes of unreliability in public transportation services or in compliance with the Federally mandated laws such as the American with Disabilities Act (ADA).[1] Problems in reliability include the variance in running times and wait times at bus stops and terminals. This unreliability generates stress and uncertainty in passengers, which ultimately affects mode choice and ridership (24).

Information offered to the users can be categorized as static or dynamic, depending upon its reliance on up-to-date information or on pre-stored information. Maps and printed schedules are the classical example of static information. During the mid 1980's agency's developed telephone systems that provided information about the operating hours of service and the schedule of the system. This information was updated when the operating timetables changed, generally once a season. However, the unreliability of public transportation services make static information less valuable to the user.

Real time systems provide information that the customer values more than static information. Different types of information provided to the user include (40,59):

- Vehicle location
- Stop name, if in-vehicle
- Estimated stop arrival time
- Passenger loads
- Transfer and connection information
- Traffic information

[1] The ADA mandates fixed route transit vehicles provide audible and visual information to passengers on major intersections, transfer points or destinations.

- Routes and schedule changes
- Emergency information

These types of information have different effects on trip planning and mode choice. For example, information on vehicle location is moderately useful because users have to calculate the expected arrival time on their own. Therefore, information on estimated arrival time is more valuable to the user than just the vehicle location (40).

An on-going study on passenger information systems has reported, on a preliminary basis, the results of focus groups conducted to establish the perceived informational needs of public transportation users (59). This information is limited to in-vehicle information, and largely coincides with the list mentioned above. In addition, the results show interest in time of day information and entertainment and trivia questions that may enhance the experience of using transit.

Knowing what type of information is not the only concern. It is important to determine if the information involves a real observation or a forecast. Arrival times to stations, for example, involves taking current information of the vehicle location and predicting the running time. As mentioned above, forecasts on arriving times to stations and terminals are valued more, but they involve a certain variability. Furthermore, if there is no way of inferring the traffic conditions and (possible) incidents on the route, forecasting running times is difficult. Agencies have generally opted for relaying information about current location of the vehicles and in the most sophisticated cases, mentioning transfer possibilities given that the new vehicle has not arrived to the transfer point.[2]

The previous situation presents the classical tradeoff between the value of the information and the cost of providing it. The agency is incurring significant costs not only in monetary terms, but in terms of public perception and reliance on both the service and the information.

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[2] As usual, there are exceptions. London Transport, for example, has ventured to forecasting arrival times at stations. Mixed results have been reported on this experiment.

When and where to provide access to real time information should also be resolved. Information can be provided at the origin of a linked trip, that is, at homes or offices in most cases. Information given at home is particularly useful because the modal decision between private auto and public transportation is made there. Once a trip has been started by driving a private automobile to work, it is very likely that the trip will be completed using the same mode. Pre-trip information can be delivered by telephone, television, radio, computer networks and kiosks, pagers and fax machines among others.

Information can also be given at the way side or at the terminals. This information is less effective because the decision domain of the user has been reduced (24). Mode shift is limited when providing wayside information because the user has already made the modal decision. However, it can assist him or her on route selection and wait time estimation. Way-side and in-vehicle information can be delivered by using audio and/or visual displays.[3] Information not related directly with ADA requirements (e.g., entertainment or advertising) should only be visual, giving the passenger the possibility of ignoring them.

Finally, the information can also be provided within the vehicle as it progresses along the route. Here, the scope of the decision is narrowed further. However, there is still the possibility of transferring to different routes given information on delays, incidents or control strategies being applied by the operator.

B. Recent Progress and Outlook

It is valuable to mention explicitly that a real time passenger information system relies heavily on having good estimates of the location of the vehicles. Therefore, such an information system is dependent upon an adequate vehicle location system. The accuracy of the location technology will improve the quality of the information and the forecasts

[3] Results of a TCRP project titled "On-Vehicle Passenger Information Displays (Visual and Audible)" prepared by Seattle Metro will be available by the summer of 1995. The report contains a comprehensive description of both audio and visual displays currently used in the transit industry.

relayed to users. From research conducted at MIT, Hickman (40) concluded that the accuracy of information had no effect on travel time savings. That is, given different levels of accuracy of the information, the expected travel times of passenger did not vary significantly.[4]

Passenger information systems will benefit from the current surge in AVL and AVI implementations in transit agencies. They are seen as the next natural step in gathering the benefits from a costly AVL system. However, there is a clear need to establish the real effects of providing pre-trip, en-route and in-vehicle information. Simulation models provide a useful starting point, but care should be taking in analyzing the assumptions inherent in the model. The field operational tests in the US, or the deployment processes in London and elsewhere provide.good empirical evidence to study both the short term and long term effects of real time passenger information.

C. Benefits and Costs

The qualitative benefits accrued form deploying a real time information system can be summarized as follows (24).

- Improve pre-trip planning process
- Generate mode shift
- Reduce anxiety about waiting at a bus stop or terminal
- Allow passenger to make productive use of the wait time
- Improve passenger circulation and movement in terminals
- Reduce passenger waiting time
- Changes in Perception of Public Transport and agency in particular

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[4] The model used developed by Hickman does not incorporate the dwell times resulting from bus boardings and alightings. Hence, it could be argued that accurate information may generate even passenger loads on each vehicle and therefore the travel times may in fact change, but perhaps not significantly.

Hickman estimates that the impacts of passenger information systems on travel times is limited to an improvement of 1 to 3 percent (40). On the long run, benefits may accrue from increased ridership due to the improved public perception and the better reliability. London Transport reports that no significant ridership gains are reported from deploying its Countdown information system.

Again, a significant effort is needed to quantify these benefits. The best approach consists in monitoring variables that may infer changes in agencies that have deployed passenger information systems. These variables may include customer complaints, ridership (i.e., boardings), revenue, true maximum load, and the like. However, most of the benefits do not manifest through variables directly observable by the agency. Focus groups and surveys are adequate tools in assessing the impact and effectiveness of such information. Nevertheless, results from the use of surveys and focus groups to assess future benefits of a passenger information system should be carefully taken. Adjustments to the stated preference of people surveyed are necessary in order to estimate accurate effects of deploying the system.

The costs of the equipment vary according to the system used and where the information is conveyed. Typical wayside and in-vehicle display unit costs are shown in Table 7.1 The costs shown in the Table account only for the hardware (i.e., the physical unit). It is assumed that the agency has the locating technology. The only additional capital cost relates to relaying the information from the control center to the individual stops. Display or audio units inside the vehicles can be activated automatically or by the operator with a manual switch, depending on the sophistication of the application.

The costs of information kiosks also vary considerably, depending on the application. An operational test found that the hardware of an individual kiosk costs between US $10,000 and $12,000 including a large interactive screen, CD-ROM capabilities to handle the information and a dot matrix printer to provide hard copies (13). Adjustments should also be made to account for the fact that these kiosks were designed for indoor use and were not rugged enough to withstand outdoor operations.

The other high costs in deploying kiosks correspond to software development costs. For the same operational test mentioned previously, software costs were between

$10,000 and $15,000. This figure should also be adjusted upward taking into account that the software was developed in-house by a graduate student. Finally, the costs presented do not reflect the costs of implementing an AVL system, nor they consider the relay of information from a control center. This relay can be provided via FM frequencies at a low per kiosk cost.

D. Implementation Sites Worldwide

Passenger Information Systems have been deployed on a worldwide basis. This report focuses on three specific case studies that provide evidence to draw interesting conclusions about the implementation of such a system. Table 7.2 provides a summary of a survey of selected transit agencies having in-vehicle passenger information systems.

As shown in Table 7.2, the major agencies in the United States are moving forward with the installation of in-vehicle information systems. However, medium size agencies are not implementing the system on a general basis. In contrast, smaller agencies are effectively implementing the system or already have one in place. These smaller agencies provide a higher level of service because they correspond to small to medium size cities which tend to have fewer budgetary constraints. Also, in these cities motor bus is the only means of transportation available for the public which may partially explain the quality of service provided.

The cases studies selected focus on pre-trip and wayside information systems. Special attention is paid to the deployment process and the barriers encountered in such systems. Customer evaluations of the system and data on daily use is also reported, as an initial measure of success.

Los Angeles Smart Traveler Information Kiosks (61,62,63)

Pre-trip planning information services have traditionally offered information on a single mode, and the development efforts have concentrated in improving the speed and quality of the information. Only until recently, multimodal information is being provided, therefore enhancing its overall quality and effectiveness by enabling the user to make informed decisions. Kiosks, telephone systems and computer systems available at major trip generation points are the medium for delivering the information in the Smart Traveler Program. Los Angeles started this program as a test of integrating information on freeway conditions, transit routes and fares and ride-matching procedures to encourage carpooling and other shared rides.

Kiosks

The kiosks are multimedia PC-based systems for accessing the information. All the information except the videos is downloaded by the computer via modem from a central database. Information provided by the kiosk include bus, light rail, heavy rail and freeway conditions (13). Additional informational transportation videos are also offered. Most of the display is done by text, although the freeway congestion problems are displayed graphically. Information in English and Spanish is available. All the kiosks are linked to a central computer located in Sacramento, California, where all the information is centralized.

The central computer receives the information from three different sources: Caltrans for freeway conditions, Commuter Transportation Services for ride matching information and the transit agency of the Los Angeles County. This case as a good example of how three different public agencies can team together to provide innovative and successful public services.

In contrast, another kiosk pilot project in Northern Virginia found significant institutional barriers at almost *every* level (60). The design of the service and type of information used were very similar to the Smart Traveler kiosks. However, every party involved in the centralization of the data had particular objections to the system. WMATA did not provide its database of transit maps and schedules because the kiosk may potentially divert riders from its system. The local Bell Atlantic company initially opposed to the system because of security reasons, even though the kiosks were all located indoors.

In addition the telephone company found that the costs of operating the system via telephone dialups was too expensive.

Kiosk Use -Preliminary Results-

Kiosk use varied significantly , as expected, by location and to a lesser extent by day of week. Forty one of the 77 kiosk were analyzed in a preliminary evaluation. The kiosks with highest use were located in Union Station, in the downtown of Los Angeles, and on shopping malls. Of the five kiosks least used, three are in office buildings, one in a grocery store and another one in the Port of Los Angeles.

The average time in use of a kiosk is less than two hours per day. This means that kiosks are idle most the day. A preliminary explanation is that the kiosks were not promoted or marketed to the population. Given the absence of descriptive information, the location becomes very important. Union Square kiosks where located next to the ticket booth. Additionally, some kiosks had maintenance and operating problems, factors that decidedly lowered their average daily use.

Given the low usage of the kiosks in office parks, and the high usage in retail centers, it is concluded that the information is used for planning future trips rather than for immediate mode or route choice. Furthermore, non-work trip planning may be enhanced by the kiosk. In addition, high levels of use was evidenced in lower income areas, suggesting how the transit dependent population may be benefiting the most from such as system. Finally, the low usage in office complexes suggest that such a system is not effective in obtaining real time information for work trip planning. Cost assessment of the project and supplemented usage data will be provided in future evaluations.

The Smart Traveler field test proves the importance of having an adequate marketing research process before deploying the kiosks at specific sites. Site selection should also be heavily correlated with the target market(s) of the service(s) provided. Unfortunately it is very hard to estimate the effects these kiosks have on trip generation, mode shift and route selection, which may be the real measure of effectiveness of the system. Nevertheless, passenger surveys showed that users were content with the system and generally found it useful and user friendly.

London Transport(24)

In London, public transportation has been recently deregulated. As a result, London Transport (LT) has focused on centralized planning activities, whereas its subsidiary in the motor bus arena, London Buses (LBL) operates the bus services with other subsidiaries and new operators under a contract with LT. Therefore, LT still has a significant role in making sure that contractors adhere to both certain basic standards and their planning decisions. This environment generates both attractive opportunities as well as complications. Decision about technological implementations and innovation have been traditionally made by LT. LT has had a worldwide tradition in technological innovation worldwide, at par with the rest of Europe and Japan.

LT implemented a way-side (i.e., bus stop) passenger information system, also called "Countdown" on selected routes as a test project. This implementation came before the bus service was deregulated. Nowadays LT is still in charge of operating the countdown system; operators use their own vehicles subject to technological and capacity standards imposed by LT. Furthermore, LT provides the countdown equipment to each operator. The system was originally implemented to improve the reliability and overall level of service provided.

A study done in 1984 found that wait times at bus stops tend to be overestimated by passengers (64). Furthermore, passenger were willing to pay more for having information on expected wait times. Other studies confirmed the intuitive fact that the value of the information increases as the frequency of the service is lower, since the expected wait times depend on the service frequency.

Countdown works by providing expected bus arrival times. Therefore, passengers can estimate if they board a specific bus or weight for another bus serving a similar route. When a bus departs a stop the information is relayed to a control center where the departure time is used to estimated the expected arrival times at the following stations. Calculations are made based on previous observed and estimated travel times for the segment in question.

A summary of the major findings of the evaluation of the Countdown system performed by LT follows:

- Ridership effects are not clear. There is no significant changes in the short term.
- Benefits accrue mainly from passenger perception that wait times are shorter.
- Prediction algorithms may be further refined to gain more accuracy. However, it is questioned if the benefits from having additional accuracy would offset the costs of its providing it. Furthermore, increased accuracy may not decrease travel times significantly (40).

Finally, the cost of deploying the Countdown system was considerable. Lams (24) reports that the total annual costs, including maintenance and annualized capital costs, reach almost $1 million. However, the marginal cost of having another vehicle in the system is very low, because most of the costs are fixed.

Ottawa-Carleton Transportation Commission (OC Transpo) (24)

OC Transpo implemented a telephone information system known as the 560 System developed by Teleride Sage. The telephone system provides information on scheduled arrivals down to the bus stop level. Major stops have telephones installed so that waiting passengers can call the "560 number" and obtain the next scheduled arrival time. Unfortunately, the system does not provide real time information on the estimated arrival time, based on real time information.

Nevertheless the system is very popular among users. A survey showed that 20 percent of the trips were preceded by calls to the 560 system (65). Six percent of the interviewed passengers said that they are using the transit system more because of the 560 system; this would imply an increase of 1.2 percent in off-peak ridership. The system therefore has been beneficial for both the users and the transit agency.

However, OC Transpo realized the need for improving the telephone information system. With the recent deployment of the AVL system reported in Chapter VI, the agency is able to provide delay information through the same telephone system.

An intermediate step is being taken to assure a better transition from the current system to the enhanced one. Training of supervisors is increasing to enable them to respond faster to changes in the scheduled timetables. Also, they are currently being trained so as to include exception messages such as emergency information and abnormal traffic conditions that would cause delays (45).

Once the human component of the agency is comfortable with the information system, the data from the AVL system will be relayed and edited for the 560 system. Parallel to the 560 system the agency is implementing information displays at selected stations with high ridership, mostly located on trunk routes served by many routes. The passenger displays show the next arriving buses to the station, and therefore the passengers will be ready to board the vehicle. The system is implemented as a result of the delay generated by late arriving passengers requesting the driver to stop and let them board even if it has already moved from its assigned boarding area and is leaving the bay. Preliminary results from this program are not available yet.

E. Implementation in Puerto Rico

The use of kiosks as part of passenger information systems can become a key tool in improving the negative perception locals have about public transportation. Kiosks may provide static information about schedules on main routes, a calendar of events and even updates on the development of Tren Urbano. These kiosks do not have to be interconnected and can function independently. Their implementation is not costly and will require one full time person for the maintenance of the machines and the update of the information. Furthermore, the services may be contracted with a local supplier.

The kiosks may be a first step in coupling technology and public transportation for Puerto Rico. The benefits accrue mostly to passengers, an issue that is critical for the early stages of Tren Urbano. Depending on the location of the kiosks, they can provide access to both users and non-users of public transportation. It is suggested that the kiosks be located in two or three major transit centers, and in two or three major trip origins or destinations, such as Plaza de las Americas, or work centers as Centro Médico and Centro

Judicial. If both users and non-users perceive improvements in public transportation, Tren Urbano's success will be more likely.

AMA and Metrobus

The effort done by Eng. Edgar Rodríguez in organizing and publishing timetables and schedules should be commended. The first step in developing successful information systems is to provide static information at critical points, such as the soon to be realized transit centers, as well as in the major trip generators such as Old San Juan and the University of Puerto Rico. This information is also provided by the few kiosks implemented. Giving this information to the public is subject to the provision of reliable service. Making public schedules that are not followed may be a risky venture. Therefore, commitment not only from the promotion but from the operating areas of AMA is needed. Gradual improvements in the service will make way for the use of maps and schedules at the stops.

On a longer time frame, it is believed that a telephone system can be developed in order to gain information on schedules and headways. Further market research is necessary to determine if the current and potential users will benefit from the use of such a system. If the results are positive, this information system will initially contain static information. If use of the telephone system proves to be significant the upgrade to real time may be feasible when an AVL system is operational.

The deployment of a fully operational passenger information system is dependent upon the installation of an AVL system. Given the existence of AVL, real time information displays can de deployed at the transit centers. Implementation at main bus stops is an alternative, but there is concern about the equipment being stolen or vandalized. Based on the current needs of the transportation agencies and of the users of the transport system, a real time passenger information may not generate enough benefits to offset the high costs of its implementation. As mentioned in recommendations for other applications, AMA should focus on improving the endogenous causes of variation while simultaneously showing its (potential) users that improvements are being made. Passenger information systems, passive or active, may become the bridge between the agency and its customers.

The nature of the service provided by Metrobus is different. The reliability of the service is good, and passengers value its high frequency. Given that the headways for Metrobus are low, it is safe to assume that passengers arrived randomly at the stops. Hence, the value of a real time information for passengers is not necessary, as long as Metrobus maintains reliable service and exhibits adequate dispatch control and running times monitoring.

Static information could be provided in the same system as AMA's telephone system. Information on the headways by time of day would be enough for a passenger, given the low headway. In addition some other static information, such as route maps and stop locations, is quite valuable to passengers and should be maintained up to date.

Públicos

Given that the públicos do not have a fixed schedule and somewhat flexible routing capabilities, it is very hard to establish a passenger information system. Nevertheless, I will reiterate the believe that currently there is a segment of the market that is not being served by public transportation and that has to resort to private auto driving at a significant expense, or for lower transportation services, such as AMA's. The segment mentioned is composed of young executives, recent graduates, secretaries and the like. Therefore, it is recommended, as mentioned in Chapter V, that a new service of express públicos ("Público Premium") be offered connecting the multiple nuclei of the San Juan Metropolitan Area. This hypothesis needs to be tested by rigorous market research and Origin-Destination survey data, which in turn can also provide information about potential Tren Urbano users.

Público Premium provides an express, more comfortable, ride to other activity centers. Since the level of service is better, the cost for the service is also higher. Nevertheless, this service will also become a link between potential Tren Urbano users and public transportation. When Tren Urbano becomes operational, Público Premium will become a demand responsive system with AVI tags providing remote seat reservations from kiosks at Tren Urbano stations.[5]

On the long term, Tren Urbano will also have some degree of passenger information systems to comply with the ADA. The contents of the messages can be drawn from the possibilities mentioned at the beginning of the current Chapter. In addition to the basic in-vehicle and station information, it is recommended that other types of information be provided at the station. The effect of having weather information, or trivia questions is twofold. First, passengers may value highly the information provided(e.g., weather reports). Second, the perceived wait time at a station decreases creating some benefits for both the passengers and the agency.

Tren Urbano information should also be provided via a dial-in telephone system, containing station location and schedule information. In addition, these services can also include emergency messages and the report of incidents and exceptional delays on the rail lines.

Finally, the information process will be completed if a truly integrated information center is conceived. This center may receive modal information about each specific agency and will distribute it via cable TV, computer dial-ins, radio reports, personal pagers and the like. Only when complete or close to complete information about the delays in every mode is provided, a system optimum equilibrium of flows (and delays) will be achieved.

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[5] See Chapter V for a more thorough description of the service.

Table 7.1: Cost to Purchase/Install/Retrofit

Type of Vehicle	Information System	Per Vehicle/Stop Cost ($)
Rail	Audio & LED	6,500
Rail	LCD	6,000
Bus	Audio & LED	3800*
Bus	Audio & LCD	4,050
Bus	Audio	5,550*

*Average Figures from various vendors

Source (59)

Table 7.2 : In-Vehicle Passenger Information Systems -Selected Agencies-

Agency	Annual Unlinked Pax Trips millions	System Operated	# Vehicles Operated in Peak Period	AVL	Audio/Visual Display System	Plans to Implement
Chicago RTA/CTA	508.7	MB;HR	1,791 ;924	No	No	In 2 yrs.
NY MTA/NYCTA	2,000	MB;HR	3,050;4,923	No	Display Yes Audio Ordered	
NJ Transit	160.6	MB;HR;LR	1,608; 627; 16	No	No	In 1 yr.
MBTA	323.7	MB;HR;LR	838; 224; 368	No*	Display limited Audio Yes	
Utah Transit	27.3	MB	422	No	No	
Portland Tri-Met	61.4	MB;LR	442; 22	Yes	No	
San Diego Transit	35.8	MB	254	No	No	
Monterrey Salinas,CA	3.6	MB	50	No	Audio Only	
Toronto Transit Commission	404	MB;HR;LR	1,398; 546; 267	Yes	No	RFP In Progress
Montreal Urban Community Transit Corp. (STCUM)	352 (linked)	MB;HR;CR	1,367; 759 ;91	Yes	Display Yes Audio Yes	
Rochester Regional Transit	14.9	MB	174	No**	Being Tested	
London Transport (London, UK)	1,885	MB;HR	6244***	Yes	Display Limited	
Hamburger Hochban (Hamburg, Germany)	383	MB;HR	826***; 855	Yes	Being Installed	
AB Storstockholms Lokaltrafik (Stockholm, Norway)	547	MB;HR;LR	1,709; 829; 17	Yes	Display Yes Audio Yes	

Source: (59)

MB: Motorbus; **HR**: Heavy Rail; **LR**: Light Rail; **CR**: Commuter Rail
*Limited Signpost System Only
** GPS being installed
***Including Contracted Services

VIII. Preliminary Conclusions and Implementation Priorities

The construction of Tren Urbano opens a window of opportunity for the deployment of modern technologies in the transportation system of the SJMA. ITS, viewed as communication and information systems and technologies, is considered as supportive of Tren Urbano, rather than competing against it. It can possibly enhance the level of service of the transportation system and can improve the public's perception of mass transit.

The focus of the study centered on three of the five core ITS applications for metropolitan areas. Since most of the core elements are interrelated, the other two elements were indirectly also addressed.

After analyzing the individual applications, a recommendation about the implementation of each technology is made. It becomes clear that in the long run, a traffic management system anchored on the successful development of electronic toll collection systems, and some public transportation and traveler information systems initiatives, are feasible for the SJMA. The early development of these anchors may prove to be critical not only to the development of ITS but to the political success of its proponents, and ultimately, to the attraction of users. A summary of the conclusions and recommendations for each application is presented next, with a summary of the prioritization of their implementation.

Smart cards

The proposed changes to the transportation system of the SJMA brought by Tren Urbano generate two decision-making scenarios for fare payments and structure: policy and technology. Policy decisions include the structure and level of the fares. It is recommended that fare policies should be integrated for both AMA and Tren Urbano to allow for better intermodal transfers and to convey a solid image of the system to the public. This suggests that the structure should be developed with the customer in mind, even though fare levels may differ. The structure should also have both rail and bus services as a common basis, resulting in the maximum allowable integration and ease of use.

The technology-related decisions include the fare collection strategy, the level of automation and the type of equipment needed. Given that fare integration is recommended, a natural step is therefore to further suggest technological integration between the motor bus system and Tren Urbano. New fare collection media provides the following benefits:

- Fare evasion decreases
- Variable pricing is enabled
- High quality data about riders is collected at low cost
- Although increase in maintenance and personnel training is foreseen, long term reduction in costs is expected, particularly from fare collection labor costs

Smartcards are a specific type of technology recently developed that can be implemented for fare collection, electronic toll collection, bank account information and handling of personal information among other applications. The cards contains a chip embedded into its thin structure hence improving security in transactions. The card also has large memory capacity (up to 2MB) to store information. After comparing the benefits and costs of a smartcard with a magnetic card, and analyzing their current implementations, it is recommended that magnetic cards be used as the common technology for fare collection. Magnetic cards offer most of the benefits of smartcards in addition to the following:

- Have a proven track record of satisfactory performance in multiple transit agencies
- Have low implementation costs compared to smartcards

Advanced fare payment media may face institutional barriers that arise from the need of sharing common goals and ensuring strategies to achieve them. In terms of smartcards, stronger public-private partnerships are needed, and several regulatory constraints need to be addressed. In the long run, information capacity, issues of security and the development of multiple applications will popularize smartcards. However, magnetic card equipment can be retrofitted to read smartcards without a significant investment.

Electronic Toll Collection

There is a need for reduction of traffic delays at the toll plazas in the SJMA. Electronic toll collection (ETC) provides benefits by decreasing delay times per person and reducing vehicle emissions. Therefore, a rigorous deployment plan should develop specific measures of effectiveness to monitor the relative success of the program. In addition, the current political will can serve as a catalyst for the deployment of electronic toll collection. The system has to be anchored in regional, if not national, architecture standards that will provide future technological enhancements and service options. Radio frequency or microwave systems are recommended for implementation, largely because they offer the best operating performance and a good platform for further services.

There are risks associated with ETC deployment, such as the enforcement of the toll. However, the system cannot have gated exits at each booth, as the T. Moscoso Bridge, because the benefits of an ETC system can become nonexistent. The success effectively depends on user market penetration which in turn may depend on the real benefits the system offers. There is a clear potential for an island-wide initiative, not limited to the SJMA. Market penetration should be ensured through an adequate planning process that includes market research and engineering studies, as suggested in Chapter IX. Consecutive bottlenecks after the toll plazas on certain highways should be studied rigorously to obtain a better picture of potential critical points if the flow at the plazas is expedited.

It is suggested that the toll levels should not change due to the development of ETC. Furthermore, a monthly flat fee toll structure is recommended as additional incentive (besides the delay savings) for públicos, in order to increase their efficiency, productivity and the supply of service.

Electronic Toll Collection, can be the first ITS success story for Puerto Rico. The ACT should act promptly in setting up a development that includes both testing and issuing a request for proposals. The time frame of this implementation is 0 to 2 years.

Automated Vehicle Location and Public Transportation

Automatic Vehicle Location (AVL) is a system that determines the location of a vehicle and communicates the information to a decision agent that acts upon it. This information is valuable to transit services because it can be used to improve operating performance. A vehicle location system has two uses: off and on-line.

On-line uses consist of a decision agent, such as a supervisor or driver, providing different control strategies(e.g., short turning, holding) to maximize adherence to the operating plan. Off-line uses are limited to the provision of information for monitoring the service and evaluating its performance, such as running time and schedule adherence information. Potential benefits of an AVL system include:

- Improved public perception of mass transit
- Increased efficiency, reliability and overall system performance
- Improved data quality and decreasing collection costs
- Potential for implementing real-time passenger information systems

However, there are also some costs and potential risks:

- Increase in operating costs due to maintenance of the equipment
- Organizational discontent due to system complexity
- Unreliable or bad quality equipment

AMA

After analyzing running time data for four AMA routes, and given the current circumstances, it is found that significant improvements in running time variability can be achieved without deploying expensive AVL technology. Several phases were recommended, agreeing with the Strategic Improvement Plan developed for AMA.

Phase I, the critical Phase in the deployment process, consists of redesign of the data collection effort, reassignment of supervision and monitoring posts, and movement towards incorporating most of the organizational constraints in the planning and scheduling tasks and abiding by them. The overall objective is to develop a reasonable operating plan that takes into account most endogenous and exogenous factors. This Plan agrees with the proposed network restructuring effort currently undertaken. The time frame for this application is between 0 and 3 years.

Phase II consists of evaluating Phase I and proceeding with testing automated data collection techniques if the results of Phase I are satisfactory. Once the organization has proved that it can effectively change, an AVL system can start to improve both the on-line control strategies and the off-line analysis. The envisioned trunk routes with low headways can benefit significantly from such a system. The recommended development for this Phase should start in 3 or 4 years.

Phase III could therefore consist of the selection and deployment of a technology chosen from those tested. Phase III is the true AVL system, and would only be deployed 5 to7 years from now, at the same time Tren Urbano opens to the public.

Metrobus

Even though Metrobus' current performance is considerably better than AMA's, some added benefits can be sought by applying AMA's first Phase. As a result of the analysis of the Northbound route, for example, it is shown that dispatching at the Capetillo and Covadonga terminals needs to be improved to reduce variability in the service.

There are some limitations to any possible real time control strategies that can be implemented. Due to the limited right of way along the contraflow lanes, it is impossible to have a bus passing another one in a leap-frogging type of scheme. In addition, having the

AMA buses on the lane also imposes some additional constraints to the operation of the system. Therefore, no AVL system is needed for Metrobus operations. Rather, supervisory improvements in the dispatching terminus and along the way can help maintain the necessary headway.

Automatic Vehicle Identification and Signal Priority for Public Transportation

The benefits accrued by signal priority schemes are decreased trip times, a possible reduction in fleetsize requirements, improved productivity, decreased fuel consumption and better headway and schedule adherence. All these translate into a better level of service for the passenger, who may experience less waiting times and better distributed loads on the buses.

AMA

AMA's current routes tend to have very low frequencies and high running times. Decreasing running times with signal priority systems would provide modest benefits to existing riders and would have little or no effect on fleetsize requirements or operating costs. On the contrary, costs of implementation and operations may probably outweigh significantly the few benefits accrued.

Under the route re-design process, the three trunk routes having ten minute headways are possible candidates for signal priority. Furthermore, signal priority systems can be critical to accessing the new transit centers to be operational in October 1995. These centers are located in activity nuclei and therefore have significant vehicle flow and controlled intersections.

As a result, the creation of a task force is recommended once the transit centers are operational. The task force is composed of ACT, AMA, Metrobus and público representatives discussing alternative locations for test priority intersections. The task force should have the specific duty of arranging test procedures for signal priority. Collaboration of the FHWA regional office may also be necessary. In addition, the task force will develop and use measures of effectiveness to assess the impact of the tests on the stakeholders (i.e., pedestrians, private vehicle driver's and each individual agency or association). If considered necessary, the task force will develop an RFP having system interoperability and general architecture concerns in mind. The implementation of this application should start in 2 to 4 years, or until completion of most of the transit centers.

Inductive loops or the proprietary detectors developed by the ACT should be used in the tests, unless accurate GPS systems are implemented on AMA's vehicles. In that case, the additional investment for system compatibility is justified.

Any analysis of signal priority implementation should be done at the most disaggregate level, almost intersection by intersection. Benefits and costs are directly linked to passenger demand for public transport and vehicular and pedestrian flow at each particular intersection.

Metrobus

Analysis of Metrobus information show that most of the traffic light delays in the Northbound direction were caused in the first third of the route. It is not surprising therefore to find that headways effectively deteriorate the most along this segment.

A signal priority system implemented in only five intersections would decrease running times approximately two and a half minutes. Given the low headway during peak hours, this may imply savings of up to one vehicle. Cross street effects are not significant. However, the MIST system that synchronizes lights and changes cycles by time of day has been recently installed by Farradyne Systems along Muñoz Rivera and Ponce de León. This implementation is centered on improving private vehicular flows and therefore hinders the possibilities of signal priority in the corridor.

Passenger Information Systems

Due to the current state of passenger information systems in the SJMA, the analysis and short-term recommendations focus on static information. Static information does not change over short periods of time and therefore does not reflect the actual field conditions. Static information can be used to provide a better level of service to current users as well as to promote the service in current markets that do not use public transportation.

Short-Term Recommendations

The use of information kiosks as part of passenger information systems can become a key tool in improving the negative perception locals have about public transportation. Kiosks may provide static information about schedules on main routes, a calendar of events and updates on the development of Tren Urbano. These kiosks do not have to be interconnected and can function independently. Their implementation is not costly and will require one full time person for the maintenance of the machines and the update of the information. Furthermore, the services may be contracted with a local supplier.

Depending on the location of the kiosks, they can provide access to both users and non-users of public transportation. It is suggested that not more than four kiosks be located in two or three major transit centers, and in two or three major trip origins or destinations, such as Plaza de Las Americas, or work centers as Centro Médico and Centro Judicial. If both users and non-users perceive improvements in public transportation, Tren Urbano's success will be more likely.

AMA and Metrobus

Passenger information systems, static or in real time, may become the bridge between the agency and its customers. It is recommended that AMA should start publishing the operating timetables and schedules as soon as possible. The first step in developing successful information systems is to provide static information at critical points, such as the soon to be realized transit centers, as well as in the major trip generators such as Old San Juan and the University of Puerto Rico. This information is also provided by the few kiosks implemented. Providing this information to the public is subject to improvements in the service, or else the results may be counterproductive.

Long-term Recommendations

Given the implementation of an AVL system, information about arrival times and bus location should be relayed to both transit centers and Tren Urbano Stations. AMA can also develop a simple and inexpensive telephone system providing static information. For Metrobus operations, it is considered that real time information for passengers is not necessary, as long as reliable service is maintained and adequate dispatch control and monitoring of running times is exhibited.

Tren Urbano will also have some degree of in-vehicle passenger information systems to comply with the ADA. Terminal and in-vehicle information may include: vehicle location, stop, transfer and connections, delays, routes and schedule changes and emergency information. The intermodal character of this information should be highlighted.

Proposed New Service -Público Premium-

The proposed new service, that may be called "Público Premium" or "Público Ejecutivo", targets a segment of the population that may shift modes given adequate incentives. This service is consistent with Tren Urbano's stated goals , since there can be potential reductions in traffic congestion.

Currently, the segment composed of young executives, recent college graduates, secretaries, middle managers and the like, is not being served by public transportation and has to resort to private auto driving at a significant expense for them and for the transportation system. Likewise, the service targets current público riders that are willing to pay a premium for reliability and a higher quality of service.

The concept relies heavily on the existing público scheme, drawing from the positive attributes and minimizing the current negative characteristics. It is also developed in recognition of the importance of providing public transportation to a market that is currently not served, as well as to provide future access to Tren Urbano. The operations of this new service can be enhanced and expedited by the use of information technologies. These technologies can also play a fundamental role in linking the Público Premium with Tren Urbano.

The service is planned in two Phases. During the first phase, Público Premium is an express service connecting nuclei of the SJMA. The market towards Old San Juan during the morning peak and outbound in the afternoon is particularly important for the proposed service. The second Phase starts when Tren Urbano opens to the public. Information technologies will enable reservations of públicos from distant Tren Urbano Stations. The transition between both Phases will be done by introducing the demand responsive service during the morning peaks before Tren Urbano opens.

The implementation of the applications studied for the SJMA is prioritized according to the benefits and costs of the systems, as well as the time frame for development. Table 8.1 on the next page summarizes the recommendations of implementation of each application presented above. Most individual applications received a graphical implementation rating. Other applications such as vehicle location systems are subdivided into the suggested evolutionary deployment; hence, each Phase is rated separately.

Table 8.1

Information Technology Application		Rating
Advanced Fare Payment Media		❸
Electronic Toll Collection		❶
Automatic Vehicle Location		
	Phase I	❶
	Phase II	❷
	Phase III	❸
Bus Signal Priority		
	AMA	❷
	Metrobus	❶
Passenger Information Systems		
	Static	❶
	Real Time	❸
Público Premium Service		❷

Rating Scale:

❶ Prompt implementation recommended

❷ Implementation in 2-4 yr. recommended

❸ Implementation in 4-6 yr. recommended

IX. Further Research

The current report opens opportunities for further study in two categories. The first category includes research that does not pertain to an individual technology but that focuses on issues regarding innovation and change in a transportation agency. The second category relates to specific issues that may be explored in individual information technologies that may have some immediate added value for the San Juan Metropolitan Area.

Category 1

-A study of the possible funding arrangements for ITS in the Island. The project may explore Section 9 funding for public transportation applications, FHWA Grants , and earmarked funds among others. It may further include the effect of the changes proposed in the US Congress on ITS financing.

-A prevalent concern of agencies that have deployed some of the applications studied was the lack of institutional readiness to adopt the new technology. The applications change the way agencies operate and their time frame. Institutional barriers within an agency can be modeled in further research. In the San Juan context, given the new service brought by Tren Urbano, inter-agency frictions and barriers may also hinder its successful development.

Hence, the research may alternatively concentrate on studying the effect new services of Tren Urbano's magnitude have on existing agencies and how to accommodate change most effectively.

-The role of a system architecture in the success of technological innovations can be a critical aspect of ITS. The architecture developed for Puerto Rico, whether regional or local, can become an interface between institutions and technologies implemented, thereby serving as a tool in overcoming questions of institutional readiness.

Furthermore, the use of the architecture as an element to reduce inter-institutional conflicts can also be explored. The architecture can become a crucial element in a succesful integration between ITS applications and Tren Urbano.

-Should developing countries have a policy on technology, or should the technology transfer process be left to private firms ? Furthermore, should a fundamental transportation investment, such as Tren Urbano, be equipped with technological add-ons such as ITS applications? Where is the line drawn? Puerto Rico may serve as a case study because its institutional arrangements are typical of many developing nations. Other cases may be drawn from both developed and developing countries.

Category 2

Smartcards

-Development of a framework for establishing fare policies given the introduction of new services, such as Tren Urbano. The framework may include the design, technology and fare structure decision-making realms. The issue of fare integration among modes may be discussed.

Electronic Toll Collection

-The benefits of ETC in Puerto Rico can be measured by the decrease in delay times per person and improvements in vehicle emissions. Therefore, a rigorous deployment plan should develop specific measures of effectiveness to monitor the relative success of the program. In addition, the current political will can serve as a catalyst for the deployment of electronic toll collection. A joint research project between MIT and UPR may be developed creating a simulation model for a toll plaza in Puerto Rico in order to quantify the effects of ETC. Input parameters may include the arrival rate, service times, number of lanes and the like. Output parameters may include the reduction in person and vehicle delay, queues, environmental effects and other performance measures.

Sensitivity analyses may be performed on market penetration of ETC and number of lanes. Collaboration of the ACT is needed to gather specific information about the traffic in the SJMA , such as arrival and service rates at toll plazas for different times of the day. This research can be furthered by using this information to produce a benefit-cost analysis.

- A less complex approach can include observing the rates at an individual station and calculating the benefits of having an ETC lane there. This analysis may also study O-D flows to come up with the possible congestion effects generated downstream from expediting flows at the toll plaza.

Bus Signal Priority

-Another joint program involving MIT and the UPR is proposed. Local knowledge is necessary for identifying intersections to develop signal priority schemes. Interaction with AMA (drivers and route planners) and observations at the intersection themselves are necessary. The bus and traffic delays, as well as pedestrian movements at the chosen intersections are recorded.

Then, the benefits of a signal priority scheme are evaluated based on the considerations of the local intersection; the results may be a persuasive argument in making a decision on signal priority for the SJMA. Three models may be needed: private vehicle delay, public vehicle delay and pedestrian delay. The group may include a UPR architecture student to evaluate the conditions of the intersections and report upon them. The MIT student may simulate the delays based on the results given by the UPR student and analyze the sensitivity to the parameters used as inputs.

Automatic Vehicle Location

-Application of control strategies for a specific AMA route and the Metrobus route. This research may focus on studying real time strategies to improve service on both routes, comparing and contrasting their operating characteristics . The project may study current control practices and suggest improvements A running time model could be developed and tested to enhance the control operations. Results may be simplified and tabulated so that dispatch supervisors can apply it without a major effort and tested if AMA and/or Metrobus are willing.

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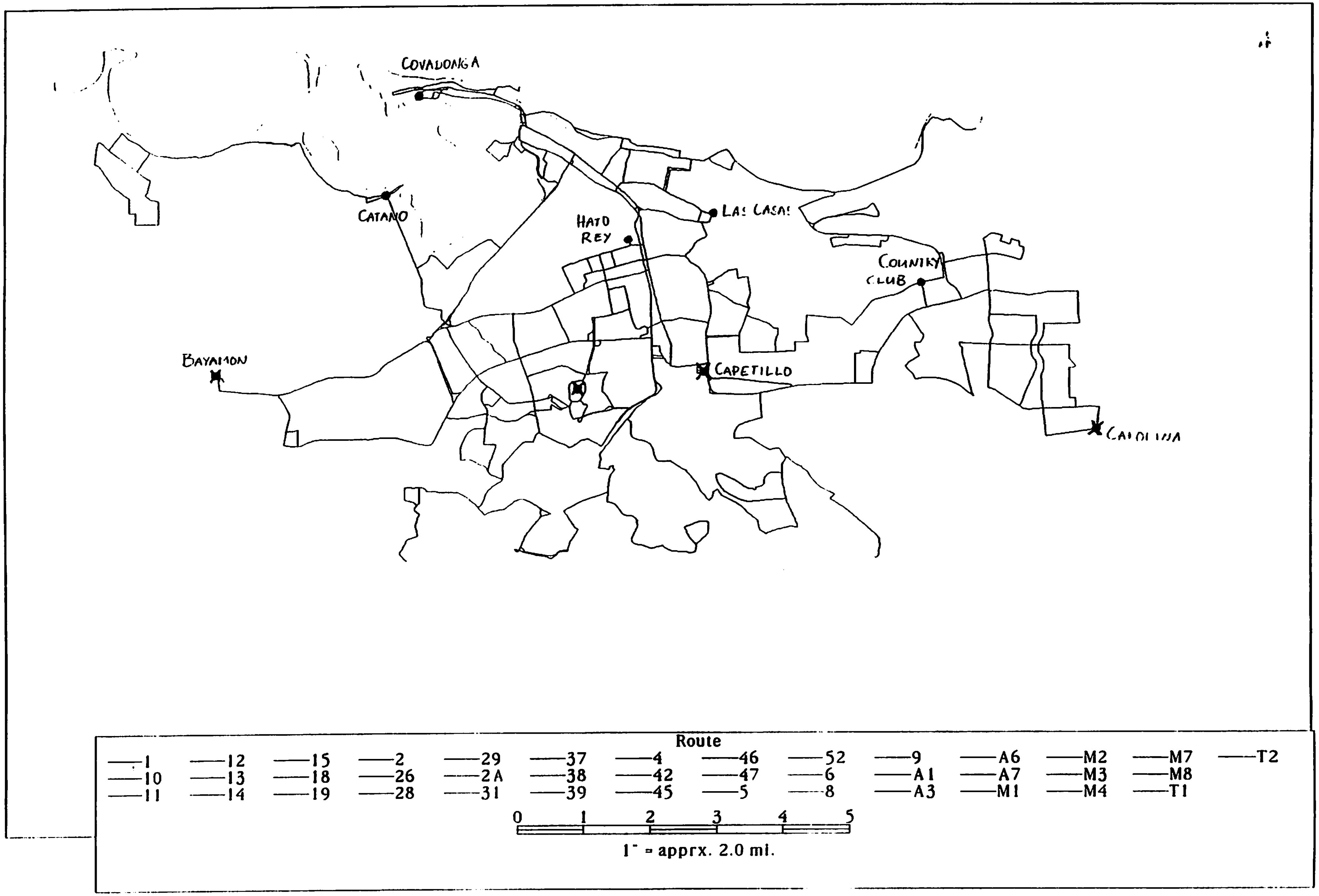
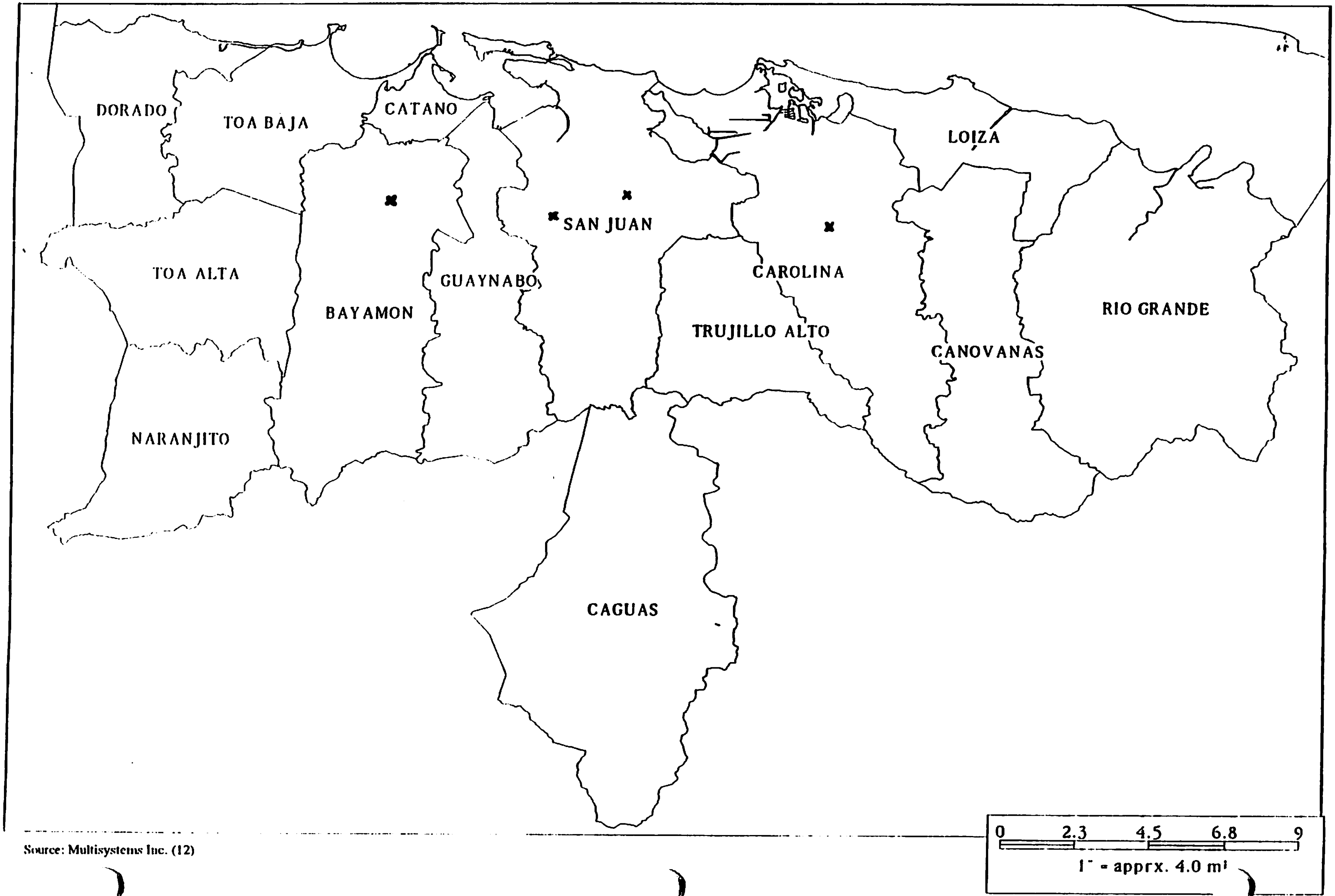
APPENDIX 1

MAP 1
AMA Routes



MAP 2

San Juan Metropolitan Region (SJMR)



Source: Multisystems Inc. (12)