National Cooperative Highway Research Program

NCHRP Synthesis 194

Electronic Toll and Traffic Management (ETTM) Systems

A Synthesis of Highway Practice

Transportation Research Board
National Research Council

National Cooperative Highway Research Program

Synthesis of Highway Practice 194

Electronic Toll and Traffic Management (ETTM) Systems

MICHAEL C. PIETRZYK
EDWARD A. MIERZEJEWSKI
Center for Urban Transportation Research
University of South Florida

Topic Panel

JIMMY D. BERRY, *Oklahoma Turnpike Authority*
CHESTER H. CHANDLER, *Florida Department of Transportation*
RICHARD A. CUNARD, *Transportation Research Board*
MAUREEN GALLAGHER, *International Bridge, Tunnel, and Turnpike Association*
TIMOTHY D. HAU, *The World Bank*
PERRY M. KENT, *Federal Highway Administration*
LESLIE G. KUBEL, *California Department of Transportation*
RICHARD L. RIDINGS, *HNTB Corporation*
GEORGE W. SCHOENE, *Federal Highway Administration*
HERBERT F. SOUTHGATE, *Lexington, Kentucky*

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

Research Sponsored by the American Association of State Highway and Transportation Officials in Cooperation with the Federal Highway Administration

NATIONAL ACADEMY PRESS
Washington, D.C. 1993

Subject Areas
Pavement Design, Management, and Performance

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NOTE: The Transportation Research Board, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

NCHRP SYNTHESIS 194

Project 20-5 FY 1992 (Topic 24-06)
ISSN 0547-5570
ISBN 0-309-05318-8
Library of Congress Catalog Card No. 93-061550

Price $15.00

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the Federal Government. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

The Transportation Research Board evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis on Electronic Toll and Traffic Management (ETTM) systems will be of interest to officials of toll authorities, traffic engineers, design engineers, law enforcement officials, financial personnel, developers and vendors of electronic vehicle identification and toll collection equipment, and others responsible for the design and operation of toll facilities. The technology, including examples of applications of several current ETTM systems, is described in this synthesis. Because the technology is in the early stages of implementation, there is little experience with the "TM" (traffic management) aspects of ETTM; however, the potential for traffic management systems is discussed.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

Various electronic toll collection (ETC) and automatic vehicle identification (AVI) systems, their characteristics, advantages/disadvantages, payment options, and performance experience are described. The computer requirements and relative costs of various applications are also discussed. This report of the Transportation Research Board presents information on specific system design and operational considerations, as well as on the more sensitive issues of enforcement, privacy, and equity in providing these advanced systems. This technology is changing rapidly, and the synthesis presents a "snapshot" of the industry at the time of its preparation.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

ACKNOWLEDGMENTS

Michael C. Pietrzyk and Edward A. Mierzejewski, of the Center for Urban Transportation Research, University of South Florida were responsible for collection of the data and preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Jimmy D. Berry, Chief Engineer, Oklahoma Turnpike Authority; Chester H. Chandler, ETTM Project Manager, Florida Department of Transportation; Richard A. Cunard, Engineer of Traffic and Operations, Transportation Research Board; Maureen Gallagher, Director of Research and Member Services, International Bridge, Tunnel, and Turnpike Association; Timothy D. Hau, Economist, Public Economics Division, Policy Research Department, The World Bank; Perry M. Kent, Transportation Specialist, Federal Highway Administration; Leslie G. Kubel, Chief, Office of Electrical and Electronic Engineering, California Department of Transportation; Richard L. Ridings, Vice President, Central Division, HNTB Corporation; George W. Schoene, Chief, IVHS Operational Tests Division, Federal Highway Administration; and Herbert F. Southgate, Chief Research Engineer (Retired), Kentucky Transportation Center.

The Principal Investigators responsible for the conduct of the synthesis were Sally D. Liff, Manager, Synthesis Studies, and Scott A. Sabol, Program Officer. This synthesis was edited by Linda S. Mason.

Valuable assistance was provided by Frank R. McCullagh, Senior Program Officer, National Cooperative Highway Research Program, Transportation Research Board.

Information on current practice was provided by many transit agencies. Their cooperation and assistance were most helpful.

ELECTRONIC TOLL AND TRAFFIC MANAGEMENT (ETTM) SYSTEMS

SUMMARY

Electronic toll collection and traffic management (ETTM) systems are not a futuristic dream, they are operating or are being tested today in locations across the United States and around the world. ETTM systems equip vehicles with electronic tags (or transponders) that communicate with roadside sensors to provide automatic vehicle identification that allows for toll collection at the toll booth, and general vehicle monitoring and data gathering beyond the toll plaza. The information in this synthesis may be expected to become outdated as the electronic toll collection industry is changing rapidly. However, this synthesis has been prepared to share general information regarding ETTM systems to inform the evaluation and decision-making processes.

ETTM systems have the potential to reduce congestion, improve safety, energy efficiency, and air quality, and enhance economic productivity at a cost significantly less than additional road construction. Automation of toll collection can reduce congestion at toll plazas. ETTM systems can also assist in the rapid detection and clearing of accidents, which can result in reduced congestion and secondary collisions. By providing real-time traffic information to travelers, ETTM can help travelers to avoid congestion by allowing them to delay their trips, choose alternative modes of travel, or bypass congested routes altogether. ETTM also provides the capacity to implement demand management systems based on road pricing.

Several major ETTM implementation issues should be carefully considered during the evaluation and decision-making processes. Several technologies exist that differ according to the operating frequency, the method by which the signal is modulated, and whether the vehicle tag, or transponder, simply reflects or generates electromagnetic signals. There are operational trade-offs with each technology, but very few field performance evaluation data are available. ETTM system design must consider factors affecting accuracy and reliability, such as the possibility of electrical interference, the ability to recognize vehicles with metal oxide windshields, and the transponder installation. Several patron payment options and agency financing/operating alternatives exist; each offers distinct advantages and disadvantages to both user and agency.

ETTM perception surveys (for existing and potential users) have not been widely conducted. ETTM generally has received favorable comments, but further user perception surveys would be useful in identifying the market potential, most effective marketing strategies, and most acceptable and desirable technology features. Also, as might be expected, legalities of ETTM operation are also being challenged. Legal issues surrounding the operation of ETTM systems primarily focus on enforcement techniques and related privacy concerns. Several states are in the process of passing legislation that would permit photographic enforcement as a means of monitoring and addressing violators.

There are also a number of other legal issues that could affect ETTM deployment, such as product liability, antitrust, procurement, and intellectual property rights.

Over the past decade, a technological revolution in transportation and information has begun to transform individual mobility into an integrated, coordinated system by providing more efficient travel choices. ETTM can contribute to completely modernizing how we drive and how we make decisions during our travels. For the transportation industry, advancements in computer and information technologies have arrived just when they are most desperately needed.

CHAPTER ONE

INTRODUCTION

A car passes through a toll plaza without coming to a stop. A tag installed on the car by the driver communicates with a computer located at the toll booth. The computer identifies the account associated with the tag and deducts the amount of the toll from the account balance. Two months earlier, the driver went to a tag store and prepaid a few months' worth of tolls with a credit card. The patron could have paid for the tag in cash to ensure privacy, but decided that using credit was the more convenient option. At the toll booth, the long lines of patrons waiting to pay tolls have disappeared. The toll agency's revenue collection process is more efficient and more secure, and the detailed information about patron's travel patterns has enabled the agency to try more experimental pricing policies, such as time-of-day flexible fares and discounts for carpools.

The scenario described above is not a futuristic dream. It describes electronic toll collection (ETC) projects operating today in the United States and around the world. In Dallas, New Orleans, Denver, and throughout the Oklahoma Turnpike system, agencies have implemented high-tech toll collection systems that have reduced congestion and improved the efficiency of revenue collection. Automatic vehicle identification (AVI) is the technology that makes these systems possible. AVI works by using wireless communications between a tag (transponder) mounted on a vehicle and a sensor located at the roadside. The vehicle can be a car, truck, or rail car. Sensors can read the information while the vehicle is stopped or while it is moving at high speeds. The communication between the tag and sensor can be one-way (read-only) or two-way (read/write). AVI can be used for a variety of purposes in addition to the collection of tolls. Transponders can be mounted on trucks to eliminate the need to stop at state and national border crossings, or on buses and taxis for more efficient fleet management.

Electronic toll collection and traffic management (ETTM) expands on AVI and ETC concepts by using communications between vehicle and roadside to provide a full range of traffic management functions. For example, vehicles passing through toll plazas can act as probes within the traffic network. The time it takes one vehicle to travel between the entrance and exit of the toll road can give traffic operators information about the level of congestion on that road. The more detailed information available to toll authorities can also be used by traffic engineers to respond to changing travel patterns. New pricing policies, made easier by the computers and tags, can be used to affect travel demand.

The interrelationship among AVI, ETC, and ETTM can be explained as follows. AVI involves wireless communication between transponder-mounted vehicles and roadside, overhead, or in-pavement sensors. ETC is the use of AVI technology for more efficient collection of tolls, without any action required by the driver or toll collector. ETC is considered to be the "foundation" for an ETTM system. ETTM uses AVI technology not only for toll collection, but for more broad-based traffic management purposes. For example, the transponder mounted on a vehicle for electronic toll collection can be used to track vehicle location and monitor travel time in real-time outside of the toll plaza environment. All ETTM systems would include a component of electronic toll collection, but not all traffic management systems include a component of electronic toll collection. While it is recognized that portions of the information contained in this synthesis will soon become outdated, the purpose of this synthesis is to outline the issues that a toll agency should consider when implementing ETC.

PURPOSE AND OVERVIEW

Electronic toll and traffic management systems are being evaluated and implemented throughout North America and abroad. Despite this broad interest, there are no fully integrated ETTM systems in operation at this writing. ETTM is the term used widely by both toll industry vendors and agencies basically to give credence to the potential for electronic toll collection systems to be integrated into more broad-based traffic management systems. This report represents more of a synthesis of electronic toll (the "ET" part of ETTM) collection, and basic background on traffic management (the "TM" part of ETTM) systems. ETTM is perceived as synonymous with ETC by the intended audience of this synthesis. Please note that a glossary of abbreviations is included in Appendix A.

Because transportation agencies are in various stages of ETTM implementation, a synthesis of emerging technologies and applications is of interest to many transportation providers. This report has been prepared for the primary purpose of sharing general information regarding ETTM systems so that the evaluation and decision-making process may be more informed and productive. Information for this synthesis was derived from available literature and surveys of operating systems, toll industry vendors, and consultants.

The synthesis discusses toll collection and traffic management system aspects of ETTM including:

- The role of ETTM in transportation,
- Alternative technologies,
- System design considerations,
- Institutional and implementation issues (including privacy, legal, and equity issues),
- Traffic management applications of ETTM (including commercial vehicle operations and bus/fleet management), incident detection and management, traffic flow and special event management, and traveler information services,
- A brief summary of the major ETTM projects,
- Results of surveys of both vendors and toll agencies conducted for this synthesis and surveys by the International Bridge, Tunnel and Turnpike Association (IBTTA), and

FIGURE 1 Congestion on Florida Turnpike.

• Future directions for ETTM systems, report conclusions, and an ETTM bibliography.

ROLE OF ETTM IN TRANSPORTATION

Many of the nation's roads are well below acceptable levels of service, and the mobility we all expect is being threatened. Congestion like that shown in Figure 1 continues to increase, while the option of building more roads is becoming financially and environmentally unrealistic. There is no single answer to the set of complex transportation problems that confront us. However, ETTM systems have the potential to reduce congestion, improve safety, energy efficiency, and air quality, and enhance economic productivity, at a cost significantly less than additional road construction (*1*). ETTM systems are not a distant vision. Many existing systems, products, and services are being tested and will be implemented soon.

Fully operational ETTM systems can help reduce street and highway congestion in a number of ways. Automated toll collection can reduce nonrecurring congestion around toll plazas. Rapid detection and clearing of incidents will reduce congestion and the secondary collisions that frequently result. Enhanced public transportation systems can reduce the number of single-occupant vehicles. Real-time dynamic traffic control systems can adapt to traffic conditions automatically. Information provided to travelers will permit many to avoid congestion by allowing them to delay their trips, choose alternative modes of travel, or bypass congested routes altogether.

ETTM systems can also provide valuable information to drivers, offering the potential for improvements in traffic safety. Advanced traffic control systems can reduce the number of vehicle stops, minimize the variations in vehicle speeds, improve traffic flow, and consequently reduce the number of accidents. Reducing congestion and the number of single-occupant vehicles will increase the energy efficiency of the transportation system. Emissions will be reduced by smoother traffic flow and a greater usage of public transportation and ridesharing. ETTM also provides the capability to implement demand management systems based on road pricing to shift or limit travel demand. Several airports in the United States (Los Angeles International, Minneapolis, Pittsburgh, and Miami International) are also using AVI technology for collecting "impact/congestion fees."

Finally, the importance of efficient transportation to the nation's economic health cannot be overstated. Because nearly all economic activity uses transportation directly or indirectly, improving the efficiency of our transportation system will boost economic productivity. For example, operators of many commercial and public-sector fleets will realize a variety of economic benefits, such as more efficiently routing vehicles and eliminating the need to stop at roadside weigh stations.

CHAPTER TWO

TECHNOLOGIES

CHARACTERISTICS OF AVAILABLE TECHNOLOGIES

All present automatic vehicle identification (AVI) technologies operate by (1) intercepting modulated electromagnetic radiation from a vehicle, (2) recovering the information contained in the signal, and (3) using a computer to identify the tag from a database. While all AVI technologies perform these tasks, the differences lie in the ways that these tasks are accomplished. For example, the relatively rapid evolution of AVI transponders used for ETTM has progressed from a Type I transponder that can only be "read" (or reflect a unique vehicle identification when interrogated), to a Type II transponder that can be "read" from, as well as "written" to, in order to store and update unique variable data such as entry/exit locations, account balance, vehicle maintenance/inspection reports, and other information. In the near future, Type III transponders will also have the capability to interact and communicate with the driver (*2*).

Technologies may be divided according to the frequency of the electromagnetic radiation, the method by which the signal is modulated (tuned or adjusted), and whether the vehicle tag generates or simply reflects electromagnetic radiation. There are three frequency ranges in use: (1) very low frequencies (below 200kHz), which are employed in inductively coupled systems; (2) microwave frequencies (500 to 3,000 MHz); and (3) optical or near-optical frequencies (30 GHz to 1,000 GHz), which include infrared.

Inductive Loop Systems

The only AVI technology that employs very low frequencies is the inductively coupled system, which uses a loop antenna embedded beneath the surface of the roadway to communicate with a tag mounted on the underside of the vehicle. The roadway antenna sends out an interrogation signal and the tag responds by returning a signal containing data stored in the tag. This is normally an active (as opposed to a passive) system since the tag normally transmits its own signal (rather than reflecting the interrogation signal). This is the earliest of the AVI technologies.

Optical Systems

Two basic types of AVI technologies employ optical or near-optical frequencies to identify vehicles. The first is a system that reads license plates directly and identifies the vehicle from a database. As the vehicle passes the tollbooth, a video camera forms an image which is digitized and processed to extract the license plate number. Typically, the image processing can take nearly one second so that multiple reads to improve reliability are not possible. The second type of optical or near-optical system employs a vehicle tag that is simply a bar code. A laser scans continuously over the area where the tag is expected to be and the reflected signal is processed to extract the code. This image processing is much simpler than trying to read a license plate, since the reflected laser signal represents a one-dimensional image, whereas the video image of the license plate must be processed in two dimensions.

Active RF/Microwave Systems

Active radio frequency (RF) AVI systems employ microwave frequencies to communicate to and from the vehicle. All active RF systems have high data rates that allow multiple transmissions (redundancy), resulting in increased reliability. These transmissions are commonly known as "handshakes" in the industry. These systems may be divided into those in which the tag generates its own microwave signal (active tag) and those in which the tag simply reflects the microwave signal that it receives (passive tag). Active tags require a power source (battery or connection to vehicle power) while passive tags may or may not require a power source. In an active vehicle tag system, the transmitter sends out a very short interrogation signal, which triggers the circuitry in the tag. The tag responds by generating a microwave signal containing the data stored in the tag. This signal is transmitted to a receiver that decodes the data and sends them to a computer for identification.

Passive RF/Microwave Systems

In a system that employs a passive vehicle tag, the transmitter usually transmits a signal continuously. This signal is intercepted by the tag and reflected to a receiver. The amount of reflection varies (the reflected signal is modulated) according to the data stored in the tag. The received signal is decoded to recover the data, which are then sent to a computer for identification. Passive RF communication is sometimes called the "backscatter" method.

Surface Acoustical Wave

Surface acoustical wave (SAW) operates at much the same frequency as RF systems. The primary difference between SAW and RF microwave systems is that the SAW transponder is nonprogrammable. Under the SAW technology, a low-power radio frequency signal from the AVI reader is captured by the transponder antenna and energizes a lithium crystal, setting up an acoustical wave along its surface. This acoustical wave travels along the surface of the crystal so that etched metal taps can be used to send back a series of time-delayed reflections of the original signal that uniquely identifies a tag.

ADVANTAGES AND DISADVANTAGES OF DIFFERENT TECHNOLOGIES (*3*)

Inductive Loop Systems

The advantages of this type of system are:

- Proximity of loop antenna and tag provides potential for increased reliability,
- Simple serviceability,
- Very low potential for electrical interference,
- Short coupling range decreases potential for interference from adjacent lanes, and
- Advanced traffic management and traveler information systems can also use inductive loops, so the infrastructure is already in place for more intelligent vehicle highway systems (IVHS) related applications.

The disadvantages of an inductively coupled system are:

- Low frequency resulting in lower maximum data rate, although it is fast enough to allow multiple transmissions to increase reliability,
- Medium difficulty in duplicating tags,
- Tag usually requires power from vehicle (active tag),
- Tag installation is not as convenient as that of a windshield-mounted tag, and
- More sensitive to environmental conditions.

Optical License Plate ID

The advantages of this type of system are:

- No special vehicle tag is needed,
- License plates are not likely to be duplicated, and
- There is no chance of interference between adjacent lanes.

The disadvantages of this type of system are:

- The processing algorithms are computation intensive,
- The relatively long time required for image processing precludes multiple reads to increase reliability,
- The system is subject to failure due to dirty or damaged license plates, the presence of bumper stickers and similar text on a vehicle, and reduction of visibility caused by rain and fog,
- Very low (80-90 percent) reliability because of the complexity involved in image processing, and
- Typically requires fully reflectorized license plate.

Bar Code

The advantages of this type of system are:

- Greater reliability than systems reading license plates because of the single dimension,
- Very simple vehicle tag that is just a bar code imprinted on an adhesive strip,
- Low potential for lane-to-lane interference because of limited range, and
- Much faster than systems that read license plates.

The disadvantages of bar code systems are:

- Tags are easier to duplicate compared to other AVI technologies,
- Susceptibility to failure caused by rain, fog, dirt, or moisture on tag,
- Finding the returned signal through image processing results in less reliability than systems employing transponders (microwave systems), and
- High restrictions on the position and speed of the vehicle as it passes the reader.

Active RF/Microwave Systems

The advantages of an active vehicle tag system are:

- Greater operating range than a passive system because the tag is not powered by interrogating beam,
- Greater reliability than a passive system because the return signal from the vehicle is stronger, and
- Less chance of electrical interference than a passive system because of the stronger signals.

The disadvantages of an active vehicle tag system are:

- Greater complexity in the tag circuitry, resulting in higher manufacturing costs,
- Greater probability of lane-to-lane interference due to stronger signal, and
- The tag must have a battery or be connected to vehicle power.

Passive RF/Microwave Systems

The advantages of a passive vehicle tag system are:

- The tag does not need to be connected to vehicle power, and
- The tag is less complex than in an active system.

The disadvantages of a passive vehicle tag system are:

- Lower reliability than an active system,
- Greater susceptibility to electrical interference because of lower signal levels, and
- Shorter operating range because the tag is powered by the interrogating beam.

Surface Acoustical Wave (SAW)

The advantages of using SAW technology to store data in the vehicle tag are:

- It is virtually impossible to duplicate the vehicle tag,
- The tag circuitry is much simpler, thus lower in cost, and
- No power is required to operate the tag.

The disadvantages of using SAW technology to store data in the vehicle tag are:

- A limited operating range (up to 15 ft), since it is typically part of a passive system,
- A limited data transmission rate because microwave energy must be converted into mechanical energy, and
- The tag cannot be programmed.

PERFORMANCE TESTING

Many of the toll collection agencies that have implemented, or are investigating, AVI/ETTM systems have conducted some type of performance testing. Unfortunately, the findings of these evaluations have not been formally documented and published, and in many cases, the results are proprietary. Test plans that are available indicate that these evaluations were not standardized tests and satisfy only specific agency concerns or requirements. Table 1 summarizes the status of AVI performance evaluations.

TABLE 1
AVI PERFORMANCE EVALUATIONS STATUS

AGENCY	STATUS (as of March 31, 1993)
New Hampshire Bureau of Turnpikes	Tested AT/Comm No results were published No reports available Started testing Dec. 16, 1991 - 100 vehicles, 2 lanes (side-by-side) Completed within 4 weeks Need better control (reconciliation of reports) and more coordination with vehicles About to commence a new round of testing of several vendors' equipment
E-Z Pass Interagency Group: Penn. Turnpike Commission NJ Highway Authority (Garden State Parkway) NJ Turnpike Port Authority of NY/NJ NY State Thruway Triborough Bridge & Tunnel Authority NY Bridge Authority	Pennsylvania Turnpike Commission: Tested Eureka and Mark IV for 6 months Did not publish findings Had speed problems reading transponders (less than 3 mph) New Jersey Highway Authority (Garden State Parkway): Testing AT&T/Mark IV and Amtech Not releasing any information at this time Port Authority of New York and New Jersey: Have tested Amtech (read only) for buses at JFK Airport Testing Amtech and AT&T/Mark IV in Fall 92 for 8 weeks, these tests extended to Feb. 1993, results are still forthcoming Currently there are no test plans available to the public Stated that the NY State Thruway has the most detailed test plans Lincoln Tunnel has ETC for buses only New York State Thruway: Tested at Spring Valley NY which resulted in two vendors being short-listed (Amtech and AT&T/Mark IV) Triborough Bridge and Tunnel Authority: Have developed Request for Proposals for the "Procurement of Compatible Electronic Toll Collection Equipment for various Participating Agencies" Test protocols (plans) are available
Illinois State Toll Highway Authority	Tested Eureka and X-Cyte Have tested Amtech (read only) at Verrazano-Narrows Bridge RFP for the "Design, Installation and Testing of a Pilot AVI Toll Collection System" is available Performance test notes and results are available Selected AT/Comm, 30-day prototype test commenced March 27, 1993
Orlando-Orange County Expressway Authority	Was to have conducted a 60-day acceptance test of Mark IV in November 92 Installation originally planned for Sept. 1992 (17-18 lanes) is delayed primarily because of system integration problems Expect to become fully operational by April 94
Virginia DOT (Dulles Fastoll Project)	Tested Amtech - 1991 Tested Mark IV, MFS Network Technologies - Texas Instruments - 1992 Selected MFS Network Technologies and will use the TIRIS-I equipment, but recently chose to not award contract Test plans or results are not available

TABLE 1 *(Continued)*

AGENCY	STATUS (as of March 31, 1993)
Castle Rock Consultants (HELP Crescent Program)	HELP/AVI final report is available
Caltrans (planned private, public/private toll roads)	Provided "Compatibility Specifications for Automatic Vehicle Identification Equipment" Published an RFP to implement electronic toll collection on Caltrans bridges Lawrence Livermore National Laboratories have developed a prototype AVI system for Caltrans which uses microwave backscatter technology
Oklahoma Turnpike Authority	Test and monitor their system for reliability
Texas Turnpike Authority	Have not done any performance testing, since the Amtech system they use is vendor owned and operated as demo project Recently decided to keep Amtech for next few years
Harris County (Houston) Tollway Authority - (Sam Houston Tollway) (Hardy Tollway)	Have an Amtech system (prime is Cubic) Installation completed and operation began in late October 1992 at both facilities
International Bridge, Tunnel, and Turnpike Association (IBTTA)	No information on performance testing is available
Ontario Ministry of Transportation	Had planned to do testing, but it was canceled Planning to test read/write technology with connection to a smart card at a later date
Florida DOT (Turnpike Office)	Five different vendors participated in controlled field performance evaluations (November 92 - January 93) Only read/write technology was evaluated Violation enforcement subsystem also was evaluated Findings will assist in finalizing system wide performance specifications RFP for procurement and installation to be advertised Nov. 1993 Public information report on field evaluations (non-vendor specific) available by end of July 93
Transport Canada	Not doing any testing, but they are looking at the technology used in the HELP project (Mark IV) They want to have an integrated system with about 38 different applications
Office of the Deputy Assistant Secretary of Defense	They are investigating RF read/write technology for: (1) Asset Location (2) Data Transfer Currently working on AVI system standard

Source: Status information obtained from telephone calls.

CHAPTER THREE

SYSTEM DESIGN CONSIDERATIONS

ACCURACY AND RELIABILITY

Electrical Interference

The possibility of a failure to properly read a vehicle tag because of the presence of an unacceptable level of electrical interference must be considered when implementing an AVI system. Electrical interference can occur in an AVI system in two different ways. The first occurs when other (non-AVI) transmitters operating on the same or nearby frequencies are close enough to produce strong interference. Possible sources of this type of interference are cellular telephones, police and other mobile communications, and radars. The possibility of this type of interference can be minimized by obtaining a Federal Communications Commission (FCC) license for a dedicated frequency. Obtaining an FCC license for a dedicated frequency has two main benefits. First, a larger transmitted power level may be used, and second, a frequency will be assigned that is different from other radio services operating in the same area. An unlicensed system, which uses a nonunique frequency, can only depend on redundancy of transmission to reduce interference and, according to the FCC, "must accept any interference that may be received including interference that may cause undesired operation." However, obtaining a license for a unique frequency through the FCC is an extremely difficult process at this time.

The second type of interference in the AVI system results from improper design or installation. This can occur if the transmitted signal from one AVI lane of traffic is allowed to overlap into another AVI lane and can result in multiple recordings of the same vehicle or failure to record vehicles. The remedy for this type of interference is careful design of the AVI system and, in particular, proper selection and placement of all antennas. In addition, the physical configuration of toll booths also plays a role in the presence of multiple readings, as the booth itself can act to block signals between lanes.

Metal Oxide Windshields

Some luxury cars are being equipped with a metal oxide coating on the windshield. This coating reduces solar radiation by 30 percent and ultraviolet radiation by 45 percent, resulting in improved air conditioner performance and prolonged interior material life. This metal oxide coating causes disruptions, or attenuation, in AVI signals that must pass through the windshield. (Other types of windshields, such as variable tint, can cause problems for AVI as well.) At this time, it is not certain how widespread the use of metal oxide windshields will be by the time AVI systems are deployed. Currently, industry experts estimate less than 2 percent of the nation's vehicle fleet is equipped with metal oxide windshields. However, it is an important implementation issue to consider. It is expected that the disruptions could be minimized if manufacturers and agencies agree on an optional external location for tag mounting on the vehicle in this situation.

Tag Installation

The reliability of AVI tags can be affected by the method of installation. For guaranteed reliability, vendors prefer, and sometimes require, that tags be permanently mounted by experienced toll agency personnel. However, for patron convenience, some tags are installed such that they can be removed. This convenience may cause "misreads" when tags are incorrectly placed. A severely angled windshield will also affect performance reliability, and thus placement of transponders is critical in this situation (higher location for mounting is generally better). An example of bar code placement, which represents the first generation of AVI, is shown in Figure 2.

HEALTH AND SAFETY FACTORS

The rapid increase in the use of electromagnetic energy in modern society has led to an increased public awareness and concern regarding possible (or perceived) effects on human health. Use of the word "radiation" causes fear in many people and, since radio frequency waves and microwaves are "radiation," their potential use in an AVI system must be addressed from the viewpoint of both actual and perceived hazards.

The effects of radiation can be divided into three categories: ionization, heating effects, and biological effects. Of these, only the latter is of importance in AVI systems. Ionization can occur only for very high frequencies such as X rays and never occurs at radio and microwave frequencies. Heating effects (such as in a microwave oven) occur only for very high power densities and are of no consequence for the power levels used in AVI systems.

The probability of harmful biological effects, the third category, is a function of both the frequency and power density of electromagnetic radiation. The frequencies used in AVI systems extend from very low to about 3 GHz, which is in the microwave region. Thus, AVI systems are generally not associated with harmful biological effects. Greater biological effects are thought to be associated with higher frequencies because of the higher energies per photon of radiation. Therefore, the higher frequencies (800 MHz to 3 GHz) will be considered in the following analysis.

An even more important factor in determining the likelihood of harmful biological effects is the power density associated with radiation. This is a function of both the power level of the transmitter and the type of antenna used. Antennas concentrate the power (similar to a lens) and the amount of concentration is specified by a term called "antenna gain." The type of antenna that produces

FIGURE 2 A bar code sticker affixed to the left rear window is read by a laser scanner as the vehicle approaches Bay Harbour Island just north of Miami.

the greatest concentration of power is the parabolic dish antenna. As an extreme example, a 4-foot diameter, parabolic antenna has a gain of approximately 20dB at 900 MHz and will be assumed in the discussion that follows. A gain of 20dB means that the power is concentrated by a factor of 10.

If we assume that the power output of the AVI transmitter is 500mW, then the maximum power density at a distance of one meter from the antenna can be calculated from standard antenna theory to be approximately $40\mu W/cm^2$. This is the power density that should be compared to nationally accepted safety standards. Table 2 summarizes several of the various standards from relevant agencies. Unless otherwise indicated, these standards are for continuous exposure.

As can be seen from Table 2, the power densities encountered in AVI systems are far below all accepted (or proposed) national standards. The AVI system can be considered to be one of the safest applications of electromagnetic energy, when one also considers that the transmitter power level will probably be less than $500\mu W/cm^2$, that the AVI user will be more than one meter from the antenna, and that the exposure time will be less than one second. To put the AVI power densities into proper perspective, one need only consider an increasingly common modern convenience — the portable cellular telephone. The associated power density is about $300\text{-}500\mu W/cm^2$ for hand-held cellular phones, and up to 3 watts for car phones. This level of power density is many orders of magnitude greater than any AVI system.

Evaluation of Safety and Technology Issues

Hard results from technological performance testing apparently are not available. Where problems have occurred, it is difficult to determine if they result from the reliability of the technology or from its application. Relative comparisons among technologies can be offered, based on information provided by vendors, visits to various AVI sites, and general discussions with recognized industry experts (see Table 3). Six major technology issues can be identified to be used in relative comparisons.

A relative comparison score of high, medium, or low can be attributed to each technology regarding each issue. It is important to note that the specific differences between high, medium, and low are not known at this time, only that there is a relative difference. System cost comparisons (not included in the technology comparison) can be very difficult to assess because the complexity and coverage of installation can vary significantly from system to system. Finally, although the issues have been identified, they have not been weighted according to their relative importance. Table 3 provides the relative comparisons.

TRAFFIC OPERATIONS

Traffic operations with and without AVI will differ significantly. In particular, current conventional treatments and methods for vehicle classification, toll collector safety, gates, and signing/channelization will require reevaluation.

Dedicated vs. Mixed-Use Lanes

The issue of dedicated as opposed to mixed-use lanes for AVI implementation depends on four basic characteristics: capacity by lane type, the relationship of speed to capacity, levels of AVI participation, and thresholds for toll plaza lane configurations. This section will discuss these characteristics and how they are interrelated.

Capacity by Lane Type

Existing and future toll plaza lanes can be characterized into five basic lane types: attended, automatic, mixed AVI, dedicated AVI (within a conventional plaza), and express AVI. Attended toll lanes require all toll transactions to be handled by a toll collector. Automated lanes collect tolls by providing coin machines. Mixed AVI lanes combine AVI with toll collection that is either manual, automatic, or both. Dedicated AVI lanes are contained within conventional toll plazas but permit AVI patrons only, as shown in Figure 3. Express AVI lanes are physically separated from all other type toll lanes permitting free-flow (55 miles per hour or greater) speeds.

Capacities for attended, automatic, and mixed AVI lanes were determined from observations and counts from existing toll facilities such as the Florida Turnpike, Tampa Crosstown Expressway, the New Jersey Turnpike, and the Dallas North Tollway. Capacities for automatic lanes were determined from Florida Turnpike automatic lanes, which all have gates. No other capacities were determined for lane types with gates. Average capacities are typically reduced by 10-20 percent when gates are used on automatic lanes. The higher capacity effect resulting from increased gate sensitivity is not known at this time. Capacities for mixed-use AVI lanes were obtained from observations on the Dallas North Tollway. Mixed AVI lanes at this site include AVI on both manual and

TABLE 2
POWER DENSITY STANDARDS

American National Standards Institute (ANSI) C95.1	3,000μW/cm^2
International Electrotechnical Commission	10,000μW/cm^2
National Radiological Protection Board	1,200μW/cm^2
Occupational Safety & Health Agency (OSHA) 1910.97	10,000μW/cm^2
Environmental Protection Agency (proposed standard)	300μW/cm^2
Soviet Occupational Standard (2 hours exposure per day)	200μW/cm^2

Source: Developed by University of South Florida Electrical Engineering Department from various sources.

TABLE 3
RELATIVE COMPARISON OF AVI TECHNOLOGIES

ISSUES/TECHNOLOGIES	RF/Microwave	SAW	Inductive Loop	Bar Code
Reliability	high	medium	high	low
Resistance to Duplication (security)	medium	high	medium	low
Potential for Multiple Reads (speed vs. reliability)	high	high	low	low
Resistance to Interference (lane-to-lane)	low	low	high	high
Tolerance to Environment	high	high	medium	low
Health Safety	high	high	high	high

Legend: "High" is most favorable; "low" is least favorable.

automatic lanes (with no gates). Capacities for dedicated AVI and express AVI lanes were estimated based on reasonable average speeds and vehicle spacing (i.e., headways).

Figure 4 illustrates the general relationship of average capacity for the basic types of toll plaza lanes. Depending on plaza lane configuration, the inclusion of AVI has the potential to increase conventional plaza lane capacity by 50–160 percent.

Speed–Capacity Relationship

Figure 5 depicts the relationship of speed to the various toll plaza lane types. As can be observed from this figure, speeds (and volumes) increase as preferential treatment for AVI increases because there is less restriction in toll processing. Average running speed is defined as the speed maintained once a vehicle first stops or slows down while approaching the toll lane queue through the point of being processed at the toll plaza. Average running speed for a manual lane is about 2.5 mph, compared to approximately 55 mph for an express AVI lane. Higher average speeds through the use of AVI lanes translate into greater lane capacity potential. However, with greater speeds, AVI lanes retrofitted into a conventional toll plaza will require significant additional planning, design, and right-of-way (as in the case of express AVI lanes).

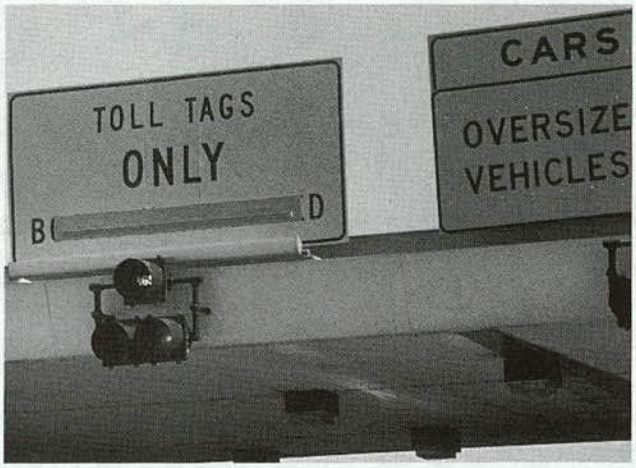

FIGURE 3 Sign for dedicated AVI lane on the Greater New Orleans bridge.

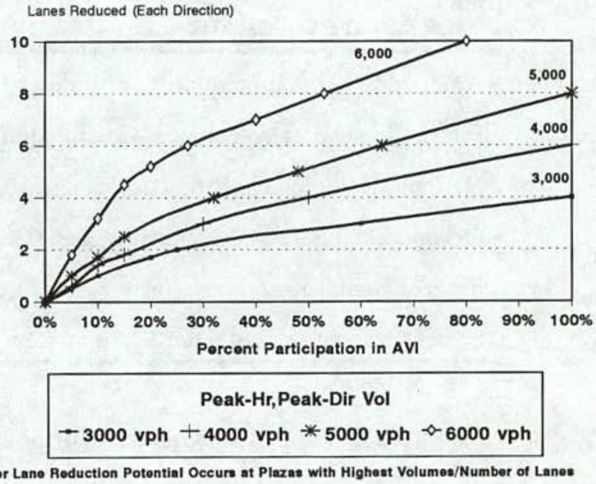

FIGURE 6 Plaza lane reduction potential.

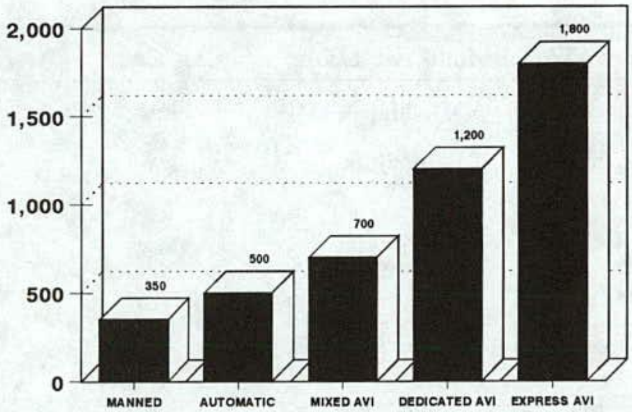

FIGURE 4 Average capacity, toll plaza lane types.

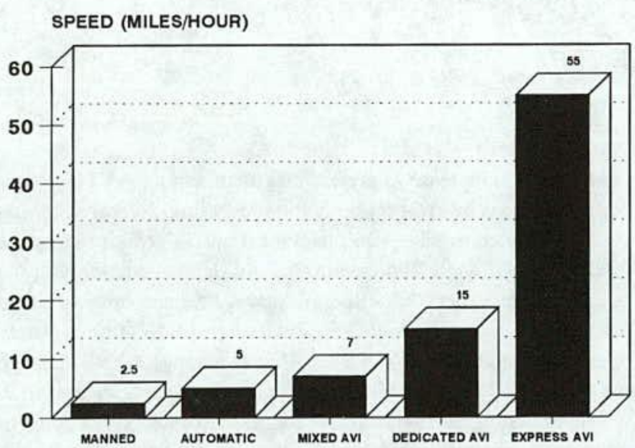

FIGURE 5 Average speed, toll plaza lane types.

Levels of AVI Participation

Actual patronage levels for AVI are extremely difficult to estimate. Therefore, full use of toll lanes that are retrofitted with AVI or are physically separated from the conventional plaza for express AVI usage can only be assumed for an estimated level of AVI participation. The highest current AVI participation rates being experienced are on the Lake Pontchartrain Causeway in Louisiana (80 percent), Treasure Island Causeway (60 percent) and Bay Harbour Island Causeway (40 percent) both located in Florida, the Oklahoma Turnpike (40 percent), and the Dallas North Tollway (23 percent). These levels of AVI participation do not come without some additional cost for marketing or publicity, such as the professionally operated, high-profile tag purchasing store in Dallas. AVI patrons using the Lake Pontchartrain Causeway enjoy a 50 percent discount off the cash price for tolls.

It is important to distinguish the effect of varying AVI participation levels on plaza lane requirements. The Florida Department of Transportation Traffic Engineering Office has developed the first generation of a basic toll plaza simulation model known as D-QUEUE. A basic validation of this model was performed successfully with results matching observed conditions at three toll plaza locations in Florida. Other personal computer-based toll plaza simulation models have also been developed across the country and are available for planning applications. D-QUEUE was used to approximate the potential for plaza lane reduction using AVI under various participation rates for various peak-hour volumes. Maximum desirable queues, used as the criteria for determining ideal plaza lane configurations, were taken to be no more than 300 ft (FDOT Turnpike planning guidelines).

Figure 6 displays the results of more than 100 D-QUEUE model runs to determine the maximum potential for toll plaza lane reduction for peak directional volumes of 3,000-6,000 vehicles per hour. Runs were made for conventional lanes only and for conventional lanes with AVI to discern the maximum potential for plaza lane reduction at similar approach volume levels. It can be observed from this figure that, as volumes (toll plaza lanes) increase, the potential to reduce the number of toll plaza lanes is enhanced by a greater AVI participation rate.

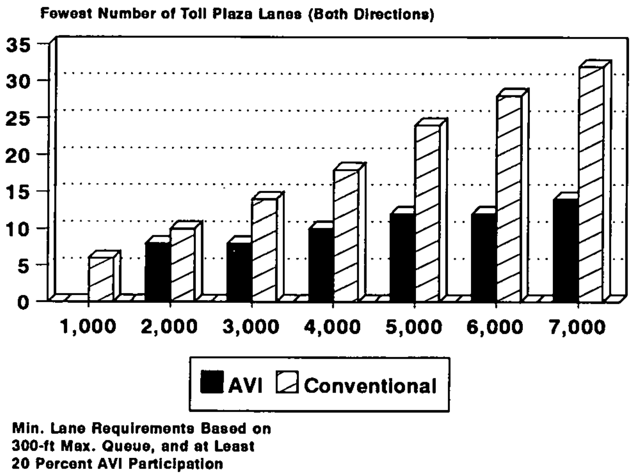

FIGURE 7 AVI versus conventional, toll plaza lanes.

Thresholds for Toll Plaza Lane Configurations

Ideal toll plaza configurations can be determined by combining the previous findings of capacity by lane type (see Figure 4), and the relationship of the potential for lane reduction with various AVI participation rates at different volumes (see Figure 6). Ideal configurations assume the least and most practical number of toll plaza lanes not to exceed the planning guideline queue length of 300 ft, used by Florida. The D-QUEUE toll plaza simulator model was again used to determine the least number of lanes for both conventional-only and conventional with AVI configurations. Figure 7, which builds from the relationship indicated in Figure 6, indicates the results of more than 100 D-QUEUE model runs to determine ideal configurations.

For example, at 3,000 vehicles/hr with a 20 percent AVI participation rate, a conventional-only lane plaza would require a minimum of seven lanes in both directions (five automatic and two attended). The most practical potential for lane reduction would require about a 25 percent AVI participation rate to reduce the number of lanes to five lanes in each direction (one attended and four mixed AVI). A 25 percent AVI participation rate would equal about 750 AVI patrons in the peak hour, peak direction. Four mixed AVI lanes would provide an additional capacity of 800 vehicles/hr (200 vehicles/hr/lane increase in capacity between automatic and mixed AVI lanes). The results indicated in Figure 7 follow the same rationale for determining the least number of toll plaza lanes in both directions. Figure 7 illustrates the most reasonable and most typical combination and least number of total lanes (conventional versus AVI) required to accommodate (i.e., 300-ft maximum queue) various peak-hour volumes. A 25 percent AVI participation has been assumed throughout to determine required AVI laneage.

Several key thresholds can be deduced from the examination of Figure 7. At 2,000 vehicles/hr, the AVI and conventional lane requirements are about the same. At 3,000 vehicles/hr, a significant difference in lane requirements becomes apparent indicating the initial threshold for AVI consideration (i.e., mixed-use AVI). A similar type of lane reduction pattern exists again at 5,000 and 7,000 vehicles/hr suggesting more intensive use of AVI laneage. These thresholds are developed under ideal conditions, but nevertheless can be used as planning guidelines for AVI implementation, as shown in Table 4.

Summary of Traffic Operation Issues

The issue of dedicated versus mixed-use toll plaza lanes is complex and must be considered on a site-specific basis. An integral aspect of this issue is the actual level of AVI participation and thus the number and configuration of lanes required. The commitment to AVI in terms of patron satisfaction does not necessarily require express AVI lanes. In particular, the position of dedicated lanes within a conventional toll plaza must consider proximity of mainline ramping to maintain safe and adequate weaving lengths. Plaza locations where exit or entrance ramps are in close proximity may create safety problems for weaving vehicles.

OTHER OPERATIONAL CONSIDERATIONS

Vehicle Classification (Axel Count Verification)

Vehicle classification (or axle count verification) is currently performed as a two-part process. Typically, the first part of this process consists of the toll collector visually classifying an oncoming vehicle to determine fare requirements based on the number of axles (preclassification). Second, treadles that count axles are used in the postclassification process to verify the manual vehicle classification. Inefficiencies result because toll collectors may not accurately determine the vehicle classification and treadles can frequently malfunction due to the wear of mechanical contact switches over time, particularly in high truck-volume lanes. Improved treadles and automatic vehicle classification systems have the potential to dramatically increase the accuracy of vehicle classification. However, vehicle classification systems that count axles only work when the vehicle is moving at relatively constant speed (*4*). Electronic toll collection, or AVI, will also reduce toll collector errors and fraud on AVI transactions by providing the audit trail for each AVI-equipped vehicle that is processed through a toll plaza lane.

Toll Collector Safety

Any implementation of AVI within a conventional plaza or a separated facility may, if not designed properly, present a safety problem for toll collectors when arriving and departing from their toll booths. As mentioned previously, with the implementation of AVI comes an increase in average speeds of vehicles through the toll plaza. Toll plazas that do not provide pedestrian tunnels or overhead walkways and safe access via separate parking areas, may not be suitable for AVI implementation because of higher traffic speed. This feature is important at AVI-retrofitted plazas as well as separated plazas where safe access may be required for maintenance purposes. Increasing the number of toll gates may be effective in mitigating dangers to toll collectors. However, careful considerations must be made of the trade-offs gates pose in processing time.

TABLE 4
VOLUME THRESHOLDS FOR AVI IMPLEMENTATION, PEAK DIRECTION

Initial Consideration for Mixed AVI	3,000 vehicles per hour
Initial Consideration for Dedicated AVI	5,000 vehicles per hour
Initial Consideration for Express AVI	7,000 vehicles per hour

Source: Determined by toll plaza simulation modeling. Threshold volumes represent the highest single peak-hour of the day.

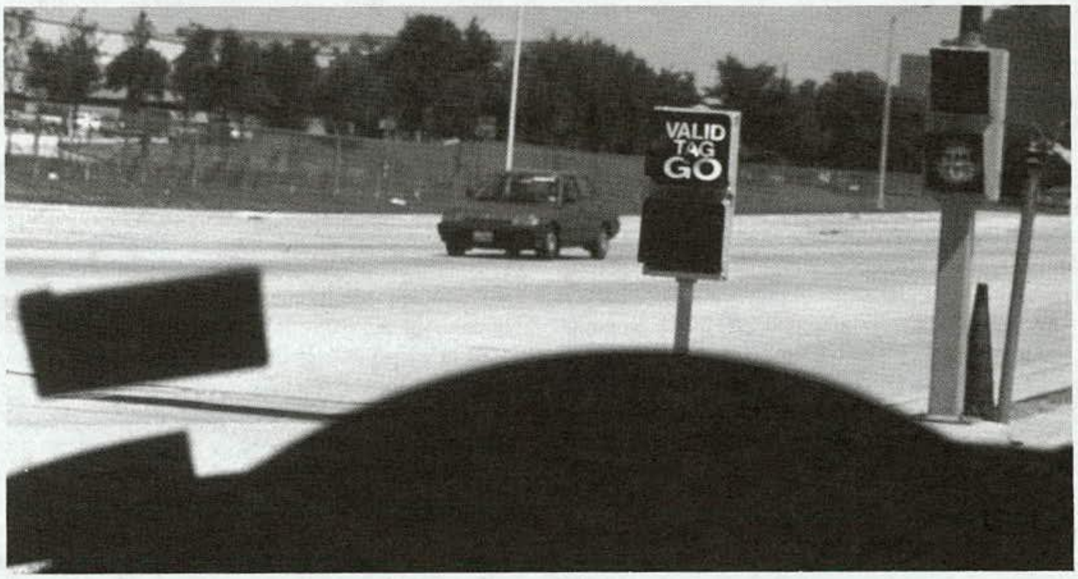

FIGURE 8 An AVI patron is quickly validated on a lane with no gate on the Dallas North Tollway.

Gates

Lanes without gates save 1 to 1 1/2 seconds in the processing time of each transaction, thereby increasing capacity of vehicle flow (see Figure 8). The presence of gates can create backups when malfunctions occur or when gate arms are broken or snapped off by vehicles passing through the plaza, which also results in delays. However, if statutes cannot be modified to allow for photographic enforcement, then gates may be the only answer to deterring violators. Photographic enforcement, if properly legislated, can provide an alternative means to deter violators. The cost-effectiveness of this means of enforcement should also be evaluated.

Advance Signing/Channelization

Procedures have been established by traffic officials regarding traffic control (signing, pavement striping, and channelization) and traffic regulations (speed and passing zones). These procedures represent criteria that apply to conventional toll plaza configurations and are intended to provide for the safety of the patron and toll collector. As various configurations of AVI intensity are implemented (mixed-use lanes to dedicated to express), more attention will be required for advance signing and channelization to safely accommodate AVI. Site-specific speed limits and transition requirements to diverge and merge AVI traffic have to be developed and established as vital design criteria. Current traffic operations should be revised as necessary with the implementation of AVI. Vehicle classification procedures and toll collector safety will be improved with the planned upgrade of toll lane equipment. New laser scanners for vehicle classification could be worthwhile components of an AVI system. The use of gates and revised advance signing/channelization needs further evaluation. The most efficient, cost-effective means of AVI enforcement and vehicle guidance should be developed.

SERVICEABILITY AND MAINTENANCE

The frequency, extent, and costs associated with the serviceability (operation) and maintenance of AVI/ETTM systems are difficult to assess at this time primarily because working AVI/ETTM systems have not been in operation long enough to establish these factors. In general, based on very limited data, maintenance costs per lane associated with AVI appear to be about 10 to 20 percent less than conventional toll lanes. Employee salary and related costs, which constitute the majority of operational costs, would not be associated with AVI lanes.

COMPUTER SYSTEM REQUIREMENTS

AVI can be added as an upgrade to a well-designed, modern toll plaza, i.e., a toll facility with state-of-the-art microprocessor-based manual toll collection and automatic coin machines, a microprocessor-based lane controller that is programmable, a plaza computer system, and a host computer system with network capabilities. These features represent the latest designs being implemented today at new or retrofitted toll facilities. Most importantly, additional computer support roles and systems administration will be created with AVI implementation, requiring staff retraining and possible organizational adjustments.

The core piece of equipment of an AVI system, in terms of toll collection management, is the host computer. It is important to evaluate many different systems on the merits of various features, such as processing power, size, expandability, networking capabilities, software compatibility, and cost. It is also important to consider the merits of a single- versus multi-processor configuration. A dual processor configuration enables maintenance, hardware upgrades, and software upgrades to be performed on one processor while the other is functioning. The host computer connects to computers located at every toll plaza, which in turn are connected to lane controller computers, forming a hierarchical configuration. (However, the industry is starting to see the first implementations of a decentralized, nonhierarchical system.) These smaller plaza and lane computers are usually of the same platform (supplied from the same vendor) as the host computer.

Another important system feature is external data storage. Disk drives connected to all levels of computers must accommodate an enormous amount of data. At the host location, the disks should be able to hold three to six months' worth of data. Transaction files should be stored in duplicate locations ("shadow recorded") for protection. Data must be synchronized with the host data to ensure recovery in case of a malfunction. Disks at this level are typically smaller but can also range to the 1 Gb size for large plazas (i.e., greater than 14 lanes). Data stored at this level include transaction data files, maintenance records of the plaza, event logs, security files, and AVI accounts list. At the lane controller, adequate storage is necessary for two or three days. This storage must also be available to handle transaction files, maintenance data files, and AVI account verification files. According to toll industry experts, one of the greatest shortcomings in the industry today is inadequate storage space provided in the lane controllers.

The computer system requires an extensive network to constantly update file data and pass transaction, maintenance, diagnostic, and electronic messages from one processing level to the next. The speed of the network and the ability to access information at all levels is essential to a toll facility. Network interfaces will range from the local area network for attached devices or lane controllers to wide area networks that tie together all the plazas in a given system.

All the local devices attached to or serviced by the host computer are interfaced through a local area network (LAN). Dispersed plazas and work stations are typically serviced by the same protocol over a wide area network (WAN). Digital data circuits are becoming more practical and affordable for WANs (*5*). Fiber optic installation provides the greatest flexibility, and newer facilities should look to the employment of their own fiber optic cable system rather than leased circuits for wide area coverage. However, detailed engineering design studies should be made of actual conditions before a decision is made.

High-speed printing can be accomplished by impact or laser printers. PC workstations, engineering workstations, and terminals are all interfaced through the LAN. Personal computers and workstations will normally require a server or network interface unit (NIU) for connection. Terminals and printers will require a different type of server. The number and types of terminals, PCs, and workstations will depend on the needs of the toll authority.

With the above understanding, the addition of AVI to such facilities is a simple and cost-effective step. The three-tier computer network (host-plaza-lane), will carry the AVI transaction load. The transaction processing will require only minor modification to encompass the additional AVI transactions. For a fully integrated system, the addition of AVI should simply add another means of collecting fares from patrons. AVI can be visualized as the replacement of existing charge accounts without the manual transaction of magnetic stripe cards, commuter tickets, or visual stickers.

At the lane level, the only additions necessary are the AVI reader/antenna units, reader/controller unit, cabling, software interface to the lane controller, and surveillance/enforcement cameras. Since these items should be low-power consumption units, excess uninterruptible power supply (UPS) should handle the new loads. If the AVI system to be installed is a high-power AVI system, then the system integration will be compounded by power and shielding considerations.

The addition of AVI to an existing, well-designed, modern toll plaza will also impact the three-tier computer network. Requirements for processor memory, on-line storage, off-line storage, volume of data transfer to and from the network ("network loading") will all be affected. The network loading will need to be studied prior to installation. Higher throughput rates will be seen and this will impact the network response times. In a manual or automatic coin lane where a transaction can occur every 4 to 10 seconds respectively, network messaging has ample time to transmit and receive digitized packets of information. AVI, on the other hand, could produce 1.5 transactions per second, and would require higher communication speeds.

With the addition of AVI will come the account lookup and verification of accounting information. The impact of this processing load on the lane controller, plaza computers, and host computers will need to be assessed. The greatest impact may occur at the lane controller level where real-time processing of the transaction may be adversely affected by a lack of central processing unit (CPU) capacity. At the host level, the additional tasks of accounting and billing for the AVI transactions will impact the load of the CPU. These tasks could be handled on a backup processor while the primary processor is handling normal functions. In the case of a processor being down, the AVI processing may affect the response time of the host system when running AVI and normal toll processing on the same computer. If the initial design accounts for ample growth and excess capacity, then little to no additional CPU costs or memory will be necessary.

The on-line and off-line memory requirements will be affected by the addition of AVI. The AVI account data, billing data, and transaction information will require additional memory for all three levels of the computer system. The lane controller is the least impacted; its storage of transaction information will remain the same. The additional AVI transaction information will represent a negligible percentage of the total number of transactions. In some real-time systems, the AVI verification file is kept at the lane controller. This allows stand-alone processing when the communications or plaza computers are down. In this type of installation, lane controller memory must be expanded to handle the size of the AVI account list. The plaza computer storage will be affected in a manner similar to that of the lane controller.

The impact is greatest on the host computer's on-line and off-line memory requirement. The host computer will require AVI account billing and long-term storage of account information for billing purposes. This storage will require additional disk space. The configuration for the host and plaza computers specifies dual or shadow recording of on-line transaction data. Therefore, two additional disks and controllers could be necessary. Disk size will depend on the size of the facility. Disks with 1 to 2 Gbs of data storage are becoming commonplace and affordable. Off-line storage will also need to be expanded at the host site. The air conditioning, power, universal power supply, and physical space requirements will be minimal and should be considered in the initial design of a new system.

Computer Software

For a fully integrated solution, the communications network, and the host and plaza configurations are supported by operating system software. The networking software should provide task-to-task communications, file management, downline system and task loading, network command terminals, resource sharing capabilities, and network monitoring capabilities. Software that controls the collection plazas and access ramps should provide for such requirements as: plaza and ramp expansion; processing AVI account transactions, violations, and conventional accounts; importing and exporting databases; monitoring lane transactions; supporting terminal security; dynamic diagnostics; accepting and transmitting data to the host computer system; providing data for local traffic management; providing various statistical information; and providing dynamic system performance graphic displays.

A database management program package, including all necessary report-generating tools and development software is required. The database program and file structures should support multifunctional, user-defined reports, distribution processing, and portable module data file transfers. The computer system software should also provide for user and system security. The internal security system files should monitor what level of user programs, database files, maintenance files, and plaza audit files will be accessible (based on user ID and password).

Historically, the general price range for plaza level software has been $150,000 for one or two plazas. However, if a larger system (10 to 40 plazas) purchases the software, the price per plaza drops to approximately $50,000. In addition, host software ranges from $250,000 to $750,000 for highly customized, new application development software (*6*). Just as with the host hardware configuration, the total cost of the host software is priced with the plaza under consideration.

REGULATION

Most AVI systems require communication with roadside stations, or would be enhanced if information were available from these facilities. These needs are quite diverse, ranging from low-power roadside transmitters and receivers to satellite communications. This range requires vastly different circuitry, electronic components, antennas, frequencies, bandwidth, and data capacity. Analysis is needed to determine the communication related requirements for ETTM product areas. Designs should be selected to minimize the number of different communication technologies, and it may also be important to consider the same communication frequencies.

To minimize RF interference, a dedicated frequency is preferable. However, RF spectrum matters usually involve extensive analysis as well as political negotiation. A number of regulatory agencies, processes, and requirements could affect the rate of ETTM deployment. If an already dedicated portion of the RF spectrum is needed, a long process may be needed for approval. In September of 1992, IVHS AMERICA began discussions and negotiations with the FCC on the issue of radio frequency spectrum allocation. Although no spectrum has yet been dedicated to ETTM usage, most existing systems are now operating in the 900-930 MHz band, which is dedicated to industrial, scientific, and experimental usage. Several frequencies in this bandwidth are currently licensed to personal communication services (PCS) manufacturers and providers (e.g., pagers, mobile cellular phones). Interference with these and other similar devices has already been experienced in the testing and evaluation of ETTM systems. Assignment of a bandwidth not currently used by AVI systems would cause additional investment in research and development before additional uses of AVI technology could become operational.

CHAPTER FOUR

INSTITUTIONAL AND IMPLEMENTATION ISSUES

CAPABILITY OF VARIOUS MANAGEMENT AND ACCOUNTING OPTIONS

Patron Account Information

As an AVI-equipped vehicle enters a toll plaza lane, the AVI system detects the approaching vehicle and prepares for the transaction. When the vehicle passes over the lane treadle, the system registers the vehicle by reading and identifying the assigned AVI code. As the code is read, the system verifies that the patron's account balance is sufficient to cover the toll charge. The vehicle is also classified for audit and tolling purposes. At this time, any lost or stolen tags, or below-balance accounts are registered. If the AVI code is associated with a valid account, the lane's traffic signal turns from red to green. If not, the light remains red, indicating either a misread, a lane violation, or a problem with the patron's account. This necessitates the manual payment of the toll by the patron either in the automatic coin machine or to a collector. Once the vehicle is cleared to leave the toll plaza, the system automatically updates the patron database files and other associated files. All lane transactions are detected and recorded, whether or not the lane is in operational mode. The processing of a standard AVI vehicle takes fractions of a second to complete.

Management and Operational Reports

The reports generated by an AVI toll system can vary depending on the toll operator's accounting and information requirements. The following is a list of reports that can be compiled through information contained in the AVI computer system data base:

- Individual lane, plaza, and systemwide transaction and status reports,
- Individual lane, plaza, and systemwide accounting and audit reports of toll revenues,
- Maintenance and diagnostics reports for system equipment,
- Traffic statistics and traffic management reports,
- Daily and monthly system accounting reports,
- Daily and monthly AVI Service Center reports,
- Daily and monthly personnel status and payroll reports, and
- Daily and monthly system audit reports.

Safeguarding of Toll Assets

Revenue collection systems are frequently targets of abuse; therefore, measures to safeguard revenues should be instituted. Within an ETTM system there are several key safeguard features. One is the ability to have surveillance cameras in place to record lane violations and possible collector violations. The computer hardware and software networking characteristic of surveillance cameras is a substantial safeguard. System-generated equipment status reports and diagnostic and maintenance reports are other safeguard features. Also characteristic of the appropriate computer system are sign-on access procedures for all levels of personnel. Employees can gain access only to predetermined system levels assigned to their specific job requirements. Even toll collectors need to sign-on for shifts using their individualized identification codes and passwords. Most important is the ability of the system to collect tolls through the electronic transfer of funds, which eliminates the extra precautions and costs needed to safeguard hard currency and related data records. In summary, two conclusions can be made with respect to operational and accounting functions. First, toll revenue tracking for accounting and auditing purposes is enhanced by electronic funds transfer. Second, the AVI system accounting hardware and software increase the accountant's auditing capabilities and sources of reliable system information.

Accountability

Operational and Accounting Functions

An important feature of any AVI system is the ability to effectively track toll revenue, process patron account information, generate relevant management and operational reports, and safeguard toll system assets. All of these operational and accounting functions are discussed in the following sections, as they relate directly to AVI toll collection systems.

Tracking Toll Revenues

The ability to track (audit) toll revenues is an important function of any toll facility. Figures 9 through 11 give an overview of manual, automatic, and express AVI lane collection processes from when toll revenue is collected until it is deposited. These diagrams were provided by the E-470 Public Highway Authority in Denver, Colorado.

First, in the manual lane collection process diagram (Figure 9), the physical flow of money is detailed. The flow begins when the toll collector's shift ends: tolls collected during the shift are counted and the amount is recorded on a deposit sheet. The collector's supervisor verifies the correctness of the deposit sheet and deposits the tolls into the money room. A designated employee other than the collector or collector's supervisor counts the tolls again to verify and record the deposit. At this time, the tolls are sorted, consolidated, and sealed in preparation for the bonded carrier to retrieve. The bonded carrier transports the toll money to the bank where it is recounted and the deposited amount verified.

In the next section of the diagram, the data processing steps are detailed to coincide with the physical flow of money. Within data

MANUAL LANE COLLECTION PROCESS

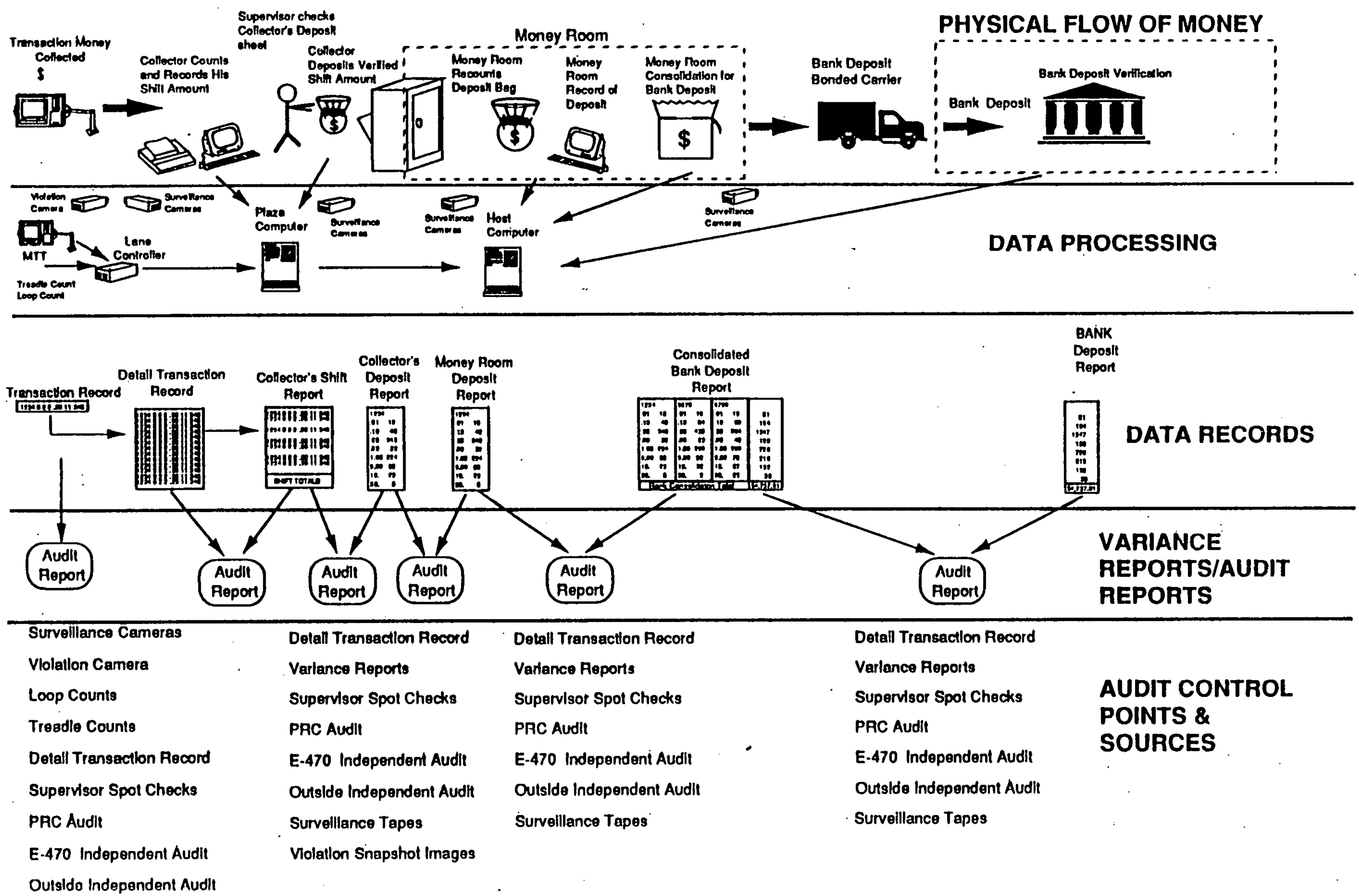

FIGURE 9 Manual lane collection process.

processing, the violation cameras are used to record lane violations while surveillance cameras are used to observe toll agency personnel. Also, the lane controller is directly linked to the host computer via the plaza computer. This enables the flow of transaction information to and from the various databases. The lane controller is also directly linked to the terminal screen, which allows the toll collector to see information concerning each AVI transaction. In addition, the treadles and vehicle detection loops give relevant axle and vehicle counts to the lane controller.

The data processing system is an important auditing tool used in verifying and recording each step in the toll collection process. Therefore, the computer software and hardware used should be flexible enough to generate data records and audit reports to meet the specific needs of an individual toll system. Shown in the third section of the diagram are the resulting data records that are generated after each step of the collection process. These records give the internal and external auditors of the AVI toll system the transaction details necessary to complete the audit reports. Points in the collection process where individualized audit reports are prepared are noted in the fourth section.

Second, in the automatic lane collection process (Figure 10), the only difference from a manual process money flow is that the toll money is deposited by toll patrons into vaults contained within the automatic coin machine (ACM). The vaults are then transported to the money room by a bonded carrier. The bonded carrier may be a courier service or a toll supervisor/official. Also, within the data processing section, the coin machines are linked by computer to the lane controller. In this collection process, the coin vault construction and safety features become important auditing controls.

Finally, the third collection process (Figure 11) is the AVI (ExpressTOLL) lane collection process. In the money flow section of this process, the collection and deposit of toll revenues are accomplished electronically. The handling of hard currency is eliminated through the electronic transfer of funds between the patron's bank and the toll operator's bank. (However, checks, credit cards, and cash transactions are processed through a separate AVI store or bank. AVI patrons of the E-470 highway in Denver are required to back their AVI accounts with bank and credit cards.) This electronic process reduces the loss of toll revenue for AVI transactions by eliminating the need for cash drawers and coin machines in express AVI lanes. It also eliminates the need to count, sort, and deposit moneys collected on these lanes.

FINANCIAL OPTIONS

There are three major ownership arrangements to consider in the process of negotiating the implementation of an AVI system. These include the agency owning and operating a system, a vendor owning and operating a system, and various lease agreements. Each of these arrangements is characterized by numerous advantages and disadvantages. Most AVI vendors are flexible with respect to the administrative arrangement that is selected for the ownership and operation of an AVI system. However, the ability of a toll agency to select an ownership/finance arrangement is controlled by the agency's charter. In some instances, an agency is not permitted to subcontract the responsibility of fare collection. This would limit the ability to subcontract AVI under the vendor operation scenario.

Agency Owns and Operates

In this ownership arrangement, the toll or traffic management agency would purchase the entire AVI system and then operate the system independent of the vendor. All responsibilities would be with the implementing toll facility, with the exception of warranties and maintenance agreements. The issues to be considered before entering into this type of ownership arrangement are listed below.

Issues:

- The implementing toll agency maintains complete control over the AVI system including operation, administration, toll collection, maintenance arrangements, and all other aspects of the system. This type of control may be preferred by many toll facilities.
- The toll agency enjoys the interest earned on all prepayments and deposits collected as part of the AVI program.
- The agency will be held fully accountable for the successes or failures of the AVI system because it maintains control over all aspects of the system. If the system does not succeed, the agency is locked in on the equipment already purchased and installed.
- Owning and operating an AVI system requires the toll facility to incur significant capital costs over and above the conventional toll collection system, unless the change is made when the conventional system is fully depreciated.
- Different support staff are required to maintain and monitor the AVI system, but overall the number of staff should be smaller when compared to a conventional system.
- Additional training of staff is required particularly as it relates to the production and analysis of the many information and audit reports that the computer system provides as a result of interfacing with the AVI system.
- Overall levels of staff may change depending on the system design.

Vendor Owns and Operates

This arrangement involves the authority hiring an independent contractor to administer the AVI system including the installation, operation, administration, and maintenance. A typical vendor-ownership arrangement would preclude the toll facility from purchasing any AVI equipment or software. An arrangement could be made where a vendor is paid a flat fee to install, administer, and operate the system or, once the system became fully operational, the facility could be required to pay a fee for each transaction processed through the AVI system. This fee could then be passed on to the patrons in the form of premium tolls, unless a volume discount can be provided. In addition, each AVI patron could be required to pay a monthly fee for the use of the AVI tag. This arrangement could also tie into a lease/purchase agreement after a time period agreed on by both parties involved.

This type of arrangement can be termed an operating or service lease because it provides for financing, operation, and maintenance. One advantage of an operating lease is that it frequently contains a cancellation clause allowing the lessee to cancel the lease and return the equipment before the expiration of the basic lease agreement. This type of agreement is already being used on

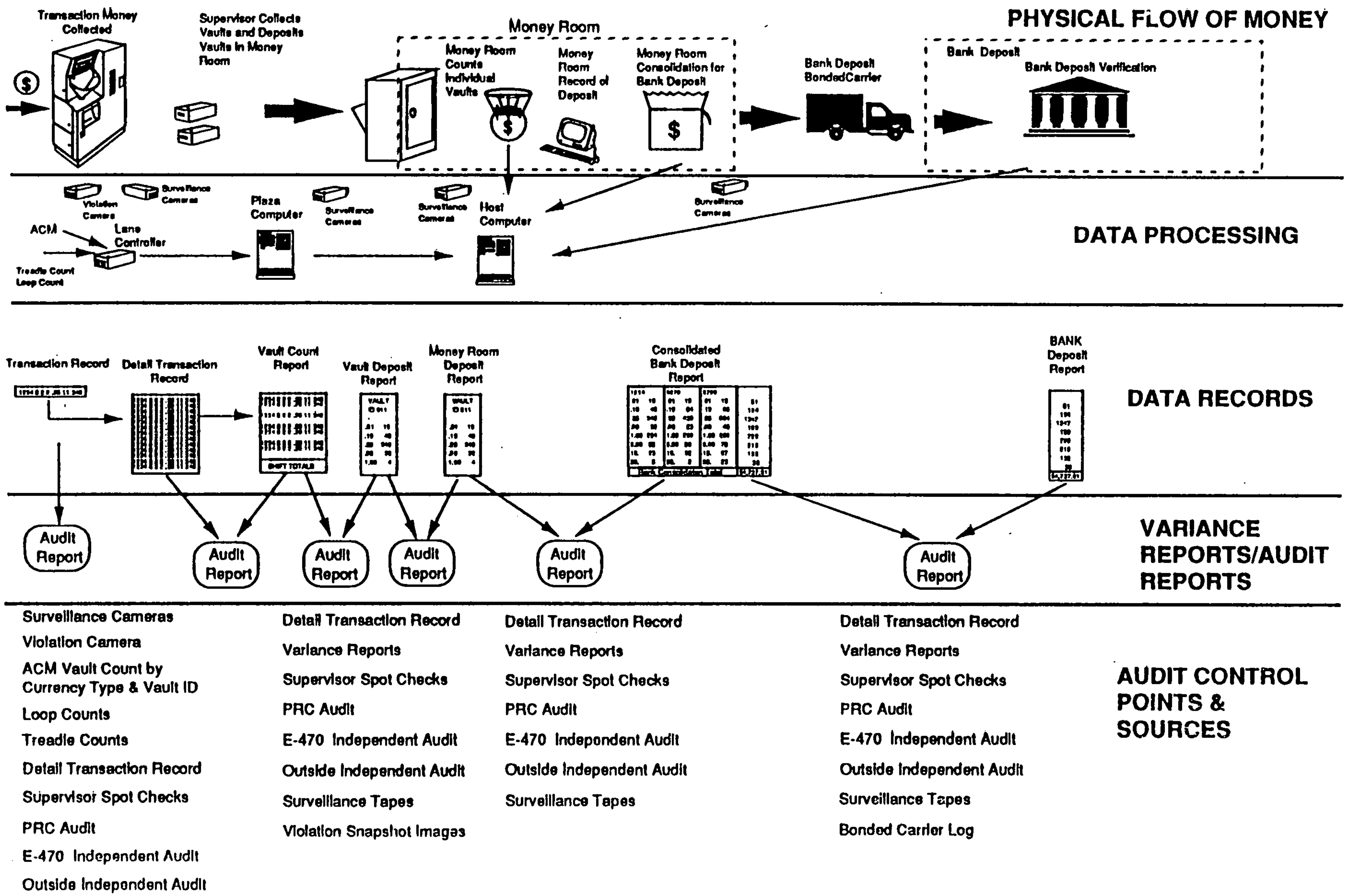

FIGURE 10 Automatic lane collection process.

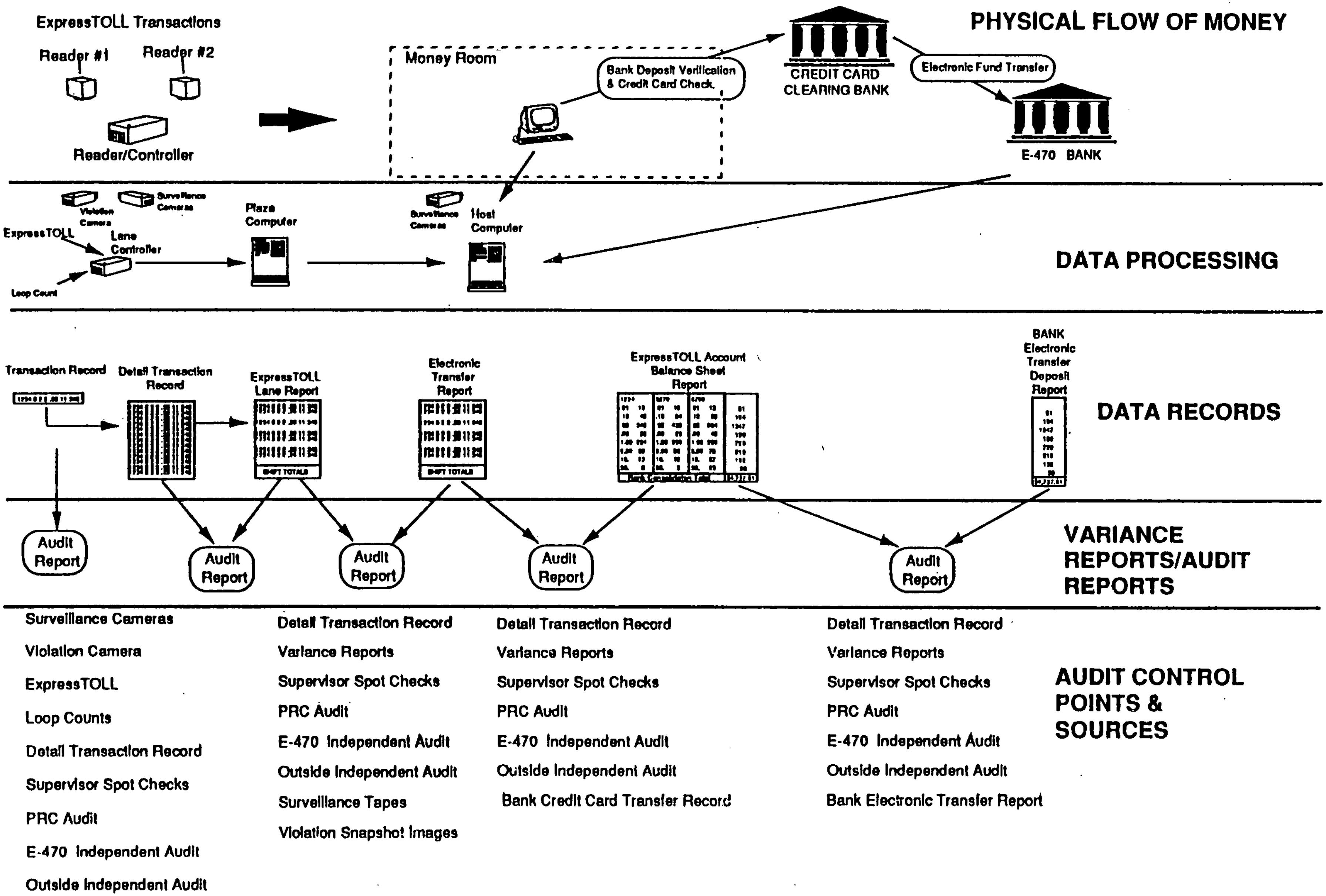

FIGURE 11 AVI (ExpressTOLL) lane collection process.

the Dallas North Tollway in Texas. However, the Texas Turnpike Authority has agreed to purchase the Amtech system and hopes to replace the user fees with a deposit requirement.

Issues:

- The agency would no longer be directly responsible for the financial success (or failure) of the AVI system. However, the agency would be responsible for monitoring and evaluating the performance of the contractor. This necessitates a much smaller support staff for AVI within the agency.
- If for some reason the agency were not satisfied with the AVI system, its removal would be less costly because the agency does not own the AVI equipment. The extent to which this is possible would depend on the negotiated contract.
- There is some incentive to succeed if compensation to the independent contractor is directly tied to the level of participation in the AVI system.
- The agency can define performance objectives/standards that must be met by the independent contractor.
- The typical independent contractor already has significant marketing resources to draw on, which increases the potential for maximizing patron participation.
- The ability of the agency to collect the proper fares depends on the private company's records of fares collected. (The agency must use its own automatic vehicle classification system and treadle counts to verify the vendor's records.) Such a system would require detailed audit controls if the agency permits an independent contractor to electronically transfer tolls collected as a result of AVI.
- Depending on the contractual arrangement, the agency may lose the "float" on toll prepayments and tag deposits collected as a result of the AVI system. "Float" issues are also dependent on state constitutions, agency rules, and bond indenture language.
- Under this arrangement, the agency owns no part of the AVI system.
- Information concerning the AVI users and their billing records could be the property of the independent contractor and not the agency. Ownership of these records is not always clear at the end of the negotiated contract.
- The agency may suffer from an identity problem. As an example, the AVI patrons on the Dallas North Tollway identify with the private vendor and not the agency.

Lease Agreements

There are numerous leasing arrangements in which an agency could become involved. A lease agreement results in sharing responsibilities between the agency and the independent contractor. The burden of these responsibilities would be negotiated in the lease contract. Probably the most popular type of lease agreement gives the implementing agency the choice of purchasing the equipment at the end of the lease.

Issues:

- There is a great deal of flexibility involved with a lease agreement. The agency could be responsible for those administrative tasks that are believed to be appropriate for the agency while the remaining tasks could be built into the negotiated contract.
- The agency ultimately assumes ownership of the equipment under most lease arrangements.
- Under this arrangement, the agency may not own the equipment over the life of the lease.

COST CONSIDERATIONS

This section provides a consideration of the capital, operating, and maintenance costs associated with the construction and operation of various lane types. In particular, consideration must be given to costs for: lane construction and right-of-way, equipment by lane type, operating and maintenance expenses, computer hardware and software, and transponders for the different technologies. It is important to note that, when the listed equipment is purchased in large quantities, the unit cost will likely decline.

Lane Construction Cost and Right-of-Way

Industry standards suggest that engineering and construction costs for the average toll lane ranges from $150,000 to $750,000, plus the cost of the booth and equipment placed in the lane. It is important to note that costs will vary significantly by region and location throughout the United States. This estimate includes planning, concept design, lane construction, right-of-way, and other associated lane construction costs.

Cost of Equipment by Lane Type

Table 5 represents line-item costs for various lane types including manual lane, automatic coin machine, AVI dedicated lane (retrofit), mixed-use lane (AVI and manual), mixed-use lane (AVI and automatic coin). Costs were averaged based on several toll agency bids for AVI lane equipment procurement obtained over the last 18 months. Tables 6 and 7 reflect recent estimates for AVI plaza and host computer equipment. Operating and maintenance costs by lane type (shown in Table 5) are based on Florida averages for conventional lanes and AVI system averages in Dallas and Oklahoma for AVI related operations and maintenance. Operating and maintenance costs for advanced traffic management systems vary significantly (as might be expected) depending on staff size, system infrastructure, and other factors. For example, the Westchester County system requires about $75,000 per year, whereas the Minneapolis system requires about $7 million per year. SmartRoutes center in Cambridge, Massachussetts requires about $750,000 per year for operations and maintenance. It is important to recognize that the cost estimates provided are extremely conservative in nature to virtually eliminate any possibility of underestimating equipment costs. The equipment depicted under each configuration assumes the maximum use of various equipment components. Some of the equipment would certainly be optional depending on the specific location and configuration.

Transponder Cost

The unit price to the agency of a one-way, read-only radio frequency transponder ranges from $5 to $50 depending on the

TABLE 5
EQUIPMENT, OPERATING, AND MAINTENANCE COSTS BY LANE TYPE

LANE TYPE	LANE EQUIPMENT COSTS PER LANE	OPERATING & MAINTENANCE COSTS PER 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

* Based on operation at 16 hrs Manual & 8 hrs Automatic Coin
Source: Florida Office of Toll Operations (conventional lanes), Dallas North Tollway, Oklahoma Pikepass, and related industry bid tabs (AVI lanes).

TABLE 5A
MANUAL LANE AVERAGE COST

EQUIPMENT	AVERAGE COST
Lane Controller	$11,400
Manual Toll Terminal	$4,000
Receipt Printer	$2,000
Slot Reader	$400
Patron Fare Display	$2,800
Loop Detector	$100
Automatic Vehicle Classifier	$2,000
Canopy Signal Light	$800
Toll Booth	$32,500
Two Contact Treadle	$2,500
TOTAL	$58,500

Source: Florida Office of Toll Operations.

technology, the vendor, and the quantity of transponders purchased. (So-called "smart cards," and transponders with read/write capability will cost from $35 to $65.) Alternatively, the unit price for a bar code decal ranges from $1.00 each for large quantities (100,000) to $2.00 each for smaller quantities (2,000 to 3,000).

TABLE 5B
AUTOMATIC COIN MACHINE LANE AVERAGE COST

EQUIPMENT	AVERAGE COST
Automatic Coin Machine	$51,600
Loop Detectors 2 @ $200	$400
Exit Gate	$2,300
Island Traffic Signal	$400
Canopy Signal Light	$800
Two Contact Treadle	$2,500
TOTAL	$58,000

Source: Florida Office of Toll Operations.

PATRON PAYMENT OPTIONS

In evaluating payment systems, there are three areas to be reviewed: prepayment versus postpayment, toll structures, and actual methods of payment (cash, check, or credit card).

Prepayment vs. Postpayment

An AVI system requires either pre- or postpayment of tolls. The operational procedures for these two methods are quite different. Within an AVI prepayment toll system, AVI users establish indi-

TABLE 5C
AVI DEDICATED LANE AVERAGE COST

EQUIPMENT	AVERAGE COST
AVI Reader (canopy mounted)	$1,300
AVI Reader/Controller	$7,300
CCTV Violation Camera	$5,200
Loop Detectors 2 @ $200	$400
Island Traffic Signal	$400
Canopy Signal Light	$800
TOTAL	$15,400
AVI Transponders (each)	$35.00

Source: Dallas North Tollway, Oklahoma Pikepass, and related industry bid tabs. Signage, striping, and channelization costs to accommodate dedicated AVI lanes have not been included.

vidual accounts with a prepaid balance either by cash, check, credit card, or electronic funds transfer. Subsequently, when the AVI user passes through a toll lane with AVI equipment, the toll amount generated is subtracted from the user's prepaid account balance. The postpayment system operates differently. It is based on a billing process whereby the AVI user is charged based on actual use of the toll system in the preceding month.

In evaluating prepayment and postpayment toll systems, numerous implementation costs and issues must be considered. A prepayment system will require the establishment of locations for opening and replenishing AVI accounts. Locations can be at various fixed office sites or advertised mobile van sites. Accounts opened and replenished through the mail can also be processed at the office sites. At a fixed office site, an AVI service center could be established. Costs associated with the center would include expenditures for construction or leasing, operations, computers, and maintenance. Another option is a mail program where opening of accounts and distribution of tags could be accomplished through the mail. The mail program would still require a central processing location. A final option is mobile registration where a mobile unit could be dispatched to register patrons.

When considering a postpayment plan, additional operational costs would need to be evaluated. The additional costs include monthly statement account mailings and collections on delinquent accounts receivable. The collection process is viewed by many to be time consuming and undesirable. The San Diego Coronado Bridge is one of the few systems to have offered a postpayment option. During a trial period two years ago, the Coronado Bridge let patrons settle up accounts after a certain amount of debt was incurred. The trial was a success; however, the San Diego system was a demonstration project only and has never been implemented on a full scale.

Payment Methods

AVI-generated tolls can be paid by cash, check, electronic funds transfer, or credit card. In addition, tolls can be either prepaid or postpaid (billed). It was surprising to find that most potential AVI customers preferred prepayment, according to patrons surveyed in Florida. Generally speaking, one would assume that the user would prefer postpayment and the agency would prefer prepayment. In Oklahoma, 90 out of 180,000 users do opt for postpayment, but only provided that the payment is made in cash. The toll agency that opts for postpayment assumes the added responsibilities of bill collection.

Prepayment of AVI-generated tolls by cash may require that the patron visit an AVI center once to open an account and subsequently to replenish the account (unless this service is available by mail). Prepayment by check can be accomplished either by visiting the AVI center or by using a mail program. Prepayment by electronic funds transfer requires that the patron visit an AVI center only once to open an account (unless this service is available by telephone). An agreement is signed that allows funds from the patron's bank to be automatically transferred to his or her AVI account to replenish it when a preset minimum balance is reached. Prepayment by major credit card is the same as by electronic funds transfer, except the patron's account is replenished by charging a credit card. Since the use of electronic funds transfer and credit cards does not require the handling of money, operational costs are reduced and implementation and maintenance of the payment program are simplified. Credit cards are by far the preferred method of payment in Dallas. While this is attributable in part to area demographics, it is also a matter of convenience, since periodic trips to the retail store are unnecessary for credit card customers.

Currently, most operators of existing AVI toll facilities accept cash or check for payment of tolls. These are the most popular toll payment options. A few existing toll facilities also accept credit card or electronic funds transfer. For example, Houston AVI patrons may use Discover cards for fare payment. Dallas North Tollway offers their patrons the option of opening an anonymous account where all transactions can take place without providing the AVI toll facility with personal information.

Toll Structures

There are three AVI toll structure options. The first option is to charge premiums in addition to existing tolls. Advocates of premium tolls believe users of AVI should pay an extra charge for these special services. The second option is to discount existing tolls. Advocates of discounted tolls believe users need to be encouraged to use AVI by offering discounts on services. They also contend that increased patron participation resulting from discounts would fully offset any declines in revenue. Experience from the Oklahoma Turnpike indicates that reduced personnel expenses more than offset the 25 percent discount for AVI. The third option is to keep the toll structure the same, neither offering discounts nor charging premiums. Advocates of this final option contend that implementation problems would not exist and any governing legal documents would not need to be reviewed for compliance.

Comparisons of premium and discount toll structures found them to be equivalent for ease of implementation and associated costs. An extensive marketing campaign would be needed to educate potential AVI patrons on the new toll structure, and additional signage detailing the new toll structure would need to be purchased and installed. An accounting and billing program would be required to keep track of patron toll charges and payments.

TABLE 6
AVI PLAZA COMPUTER EQUIPMENT

QUANTITY	EQUIPMENT*	AVERAGE COST
2	Plaza Computers	$38,500
4	Disk Drives (2 System Disks, 4 Data Disks)	$33,400
2	4mm DAT Tape Drives	$8,000
1	Network Interfaces	$3,800
1	Fiber Optic Lane Network Routers	$4,500
1	Terminal Server	$4,000
1	Supervisor Workstation (Workstation, Terminal, and Printer)	$4,200
3	Terminals (Color with 14 inch Monitors)	$8,100
3	Printers (System, Maintenance, etc.)	$3,000
2	Modems	$2,000
1	Communication Cabinet	$1,600
1	Uninterruptible Power Supply System	$13,300
	SUB TOTAL	$124,400
1	Plaza Software	$3,900
	TOTAL	$128,300

* High-end design; total cost may not apply in all systems.
Source: Dallas North Tollway, Oklahoma Pikepass, and related industry cost proposals.

Information is not widely available for evaluating toll structures based on experiences from other existing AVI toll systems. The Dallas North Tollway is the only large-scale functioning AVI system charging premiums. However, careful consideration must be given to area demographics, traffic volume, and unique system characteristics before applying this system elsewhere. On the other hand, the majority of other functioning AVI toll systems, large and small, offer discounted tolls. Most systems confirmed that discounts encourage AVI use.

It is useful to consider historical data concerning transportation demand elasticities. For work-related commutes, demand is relatively inelastic when associated with price. An inelastic demand indicates that a one percent change in price will result in a less than one percent change in the quantity demanded. Therefore, despite the positive reaction to discounted tolls in the survey research, it is expected that a minor toll discount would not significantly increase participation in the AVI system. However, a substantial discount can increase participation during off-peak hours on heavy commuter routes. The Harris County Toll Road Authority reduced fares by 50 percent on its Hardy Toll Road during non-peak-hour periods only and experienced a 20 percent increase in AVI participation during nonpeak periods. Oklahoma Turnpike experienced a 20 percent increase in AVI participation after offering a 30 percent discount off cash toll rates. However, this action occurred at a time when a new, higher toll structure was being implemented.

Other Issues

As with all AVI systems, whatever the payment options offered, the proper installation of the tag (decal or transponder) in the vehicle is essential. Instructions should be given or sent to the user when an AVI tag is purchased. In addition, an AVI system test lane should be set up at the AVI Center that allows the patron to test tag placement before using the tag at an actual AVI toll plaza. Some AVI operators insist that trained personnel install the AVI

TABLE 7
AVI HOST COMPUTER EQUIPMENT

QUANTITY	EQUIPMENT	AVERAGE COST
2	Host Computers	$127,200
6	Disk Drives (2 System Disks, 4 Data Disks)	$63,100
2	4mm DAT Tape Drives	$7,000
2	Network Interfaces	$6,600
2	Network Routers	$10,200
2	Terminal Server	$7,000
2	Network Workstation (Workstation, Terminal, and Printer)	$7,300
8	Terminals (Color with 14 inch Monitors)	$19,000
4	High Speed Printers (System, Maintenance, etc.)	$27,800
12	Modems	$10,400
2	Communication Cabinet	$2,700
1	Uninterruptible Power Supply System	$8,500
	SUB TOTAL	$296,800
1	Host Software (including Service Center)	$10,600
	TOTAL	$307,400

Source: Dallas North Tollway, Oklahoma Pikepass, and related industry cost proposals.

tag for the user, thereby reducing the probability of misreads resulting from faulty tag placement.

Another issue to be considered is the establishment of a toll-free (800) phone number so that trained personnel could address problems and field questions from current and potential AVI users. Also, the agency should consider the possibility of establishing a direct computer link between the Department of Motor Vehicles and the AVI system. This would provide new and current residents the option of signing up for AVI when they register their vehicles.

SYSTEM BENEFITS

Numerous benefits could result from the implementation of an AVI system. A list of these benefits along with a brief description is provided in this section.

Throughput Efficiency

The implementation of AVI will increase toll lane capacity, thereby reducing toll processing time and queue lengths at toll plazas. Most importantly, AVI can substantially reduce or, in some cases, eliminate the need for future expansion of toll plaza lanes. Depending on the participation rate for AVI, the reserve capacity for plaza lanes can be "banked" and additional right-of-way may not be needed. Significant cost savings can be realized, especially in developed urbanized areas.

Payment Alternative for Patrons

AVI allows toll patrons more flexibility and convenience in paying tolls. Opening prepayment accounts eliminates the need for patrons to be concerned with having cash ready for each toll plaza passage. Prepayment also provides patrons the flexibility of paying tolls by cash, check, credit card, or electronic funds transfer. In addition, AVI reduces the handling of hard currency by toll system operators. Furthermore, commercial users of AVI are given a faster and more reliable tracking system of when and where their vehicles use the toll system.

Increase in Patron Satisfaction and Loyalty

By offering the patrons an additional payment alternative that makes their travel quicker and more convenient, the agency can expect the typical customer to be much more satisfied with the facility as a whole. In addition, once patrons experience time savings and other benefits of an AVI system, they will be much more likely to choose the system over an alternate parallel facility.

Environmental Issues

Pollution in any form is a great concern to environmental groups, and as gas prices rise, fuel consumption will become a major priority among AVI/ETTM patrons. Dedicated AVI lanes may eliminate the need for AVI-equipped vehicles to stop at toll plazas, which can reduce noise pollution, air pollution, and fuel consumption. Fewer vehicles stopping means less gear shifting during acceleration; in the case of trucks and other heavy vehicles, this has the potential to dramatically reduce noise pollution. According to the Environmental Protection Agency's modeling software, emissions decrease after a vehicle accelerates and reaches a constant speed. Since the smooth flow of traffic is increased by implementing AVI, it would result in less fuel consumption and less pollution per vehicle.

Security Against Loss of Funds

Most revenue funds lost by a toll collection system result from human error or fraud. The automation of systems resulting from the implementation of AVI increases security against error or fraud. Processes once done manually, such as reconciliations, axle classifications, transaction report generations, and toll evasion enforcement, can be accomplished through the system's computer and video cameras. The ability to generate a clear audit trail of revenue funds through an automated and networked AVI system is a major security benefit for those revenues collected from AVI-equipped vehicles.

Improved Accountability

A computerized AVI accounting system leads to the benefit of improved accountability for AVI transactions. First, the system eliminates errors caused by the manual processing of accounting and operational reports. Second, the system provides improved statistical traffic reports, since all AVI-equipped vehicles passing through the toll system can be accounted for electronically. Also, by computerizing many functions of a toll system, audit control points are easier to implement and maintain.

Reduced Construction Costs

Agencies can select from three alternatives when an existing plaza is at or near capacity:

- Expand the number of lanes at the plaza,
- Increase traffic throughput through the existing configuration, or
- Accept a lower level of service.

Accepting a lower level of service is an unlikely choice because of the resulting loss of revenue and safety. Expansion of the plaza has typically been the solution implemented most often in toll facilities across the United States. However, expansion involves significant capital outlays (according to recent Florida DOT Turnpike cost estimates, approximately $500,000, excluding right-of-way, plus booth and equipment costs) per lane. In addition, in many cases expansion may be impossible where there is no right-of-way available. A third alternative is the implementation of AVI on the existing configuration, which can significantly increase the capacity of the existing lanes. This increase in capacity can result in a significant reduction in necessary lane construction that may otherwise be needed. Perhaps an even more feasible alternative is to implement AVI in conjunction with some degree of expansion, which the Florida Turnpike has chosen to do.

Reduced Operating Cost

The operating costs associated with a typical manual lane include the costs of maintaining the lane equipment, collector and supervisor salaries, auditing functions, banking and cash handling, and lighting and environmentally controlling the booth that houses the toll collector. Similarly, the costs of operating an automatic coin machine lane include those associated with maintaining the lane equipment, supervisory salaries, auditing, and banking and cash handling. For each manual lane eliminated as a result of AVI, these particular operating costs will be significantly reduced.

The collection costs for an AVI system include those associated with maintaining the AVI equipment, issuing tags, and servicing accounts. In addition, the system operates 24 hours a day. These collection costs will also be partially offset by the moneys collected as part of the sale or lease of the tags and the interest realized on prepayments and deposits.

Potential for Increased Revenue

By increasing capacity, toll roads may encourage users of an existing parallel facility to convert to using toll roads. This is particularly true in a location where an existing parallel facility is undergoing construction. The increase in toll road patronage could result in an increase in total revenue.

Psychological Benefits

Several other nonquantifiable benefits can also be attributed to AVI implementation. These would include benefits to travelers who do not use AVI and those who use AVI facilities during nonpeak hours. Both groups would experience less overall plaza congestion but nonusers would benefit, particularly in mixed-use lanes. Since differences in vehicle delay cost are typically considered for the peak direction, peak-hour analysis, additional benefits can also be expected in the nonpeak direction and in nonpeak time periods of the day. As other adjacent roadway facilities become congested, variable toll pricing (reducing normal toll rates) can be used as an incentive for patrons to divert their travel to the uncongested or less congested toll facility. Finally, AVI can facilitate the implementation of variable (congestion) pricing. The programmability of AVI systems enables the operator to change the amount of tolls on short notice, even in real time.

STANDARDS AND PROTOCOLS

The communication, software, and hardware industries, all suppliers of ETTM technology, play a crucial role in successful long-term product development and broad-based consumer acceptance. Establishing standards too early can stifle innovation. However, the ETTM industry cannot realistically be expected to curtail product development while waiting for nationwide standards to be defined.

Benefits to be gained from standardization at the appropriate time include:

- Interchangeability of system components,
- Elimination of unnecessary product development costs caused by changes in product interaction,
- Fostering of area-wide deployment,
- Promotion of application stability, and
- Establishment of a basis for liability limitation.

The standards process for ETTM systems and technologies has already begun although no specific standards have been established. An IVHS AMERICA committee on Standards & Protocol has been established to serve as an oversight and coordinating agency for all standards activities in the United States relating to ETTM. The committee does not expect to create or promulgate standards itself, except in cases of last resort. Rather it will rely on other established standards-generating bodies (e.g., American National Standards Institute (ANSI), International Organization for Standardization (ISO), International Electrotechnical Commission (IEC), American Society for Testing and Materials (ASTM), Society of Automotive Engineers (SAE), Institute of Electrical and Electronic Engineers (IEEE), and others) to carry out the work of defining, publishing, and securing industry acceptance for standards. The objective of the committee will be to assure appropriate attention to ETTM needs, promote effective communication among interested parties, and minimize duplicated efforts (*7*).

IVHS AMERICA's committee on IVHS Standards & Protocols has the following objectives:

- Determine the most appropriate group to set a given standard,
- Identify all ETTM interfaces, subsystems and elements that require standards,
- Act as a liaison in international standard efforts,
- Encourage the inclusion of standards and protocols in the definition of future operational tests,
- Adopt or upgrade existing standards whenever required,
- Assist organizations responsible for the tests in defining, acquiring, and analyzing standards related data, and
- Coordinate standards related information between operational tests and standards-making organizations.

As an example, the IVHS AMERICA Standards & Protocols committee is already working with the SAE Map Database Standards committee. Several other organizations, ASTM for example, have also established committees for the standardization of IVHS technologies.

MARKET IDENTIFICATION AND PERCEPTION SURVEYS

Survey of Existing AVI Users

The management of many ETTM systems provided a profile of the typical patron based on observations. It is important to note that the potential market for ETTM use varies with each installation, given the socio-economic and travel characteristics of the area. However, some general observations can be made regarding the profile of existing ETTM users. In Dallas, most ETTM users are in the middle- to high-income brackets and travel the facility frequently in their commute to work. The income factor indicates that these individuals are more likely to value their time, while the greater use of the facility indicates that these individuals will realize significant time savings. Also, if additional costs are required to participate in the ETTM system, those in the middle- to high-income brackets are more likely to pay the additional cost.

Other ETTM Related Surveys

Several previous ETTM related survey findings were obtained while gathering information for this project. In particular, three surveys were undertaken by toll agencies that did not yet have AVI at the time. The intent of these surveys was to identify characteristics of current users of the facility as well as to ascertain perceptions and attitudes toward AVI. These surveys were conducted by the Virginia Department of Transportation, the Illinois State Toll Highway Authority, and the Oklahoma Turnpike Authority. Further (existing and potential) user perception surveys must be conducted to identify the most effective AVI marketing strategies and technology features.

Virginia Department of Transportation

As part of the Dulles Fastoll project, the Virginia Department of Transportation (VDOT) conducted a survey of existing users of the Dulles Toll Road several years ago to determine the market potential of AVI on that facility. The respondents interviewed were representative of the most frequent users of the facility as they traveled it approximately 11 times per week on average. Nearly 75 percent of the trips made by these respondents were trips to and from work. The remaining trips were typically for leisure or for other personal reasons. Very few trips were related to other business purposes. Respondents had questions regarding the operation of the system, the degree of safety, and the consequences of lost, stolen, or damaged tags. There was also some concern about the possibility of the system misreading tags and charging improper accounts. Other comments indicated a preference for transponder mobility; that is, users with more than one car wanted the ability to transfer a transponder from one car to another. The majority of negative comments stemmed from those users who believed they should not be paying tolls at all. Very few negative comments were received regarding the actual Fastoll system. In summary, the majority of comments were encouraging and supported the efforts of the Fastoll project.

Illinois State Toll Highway Authority

In early 1989, the Illinois State Toll Highway Authority conducted a relatively short survey of its toll facility users to determine their level of interest in an AVI system; 1,119 successful surveys were completed. More than 69 percent of respondents indicated they were either very interested (36 percent) or moderately interested (33 percent) in an AVI system on the Illinois toll roads. The remaining 30 percent were not interested in AVI. Respondents were also questioned regarding the amount they would be willing to pay for the transponder necessary to participate in an AVI system. Approximately 50 percent were willing to pay between \$20 and \$35. This willingness to pay drops to 12 percent when the cost of the transponder is between \$35 and \$50. Only 4 percent are still willing to purchase a transponder if the cost were between \$50 and \$65.

Oklahoma Turnpike Authority

The Oklahoma Turnpike Authority conducted a survey of turnpike patrons in 1989 to determine their attitudes toward AVI and to determine some basic user characteristics. A five-question survey instrument was distributed to 15,000 vehicles on the Turner Turnpike and to 15,000 vehicles on the Rogers Turnpike. Of the 30,000 distributed questionnaires, 3,003 were returned. The survey instrument was designed to establish how often patrons traveled on the turnpike, the purpose of the trips, and the level of interest in AVI. Based on the survey results provided, 56 percent of the 2,688 useable responses indicated that they were interested and would likely use AVI if it were provided at these locations.

Florida Department of Transportation (Turnpike Office)

In mid 1990, the Florida Department of Transportation conducted a three-part survey to determine the market potential of a future AVI system. The surveys consisted of interviews, mail-back surveys, and two focus group meetings. Interviews were conducted at two mainline barriers as well as six exit ramps. The mail-back survey was handed out at the same mainline barrier and exit ramp locations. The focus groups were conducted at a convenient location in South Florida.

The purpose of the survey was to determine patron perception of the AVI concept and its related operational aspects, as well as to develop a profile of the typical turnpike user. The survey focused on a number of important issues including willingness to pay for the convenience of AVI, method of payment, trip purpose, trip frequency, and other demographic characteristics. The user profile and perceived level of participation indicated a great market potential for an AVI system at the interview and mail-back survey locations. These surveys were also supported by the observations made during the commercial and commuter focus group meetings.

CHAPTER FIVE

PRIVACY AND LEGAL ISSUES

ENFORCEMENT

AVI lane violations are important both to the customers, because of the delays and inconvenience that violators can create, and to the agency, because of lost revenue. A successful AVI toll system will need a high-speed video camera system to deter AVI lane violators. Most states (Colorado, Florida, Illinois) where AVI systems are located have passed laws enabling AVI violators to be legally identified and cited based on videotape evidence. On the other hand, New Jersey has turned down legislation enabling photo enforcement.

A Colorado toll authority entered into an agreement with local law enforcement specifically for the prosecution of AVI violators using the new E-470 toll highway. Also, the City of Pasadena, California used a photographic system called "PHOTO-COP" that identified speeders and sent a citation through the mail. This system was discontinued because of the cost. State laws allowing pictures generated from remote video cameras to support prosecutions are not uniform; Illinois was the first state to win conviction of a driver using this evidence. Photo enforcement has been used in Europe for almost a decade. Zurich, Switzerland added a photo enforcement component to its toll collection system in 1983.

AVI patrons incurring violations on the Dallas North Tollway were sent numerous letters detailing their violations. It took Dallas patrons only a short time to realize the legal evidence generated from the Tollway's video cameras was not supportable in the state court system. The laws in New York are another example. New York recently passed legislation detailing the need for an "enforcement agent" to witness the patron avoiding payment of the toll and to issue a summons at that time. Florida has a similar situation. The infraction must be witnessed by an officer and the citation must be issued to the driver of the vehicle avoiding the toll and not the registered owner of the vehicle. Toll violation enforcement legislation passed the Florida state legislature in April 1993. This legislation will provide for photographic imagery as evidence against alleged toll violators.

Camera Equipment

Camera equipment is an important part of the AVI enforcement system and specifications should be reviewed carefully. All lanes typically include remote control, high-speed video cameras to record violations, whether the lane is open for operation or not. As a violation occurs, the camera is activated. It records the offending vehicle, its license plate, the lane's traffic signal, and the violation indicator as the vehicle travels over the lane's exit loop. It is believed that some cameras in operation now can provide legible vehicle license plate pictures for speeds of up to 100 miles per hour.

The specific capabilities of the video cameras and related equipment need to be flexible to meet the needs of various AVI systems.

FIGURE 12 A driver is instructed to call the tag office because of a lost, stolen, or low-balance tag, on Dallas North Tollway.

However, all video enforcement systems should record on the video picture the date, time, and lane number of the violation. The system-generated video picture should also be recorded on a computer disk and retrieved when a hard copy of the picture is required. The software that drives the operation of the video lane cameras should trigger the cameras to record not only when nonpayment violations occur but also when a vehicle passes that is using a reported lost or stolen tag, when the patron's account is below a predetermined minimum balance, when the account has been suspended, or when the axles classified do not match the treadle count indicated (see Figure 12).

SECURITY

Electronic toll collection will afford toll agency operators the opportunity to automate the handling of cash transactions through automatic debiting and electronic funds transfer. As AVI participation increases, more and more of the total revenue collection process will be automatically performed. Reconciliation of each transaction can be more readily isolated and checked, and audit trails generated by system software will deter collector fraud and misreporting. Chapter Four has previously discussed the safeguarding of toll assets as a result of AVI implementation.

PRIVACY

Appropriate safeguards and guidelines on the control and use of ETTM information must be established to protect the privacy of individual vehicle users. On the other hand, it is important to note that according to surveys conducted among San Francisco Bay Area motorists, only 7 percent of the respondents indicated a strong concern that electronic tags could permit tracking of their vehicle. The law of privacy regarding information that is collected through electronic means is undergoing rapid change. The Electronic Communications Privacy Act (ECPA) was adopted in 1986 to protect wire or electronic communications from illegal interception by unauthorized third parties. This act creates standards and procedures for court-authorized electronic surveillance, regulates when electronic communication firms may release information, and provides legal protection of the privacy of stored electronic communications from outside intruders and unauthorized government officials. Because of changes over the last 5 years, a major revision of the ECPA is under consideration. The revision may include privacy protection for ETTM travelers. It should be noted that, in most places, toll road use is essentially voluntary because toll roads usually run parallel to a free facility. In addition, participation in an electronic toll collection system is also voluntary. Drivers who do not want to be tracked or photographed can always use the free facility or pay in cash.

EQUITY

The implementation of an ETTM system creates alternative methods for customer payment, and the possibility also may exist for discounts or premiums for ETTM users. As stated previously, an AVI/ETTM account may be initiated through cash, check, or credit card down payment. In selecting a method of payment, patrons should not have to face discrimination. For example, if the only form of payment or account replenishment is through a major credit card, as in Denver, some potential patrons may be excluded from participation. Also, if AVI/ETTM patrons are required to pay an additional transaction fee or get a reduced toll fare, further discrimination may result. The toll agency bond indenture must be reviewed carefully to assess the legal options that can be offered to toll patrons. If it can be proven to the bond holders that projected revenue will not be jeopardized, then payment and transaction options can be created with their approval vote.

OTHER LEGAL ISSUES

A number of other legal issues could greatly affect ETTM deployment. They include product liability and other tort liability, antitrust, procurement, and intellectual property rights. Liability doctrines and practices may significantly deter private sector designers and manufacturers from the development and introduction of new technologies to the surface transportation system. Exposure to risk of expensive product liability suits raises the cost to the private sector. Vehicular accident cost, primarily borne by the driver today, may fall on ETTM product manufacturers.

There has also been some uncertainty about the extent to which antitrust law restricts collaborative research. Although the United States is more concerned with industrial collusion than the Japanese or Europeans, in reality there is a wide latitude in the types of research activities that can now be undertaken. Although there is increased flexibility for U.S. companies to work cooperatively, consideration of additional changes may be needed to allow firms to compete more effectively in the ETTM industry. The difficulty of doing business with the government is of great concern to private sector firms. It is still widely believed that procurement and government contracting requirements are far too complex and time-consuming, often constraining effective and timely implementation. Another issue is how toll agencies may effectively fund productive, creative research and development and whether current contracting and procurement practices support or delay that goal.

Many cooperative arrangements among government, the private sector, and universities are expected as part of the IVHS development process. These will include research consortia and operational test joint ventures. Therefore, it is important that understandings and agreements regarding rights to intellectual property be reached at the beginning of each project. The policy for copyrighted material (including computer software) must also be understood. The nonfederal party generally may copyright the material developed under the funding agreement, as long as the federal agency reserves a royalty-free, nonexclusive, and irrevocable license to reproduce, publish, or use the copyrighted material for government purposes.

CHAPTER SIX

MANAGEMENT SYSTEMS

TRAFFIC FLOW AND SPECIAL EVENT MANAGEMENT

Advanced traffic management systems, such as ETTM systems that use AVI, employ innovative technologies and integrate new and existing traffic management and control systems in order to be responsive to dynamic traffic conditions while servicing all modes of transportation. Transponders, initially used for toll collection, also can allow for the collection and integration of real-time traffic data as the "tagged" vehicle travels to areas outside of the toll collection environment. Real-time traffic data can assist traffic management agencies to react more effectively to changes in traffic flow with timely traffic management strategies. Areawide surveillance and detection systems can predict when and where congestion will occur based on real-time traffic information. Traffic flow and special-event management integrate various functions including transportation information, demand management, freeway ramp metering, and arterial signal control. Advanced detection technologies such as image processing, automatic vehicle location, and the use of AVI-equipped vehicles themselves as traffic probes are now being applied to traffic management. Projects such as INFORM, the Smart Corridor in Los Angeles, GuideStar, and Transcom (each briefly discussed in Chapter 7) are examples of advanced traffic management.

INCIDENT DETECTION AND MANAGEMENT

Artificial intelligence capabilities and expert system techniques are being applied to assist in rapid incident detection, related congestion anticipation, and control/response strategies. The state of California is one of the leading advocates in this regard (*8*). Incident management teams, typically consisting of highway patrol, police, fire, and emergency medical personnel, attempt to recreate past incidents to help assess their performance and discuss alternative response techniques. If real-time traffic data are available, a previous incident can be graphically recreated through expert system software, and incident management team members can more effectively predict response times and evaluate the feasibility of various traffic management techniques in minimizing the time to restore normal traffic operations (see Figure 13).

Local familiarity with roadway traffic conditions and geometry can be cataloged so that, with a minimum of input traffic volume and speed data, congestion and back-up levels can be accurately predicted given alternative schemes for lane closures and emergency response times. Basically, incidents can be managed more effectively because they will have been responded to in advance.

COMMERCIAL VEHICLE OPERATIONS (CVO)

CVO systems apply various ETTM technologies to improve the safety and efficiency of commercial vehicle operations. A key CVO productivity goal is the creation of "transparent borders," that is, unimpeded commercial traffic across state and international boundaries. This will in part be achieved by automating the collection of information required by governmental agencies. Potential benefits will be enhanced further if the information is shared by several states. Many motor carrier safety regulations exist to reduce safety hazards. A number of CVO initiatives will apply ETTM technology to improve driver and vehicle compliance with those safety regulations. Some of the safety related ETTM systems that specifically address CVO issues include:

FIGURE 13 A toll and traffic monitoring system on the Denver E-470 toll facility.

- *Driver/Vehicle Real-Time Safety Monitoring.* Monitors and electronically records the status of critical safety factors and, as appropriate, reports on them while the vehicle is traveling.
- *Hazardous Material Information Systems.* Electronic tracking technologies are being developed to accurately track cargo contents and react properly to emergency situations.
- *Automated "Mayday" Capabilities.* In emergency situations, drivers would be able to communicate with their dispatchers or with local police agencies using the same ETTM technologies for communication and vehicle tracking.
- *Electronic Credentials.* The motor carrier will be able to electronically file for, obtain, and pay for all required licenses, registrations, and permits. A supporting database will contain information about those transactions for access by appropriate governmental authorities.
- *Electronic Mileage Recording and Trip Logs.* The collection of mileage data will require road-to-vehicle communication to transmit location, date, and time information to an in-vehicle recording device. The fuel tax rates for each state can be recorded electronically if AVI beacons are located at all state boundaries, thus eliminating the need for paper records for both government agency and motor carrier.

• *Automated Credential and Weight Checking.* Motor carrier credentials and weights (through weigh-in-motion scales) can be checked and cleared for transponder-equipped vehicles through bypass facilities at ports of entry and weigh stations allowing speeds of 30-40 miles per hour. However, the weigh-in-motion (WIM) technology is continually undergoing testing and refinement to improve its accuracy and reliability (*9*). At this point, the reliability and accuracy does not permit WIM to be used as an enforcement method.

BUS OR FLEET MANAGEMENT

Advanced Public Transportation Systems (APTS) define the application of ETTM technologies to the deployment and operation of high-occupancy and shared-ride vehicles, including conventional transit buses, rail vehicles, and the entire range of paratransit vehicles (taxis, shuttle vans, etc.). APTS will enable transit authorities to provide a more flexible, cost-effective, user-friendly service to their customers. Some of the APTS features and products include:

• Ride-matching information that allows the flexibility to change arrangements on short notice, even during travel,
• Traffic control measures that provide preferential treatment, such as separate lanes and coordinated signal preemption, for high-occupancy vehicles, thus reducing delays for mass transit and shared-ride vehicles operating in congested areas (see Figure 14),
• Convenient user fare methods that allow faster loading and unloading, while maintaining records for marketing and planning functions,
• Automated monitoring and enforcement of specialized lane use, and
• Fleet-monitoring information and control techniques that integrate computer-assisted dispatching, customer information, and passenger security (*10*).

FIGURE 14 A bus equipped with an AVI tag passes through a dedicated transit lane on the Lincoln Tunnel approaching Manhattan.

Operational tests are already being designed and implemented in several cities, including such projects as Smart Bus and Smart Traveler (see Chapter Seven). The Smart Bus concept is patterned after a European program that integrates regular fixed-route transit, dial-a-ride minibus, and contract taxi services to provide for a more efficient system that serves a larger geographic area. Real-time travel and ride-sharing information is the focus of the Smart Traveler projects. The information is used by customers in planning travel and choosing modes, and by dispatchers in directing services. Mobility Manager is another program similar in concept to the Smart Traveler program. Its goals are to provide alternatives to single-occupant auto travel, and to provide greater mobility for special population groups (e.g., elderly or disabled) by providing a single point of contact for arranging the details of a journey.

TRAVELER INFORMATION SERVICES

Advanced Traveler Information Systems (ATIS) acquire, analyze, communicate, and present information to assist surface transportation travelers. The travel may involve a single mode of transportation, or it may link multiple modes together during various parts of the trip. A major component of ATIS is providing real-time information to the driver of a vehicle. Real-time information could include locations of accidents, weather and road conditions, optimal routes, recommended speeds, and lane restrictions. ATIS equipment in a vehicle can also be used to provide safety warning information on potentially dangerous road or environmental conditions.

According to IVHS AMERICA, specific ATIS products and features include:

• Navigation systems with electronic vehicle or traveler position determination, which provide maps, traffic information, route guidance, road sign information, and other travel information,
• Data communication providing information from traffic management centers to in-vehicle, home, hand-held, and kiosk transceivers, and
• Automated vehicle identification for vehicle tracking, toll debiting, or commercial vehicle credential processing and verification.

In ATIS systems, it is important that the traveler not be confused by an overload of information. It is particularly important that a driver not be distracted. The types and amounts of information and the methods of presenting information must be evaluated carefully to ensure that highway safety and traveler efficiency are enhanced and not degraded by information systems. Advances in electronic technology have encouraged development of a variety of communication systems and media that make it easier to provide information. They allow information to be provided either to a driver in a vehicle or to a traveler in the home via a personal computer. Information such as electronic route maps, tourist guides, and service directories can be self-contained within the vehicle. Vehicle status and warning indications can also be provided through self-contained, in-vehicle sensors.

CHAPTER SEVEN

CURRENT STATE OF THE ART OF ETTM PROJECTS

According to research by IVHS AMERICA and the Center for Urban Transportation Research (CUTR), there are currently 22 electronic toll collection (ETC) facilities or systems operating or under development in the United States. Tables 8 and 8A list operating and planned ETC projects by location. (Tables 8-14 show the status as of April 1993, with some exceptions.)

Advanced Traffic Management Systems (ATMS)

Advanced Traffic Management Systems (ATMS) integrate innovative technologies to respond to dynamic traffic conditions in real-time. ATMS will efficiently manage multiple roadway functions such as: freeway ramp metering, arterial signal control, predicting traffic congestion, and providing alternate route selections to vehicles over a wide area. ATMS will collect, analyze, and disseminate information in real-time to provide readily available information to vehicles enroute to their destinations. Table 9 lists a small sample of ATMS projects with a brief description and status of as March 31, 1993.

Advanced Traveler Information Systems (ATIS)

ATIS technology uses on-board navigation systems to assist travelers in reaching their destinations. Equipment in vehicles, sidewalk kiosks, and portable receivers will provide traffic information on conditions, routes, and schedules. ATIS can link travelers via single or multiple modes of travel. ATIS provides up-to-date information to travelers in real-time, thereby allowing travelers to reach their destination in a most timely manner. Table 10 lists ATIS programs.

Commercial Vehicle Operations (CVO)

CVO are intended to efficiently move fleets of vehicles through vehicle-to-dispatcher communication, which leads to increased productivity through real-time path routing, scheduling, and vehicle-load matching. CVO applications will recognize regulatory restrictions such as weight limits, and hazardous waste shipments. CVO technologies will enhance fleet productivity and improve free-flowing traffic for all vehicles. Commercial vehicle operations have the strongest link of any of the IVHS function areas to electronic toll collection, since fleet tracking is accomplished by AVI transponders placed on heavy vehicles. Table 11 lists CVO programs.

Advanced Public Transportation Systems (APTS)

Advanced public transportation systems (APTS) combine various applications of ATMS, ATIS, and advance vehicle controls systems (AVCS) to help high-occupancy vehicles reach their destinations in the most efficient way. APTS use multiple technologies (i.e., ATMS, ATIS, AVCS, and CVO) for transit and rideshare operations. Travelers can by-pass high congestion areas via traffic management of facilities and through the use of HOV lanes. Table 12 lists APTS programs.

European and Japanese IVHS Test Projects

Both the Europeans and the Japanese have invested significant funding and research into ETTM systems for their countries. Table 13 lists the operational tests that are currently underway in Europe, and Table 14 lists those in Japan.

TABLE 8
OPERATING ELECTRONIC TOLL COLLECTION PROJECTS

Project Name	Description
Dallas North Tollway - TX	The system is 17 miles in length with 62 toll stations equipped with coin counting and AVI equipment, encompassing all of the toll collection stations and plazas. Technology: Radio Frequency (RF) - Amtech
Greater New Orleans (GNO) Bridge and Lake Pontchartrain Causeway - LA	The GNO bridge consists of two parallel bridge spans of four and six lanes each. The six-lane east bank span is a 12-lane AVI-equipped toll facility. Technology: Radio Frequency (RF) - Amtech
San Diego-Coronado Bay Bridge - CA	In late 1988, a six month AVI test was conducted to determine the feasibility of implementing an AVI system at each of the other nine toll bridges in the state. The project began with 1,000 volunteer users, but this demonstration has now ended. Technology: Radio Frequency (RF) - X-Cyte
Grosse Ile Bridge - MI	The system has two, two-lane, two-way bridges that provide the only access to the primarily residential island. The northern most point of the two bridges is an AVI equipped facility. Technology: Surface Acoustical Wave (SAW) - X-Cyte
Pinellas Bayway - FL	The system is a series of causeways and bridges that connects the lower Gulf Beaches of Pinellas County, with three toll collection points on the 15.2-mile facility. AVI users comprise 30 percent of the total Bayway users. Technology: Bar Code - LazerData
Treasure Island Causeway - FL	The system consists of a single toll plaza with two east lanes and two west lanes, all of which are equipped for AVI use. Approximately 16,000 AVI passes are purchased annually for use on this facility. Technology: Bar Code - Leased from Automatic Toll System
Sanibel Causeway & Cape Coral Bridge - FL	Sanibel Causeway comprises two manned booths and one unattended lane. Toll are collected in one direction only, as motorist are travelling to Sanibel Island. The Cape Coral Bridge toll plaza consists of four manned booths and six unattended lanes. Tolls are collected both directions. Technology: Bar Code - Automatic Toll Systems & LazerData

TABLE 8 (*Continued*)

Project Name	Description
Broad Causeway - FL	The Broad Causeway connects the Bay Harbor Island to mainland Florida, about 10 miles north of Miami. Bar code readers can identify a car traveling at 6 to 7 miles per hour. Technology: Bar Code - Cubic Toll Systems
Delaware River Port Authority - PA	The Delaware River Port Authority owns and operates four toll bridges in the greater Philadelphia area. AVI patronage on all four bridges is 30 percent of total traffic. Technology: Bar Code - LazerData
Port Authority of New York and New Jersey	The Lincoln Tunnel AVI lane, used by buses only, was established to expedite bus movement entering Manhattan on weekday mornings. Approximately 3,000 buses are equipped with transponders travelling 1.5 miles on a dedicated contraflow lane for buses only. Technology: Radio Frequency (RF) - Amtech
Nassau County Bridge Authority - NY	The system consists of an 11-lane toll plaza with two lanes in each direction that have been retrofitted with AVI equipment. Technology: Bar Code - LazerData & Automatic Toll Systems
Maryland Transportation Authority	The Thomas J. Hatem Memorial Bridge (1.6 miles) is an eight-lane toll bridge with two lanes in each direction that are designated for AVI purposes. Technology: Bar Code System
ExpressToll E-470 Public Highway Authority - CO	E-470 is a 5.5 mile four-lane highway just outside of the metropolitan Denver area. The facility is equipped with manual, automatic, and AVI toll equipment. This is the only facility that was designed with AVI in mind. The facility has two lanes in each direction exclusively for AVI operating at 55-60 mph. Technology: X-Cyte
PIKEPASS - Oklahoma Turnpike Authority	The Oklahoma Turnpike system comprises six rural interstate routes totaling 478 miles with 37.9 million transactions per year. Amtech has been selected to handle the installation of an AVI system. Technology: Radio Frequency (RF) - Amtech

Source: Compiled from previous Center for Urban Transportation Research reports and telephone interviews of agencies.

TABLE 8A
PLANNED ELECTRONIC TOLL COLLECTION PROJECTS

Project Name	Description
Dulles Fastoll - VA, D.C.	The System is a 13-mile east-west toll facility, currently handling over 125,000 vehicles per day. VaDOT has selected MFS Network Technologies as their vendor. Technology: Radio Frequency (RF) - TIRIS-I
E-Z Pass Interagency Group - NY, NJ, PA	The Interagency Group is seven toll agencies in the region that have decided to test, procure, and use a unified AVI system. The group is now testing Mark IV/AT&T and Amtech.
Illinois State Toll Highway Authority - Il	The Illinois State Toll Highway Authority has tested several technologies. The Authority issued an RFP for the "Design, Installation and Testing of a Pilot AVI Toll Collection System." At/Comm has been selected.
Orlando/Orange County Expressway Authority (OOCEA)- FL	The OOCEA will conduct a 60-day acceptance test of Mark IV/SAIC. Original installation was planned for September, 1992 but was delayed. Technology: Radio Frequency (RF) - Mark IV/SAIC
Rickenbacker Causeway - FL	The Dade County Public Works Department is planning to install AVI on bridges connecting Virginia Key, Key Biscayne, and Miami Beach to the mainland. The Department has sent out a preliminary bid for vendors; responses are due April 1993. Technology: read-only with capability to expand to read-write
Sam Houston Tollway and Hardy Road Tollway - TX	The agency that manages this pair of tollways has selected Cubic as their prime vendor. Operation began October 1992. Technology: Radio Frequency (RF) - Amtech
Caltrans Bridges - CA	California Department of Transportation has sent out a bid for AVI on seven of its bridges; responses are due April 1993. Technology: modulated backscatter Radio Frequency (RF)
Georgia 400 - Georgia State Department of Transportation	6.4-mile extension of 6-lane State Road 400, just north of Atlanta, will have one toll plaza with 9 lanes in each direction. Seven lanes in each direction will be mixed AVI, and two lanes in each direction will be dedicated AVI. Anticipated opening date is July, 1993. Technology: Read-only, radio frequency (Amtech)
Sun Pass - FL	Florida Department of Transportation conducted field performance evaluations of six vendors from November 1992 to January 1993. These findings were incorporated into specifications for an RFP which would be issued in the third quarter of 1993.
California Private Toll Roads	Four proposed private toll roads (one east of San Francisco, one south of San Diego, and two southeast of Los Angeles). Franchise teams are seeking the necessary environmental clearances. Most ambitious private road building program in the U.S.

Source: Compiled from previous Center for Urban Transportation Research reports and telephone interviews of agencies.

TABLE 9
ADVANCED TRAFFIC MANAGEMENT SYSTEMS

Project Name	Description
Connecticut Freeway ATMS	Will evaluate the use of roadside mounted radar detectors in combination with CCTV for incident detection and verification Status: Plans, specifications, and estimates are being finalized.
GuideStar - MN	Gathering and distribution of traffic information for the use of traffic managers and motorists Status: A number of IVHS projects are under design and implementation.
INFORM - NY	Traffic Information Center controls three freeways with adjacent cross and selected parallel arterial streets to facilitate traffic flow. Status: INFORM is operational
Integrated Corridor Management - NJ, PA	Traffic information system key routes, and a study of overall traffic and incident management needs. Status: concept definition stage
MAGIC - NJ, NY	Surveillance and traffic control system designed to divert motorists from congested or emergency areas to alternative routes. Status: The first phase is in final design, with the advertisement for receipt of bids to construct anticipated in June, 1993.
Maryland Arterials & Baltimore/Washington Parkway	A proposed comprehensive feasibility study for the Baltimore/Washington corridor. Status: concept definition stage
Satellite Communications Feasibility Study I-95/I-476 - PA	The first phase will assess the feasibility of using satellite communications with freeway surveillance on I-95 and I-476. Status: Based on study findings, design and installation will follow.
SMART Corridor - CA	Advanced technologies will be used to advise travelers of current conditions and alternate routes, improving emergency response, and providing coordinated interagency traffic management. Status: Project is under development, and is expected to be operational by Spring of 1993.
Southern State Parkway - NY	This project will probably be coordinated with INFORM and will use surveillance and control techniques similar to those used in INFORM, but state-of-the-art hardware/software systems will be used. Status: The state DOT is defining the scope of system feasibility.
New Jersey Toll Road ETTM	An interagency effort involving toll agencies from neighboring states to develop a compatible region-wide ETTM system. Status: The project is under design.
TRANSCOM Congestion Management Program - NJ, NY	A cooperative effort has been initiated to equip approximately 1,000 commercial vehicles with AVI transponders. The test will evaluate the use of this data to determine real-time traffic information. Status: A consultant contract has been awarded for the feasibility of an ETTM system and project design, installation, and evaluation.

Source: Strategic Plan for IVHS in the United States.

TABLE 10
ADVANCED TRAVELER INFORMATION SYSTEMS

Project Name	Description
ADVANCE - IL	Up to 5,000 private and commercial vehicles will be equipped with in-vehicle navigation and route guidance systems. Vehicles will serve as probes, providing real-time traffic information. Status: Initial design is underway
DIRECT - MI	A Metropolitan Transportation Center will collect traffic information from various sources and provide traffic updates, via low cost methods of communication, to travelers on an exception basis. Status: A consultant has been selected to develop a system design.
FAST-TRAC - MI	The integration of ATMS and ATIS will provide a two-way flow of information between the SCATS and Ali-Scout central computer systems in a shared Traffic Operations Center. Status: 28 intersections are under SCATS control and testing of the Ali-Scout beacons has begun.
In-Vehicle Signing and Variable Speed Limit - WA	Variable speed limit signs, variable message signs, and in-vehicle communication equipment will be used to improve safety along a 40-mile stretch of I-90. Status: Project design is underway.
Pathfinder - CA	25 specially equipped cars will provide up-to-date information about accidents, congestion, highway construction, and alternate routes as they operate in Los Angeles' SMART corridor. Status: The second stage of a 3-stage evaluation is complete.
TravTek - FL	The goal is to provide traffic congestion information, motorist services information, tourist information and route guidance to operators of 100 test vehicles equipped with an in-vehicle device. Status: The TravTek project is operational and evaluation of the data has begun.

Source: Strategic Plan for IVHS in the United States.

TABLE 11
COMMERCIAL VEHICLE OPERATION PROGRAMS

Project Name	Description
Advantage I-75 - FL, GA, TN, KY, OH, MI, Ontario, Quebec	The project will facilitate motor-carrier operations by allowing transponder equipped and properly documented trucks to travel any segment along I-75 at mainline speeds with minimal stopping at weigh/inspection stations. Status: Final design phase of this project is complete.
HELP/Crescent - BC, WA, OR, CA, AZ, NM, TX	This project is a multi-state, multi-national research effort to design and test an integrated heavy vehicle monitoring system using AVI, AVC, and WIM. Status: AVI, AVC, and WIM equipment has been installed. Approximately 2,000 trucks are equipped with transponders.

Source: Strategic Plan for IVHS in the United States.

TABLE 12
ADVANCED PUBLIC TRANSPORTATION SYSTEMS

Project Name	Description
Bellevue Smart Traveler - WA	This project examines ways in which mobile communications, such as cellular phones, can be used to make ridesharing (carpooling and vanpooling), more attractive. Status: The project is nearing completion of the planning phase.
California Smart Traveler	Both the private and public sectors will jointly test an audiotex/video-based ATIS to permit residential and business users to interact using remote systems over telephone lines to exchange transportation information. Status: A draft report has been prepared describing a California Smart Traveler Information Network (CASTINET) for carpool matching services.
Houston Smart Traveler - TX	This project works toward the development of a real-time traffic and transit information system. Status: The concept development phase has been completed. The final draft report is being circulated for comment.
Twin Cities Smart Traveler - MN	The Regional Transit Board is conducting a preliminary study of the potential uses of smart cards to improve transit services. Status: System design is underway
Ann Arbor Smart Bus - MI	The Ann Arbor Transportation Authority (AATA) will develop and implement a test of an RF Smart Card for transit and parking lot use. Status: The initial phase is underway, and will receive a $1.5 million capital grant from FTA for equipment procurement.
MTA (Baltimore) Smart Bus - MD	The MTA has equipped 50 buses with LORAN-C receivers and 800-mhz radios to implement an AVL system for bus status information and improving timely bus arrivals. Status: The initial system is operational with 50 buses, 4 cars, and 2 consoles with map displays.
CTA Smart Bus - IL	This project is to identify AVL and bus traffic signal preemption technologies and analyze their impact on vehicular traffic and bus operations. Status: An extensive review of AVL and traffic and traffic signal preemption specifications.
RTD (Denver) Smart Bus - CO	The RTD is installing an AVL system to provide bus location information to transit dispatchers to increase efficiency, ridership, and safety. Status: A contract has been awarded for an upgraded communications system to be installed in the RTD's 833 buses and 66 supervisory vehicles.

TABLE 12 (*Continued*)

Project Name	Description
Portland Smart Bus - OR	This project reviews the German-made Flexible Operation Command and Control System (FOCCS) that integrates fixed-route transit, dial-a-ride minibus, and contract taxi services. Status: The investigation of FOCCS has been completed and the evaluation is currently underway.
Norfolk Mobility Manager - VA	This project will operationally test and evaluate how transit and paratransit user-subsidies can improve transportation services available to low-income transit riders. Status: This project has tested various approaches to user-subsidies and is now working with employers and social service agencies on new methods of making the subsidies available.
Rouge Valley Mobility Manager - OR	Advanced electronic technology will be used to record financial transactions and will include Smart or magnetic-stripe fare cards. Status: A project steering committee has been organized to assist in the development and management.
Anaheim IVHS Operational Test - CA	This project will develop a concept plan and project design for advanced information systems to be provided to travelers at bus stops, transfer stations, and in transit vehicles. Status: The project has recently been initiated and a concept plan is being developed for an operational test of the display system.
Detroit Transportation Center Transit Information - MI	This project is to provide real-time traffic condition information to dispatch centers of public transit agencies. Status: The initial project has begun with the purchase of computer hardware and software.

Source: Strategic Plan for IVHS in the United States.

TABLE 13
EUROPEAN IVHS PROJECTS

Project Name	Description
PROMETHEUS (Program for European Traffic with Highest Efficiency and Unprecedented Safety)	This project is led by 18 leading European car manufacturers with assistance from 40 research institutions looking at improving the competitive strength of Europe, by stimulating development in areas such as information technology, telecommunications, robotics, and transport technology.
DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe)	There are 70 projects in the DRIVE program falling under six categories: (1) Evaluation and Modeling (2) Behavioral Aspects and Traffic Safety (3) Traffic Control (4) Route Guidance, Vehicle Location and In-Vehicle Information Systems (5) Public Transport and Freight Management (6) Telecommunications
Autoguide	This is an infrastructure-based, dynamic route guidance system adopted by the British government. Inside each vehicle, a device keeps track of the vehicle's location using a combination of roadside beacons, dead-reckoning and map-matching. A demonstration system has been operational in London since early 1988.
CARIN (CAR Information and Navigation system) and CARMINAT	CARIN is a route guidance system, which calculates shortest routes based on the on-board computer map data. CARMINAT is a project investigating the use of Radi-Data Systems (RDS) to provide a limited amount of dynamic traffic information to an on-board CARIN unit.
LISB (Leit and Information System Berlin)	This project was launched in 1988 employing the ALI-SCOUT system, which is a dynamic route guidance system utilizing a network of roadside beacons to provide two-way communications between vehicles and the control center.
Trafficmaster	This is the first commercially available, in-car traffic information system capable of automatically alerting drivers with up-to-the-minute information on motorway congestion to become operational in the U.K.
SOCRATES (System Of Cellular Radio for Traffic Efficiency and Safety)	SOCRATES is the largest DRIVE project. The concept is to use specific frequencies from the pan-European GSM system (which will replace current European cellular radio systems in the 1990's) to broadcast data to all equipped vehicles with a cellular phone.
INF-FLUX (Paris, France)	This project will install infrared beacons, which together with 2,000 equipped public service vehicles, will provide a detailed traffic monitoring system.

Source: IVHS AMERICA

TABLE 14
JAPANESE IVHS PROJECTS

Project Name	Description
RACS (Road/Automobile Communications System)	Initiated in 1984, RACS is a joint program involving the Public Works Research Institute of the Ministry of Construction and 25 private companies. Its goal is to establish a roadside beacon-based driver navigation and communication system. The information beacons are connected to a road-traffic information center to update dynamic traffic information.
AMTICS (Advanced Mobile Traffic Information and Communication System)	Initiated in 1987 by the National Police Agency and supported by the Ministry of Posts and Telecommunications, AMTICS is a vehicular navigation system that uses dead-reckoning and map matching with CD-ROM-stored digital maps in conjunction with traffic data received via teleterminals.
VICS (Vehicle Information and Communication System)	VICS was recently started in an attempt to integrate AMTICS and RACS. Plans call for the National Police Agency to expand Traffic Control Centers and analyze traffic for the Ministry of Construction to operate a system of roadside communication beacons.

Source: IVHS AMERICA

CHAPTER EIGHT

SURVEY RESEARCH

Survey research is a valuable tool for assessing and evaluating the perceptions, attitudes, and characteristics of selected market segments regarding new products and services. ETTM is a service that has the potential to benefit the user, the nonuser, and the community as a whole. The surveys used for this synthesis help measure the potential trends and provide the status of several ETTM projects. The use of survey research in this analysis includes the following three surveys: (1) mail-back questionnaire survey of traffic management system operators, (2) mail-back questionnaire survey of ETTM vendors and consultants, and (3) mail-back questionnaire survey of toll agency operators conducted by the International Bridge, Tunnel, and Turnpike Association (IBTTA). Each of the surveys is summarized and reviewed in this section.

Traffic Management Operator Survey

The operator survey consisted of 20 questions designed to measure the potential trends and provide status of several ETTM projects (see Appendix A). The operator surveys were mailed to the 43 operators (see Appendix B). The operator survey response was 63 percent. The foreign operator response was 60 percent (3 of 5). Fifty-six percent of the operators that responded have a fully operational system. Fifty percent (5 of 10) of the systems that are not fully operational expect to be within the next 2 years. The operational systems serve from 4,700 vehicle fleet to 2 million average daily traffic volume; and from 100 to 1.2 million peak-hour travelers. Three of the fully operational systems pass service fees on to the user. Sixty percent (10 of 15) have a formal traffic or fleet management system, marketing, or public information program. Extensive monitoring and evaluation programs are generally lacking. Table 15 summarizes the basic type of traffic management features for the various operators surveyed.

TABLE 15
TRAFFIC MANAGEMENT FEATURES OF SURVEYED OPERATORS

TYPE OF MANAGEMENT EQUIPMENT	NUMBER OF OPERATORS (% OF TOTAL)
Loop Detectors	3 (12%)
Weigh-In-Motion	1 (4%)
Automatic Vehicle Classification	1 (4%)
System Detectors	1 (4%)
Adaptive Traffic Signal Control	2 (8%)
Radar Detectors	1 (4%)
Magnetometer	1 (4%)
Variable Message Signs	5 (20%)
Citizens Band Highway Advisory Radio	2 (8%)
Graphic Maps	1 (4%)
Public Traffic Telephone Number	1 (4%)
Closed Circuit TV for Incident Detection	9 (36%)
Intelligent Traffic Reporter	2 (8%)
High Occupancy Vehicle Priority Corridors	2 (8%)
Smart Bus	1 (4%)
Ramp Metering	4 (16%)

ETTM Vendor/Consultant Survey

The ETTM vendor/consultant survey consisted of 22 questions designed to identify the available technologies. This survey is shown in Appendix C. The vendor/consultant surveys were mailed to 63 vendors and consultants (see Appendix D). Thirteen of these responded to the survey. Foreign companies make up 40 percent of the vendor respondents. The predominant technology available from the vendors is a radio frequency microwave with read/write capabilities. Although the overhead operational configuration was most preferred by the vendors, most could use more than one operational configuration. Most vendors produce transponders that are re-codeable and transferable. The subsystem for enforcement primarily depends on video. Vendors generally provide design and initial operational assistance to the customer. Many of the vendors also take care of follow-up needs, such as system operations and maintenance, tag store operations, software, and technical support. The technologies are currently employed in fleet management, automatic electronic identification for light and heavy rail, intermodal and air freight container tracking and handling, airport traffic management, port-of-entry bypass operations, parking and access control, terminal gate control systems, and real-time traffic

TABLE 16
ETTM VENDOR/CONSULTANT OPERATING FEATURES*

VENDOR	DATA TRANSMISSION RATE	TRANSPONDER STORAGE CAPABILITIES	SPEED RANGE(kph) DURING TRANSMISSION
Allen Brady Co	200kbps	Preprogrammed 6 digits, 20 or 40 characters	0-160 6 digits 0-88 20 characters 0-48 40 characters
Alta Technology+	192kbps	512 bytes	0-160
Amtech+	10kbps	Fixed 16 bytes Variable 16 bytes	toll plaza 0-80 highway 0-128
AT/Comm Inc+	9600bps/programmable	16kB	0-149
Autostrade+	1m upstream 144kbs downstream	1000 bytes	0-120
AWA	250bps	4 bytes	0-160
Laserdata Corp+	9600bps	none	dependent on label size
Mark IV+	500kbs	16 bytes, 32 bytes	0-160
Micro Design+	250kbps, 300kbps 8Mbps, 16Mbps	32 bytes	0-160
Mitsubishi Hv Ind	4kbps	500 bytes	0-150
Motorola Inc	40kbps	12 byes	0-128
Rockwell Int	N/A	N/A	0-100
Saab Automation+	3kbps, 167/267kbps (Read/Write)	15 bytes, 32kB	0-104 0-160

* Vendor supplied survey responses as of January 1993.
+ ETC systems operational as of September 1992.

monitoring. Table 16 summarizes some of the basic features offered by the ETTM vendors and consultants who responded to the survey, and therefore this listing should not be considered comprehensive.

IBTTA Survey

In March 1992, the International Bridge, Tunnel, and Turnpike Association (IBTTA) conducted a survey concerning ETTM systems that were either in place or being planned by their various toll collection agency members. This 26-question survey contained inquiries regarding average daily traffic, vehicle mix, number of toll lanes by type, average transactions per hour by type, ETTM manufacturer, payment options, method of enforcement, percent existing or expected ETTM usage, and many more ETTM characteristics. Table 17 summarizes some of the ETTM characteristics obtained from the IBTTA survey for existing or proposed systems.

TABLE 17
ETTM SYSTEM CHARACTERISTICS

Project Name	ADT	% ETTM	Lanes	Vendor	AVC	Enforcement	ETTM Discount
E-470 Public Highway	3,250	43%	4 dedicated 2 mixed	X-Cyte	Yes	video camera	none
Lake Pontchartrain Causeway	22,500	60%	6 mixed	Amtech	No	manual	50% discount
Crescent City Demonstration	60,000	30%	3 dedicated 9 mixed	Amtech	No	none	30% discount
Thomas Hatem Bridge - MD	21,382	80%	5 mixed	LazerData	No	automatic gates	none
Oklahoma Turnpike	100,000	32%	46 automatic 56 dedicated 117 mixed	Amtech	Yes	video camera	30% discount
Lincoln Tunnel	57,313	3% buses only	12 manual 1 dedicated	Amtech	No	video camera	10% discount
Dallas North Tollway	196,700	25%	4 dedicated 59 mixed	Amtech	No	video camera	none
E-Z Pass Interagency Group	2.6 million	30%	277 manual 273 automatic	not decided	Yes	video camera* & manual	yes, amount not decided
Private Toll Roads - California	697,108	30%	73 manual	not decided	Yes	video camera	yes, amount not decided
Florida Turnpike	407,000	20%	32 dedicated 213 mixed	not decided	Yes	video camera*	none
Golden Gate Bridge	113,550	45%	11 manual	not decided	No	video camera	probably
Illinois State Toll Authority	694,366	25%	179 manual 49 automatic 167 mixed	not decided	No	video camera	none
New Hampshire Turnpikes	195,700	40%	34 manual 13 automatic 31 mixed	not decided	Yes	video camera	yes, amount not decided

TABLE 17 (*Continued*)

Project Name	Number of Tags Issued	Deposit Required	Available At	Payment Options	Pre-Payment	Minimum Balance
E-470 Public Highway	1,460	$20 tag	toll plaza	check, credit	Yes	$5
Lake Pontchartrain Causeway	11,500	$25 tag	tag store	cash, check, credit	Yes	$5-$20
Crescent City Demonstration	25,000	$25 tag	toll agency	cash, check, credit	Yes	$10
Thomas Hatem Bridge - MD	110,000	$2 tag	N/A	cash, check	N/A	N/A
Oklahoma Turnpike	99,553	$30 tag	retail mall outlets	cash, check, credit card	Yes	$40
Lincoln Tunnel	55,752	$60 tag	bill by mail	cash, check, credit card	Yes	2 months of usage
Dallas North Tollway	not available	$2 tag	tag store	cash, check, credit card	Yes	$40
E-Z Pass Interagency Group	80,400	$10 tag	contract to vendor	cash, check, credit card	Yes	not decided
Private Toll Roads - California	250,000	not decided	retail mall outlets	cash, check, credit card	Yes	not decided
Florida Turnpike	92,000	$50 tag	800 number & mail	cash, credit card	Yes	not decided
Golden Gate Bridge	not decided	not decided	not decided	not decided	Yes	not decided
Illinois State Toll Authority	157,000	$35 tag	not available	not decided	Yes	$10
New Hampshire Turnpikes	55,000	not decided	bill by mail & tag stores	cash, check, credit card	Yes	$5

* Change in legislation required for video enforcement
Source: IBTTA

CHAPTER NINE

FUTURE DIRECTIONS AND CONCLUSIONS

In the United States, the transportation system has shaped our society. We build our cities, buy our houses, and choose our jobs based on the premise that the transportation system provides reasonable mobility. In recent years, however, our ability to travel freely in many areas has become constrained by congestion, by the cost of highway travel, and by the financial problems that reduce services offered by public transportation. Despite soundly engineered roadways, mobility is declining and safety is at risk. The U.S. transportation system is at a crossroads. Public transit, which should be a relief and a welcome alternative, is too often viewed as an unattractive alternative to driving. Commercial vehicle drivers spend significant time waiting in line to be weighed or to pay tolls, and handling administrative paperwork. Furthermore, mobility and safety have depended on decisions by individual drivers who based their decisions on past experience, with little guidance from advanced technology and real-time traffic information. *(11)*

During the past decade, we have also seen an explosion in the speed and power of computers. Modest personal computing power used to be available to only a few, and cost as much as a luxury car. Now enormous personal computing power is available for the cost of a medium-priced sound system. At the same time, a parallel explosion has occurred in personal and business communications. Cellular telephones, nationwide satellite networks, low-cost sensors, and fiber optic links to home and office are beginning to change the way we work and live.

A technological revolution in transportation and information has transformed individual mobility into an integrated, coordinated system by providing more travel choices and assistance in selecting the best trip for a particular traveler. IVHS technologies have already begun to interconnect formerly independent traffic management jurisdictions and transit dispatch centers, and new systems are already collecting tolls automatically. The IVHS programs developed to this point represent just the beginning. According to the Strategic Plan for IVHS in the United States, in the coming decade, we can expect to also see the following developments:

- Improved access to information on the availability, schedules, and proximity of public transportation;
- Transportation management systems that adjust lane usage, speed limits, traffic signals, and roadway access based on actual traffic conditions;
- Traffic information and communication systems that advise drivers about current and expected traffic conditions, road hazards, weather, recreational/tourist attractions, and where to park;
- On-board electronics in vehicles to assist drivers in planning and following safe and efficient routes;
- Additional capabilities allowing commercial fleet and transit operators to track their vehicles, and communicate with their drivers in order to offer alternate routes;
- New interactions between roadway jurisdictions and vehicles that will allow all tolls to be collected, trucks to be weighed, truck permits to be issued, and cargos to be checked and monitored, largely without requiring vehicles to stop; and
- The first demonstration of an automated vehicle/highway control system.

These impressive gains cannot be made without first overcoming some formidable obstacles, however. Assessments of this new technology list three barriers to the widespread implementation of ETTM and other IVHS technologies: scarce financial resources, coordinating diverse systems, and consensus on technical standards. Already, several large ETTM projects are in the process of selecting different vendors, with different (and sometimes incompatible) systems. At present, the battle over standards for short-range vehicle-to-roadside communication used in ETTM is a hotly contested one. Without strong leadership from industry-wide standard-setting associations, a nationwide compatible toll collection program may never become a reality.

According to the Strategic Plan for IVHS in the United States, if these barriers can be overcome, we can expect to see implementation of a national program in IVHS in the next 20 years. Designs for this program are comparable in scope to the Interstate Highway System and participation from both the private and public sectors is required. The primary focus of this program is a balanced transportation system including a national system of travel-support technology; a new level of cooperation between public and private sectors, government, and academia to create the infrastructure for the mobility revolution; a vigorous IVHS industry supplying both domestic and international needs, and an attractive, efficient public transportation system that complements and interacts effectively with improved highway operations.

CONCLUSIONS

ETTM systems comprise advanced technologies in information gathering, processing, and communication. ETTM offers a feasible alternative to improving the efficiency of transportation systems. Its technology enhances existing roadway systems so that vehicles can operate more efficiently, safely, and economically. This report represents a "snapshot" of the ETTM industry, an industry which is constantly growing and changing.

Although very few ETTM technology performance evaluation data are available, basic operational differences are generally known. It appears that, for any given set of operational parameters and protocol, a compatible ETTM technology can be developed. However, tradeoffs exist between such operating characteristics as data rate transmission and information storage capabilities. Most technologies have now advanced to second and third generations to keep up with the market demands for performance. ETTM standards are not yet in place, but they are being rigorously discussed and evaluated in transportation applications.

More important than the technology issues are the system design considerations. For example, ETTM systems present additional computer system requirements, different traffic operational factors to assess, and financial and user payment options. With the implementation of ETTM, one can expect many benefits resulting from the more efficient and safer flow of traffic. Careful consideration must be given to choosing an appropriate scale for the ETTM system. Market identification and user perception surveys will be essential for project success.

Issues also exist with the enforcement, privacy, and equity in providing such an advanced electronic toll and traffic management system. The implementation of ETTM will necessitate the passage of new legislation regarding access to information that is retrieved electronically. Management systems involving improved traffic flow and early incident detection also have evolved from ETTM technologies. In addition, commercial carriers and public transportation vehicles benefit from real-time traffic information passed on by highway operations. Commercial fleets will be able to transport their cargos more efficiently, and transit services will become an attractive alternative to the single-occupant vehicle.

Many ETTM projects and programs have been developed and implemented throughout the country and abroad. Their common feature is providing more convenience and real-time information to the motoring public. However, the evaluation of these systems remains to be accomplished, documented, and shared. ETTM is now on a course to completely modernize how we drive and how we make decisions during our travels. Current research efforts and operational tests provide the opportunity for everyday usage of ETTM systems to become a reality. For the transportation industry, advancements in computer and information technologies have arrived just when they are most desperately needed.

REFERENCES

1. "Strategic Plan for Intelligent Vehicle-Highway Systems," IVHS AMERICA, May 1992, Washington, D.C.
2. Koelle, Alfred R., Advances in Practical Implementation of AVI Systems, Presented at the 71st Annual Meeting of the Transportation Research Board, Washington, D.C. (1992).
3. Center for Urban Transportation Research, "Analysis Of Automatic Vehicle Identification Technology and Its Potential Application On The Florida Turnpike-Technical Memorandum 2," University of South Florida, Tampa, FL (1990).
4. Davies, Peter, Chris Hill, and Jeremy Siviter, AVI Research for Commercial Vehicle Operations, Presented at the 70th Annual Meeting of the Transportation Research Board, Washington, D.C. (1991).
5. *Transportation Research Circular 254: Research Problems in Transportation Communications*, Transportation Research Board, National Research Council, Washington, D.C. (1983).
6. Center for Urban Transportation Research, "Cost-Effectiveness Analysis of AVI/ETTM for Florida's Turnpike System," University of South Florida, Tampa, FL (1992).
7. "Federal IVHS Program Recommendations for Fiscal Years 1994 and 1995," IVHS AMERICA, prepared October 15, 1992, Washington, D.C.
8. Kay, Jack L., Advance Traffic Management Systems-An Element of Intelligent Vehicle-Highway Systems, presented at the 69th Annual Meeting of the Transportation Research Board, Washington, D.C. (1992).
9. Sabounghi, Lewis R., Intelligent Vehicle Highway System-The Universal Close-Range Road/Vehicle Communication System Concept-The Enhanced AVI and Its CVO Applications, presented at the at the 70th Annual Meeting of the Transportation Research Board, Washington, D.C. (1992).
10. Davies, P. et al, *National Cooperative Highway Research Program Report 340: Assessment of Advanced Technologies for Relieving Urban Traffic Congestion*, Transportation Research Board, National Research Council, Washington, D.C. (1991).
11. *Smart Highways: An Assessment of their Potential to Improve Travel*, No. GAO/PEMP-91-18, General Accounting Office, Washington, D.C. (1991).

BIBLIOGRAPHY

Center for Urban Transportation Research, "Analysis Of Automatic Vehicle Identification Technology and Its Potential Application On The Florida Turnpike-Technical Memorandum 1," University of South Florida, Tampa, FL (1990).

Center for Urban Transportation Research, "Analysis Of Automatic Vehicle Identification Technology and Its Potential Application On The Florida Turnpike-Technical Memorandum 2," University of South Florida, Tampa, FL (1990).

Center for Urban Transportation Research, "Assessment of Benefits for Advantage I-75," University of South Florida, Tampa, FL (1992).

Center for Urban Transportation Research, "Cost-Effectiveness Analysis of AVI/ETTM for Florida's Turnpike System," University of South Florida, Tampa, FL (1992).

Chandler, Chester and Al V. Palmer, "Toll Collection System; AVI Questionnaire - Manufactures & Vendors," Corridor Design Management Group (1990).

Fleming, Daryl S., "Laying the Foundation For Congestion Pricing," Irvine, CA (1991).

General Accounting Office, "Smart Highways: An Assessment of their Potential to Improve Travel," No. GAO/PEMP-91-18, Washington, D.C. (1991).

Harris County Toll Road Authority, "Specifications and Bid for Roadway Signing for EZ Tag System on Hardy Toll Road and Sam Houston Tollway," Houston, TX (1992).

Henry, Kim C., and Omar Mehyar, "Six-Year FLOW Evaluation," Washington State Department of Transportation, Seattle (1989).

Hills, P., and N. Thorpe, "Traffic-Demand Management in Urban Areas the Role for Pricing," Transport Operations Research Group, University of Newcastle upon Tyre, England.

IVHS AMERICA, "Strategic Plan for Intelligent Vehicle-Highway Systems," prepared May 20, 1992, Wash., D.C.

IVHS AMERICA, "Federal IVHS Program Recommendations for Fiscal Years 1994 and 1995," prepared October 15, 1992, Washington, D.C.

Proceedings of the IVHS AMERICA 1992 Annual Meeting-Newport Beach, California, "Surface Transportation and Information Age," Volumes 1 and 2, May 17-20, 1992.

Smith, Steven, "INFORM Evaluation," U.S. Department of Transportation; Federal Highway Administration, U.S. Government Printing Office (1991).

Texas Transportation Institute, "Houston Smart Commuter IVHS Demonstration Project; Concept Design and Implementation Program Outline," Texas A&M University (1991).

Transportation Research Board, *NCHRP Report 340: Assessment of Advanced Technologies for Relieving Urban Traffic Congestion*, National Research Council, Washington, D.C. (1991).

Transportation Research Board, *Transportation Research Circular 290: Conference on Transportation Partnerships: Improving Urban Mobility Through Public-Private Partnerships,* National Research Council, Washington, D.C. (1985).

Transportation Research Board, *Transportation Research Circular 254: Research Problems in Transportation Communications,* National Research Council, Washington, D.C. (1983).

Transportation Research Board, *Special Report 172: Transportation System Management,* National Research Council, Washington, D.C. (1977).

Transportation Research Board, Transportation Systems Planning and Applications, in *Transportation Research Record 1283*, National Research Council, Washington, D.C. (1990).

U.S. Department of Transportation; Federal Highway Administration, *Toll Facilities in the United States*, U.S. Government Printing Office, Washington, D.C. (1991).

U.S. Department of Transportation; Federal Highway Administration, *Urban Corridor Demonstration Program Manhattan CBD-North Jersey Corridor Automatic Bus Identification*, Government Printing Office, Washington, D.C. (1972).

Wilbur Smith Associates, "Electronic Toll and Traffic Management Feasibility Study," New Haven, CT (1992).

APPENDIX A
TRAFFIC MANAGEMENT SYSTEM OPERATOR SURVEY

NCHRP PROJECT, 20-5 TOPIC 24-06,
"ELECTRONIC TOLL AND TRAFFIC MANAGEMENT SYSTEMS"

MAIL SURVEY OF TRAFFIC MANAGEMENT SYSTEM OPERATORS

The Transportation Research Board has identified your agency as a traffic management systems operator. Your assistance in completing this survey is greatly appreciated.

Agency ______________________________

Address ______________________________
____
____
____

Telephone ______________ **Fax** ______________

Contact ______________ **Title** ______________

Name of Facility(ies) ______________________________

1. Is your electronic traffic and/or fleet management system fully operable?
A. __ Yes B. __ No

2. If No to question #1, when do you expect your system to be fully operable?
____

3. What is (or will be) the length of your traffic management system in:
Center-Line Miles? ______________
Lane Miles? ______________

4. Please describe your <u>current</u> electronic traffic and/or fleet management system.
____
____
____
____

5. What expansion and/or IVHS integration plans do you have for your system in the future?
____
____
____
____

6. What is the approximate <u>TOTAL</u> fleet size and/or daily traffic volume (ADT) served by your facility?
____

7. Approximately how many TOTAL peak-hour travelers does your electronic traffic and/or fleet management facility serve?

____

8. Are any service fees passed on to system users?
A. __ Yes B. __ No

9. If yes to question #8, what amount? ______________

10. Have there been any impacts to traffic on OTHER ADJACENT non-system roads?
A. __ reduction in traffic B. __ increase in traffic
C. __ no change

11. Have there been any safety problems/accidents since system implementation?
A. __ Yes B. __ No

12. If yes to question #11, how severe?
A. __ minor B. __ moderate
C. __ fatal

13. Has there been any reduction in roadway capacity expansion as a result of system implementation?
A. __ Yes B. __ No

14. Do you have a formal traffic or fleet management system marketing and/or public information program(s)?
A. __ Yes B. __ No

15. Has marketing or public information improved system usage?
A. __ Yes B. __ No
C. __ Difficult to determine

16. Have you performed any traffic or fleet management system user surveys?
A. __ Yes B. __ No

17. Have you performed any system technology(ies) performance tests?
A. __ Yes B. __ No

18. What has/have been the greatest benefit(s) of your traffic and/or fleet management system?

____
____
____
____

19. What has/have been the greatest drawback(s), if any, of your traffic and/or fleet management system?

____
____
____
____

20. Are there any reports available on your traffic and/or fleet management system? If Yes, please list each document title.

____
____
____

APPENDIX B
TRAFFIC MANAGEMENT SYSTEM OPERATOR MAILING LIST

ADVANCE Project
Illinois Department of Transportation
201 West Center Court
Schaumburg, IL 60196

Advanced Traffic Management Systems Model
Study for the Denver Metropolitan Area
Colorado Department of Transportation
Traffic Section
2000 South Holly Street
Denver, CO 80222

Advanced Traffic Management Systems Model
Study for the Portland Metropolitan Area
City of Portland
1120 S.W. 5th, Room 730
Portland, OR 97204

Advantage I-75
University of Kentucky
Transportation Research Bldg.
Lexington, KY 40506-0043

Anaheim IVHS Operational
Test/Integrated System Project
Public Works - Traffic Engineering
Department City of Anaheim
200 S. Anaheim Blvd.
Anaheim, CA 92085

Ann Arbor Smart Bus
Ann Arbor Transportation Authority
2700 S. Industrial Highway
Ann Arbor, MI 48104

Baltimore Smart Bus
Mass Transit Administration
300 West Lexington Street
Baltimore, MD 21201-3415

Bellevue Smart Traveler
University of Washington
Technical Communication FH-40
Seattle, WA 98195

California PATH Program
University of California
Institute of Transportation Studies
1301 S. 46th Street Bldg 452
Richmond, CA 94804

California Smart Traveler
California Department of Transportation
Traffic Improvement Office
P.O. Box 942874
Sacramento, CA 94274

Central Artery/Tunnel
Massachusetts Highway Department
One South Station
Boston, MA 02110

Connecticut Freeway ATMS
Connecticut Department of Transportation
38 Wolcotthill Road
Wethersfield, CT 06019

CTA Smart Bus
Chicago Transit Authority
P.O. Box 3555
Chicago, IL 60654

Denver Smart Bus
Denver Regional Transportation District
1900 31st Street
Denver, CO 80216

Detroit Transportation Center Transit Information
Michigan Department of Transportation
P.O. Box 30050
Lansing, MI 48909

DIRECT
Michigan Department of Transportation
425 West Ottawa St., P.O. Box 30050
Lansing, MI 48909

DRIVE
Commission of European Communities
61 Rue De Treves
Rm 613 B-1040
Brussels, BELGIUM

ERTICO - SCETAUROUTE
2 Rue Stephenson
78181 St. Quentin
Yvelines Cedex, BELGIUM

FAST-TRAC
Road Commission of Oakland County
31001 Lahser Road
Beverly Hills, MI 48025

GuideStar
Minnesota Department of Transportation
117 University Ave.
St. Paul, Mn 55155

HELP/Crescent Project
California Department of Transportation
P.O. Box 2048
Stockton, CA 95201

Houston Smart Traveler
Metropolitan Transit Authority
P.O. Box 61429
Houston, TX 77208-1429

I-95 International Mobility Project
Pennsylvania Department of Transportation
200 Radnor-Chester Road
St. Davids, PA 19087-5178

I-95 Urban Congestion Alleviation
Demonstration
Virginia Department of Transportation
1401 East Broad St.
Richmond, VA 23219

Incident Management
Traffic Management Center
Minnesota Department of Transportation
1101 4th Ave. South
Minneapolis, MN 55404

INFORM
New York Department of Transportation
State Office Building
Veteran's Memorial Highway
Hauppdug, NY 11788

Multi-Jurisdictional Live Aerial Video
Montgomery County Department of Traffic
Division of Traffic Engineering
101 Monroe Street, 11th Floor
Rockville, MD 20850

Multi-Jurisdictional Live Aerial Video
Virginia Department of Transportation
1426 Columbia Pike
Arlington, VA 22204

Norfolk Mobility Manager
Tidewater Transportation District Commission
1500 Monticello Ave.
Norfolk, VA 23501

Portland Smart Bus
Tri-Met
4012 S.E. 17th Ave.
Portland, OR 97202

PROMETHEUS
Care of Daimler-Benz AG
Department of FGF/F
POSTFACH800230
Stuttgart, D-7000 GERMANY

Rouge Valley Mobility Manager
Rouge Valley Council of Governments
P.O. Box 3275
Central Point, OR 97502

Route 91 Express Lanes
California Private Transportation
Corporation
2500 Michelson, Suite 100
Irvine, CA 92715

Seattle Incident Management and
Integrated Systems
Washington Department of Transportation
Washington State Transportation Center
4507 University Way N.E., Suite 204
Seattle, WA 98105

SMART Corridor
Los Angeles County Transportation
Commission
818 West 7th Street
Los Angeles, CA 90017

SmartRoute Systems
141 Portland Street
Suite 8100
Cambridge, MA 02139

TRANSCOM
25 Journal Square, 1st Floor
Jersey City, NJ 07306

Travelguide
Ontario Ministry of Transportation
Transportation Control Technology &
Systems Office
1201 Wilson Ave.
Downsview, Ontario
M3M1J8 CANADA

TravTek
City of Orlando
400 South Orange Ave.
Orlando, FL 32801

Twin Cities Smart Traveler
Regional Transit Board
Nears Park Center
230 E. 5th Street
St. Paul, MN 55101

Urban Congestion Alleviation Demo Project
Maryland State Highway Administration
7491 Connelley Drive
Hanover, MD 21076

APPENDIX C
ETTM VENDOR/CONSULTANT SURVEY

NCHRP PROJECT 20-5 TOPIC 24-06
"ELECTRONIC TOLL AND TRAFFIC MANAGEMENT SYSTEMS"

MAIL SURVEY OF ETTM VENDORS/CONSULTANTS

The Transportation Research Board has identified your firm as a vendor or consultant of electronic toll and traffic management systems or subsystems. Your assistance in completing this survey is greatly appreciated.

Vendor/Consultant ________________________________

Address ________________________________
____
____
____

Telephone ____________________ **Fax** ____________________

Contact ____________________ **Title** ____________________

1. What is your system's trade name, if any?

____

2. What type of transmission technology(ies) do you provide? (check all that apply)
A. __ acoustical waves B. __ optical scanner
C. __ infrared D. __ radio frequency microwaves
E. __ read/write F. __ other, please specify ____________________

3. What operational configuration does your system employ?
A. __ overhead B. __ lane side
C. __ in pavement D. __ other ____________________

4. What type of transponders do you provide? (check all that apply)
A. __ active B. __ semi-active
C. __ passive

5. What is your data transmission rate?

____

6. What are your transponder data storage capabilities?

____

7. What is the <u>MAXIMUM</u> traffic speed that can be maintained during transmission?

____

8. What is the <u>MINIMUM</u> traffic speed that can be maintained during transmission?
____

9. What is the <u>MAXIMUM</u> reader antenna target distance required?
____

10. What is the <u>MINIMUM</u> reader antenna target distance required?
____

11. Do you provide for re-codeability of transponders (i.e., for carpooling, vanpooling, etc.)?
A. __ Yes B. __ No

12. Do you provide for transferability of transponders (i.e., for carpooling, vanpooling, etc.)?
A. __ Yes B. __ No

13. Describe your enforcement subsystem?
____

14. What are your <u>AVERAGE</u> ETTM system capital costs per lane? ____________________

15. What are your <u>AVERAGE</u> annual ETTM operating and maintenance costs per lane? __________

16. Does your system require an FCC license?
A. __ Yes B. __ No

17. What services do you provide to your clients? (check all that apply)
A. __ design B. __ operations
C. __ accounting D. __ marketing
E. __ other, please specify ____________________

18. What have been the typical follow-up needs of your clients?
____
____
____

19. What are the appropriate applications of your technology (if any), besides electronic toll collection?
____
____
____
____

20. Do you have any available performance evaluation results of your technology?
A. __ Yes B. __ No

21. If yes to question #20, please specify laboratory, field test, or test-track location and date.
____

22. Name the facility(ies) and agency(ies) you currently provide services to? (also include number of transponders, number of lanes installed, etc.)
____
____

APPENDIX D
ETTM VENDOR/CONSULTANT MAILING LIST

AEG
Secor Corp. (US Distributor)
4635 Fairmont
Troy, MI 48098

Alta Technology, Inc.
81 Main Street, Suite 101
White Plains, NY 10601

AMSKAN, Inc.
P.O. Box 14045
Research Triangle Park, NC 27709

Amtech Systems Corporation
17304 Preston Road,Bldg E100
Dallas, Texas 75252

ASFA-Scetauroute
2 Rue Stephenson
St. Quentin-en-Yvelines,
78181 FRANCE

AT/Comm, Inc.
America's Cup Building
Little Harbor Way
Marblehead, MA 01945

AT&T Network Systems
Crawsford Corner Road
Room 1J-329
Holmdel, NJ 07733

AT&T Smart Card Group
295 N. Maple Avenue, Rm 6347F2
Basking Ridge, NJ 07920

Automatic Identfication
Mfrs. Assoc.
1326 Freport Road
Pittsburgh, PA 15238

Autostrade S.P.A.
Via Antonio Nibby 20
Rome, 00161 ITALY

AWA Traffic Systems America, Inc.
2127 University Park Dr,Ste 300
Okemos, MI 48864-3975

Barrier Systems Inc.
P.O. Box 8565
Incline Village, NV 89452

Battelle-Columbus
505 King Avenue
Columbus, OH 43201

Controlled Access, Inc.
1100 Wright Avenue
Camden, NJ 08103

Cotag International, Inc.
103 Springer Building
3411 Silverside Road
Wilmington, DE 19819

Cubic Toll Systems
150 Broad Hollow Road
Melville, NY 11747

Detector Systems, Inc.
11650 Seaboard Circle
Stanton, CA 90680

Digital Equipment Corp.
20 Corporate Place South
Piscataway, NJ 08855-1345

Electronic Data Magnetics, Inc.
210 Old Thomas Road
P.O. Box 7208
High Point, NC 27264

Elsydel-Trindel
63 Boulevard Bessieres
75017 Paris, FRANCE

EMX
3570 Warrensville Center Road
Shaker Heights, OH 44122

Eureka Systems, Inc.
1 Oliver Plaza
Pittsburgh, PA 15222

Grenobloise d'Electronique et
d'Automatisme
CGA-HBS, B.P. 85
Meylan Cedex, 38243 FRANCE

GTM Enterpose Electricite
61 Avenue Jules Quentin BP 315
Nanterre Cedex, 92003 FRANCE

Hughes Ground Systems Group
Bldg. 618, MS 302
P.O. Box 3310
Fullerton, CA 92634

IBM Corporation
Public Transportation System
10401 Fernwood Road
Bethesda, MD 20817

International Road Dynamics, Inc.
702 43rd Street
Saskatoon, Saskatchewan
CANADA, S7K 3T9

MFS Network Technologies
1100 Kiewit Plaza
Omaha, NE 68131

Lazerdata Corporation
2400 Diversified Way
Orlando, FL 32804

Lockheed Info Management Systems
2100 Torey Pines Road
Ames, Iowa 50010

Mark IV IVHS Division
6020 Ambler Drive
Mississauga, Ontario
CANADA L4W 2P1

Micro Design A/S
P.O. Box 3974
Trondheim, N-7002 NORWAY

Microsense, Inc.
4800 Dethania Station Rd.
Winston Salem, NC 27105

Microwave Sensors
7885 Jackson Road
Ann Arbor, MI 48103

Mitsubishi Heavy Industries, Ltd.
Kobe Shipyard & Machinery Works
Central P.O. Box 1086
Kobe, 650 JAPAN

Mitsubishi International Corp.
520 Madison Avenue
New York, NY 10022

Motorola, Inc.
4000 Commercial Avenue
Northbrook, IL 60062

NDC Automation
3101 Latrobe Drive
Charlotte, NC 28211

Norske Vegfinansieringsselskapers
Forening
P.O. Box 176 N-5430
Bremnes, NORWAY

Peek Traffic
4920 Woodlane Circle
Tallahassee, FL 32303

The Perot Group
777 Main Street, Ste 1480
Fort Worth, TX 76102

PHILLIPS ELECTRONICS, INC.
85 McKee Drive
Mahwah, NJ 07430

Proxim
295 North Bernardo Avenue
Mountain View, CA 94043

Rand McNally and Company
DocuSystems Group
8255 N. Central Park Avenue
Skokie, IL 60076

Rockwell International
3370 Mira Loma Ave.
Bldg. 253, MS DM08
Anaheim, CA 92803

Saab Automation AB
Box 33
S-164 93 Kista, SWEDEN

Sensor Systems, Inc.
1704 Oak Creek Dr. #307
Palo Alto, CA 94304

Siemens Corporation
186 Wood Avenue South
Iselin, NJ 08830

Sierra Semiconductor
2075 North Capitol Avenue
San Jose, CA 95132

Smart Card International
363 Seventh Avenue, 15th Floor
New York, NY 10001

State of Russian Highway Company
ROSAVTODOR
129301, 4 Bochkov Street
Moscow, RF

Syntonic Technology, Inc.
7611 Derry Street
Harrisburg, PA 17111

TDC Electronics, INC.
222-15 Northern Blvd., 3rd Floor
Bayside, NY 11361

Tecnotel SRL
Via Lazio, 25
Zola Predosa (BO), 40069 ITALY

Texas Instruments, Inc.
TIRIS-Business Development
12501 Research Blvd., MS 2243
Austin, TX 78714-9149

3M
Special Enterprises Program
3M Traffic Control/Materials Division
1010 Hurley Way, Ste 300
Sacramento, CA 95825

Toll Systems Technology Pty.
21 Smith Street
Capalaba, Queensland, 4157
Australia

Toshiba Corporation
Soc. Autom. Sys. Div./2-1
Shibaura 1-chome, Minato-ku
Tokyo, 105 JAPAN

APPENDIX E
GLOSSARY

ACM	Automatic Coin Machine Machines which collect exact change from toll patrons and control one access gate.
ADT	Average Daily Traffic A measure of traffic flow over a 24-hour period.
ANSI	American National Standards Institute A national standards-setting organization.
APTS	Advanced Public Transit Systems The application of advanced technologies to improve the efficiency and quality of service of public transit modes. A subset of Intelligent Vehicle Highway Systems.
ASTM	American Society for Testing and Materials A national standards-setting organization.
ATIS	Advanced Traveler Information Systems The application of advanced technologies to improve information available to travelers. A subset of Intelligent Vehicle Highway Systems.
ATMS	Advanced Traffic Management Systems The application of advanced technologies to improve the management of urban traffic systems. A subset of Intelligent Vehicle Highway Systems.
AVC	Automatic Vehicle Classification A method of classifying vehicles (car, 4-axle truck, 6-axle truck, etc.) when they pass over sensors mounted in the pavement, overhead, or roadside.
AVCS	Advanced Vehicle Control Systems The development of technologies which can relieve the human driver of partial or total control of a vehicle, in order to improve safety and increase road capacity. A subset of Intelligent Vehicle Highway Systems.
AVI	Automatic Vehicle Identification Wireless communications between a transponder mounted on a vehicle and a sensor located at the roadside. Uses include toll collection, traffic management, fleet management.
AVL	Automatic Vehicle Location The installation of devices on a fleet of vehicles (e.g. buses, trucks or taxis) to enable the fleet to function more efficiently by knowing location of vehicles in real-time.
bps	Bits Per Second A measure of the speed of information flow: 1 bit per second
CCTV	Closed-Circuit Television A method of monitoring external conditions using television cameras which feed images to a small number of TV monitors.
CPU	Central Processing Unit The part of a computer or computer system which performs core processing functions.

CUTR	Center for Urban Transportation Research Performed surveys of electronic toll collection system operators and vendors.
CVO	Commercial Vehicle Operations The application of advanced technologies for commercial vehicle fleet management. A subset of Intelligent Vehicle Highway Systems.
DAT	Digital Audio Tape A method of external data storage. Cartridges are the size of a common audio cassette.
D-QUEUE	A toll plaza simulation model developed by the Florida Department of Transportation.
ECPA	Electronic Communications Privacy Act Legislation which protects wire or electronic communications from illegal interception by unauthorized third parties.
EPA	Environmental Protection Agency The federal agency which enforces environmental legislation.
ETC	Electronic Toll Collection Use of automatic vehicle identification to eliminate the need for a vehicle to stop to pay tolls.
ETTM	Electronic Toll and Traffic Management Uses two-way communications between vehicles and roadside sensors for toll collection and other traffic management functions.
FCC	Federal Communications Commission The federal agency which regulates telecommunications in the United States.
Gb	Gigabyte A measure of information volume: 1 billion bytes.
GHz	Gigahertz A measure of frequency: 1 billion waves per second.
HOV	High Occupancy Vehicle Can describe any vehicle containing more than one person, such as buses, carpools, vanpools.
IEC	International Electrotechnical Commission An international standards-setting organization.
IEEE	International Institute of Electronics and Electrical Engineers An international standards-setting organization.
ISO	International Standards Organization An international standards-setting organization.
IVHS	Intelligent Vehicle Highway Systems The application of advanced technologies to improve the efficiency and safety of transportation systems.
IVHS AMERICA	Intelligent Vehicle Highway Society of America

An industry trade group which promotes the application of emerging technologies to transportation systems.

Kb	Kilobyte A measure of information volume: 1,000 bytes or 8,000 bits
kbps	Kilobits Per Second A measure of the speed of information flow: 1000 bits per second
KHz	Kilohertz A measure of frequency: 1000 waves per second.
LAN	Local Area Network A method of connecting several computers together using thick or thin wires.
MHz	Megahertz A measure of frequency: 1 million waves per second.
NIU	Network Interface Unit Software and equipment allows clusters of individual computers to communicate with a local area network.
OSHA	Occupational Safety and Health Agency The federal agency which enforces workplace safety laws.
PC	Personal Computer
PCS	Personal Communication Services A variety of mobile communication technologies including pagers, cellular phones.
RF	Radio Frequency A method of wireless communications which uses electromagnetic energy.
SAW	Surface Acoustical Wave A method of wireless communications. A lithium crystal converts the RF energy into sound waves.
TCP/IP	An internationally recognized protocol for communications between different computers.
WAN	Wide Area Network A method of connecting several computers together using fiber optic cable.
WIM	Weigh-In-Motion A method of weighing commercial vehicles when they pass over sensors mounted in the pavement.
UPS	Uninterruptible Power Supply A power supply with external storage capacity used to keep computers in operation when power outages or surges occur.

THE TRANSPORTATION RESEARCH BOARD is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. It evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 270 committees, task forces, and panels composed of more than 3,300 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, the National Highway Traffic Safety Administration, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce Alberts and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

ADDRESS CORRECTION REQUESTED

NON-PROFIT ORG.
U.S. POSTAGE
PAID
WASHINGTON, D.C.
PERMIT NO. 8970

000021-05
Robert M Smith
Research & Asst Matls Engr
Idaho Transportation Dept
3311 W State St
P O Box 7129
Boise [illegible] 83707-1129