
CHAPTER 5

Electronic Toll- Collection System

Electronic Toll and Traffic Management (ETTM) is an element of ITS that allows for nonstop toll collection and traffic monitoring. ETTM utilizes vehicles equipped with transponders (electronic tags), wireless communication, in-road/roadside sensors, and a computerized system (hardware and software) to uniquely identify each vehicle, electronically collect the toll, provide general vehicle/traffic monitoring and data collection. ETTM technologies and infrastructures provide the necessary capabilities for future applications such as incident management, alternate route guidance, and travel demand management. Properly implemented, ETTM can reduce congestion, increase operating efficiency, improve travel time, reduce pollution, and improve safety of the roadway facility and surrounding corridors.

5.1 ETTM COMPONENTS

A major component of the ETTM is Electronic Toll Collection (ETC). ETC is combination of techniques and technologies that allows vehicles to pass through a toll facility without requiring any action by the driver (i.e., stopping at toll plazas to pay cash). In fact, today's conventional toll plaza is not necessary in a fully dedicated ETC facility.

ETC components can be categorized as in-lane/roadway components and Facility Management and/or Customer Service Center components. Three major in-lane/roadway components are required for the successful implementation of an ETC. These components are:

- Automatic Vehicle Identification (AVI);
- Automatic Vehicle Classification (AVC); and
- Video Enforcement Systems (VES).

All in-lane/roadway components are in communication with and controlled by a computer called the "lane controller." The lane controller takes input from the AVI, AVC, and VES components. Its database, through which a list of valid tags is maintained, is used to validate the AVI and charge the customer's account. The information from each lane controller is passed on to a plaza host computer. Each plaza host computer is in constant communication with the central computer in the Facility Management and/or Customer Service Center, thereby consolidating the database, as well as equipment requirements. The Customer Service Center manages the accounts, enrolls customers and issues tags, processes the violations, handles all inquiries, and serves as the facility management center.

5.1.1 AUTOMATIC VEHICLE IDENTIFICATION

Automatic vehicle identification refers to various components and processes that allow for the identification of vehicles and their owners for the purposes of charging the toll to the customer and providing mechanism for data collection for various traffic-management strategies. AVI technology can be broken into two main categories: laser and Radio Frequency (RF.) Laser systems utilize a bar-coded sticker attached to the vehicle and read by a laser scanner as the vehicle passes through the toll lane. Laser technology has several drawbacks that limit its use in the open-road toll collection

environment. Chief among these are sensitivity to weather and dirt, ease of forgery, and location and installation of the scanner in the close proximity of the toll lane.

On the other hand, RF systems utilize a transponder (or electronic tag). An RF tag is a device located in or on the vehicle that is used in conjunction with an in-lane RF antenna-reader to communicate identifying information about the vehicle and customer to the toll system. Each toll lane is equipped with an RF “antenna,” usually mounted in the center of the lane above the roadway (however, there are implementations where the antenna is mounted in the roadway itself). Each antenna is connected to a “reader,” which controls communications between the tag mounted on the vehicle and the antenna in the lane. The reader sends out a signal (via the antenna) to the tag that lets the tag know it should begin communication. The tag returns a unique ID number used to identify the vehicle (customer) to the ETC system. In the case of read/write tags, smart tags, or smart cards with transponders, additional information may be transmitted by the tag (such as account balance, point of entry, etc.) and the reader may send back updated information to be encoded on the tag/smart card.

5.1.2 AUTOMATIC VEHICLE CLASSIFICATION

Automatic vehicle classification refers to the various components and processes of the toll-collection system with which the toll equipment is able to determine the configuration of the vehicle in order to determine the appropriate toll to charge.

Vehicles are segregated into classes, such as cars, trucks, and buses, primarily to charge different tolls by such classes. AVC systems, of which there are many variations, consist of various in-lane devices that measure the physical characteristics of vehicles and an AVC processor that uses the outputs of those devices to categorize vehicles into distinct classes. In manual toll-collection systems, AVC systems are used to verify the classifications assigned by toll collectors. In electronic toll-collection systems, AVC systems are used to calculate the amount of toll due or to verify precoded classifications on vehicle tags.

An automatic vehicle classification may need to determine vehicle height, number of axles, presence of dual tires, and vehicle weight to distinguish between vehicles and assign the correct class. In addition, automatic vehicle classification must provide for vehicle separation (i.e., assigning the various class determinants to a single unique vehicle). When a vehicle’s class is dependent on the number of occupants of a vehicle, there is no practical way to determine the class by automated means. Similarly, there is no way to automatically determine the purpose for which a vehicle is being used (e.g., a taxi cab cannot be distinguished from a private passenger car). Determinants of vehicle class may include:

- Number of axles and/or tires of a vehicle.
- Dimensions (e.g., height, length, wheelbase, height over first axle) of a vehicle.
- Weight of a vehicle.
- Number of occupants in a vehicle (e.g., a special class assigned to commuter pools with a minimum number of occupants).

- Purpose for which a vehicle is being used (e.g., a special class assigned to taxi cabs).

5.1.3 VIDEO ENFORCEMENT SYSTEMS

The term “video enforcement systems” or “violation enforcement systems” refers to the various components and processes of the toll collection system with which the toll equipment is able to capture information on vehicles that have not paid the proper toll.

VES is used to capture images of the license plates of vehicles that use ETC lanes without valid ETC tags. These images are used to extract the license plate number and State (either by an automatic system or manually) and that information is used to perform a search of the applicable State’s motor vehicle records to determine the registered owner of the vehicle. A notice is then sent to the owner, indicating that a toll is due. Most agencies also levy a processing fee that, relative to the toll, can be very high. The main purpose of the fee is to deter motorists from habitually violating the toll and to offset the cost of processing the violation. In the event that the owner does not pay the toll, agencies can forward the matter to the local judicial system for resolution.

If patrons believe that an ETC lane is operating without VES, they will take advantage of the situation and violation rates will increase. VES is necessary to record the image information needed for the agency to pursue evaders, recover tolls and issue fines, thereby deterring toll evasion.

5.2 TECHNOLOGIES

5.2.1 AVI TECHNOLOGIES

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 returns with 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). The system is the earliest of the AVI technologies.

Advantages:

- Proximity of loop antenna and tag provides potential for increased reliability.
- Simple serviceability.
- Low potential for electrical interference.
- Short coupling range decreases potential for interference from adjacent lanes.

- Advanced traffic-management and traveler-information systems can also use inductive loop, so the infrastructure is already in place for other ITS-related applications.

Disadvantages:

- Low frequency results in lower maximum data rate, although it is fast enough to allow multiple transmissions to increase reliability.
- Moderate 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.
- More sensitive to environmental conditions.

Optical Systems

Two types of AVI technologies employ optical or near-optical frequencies to identify vehicles. The first system, optical license plate identification, reads license plates directly and identifies the vehicle from a database. As the vehicle passes the toll booth 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, precluding multiple reads for improved reliability. The second type of optical or near-optical system, bar coding, 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.

a. *Optical License Plate Identification*

Advantages:

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

Disadvantages:

- 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.

- Low (80 to 90 percent) reliability because of the complexity involved in image processing.
- Typically requires highly reflective license plate.

b. *Bar Coding*

Advantages:

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

Disadvantages:

- 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).
- High restrictions on the position and speed of the vehicle as it passes the reader.

Active RF/Microwave Systems

Active radio frequency AVI systems employ microwave frequencies for communications 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. Active RF/microwave 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 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 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.

Advantages:

- 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.
- Less chance of electrical interference than a passive system because of the stronger signals.

Disadvantages:

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

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.

Advantages:

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

Disadvantages:

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

Surface Acoustical Wave

Surface Acoustical Wave (SAW) technology 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. With the SAW technology, a low-power radio frequency signal from the AVI reader is captured by the transponder antenna and energizes a lithium crystal, generating 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:

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

Disadvantages:

- 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 to mechanical energy.
- The tag cannot be programmed.

5.2.2 ELECTRONIC TAGS/TRANSPONDERS

RF Tags

The information stored in the tag is fixed (read only) and cannot be changed and the tag does not have any processing capabilities. These tags are often referred to as Type I tags. However, some tags contain an updateable (read/write) area on which the antenna/reader may encode information (such as point of entry and date/time of passage.) These tags are often referred to as Type II tags. RF tags have been in use for several years at many installations both in the United States and around the world.

RF tags operate in half duplex mode, meaning that they cannot send and receive data at the same time. They generate the signal used to communicate with the antenna/reader in one of two ways: actively, whereby the RF tag contains a transmitter and generates its own RF signal; and passively, whereby the RF tag reflects the signal it received from the antenna/reader (and, as such, the tag does not contain a transmitter). Three frequency ranges are used by RF tags:

- 900 to 928 MHz
- 2.45 GHz
- 5.8 GHz

Only the 900 to 928 MHz frequency range is used in the United States, with the other frequencies in use in other parts of the world.

The maximum read/write range of RF tags does not extend much beyond 100 feet and in actual use they are usually within 20 or 30 feet of the antenna during communications.

The RF tag contains from 128 bits to 512 bits of memory in the form of EPROM and/or EEPROM. However, some RF tags can be augmented to contain as much as 16 megabits of memory. The RF tag also contains a battery that is not user replaceable and has a useful life of between 5 and 10 years. Other features of RF tags include:

- LED, controllable via the reader to indicate information to the driver.
- LCD, controllable via the reader to display a message to the driver.

- Buzzer (or other sound generating device), to alert the driver.
- Scroll buttons - to allow the driver to scroll through messages received from the reader.
- Communication ports, to allow the tag to communicate with other devices in the vehicle. Note that tags with this feature are often referred to as Type III tags.

Among the many communications standards supported by RF tags are:

- Crescent HELP;
- ATA 5/16/90;
- ISO 10374.2;
- AAR S-918-92;
- ANSI MH5.1.9-1990; and
- California Title 21.

RF Smart Tags

An RF smart tag is an RF device, located in the vehicle, that is used in conjunction with an in-lane RF antenna/reader to communicate identifying information about the vehicle, customer, and account balance information to the toll system. Some portions of the tag information are fixed (such as vehicle and customer data) while others are updateable (such as balance information). The smart tag contains a microprocessor, which maintains account balance information updated each time the smart tag is used. RF smart tags have not been used extensively either in the United States nor around the world.

RF smart tags operate in full duplex mode, meaning that they are able to send and receive data at the same time. They actively generate the signal used to communicate with the antenna/reader via a transmitter. Three frequency ranges are used by RF smart tags:

- 900 to 928 MHz
- 2.45 GHz
- 5.8 GHz

Only the 900 to 928-MHz frequency range is used in the United States with the other frequencies in use in other parts of the world.

The maximum read/write range of RF smart tags is greater than that of RF tags (owing to their use of active transmission); however, in actual use they are usually within 20 or 30 feet of the antenna during communications.

The RF smart tag contains from 16 kilobits to 64 kilobits of memory in the form of EPROM, EEPROM, ROM, and/or RAM. The RF smart tag also contains a user replaceable battery that generally has an operational life of between one and two years. Other features of RF smart tags include:

- LED, controllable via the reader to indicate information to the driver.
- LCD, controllable via the reader to display a message to the driver.
- Buzzer (or other sound generating device), to alert the driver.
- Scroll buttons, to allow the driver to scroll through messages received from the reader.
- Communication ports, to allow the tag to communicate with other devices in the vehicle.

At this time, RF smart tags utilize proprietary communications standards.

Smart Cards With RF Transponders

For toll collection, use of smart cards actually requires two components: the smart card itself and a separate RF transponder (tag). The smart card is an Integrated Circuit (IC) device that contains a microprocessor and memory and stores account balance information. The RF transponder is an RF device, located in the vehicle, that interfaces to the smart card and allows the smart card to communicate with the in-lane antenna/reader. Often, this RF transponder is actually a Type III RF tag. In addition, the RF transponder contains information about the vehicle that it transmits to the antenna/reader along with the smart card information. Smart cards with RF transponders are undergoing extensive trials in Europe.

The tags used with smart cards employ either full or half duplex communication with active or passive transmissions. The frequency ranges used conform to those of other RF tags, as do their communication ranges and other features.

5.2.3 AVC TECHNOLOGIES

Various equipment used to determine vehicle classification include:

Inductive Loops

Inductive loops are wires placed in channels cut into the road bed and used to detect vehicle presence by sensing the metallic mass of the vehicle.

Treadles

Treadles are pressure-sensitive devices placed in frames installed in the road bed and used to determine the number of axles, number of wheels, and direction of a vehicle crossing the treadle. A parallel series of sensor devices detects the direction of axle movement by the sequence of sensor activation. Treadles can be classified into several types based on the physical principle used to convert the pressure of a vehicle's wheel into electrical signals recognized by the logic units of the treadles.

- a. *Electromechanical Treadles* - These devices are simple electromechanical devices in widespread use for low-speed applications; however, they are reported to be inaccurate at speeds of above 55 mph. They also have a high maintenance cost.
- b. *Resistive Rubber Treadles* - These devices are similar to electromechanical treadles, but use resistive rubber rather than metal for contact closure. They are specified to operate accurately at speeds from 2 to 80 mph. They also have a lower maintenance cost than metallic units.
- c. *Optical Treadles* - These devices utilize infrared beams inside a tube. The beam is broken and an electrical signal is generated when an axle crosses the treadle. These devices are reported to be accurate at higher speeds and have a long life and low cost of maintenance. They can be installed in standard treadle frames.
- d. *Piezoelectric Treadles* - These devices utilize special material inside a tube. The material generates an electrical current when subjected to pressure caused by an axle crossing the treadle. The devices are reported to be quite accurate at speeds of above 5 mph, but not accurate at speeds between 0 and 5 mph.

Weigh-In-Motion Devices

These are pressure-sensitive devices generally placed in frames installed in the roadbed and used to determine the axle weight of vehicles. Many of the sensors used in weigh-in-motion devices are the same as those used in treadles. They differ in that treadles utilize a series of sensors to detect the direction of axle movements.

- a. *Bending Plates* - These devices utilize a bending plate to determine the axle weight of a vehicle. The device generates an electric current when subjected to pressure caused by an axle crossing the plate.
- b. *Capacitive Strip* - The degree of pressure on strip as axle crosses strip allows calculation of axle weight.
- c. *Piezoelectric Sensors* - These devices utilize special material inside a tube. The material generates a varying electrical current proportional to the weight of the axle crossing the sensor.

Light Beams

These are devices consisting of a single infrared light beam that is broken as a vehicle passes through the beam. They are used to detect vehicle presence and vehicle height. The functionality of light beam devices is limited in that they cannot accurately separate vehicles with trailer hitches or provide a profile of the vehicle. Another disadvantage of light beams is that the single beam of light is transmitted through vehicle windows without impediment, thereby causing the appearance of a separation of the vehicle where none exists.

Light Curtains

Light curtains emit multiple horizontal light beams to measure vehicle presence and profile. A transmitting tower sends light beams across the lane to a receiving tower. As a vehicle breaks the light

beams, a two-dimensional profile of the vehicle can be produced. Objects such as trailer hitches can be detected down to approximately one-half inch.

Scanning Devices

These devices generate radiation at various frequencies to detect vehicle presence and profile. Scanning devices that may be useful in AVC applications include the following.

- a. *Ultrasonic Scanners* - These devices emit ultrasonic waves that are reflected back to the transmitting device to detect vehicle presence and two-dimensional profile. Ultrasonic devices are subject to distortion from air turbulence and changes in temperature and humidity. Despite this, Japan uses ultrasonic technology extensively for vehicle classification.
- b. *Infrared Scanners* - This technology is used to separate and profile vehicles using a vertical or horizontal infrared scanning camera system. Output from the equipment is processed to produce two-dimensional images, which are compared to vehicle class templates to determine vehicle classification.
- c. *Laser Scanners* - Laser scanners use scanning laser beams to detect and classify vehicles operating in high-speed, high-volume conditions. Output from the device is processed to produce three-dimensional images, which are compared to stored templates of various vehicle profiles to determine vehicle classification.

Video Image Processing

These devices use video cameras to scan traffic and use built-in software to determine vehicle profile information such as length, width, and height from the scanned vehicle images.

5.2.4 VES TECHNOLOGIES

Photographs

The very earliest video enforcement systems utilized cameras to take photographs of toll-evading vehicles. This approach was soon abandoned because of the labor-intensive, manual extraction of plate information from the photographs. Other problems, such as triggering the camera, image correlation with lane, date, and time, and storage of photographs, made this approach unacceptable.

This approach generally required each lane to be equipped with a camera and film storage device.

Videotape Recording

Videotape recording devices (VTR/VCR) were subsequently used to capture images of vehicles going through the lane. The videotape would be replayed at a later time to review the images and extract license plate information. Image review was a time consuming activity that was done using a stand-alone videotape playback unit. Several implementations of this technology added lane number and date/time information, which was overlaid onto the tape. For image retrieval and ease of locating

images, the relationship between an image number and the tape position information was recorded. Also, the recording was done with a dual tape speed to allow for greater image storage and for more efficient post-processing image review. Besides the potentially large amount of storage space required, this approach required manual handling of tapes from the image capture location to the violation processing location. This approach, while still in use today, is still labor intensive.

This approach generally required each lane to be equipped with a video camera as well as a dedicated VTR.

Digital Imaging

The latest implementations of VES are video-based systems that utilize digital capture and storage of images. Digital systems feature the ability to digitize images, store them electronically, and transmit them to remote locations. In addition, digital systems can be enhanced through the use of License Plate Recognition (LPR) systems. LPR allows the VES to automatically determine where in the image the license plate is located, read the license plate number and State, and store this information on the transactions. This can alleviate the need for manual intervention in the violation process and greatly reduce the operating cost of the electronic toll-collection system.

This approach generally requires each lane to be equipped with a camera; however, the images can be stored in the lane or several cameras can be connected to a central image storage location.

License Plate Recognition

VES has one primary objective — to capture an image that has high enough quality to allow for the extraction of the license plate data. This data includes the plate number and the State that issued the plate. With this information the owner of the vehicle can be identified by searching for a match in a local vehicle plate database or by obtaining this information by some arrangement with the associated State division of motor vehicles. The challenge is the accurate and cost-effective extraction of the plate information. Currently, most systems rely on a human being to review the image and key in the plate number and State. This manual method is labor intensive and allows the possibility of incorrect image reading or keying of the information. However, Optical Character Recognition (OCR) technology has advanced to a level where some vendors are proposing and actually building systems that incorporate automatic recognition of the license plate and OCR to extract the license plate number and State from the image.

The major problem with automatic LPR extraction is its level of inaccuracy. There is not necessarily a problem with the technology itself, but rather a combination of factors inherent in the way license plates are designed, issued, and used. Among these factors are:

- Lack of standards for license plate uniformity.
- Dirty plates, damaged plates, and obstructions.
- Plate is mounted incorrectly or missing; temporary tags.
- Supplemental lighting systems aren't effective for all plates (e.g., those with plastic covers).

- Differences in vehicle design and license plate position.
- Ambiguity and similarity of letters/numbers cannot be explicitly determined (such as the letter O and the number 0).

As a result of these factors, LPR systems often still require manual intervention to read images and confirm the results. To improve the overall results, some vendors have provided the capture of multiple images with LPR run on several images. If the LPR determines the same plate information over multiple images, the confidence level of the data is improved and manual review may not be required. Any discrepancy is placed into a manual review queue or treated as a lost-revenue transaction. These limitations have constrained the use of LPR in VES, and most system in use or under development do not use LPR.

SOURCES:

- *An ETTM Primer for Transportation and Toll Officials*, March 1995, ITS America, ETTM Task Force.
- *Electronic Toll & Traffic Management (ETTM) User Requirements for Future National Interoperability*, January 1995, ITS America, Standards and Protocols Committee.
- *ETTM - An Early ITS Winner*, *ITE Journal*, December 1995, Lawrence Yermack, Maureen Gallagher, K.R. Marshall.
- *Electronic Toll and Traffic Management (ETTM) Systems*, NCHRP Synthesis of Highway Practices 194, 1993, Michael C. Pietrzyk, Edward A. Mierzejewski, Transportation Research Board.

5.3 CASE STUDIES

FasTrak

The Transportation Corridor Agencies opened the San Joaquin Hills corridor in California and uses the FasTrak electronic toll collection system to allow commuters to use the same transponder that they use on other toll roads in the state. The system will work with SR-91 express lanes and various others in the state.

Fastoll

Fastoll is Virginia's toll collection system, operating on Virginia DOT facilities, the Dulles Toll Road, and the Coleman Bridge. Within five months of the Fastoll opening, in April 1996, over 50,000 Fastoll transponders were issued and 35,000 accounts opened. More than 60,000 toll accounts are being processed each day. Fastoll patrons are able to open accounts via prepaid mail-in applications, toll-free telephone calls, or via an internet application form, or by visiting one of the service centers in person (Traffic Technology International, Dec 1996/Jan 1997).

Oklahoma

The Oklahoma Turnpike Authority manages 10 turnpikes each with some Electronic Toll Collection. The system has been operating since 1991, and is claimed to have 99.5 per cent accuracy. Currently, there are about 310,000 toll tags in circulation, representing 165,000 accounts with the turnpike authority. On interstate highways there is as little as 25 per cent Electronic Toll Collection while in local commuting routes the per cent is about 70. To encourage users to adopt Electronic Toll Collection, a 10 per cent discount applies and during holiday periods Electronic Toll Collection users save 10 to 15 minutes per trip (TollTrans, Oct/Nov 1996).

Illinois I-Pass

The Illinois I-Pass began in 1993 and initially had 30,000 transponders. An expansion to the system, July 1998, will add another 250,000 transponders and will include 513 electronic lanes. It uses an axle-based classification system and features open tolling and barrier plazas. Each transponder is programmed for a specific class of vehicle based on the number of axles while each toll lane has an embedded axle counting device. In addition, for the expanded system, an auto-credit feature of the system will be enabled. When the system senses that a pre-approved motorist's account has dropped below \$10, it will automatically replenish that account by \$40, charging the additional amount to the individual's major credit card. The information from the I-Pass toll plazas is transmitted back through the Toll Operation Management System networks which relays the data to the host, a mainframe located at the Illinois Toll Authority's central administration office. (Katie Brazel, 1996).

TransPass

The Maine TransPass system, currently with 122 automated toll collection lanes, has purchase 60,000 transponders with plans to purchase more. The system is very similar to the Illinois I-Pass.

E-ZPass

The E-ZPass, by year 1999, will be available at all participating toll facilities in the New York, New Jersey, Pennsylvania, tri-state region. The New York State Thruway Authority reports that approximately 40 per cent of all their toll transactions are made using E-ZPass transponders. At the Tappan Zee Bridge 75 per cent of the a.m. peak period transactions are made through E-ZPass. On the New York State Thruway west of the Tappan Zee Bridge, vehicles equipped with E-ZPass transponders have recently been detected at a rate of 19,500 per hour. On average, TRANSCOM's System for Managing Incidents and Traffic (TRANSMIT) counts over 400,000 reads per day on the New York State Thruway and Garden State Parkway.

Metro-Dade County, Florida

To facilitate faster passage through the toll area for both residents and visitors, Metro-Dade County implemented an electronic toll system. With transponder devices (looking much like bar codes, but essentially wireless radios) affixed to their windshields, vehicles can cruise through the toll plaza. The toll road's eight lanes are equipped with custom-designed transponder technology capable of detecting and reading information from moving sources-in this case, the number of axles on each passing vehicle, used to calculate toll fares for electronic collection-at speeds of up to 55 miles per hour. The

system has a useful life of 12 to 15 years and can be technologically upgraded as needed or appropriate. Additional lanes offer customers more traditional payment options, such as paying a toll attendant or tossing coins in a basket.

The electronic system has several advantages. Since users of the transponder devices must establish pre-paid accounts with the county, Metro-Dade collects toll revenue in advance and in greater increments, instead of dollar by dollar. The electronic system improves traffic flow, minimizes delays due to toll-collection procedures, and enhances collection accuracy and revenue projections for the jurisdiction.

California SR-91

The State Route 91 Variable-Toll Express Lanes is the first fully automated toll road in the world. It opened for revenue service on December 27, 1995. The four-lane toll facility is located in the median of the existing eight-lane Riverside Freeway in Orange County, California, between the City of Anaheim and the Riverside County line. Unlike other variable-toll roads which exist in Singapore, Scandinavia, France, and elsewhere, the SR-91 project is a single highway section serving an urban commute corridor, where a free, although congested alternative route is readily available.

The privately built and operated facility charges tolls which vary with the time of day, reflecting the travel time saved by toll lane customers compared to users of the adjacent public freeway. The greater the traffic delays on the adjacent freeway lanes, the greater the toll. Currently, tolls follow a published schedule, although the technology would permit the toll levels to vary dynamically if this should someday be desired.

All tolls are collected by Automatic Vehicle Identification (AVI), in part because there is not enough space in the freeway median for conventional toll booths. Non-AVI-equipped vehicles are prohibited from the facility. The electronic toll-collection concept is marketed regionally as the FasTrak. The FasTrak system on State Route 91 is inter-operable with FasTrak lanes on the other publically operated toll roads in Orange County, where conventional toll booths are also provided.

Rideshare groups with three or more persons (HOV-3+) currently travel toll-free, although they may be charged a discounted toll sometime in the future. A special lane is provided for HOV-3+ vehicles to bypass the electronic toll-taking which occurs about halfway along the length of the facility. Proper use of the automated toll lanes is enforced by the California Highway Patrol (CHP), under contract to the California Private Transportation Company (CPTC), and through the use of video surveillance equipment. The CPTC operates the toll lanes on land leased from the State of California. The CPTC has thirty-five years to return a profit to its investors, after which time the toll lanes revert to full state control (airship.ardfa.calpoly.edu/~jwhanson/sr91info/sr91info.html).

Sullivan (1997) summarizes some early findings which have emerged to date from approximately one year's experience with the SR 91 toll facility:

- The SR 91 toll lanes have been an early market success. By the end of the first year, peak period traffic had increased to the level where a toll increase was warranted to protect the toll lanes from the onset of congestion.

- Even though 75-80% of peak period travelers on SR 91 are engaged in home-to-work trips, most customers do not use the toll lanes on a daily basis.
- Overall traffic volumes on SR 91 appear to have increased only a small amount during the first months of toll lane operation.
- The capacity increase due to adding two new toll lanes in each direction on SR 91 has resulted in substantially reduced peak period congestion which has encouraged some traffic shift back to the freeway from parallel arterials.
- Preliminary indications are that many toll lane users choose to enter the toll lanes under conditions where the expected value of their time savings is apparently less than the tolls paid.
- Prior to and since the opening of the variable-toll lanes, average vehicle occupancy in the SR 91 and SR 57/60 corridors has changed very little. Initial post-opening results show an increase in the percentage of HOV-3+ vehicles in the SR 91 traffic stream, perhaps reflecting the fact that HOV-3+ toll lane users pay zero tolls.
- Commuters who use the toll lanes most frequently have higher income distributions than commuters who use the lanes less frequently or not at all.
- Surveys conducted in November-December 1995, April-May 1996, and late 1996 explored the traveler's degree of approval of congestion-based tolls. Through all the surveys, the idea of providing additional toll-financed lanes to bypass congestion consistently met with approval in the 60-80% range. However, the idea of varying tolls based on the severity of the congestion bypassed was not initially very popular, registering about 45% approval rating.
- Approval levels for operating the highway as a private business were in the 35-45% range both before and five months after the facility's opening. The most recent survey in the winter of 1996 shows that travelers appear to be getting used to this innovative idea, and approval levels for most traveler categories increased to the 50-60% range.

I-15 ExpressPass

The I-15 ExpressPass is a three-year pilot program funded by the FHWA and developed by the San Diego Association of Governments (SANDAG) in cooperation with Caltrans. The goal of the program is to reduce rush hour congestion on I-15 by making the maximum use of all traffic lanes.

ExpressPass will allow a limited number of solo drivers to use the two reversible lanes normally reserved for carpools. These lanes stretch 8 miles down the middle of I-15 between State Route 56 and 52.

I-15 ExpressPass is a monthly subscription program that allows single drivers to pay a monthly fee in order to use the I-15 Express Lanes carpool facility. To participate, drivers must have an ExpressPass account and display a permit in their windshield when they use the lanes.

Early observations of the program include: express lane traffic continue to remain free-flowing; actual expressPass use is less than expected; HOV use of the express lanes has increased; express lane violations have declined; customer satisfaction with the program is very high; perceived travel time savings is high; primary purpose of using the ExpressPass is work.

5.4 EVOLVING TECHNOLOGIES

Intelligent Tags

These tags can perform computations on tolls and maintain customer accounts. These tags do not require validation based on a centrally-maintained database. Validation is done in the individual microprocessor-based transponders. Some systems can also interface with external peripherals to receive on-board displays.

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