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# STANDARDIZING ELECTRONIC TOLL COLLECTION

*by*

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## EXECUTIVE SUMMARY

As California develops toll roads during the 1990s and considers the use of congestion pricing to resolve freeway congestion, electronic toll collection technology will assume increasing importance. These electronic, computer-based systems permit nonstop collection of charges for highway use, without requiring costly toll booths. They also facilitate charging different prices at different times of day and for different segments of a highway—qualities necessary for congestion pricing.

It would be desirable for drivers to be able to use a single electronic “tag” statewide, rather than having to obtain separate tags for each tolled facility. A 1990 state law required the California Department of Transportation to develop a statewide technical specification for electronic toll collection systems. This statewide specification was issued in July 1992.

This paper reviews the technical and policy (economic, legal, and social) implications of electronic toll collection systems. It finds that the technology is developing rapidly, with new approaches being developed by both U.S. and European firms. First-generation systems which are in use today possess few of the features promised by second-generation systems now in the prototype stage.

The Caltrans specification is unnecessarily restrictive, demanding some features which first-generation systems cannot provide but precluding other promising technological approaches. It therefore risks holding back both the first several toll road projects and the expected evolution of this new technology. The preferable approach would be to set only interim, regional, performance-based specifications that would encourage ongoing improvements in the technology. Over the longer term, the marketplace is the preferable means of determining standards, as has occurred in both the consumer electronics and personal computer industries.

# I. INTRODUCTION

## *A. Background*

Although California is known as the land of the freeway, direct payment for highways is on the way. Besides the existing toll bridges in the San Francisco Bay Area, Los Angeles and San Diego will add at least seven toll highways during the 1990s. In Orange County, the Transportation Corridors Agencies are developing three public toll highways: the Foothill, Eastern, and San Joaquin Hills. And the California Department of Transportation (Caltrans) has authorized four private toll roads under AB 680, enacted in 1989. The four projects include the Mid-State Toll Road in the East Bay region, the San Diego Toll Road, and the Route 91 and Route 57 tollway projects in Orange County.

The growing popularity of toll roads stems in part from recent developments in the technology of toll collection. Using microchips and low-power radio signals, it is now possible to “charge” a vehicle for driving past a specific point on a highway electronically, without the vehicle even having to slow down, let alone stop at a toll booth. The initial uses of this technology have been to automate certain of the toll lanes on existing toll roads and bridges in Louisiana, Oklahoma, and Texas. Compared with manual toll collection, nonstop automatic toll collection (ATC) is much faster and significantly less costly.

The obvious benefits of ATC have attracted the interest of the operators of California's existing toll bridges, as well as the developers of the seven planned toll roads. The prospect of a number of different ATC—potentially incompatible with one another—led Senator Quentin Kopp to sponsor S. B. 1523 in 1990 to promote standardization by requiring Caltrans to develop a statewide technical specification which all ATC systems would be required to meet.

Another reason for the increased focus on ATC is the growing interest of transportation planners in congestion pricing. Conferences and seminars sponsored by the University of California Transportation Center and the Federal Highway Administration in 1991 helped inspire the inclusion of congestion pricing provisions in the Intermodal Surface Transportation Efficiency Act of 1991. The Act calls for federal support for up to five congestion pricing pilot projects in large urban areas. A major focus of such projects could include charging for the use of some existing freeway capacity. Obviously, the ability to do such charging nonstop, without the addition of costly toll booths, would make congestion pricing considerably easier, less costly, and more user-friendly to implement.

For all these reasons, the subject of standardization of automatic toll collection is of great current interest in California. This paper explores the technical and policy issues that must be addressed in moving toward standardized systems.

*B. Legislative and Regulatory Impetus*

California's urban highways are overburdened, and by the year 2010, state officials estimate that traffic will be moving at less than one-third of today's average.[1] Expansion would help alleviate the problem, yet budget constraints mean that supply will usually lag demand. In addition, public aversion to tax increases limits funds collected at the gas pump for operation and maintenance. Private-sector funding is an answer, but companies will only invest on the expectation of adequate returns.

Not only must highway capacity be increased, but more efficient use of this scarce resource must be encouraged. Toll roads are the only viable solution to the capacity problem, and their ability to accommodate congestion—or demand—pricing make them an attractive approach to improving efficiency.

On 18 September 1990, Governor Pete Wilson signed into law Senate Bill S. B. 1523, which directed the Department of Transportation (Caltrans) to "develop and adopt functional specifications and standards for an automatic vehicle identification (AVI) system. . . ." There were three basic constraints on devices for carrying out AVI, motivated by concern over costs, safety, congestion, and air pollution:

- speed reductions would not be required;
- no owner should be required to purchase more than one device;
- more than one commercial source had to be available for the devices.

(State Senator Quentin Kopp, the author of S. B. 1523, has since indicated that—to encourage timely implementation of ATC—he may entertain an amendment allowing nonconforming systems, if they fully conform with the law in five to seven years.[2])

On 9 January 1991, Caltrans responded to the passage of S. B. 1523 with its first draft of the *Compatibility Specification for Automatic Vehicle Identification (AVI) Equipment*, a proposed new Chapter 16 of the Streets and Highways Code. This document described in considerable detail parameters such as radiation levels, message formats, reader positioning, etc.

Caltrans' Office of Electrical and Electronics Engineering (OEEE) submitted its final draft to the Office of Administrative Law (OAL) on 14 May 1992. After a thirty-day review, OAL will either return the draft to OEEE, or file it with the Secretary of State; thirty days after that, it will acquire the force of law.[3]

## II. TECHNOLOGY OVERVIEW

*A. Introduction*

ATC depends on some form of automatic vehicle identification (AVI). All such systems have three essential elements:

- a reading device (commonly called a “reader” or “antenna”), located in the pavement or above or alongside the roadway, which identifies passing vehicles; this can be done through some visual recognition scheme, or by RF communications;

- a transponder (*trans*mission res*ponder*), commonly known as a “tag,” located on or inside the vehicle; an optical reader records the tag's bar code, or the transponder responds to queries from an RF reader;

- some means of correlating toll accounts, vehicle passages, etc.; these are the so-called “back-room” activities.

In actual highway operations, vehicles without tags are typically shunted off the main roadway to separate lanes, which have manual or automatic coin toll collection.

*B. Tag Technology*

Since the tag—because of its onboard location and user cost constraints—tends to drive the design of the entire system, its mode of operation defines the whole system. Consequently, the discussion of technical approaches will center on tag technology.

1. “Read-Only” Tags

Tags with fixed data content (e.g., an identification number), which can be read but not altered, are known as “passive” or “read-only” tags, and they characterize the first generation of ATC technologies. The tag contains the identification code, which a central computer compares to account information on its data bank. These systems are optical or electronic.

Optical systems make use of the reflection of light from bar-coded tags. They use video cameras or lasers (similar to the automated check-out systems in use in supermarkets) to read the codes. Such systems are extremely sensitive to atmospheric obscurants (fog, rain, snow, dust, etc.) and the physical location of the tag and reader. There must be one reader per lane, and vehicles must be well-centered in the lane; finally, this approach can only handle vehicles moving at 35 miles per hour or less.

These constraints require toll gates, thus eliminating a key advantage sought with AVI systems:

unrestricted movement of traffic, minimizing air pollution, congestion, and the safety problems inherent with physical barriers and speed variations. Such systems drive the infrastructure costs higher.

Optical systems are more useful in the automation of pay parking lots, where environmental and speed constraints are less of a problem than on highways, and their low cost makes them competitive in that regime. In addition, they are ideal for enforcement subsystems for Electronic Toll Collection installations.

Commercially available electronic read-only tags include Amtech Corporation's current modulated backscatter (MB) and X-Cyte's, surface acoustic wave (SAW) devices. MB tags modulate (impose a code on) the unmodulated ("plain") signal received and backscatter it (reflect it back) to the reader. (The California standard mandates this type.) SAW devices also reflect back a received signal, but their coding is analog rather than digital, and it is reflected over a narrow band of frequencies.[4]

The sole advantage of read-only devices is low cost, but their simplicity requires a larger infrastructure (e.g., communications networks, centralized data storage and processing facilities, and the corollary personnel and processes), which tends to negate any savings. In addition, they imply a fiduciary responsibility by the operating agency.

There is a variation of this approach known as "read/erase." Similar to the magnetized cards used on the Illinois Central Railroad's commuter lines and on the Washington Metro, this system employs tags with a stored account balance, divided into equal units. Each time the tag is read, one unit is erased. Although this method is simple and requires little infrastructure, it does not easily lend itself to congestion pricing. Since the units are of fixed value, there are tradeoffs among unit value, card memory, and data transfer rates: smaller value units require more memory and higher data rates. And it would require a relatively expensive tag (i.e., up to $150) with a built-in device to read and erase the card, which would be inserted into the tag like a "smart" card.[5]

2. "Read/Write" Tags

These devices, also known as "active," constitute the second generation of electronic toll collection (ETC) technology. Using an onboard battery, such tags can accept and store data as well as transmit it. For example, when a vehicle enters the tollway, the tag can have the location "written to" its memory. When the vehicle exits the highway, a second reader determines where the trip originated, calculates the appropriate toll, deducts it from the account balance stored on the tag, and writes the new balance to the tag.

Since correlating readings from successive antennas requires no data network, there is no need for a buried-cable or radio network, which may have to compete with other traffic on scarce frequency bands. Nor are expensive data processing and storage infrastructure required. Read/write systems are also a boon to persons concerned with privacy, since any permanent record of such transactions (i.e., for audit purposes) does not have to contain personal information.

The tag can be a relay device, into which one inserts a "smart" card, a credit card-like device with an embedded microprocessor with continuous memory; the reader would query the tag, which in turn would debit the toll from the card and confirm the transaction. This latter scheme could be multifunctional, in that it could work like a debit or automatic teller machine (ATM) card, and one could use it in several vehicles without compromising security or rate-setting; these mechanisms could reside in the tag. "Smart" cards offer a high level of security, both that inherent in the data storage mechanism and that afforded by portability. However, the tag would become more complex (and expensive).

Active (powered) tags afford other benefits as well. Since they do not depend on the reader for power, they do not require high—and possibly unsafe—reader power levels, and a single reader can cover all lanes in both directions.

The major drawback to the active-tag approach is the battery. Prototype systems use a replaceable cell with a 2- to 3-year life, and an audible low-voltage tone alerts the motorist to the need for replacement.

### *C. Communications Protocols*

These are the rules governing the "what," "when," and "how" of the communication process between readers and tags, rationalizing it so that all vehicles are uniquely identified and queried, while minimizing errors or data collisions. They may specify frequency, message content, transaction queuing, etc. The following discussion covers protocols being used by the ETC industry.

#### 1. Time-Division Multiple-Access (TDMA)

In this protocol the reader transmits an activation signal, to which all nearby transponders respond in randomly-selected slots. The readers then assign data slots in a queue to the transponders, which respond with full data messages during their assigned time slots. The reader issues an acknowledgement message, ending the transaction.[6]

#### 2. Spread Spectrum (SS)

This analog protocol distributes signals over a relatively narrow frequency band, resulting in complex parallel data streams spread over several frequencies. Although some ETC tags use this protocol, such devices would not satisfy the current Caltrans compatibility specification.

3. Dedicated Half-Duplex (DHD)

This protocol allows a single tag to communicate with a reader at any given time, and is generally used in installations which have one reader per lane. The half-duplex format allows communication one way at a time, as do the others mentioned above.

## III. TECHNICAL ISSUES

### *A. Safety*

Since RF field strength decays as the fourth power of transmitter-to-receiver distance (i.e., doubling that distance requires sixteen times the radiated power), this becomes an issue with respect to hazards to human beings. It is particularly relevant to passive systems, which draw power for their response cycle from energy radiated by the reader: since they have no internal power source, the incident power level must be high enough to drive the internal circuitry, with sufficient power remaining to be detected by the reader. If one designs the readers for a great enough range, high power levels could be experienced by closer vehicle occupants. This is a concern with the Caltrans approach, although data on actual power levels are scarce and there is no clear consensus that the danger is real.

### *B. Reader Location Effects*

Some proposed systems require only a single roadside reader to monitor all traffic in both directions, while others require overhead or in-pavement mounting at each lane. Overhead location is easy to manage where there are already many signs, overpasses, light standards, etc., installed on highways. Modern materials technology makes in-pavement reader antennas equally attractive, however. Installation costs are about equal, but subsequent maintenance costs tend to favor in-pavement installations.[7]

In-pavement antennas virtually eliminate cross-lane reads, but good read-write systems can make overhead or roadside readers just as accurate.[8]

The closer the reader antenna can be located to vehicles, the lower the power required, which tends to favor buried antennas. They, in turn, require externally-mounted tags, which are vulnerable to damage or theft, and some of these must be professionally installed. The Caltrans specification requires systems that can operate either way.

### *C. Reliability*

For the open-highway implementation mandated for California, reliability—that is, the system's ability to remain on line and to function as intended—is of concern mainly to the owners and operators of toll roads. Although there are no guarantee clauses in Amtech's turn-key contracts for the Oklahoma Turnpike or the Dallas North Tollway, the company has often reimbursed toll authorities for losses due to equipment problems.[9] They cross-correlate data streams from their vehicle classification equipment (i.e., treadles) and their ETC equipment, and are satisfied that their system works well. In actual installations, the reliability of ETC systems approaches 100 percent (see Figures 1 and 2), and none of the current operators have any concerns about it.

*D. System Accuracy*

1. Missed Reads

This refers to a complete miss of a tagged vehicle passing through the read zone, whatever the reason. Again, this is of concern to owners and operators, rather than users. In practice, ETC systems are achieving near-perfect performance in this regard (see Read Accuracy, Figures 1 and 2).

2. Undetected Incorrect Reads

This refers to an incorrect read of a tag that the registration hardware or software does not catch. This scenario constitutes either a "free ride" for the motorist, or an undeserved fine for failure to pay. Too many of the former can break a toll project, and too many of the latter can hurt public acceptance. With proper hardware and software design, this situation will occur only once in 800 *million* passes.[10] The experience reflected in Figures 1 and 2 corroborates this.

3. Detected Incorrect Reads

This refers to an incorrect read of a tag that is caught, and then must be reread, reverified, or otherwise corrected by the registration hardware or software. This factor is part of Identification Accuracy (Figures 1 and 2). The data transmission rate of most available systems enables 20 or more attempts to complete a toll transaction, which virtually ensures success: at 55 miles per hour, a typical communication cycle between tag and reader occurs in about an inch of vehicle travel.

*E. Security*

1. Theft

The tags are, in essence, "electronic money," and therefore there will be motivation to steal them. Theft can be deterred by specially-designed tags, permanently affixed to the windshield so that any attempt at removal will result in destruction of the tag. Such a system would require updating by a transmitter located in a parking lot where users might go to replenish their accounts; once the toll operator verifies the transaction, the transmitter could send the appropriate update to a specific tag in the lot. This approach implies a read/write system, and sacrifices portability.

If it is desirable to make the tags portable, as favored by the California standard, theft can be deterred through a combination of system software and network design. If a potential thief knows that a stolen tag can be tracked, making it easy for authorities to apprehend unauthorized users, he or she will be deterred. In actual installations, ETC has improved stolen-vehicle recovery rates through a toll-free number for reporting theft. This situation is parallel to that of ignition keys: if a user insists on leaving them in the vehicle, he or she can hardly fault the system for any losses that ensue.

2. Tampering

Preventing “hackers” from changing account numbers or valuations can be achieved in a variety of ways:

- employing signal generation technologies that are inherently difficult to decode, reproduce, or alter, such as SAW;
- encryption and decryption of the signal at the reader or the tag, preventing unauthorized access to codes;
- maintaining only the account number, not the balance, on the tag.

None of these have a significant impact on the cost or ease of use of the system.

*F. Metallized Windshields*

A recent development in automotive windshield technology—metal coatings that are electrically heated for defrosting—absolutely prevent the passage of RF energy, including that produced by cellular telephones and ETC transponders in the frequency band specified by Caltrans.

Vendors do not feel that this will prevent the introduction of ETC systems. One mitigating factor is the limited availability and three-figure cost of the option.[11] Tags complying with the Caltrans standard can be located where metallized windshields will not interfere with proper operation. It is even conceivable that small “windows” could be left in the coating to permit the use of ETC tags in the preferred windshield-mounted location.

Rear location would be problematic for any system, since the vehicle would be rapidly moving beyond the range of any enforcement subsystem. Side location may create a problem for overhead readers. License plate location is another viable alternative, as is the use of a separate external antenna, using inductive coupling through a window to an internal tag (an approach used with many cellular phone antennas).

There are also low-frequency systems under development that could overcome the metallized windshield problem, but the current Caltrans draft specification would prevent their use.

*G. Growth Capability*

The near-term goal of the California legislation and standard is to facilitate toll collection on state highways, although the Highway Patrol and other agencies favor better identification and surveillance capabilities. Although that goal is likely with strong resistance from some users, there is a lot to be said for some capability for two-way communications beyond simple toll transactions.

The current Caltrans draft standard requires limited two-way communications. However, it is strictly a "gateway" system with limited range, not continuously accessible to roadside transmitters; it could not, for example, allow a motorist to report a breakdown. It could receive data based on location, such as a message alerting motorists passing a specific reader to the fact that there is a reduced speed limit in force ahead.

To do this, there would have to be on on-board readout device that could be connected to a port on the tag. No agencies have established data transfer protocols, connector types, etc., to encourage development in this area, although auto manufacturers and after-market vendors are already pursuing this potential market. The TDMA protocol is good for beacon (i.e., message transfer) applications, but is not the most efficient for toll collection. Multiple protocols might be built into the tags, giving the readers command-switching capability to select the appropriate format for the task at hand.

Since the unit costs of tags could go below $10 once large quantities are in use, it might be worthwhile to consider the addition of new tags specifically designed to handle new tasks in an optimal fashion when manufacturers add those tasks to on-board vehicle systems. For the time being, however, it is less costly and more efficient to require only toll transaction capability.

Figure 1 compares technologies, communications protocols, and various performance parameters for several systems; it is representative, not necessarily complete, and some data result from limited test cases or projections from limited test cases.

## IV. NONTECHNICAL ISSUES

*A. Economic*

The major cost of ETC systems is not in the hardware (i.e., readers and tags), but in the so-called "back-room" activity: software development, verification, maintenance, and administration.[12] Almost any hardware alternative could pay for itself in a very short time, although it is typically depreciated over a fixed period (e.g., five years).

The cost of a tag to motorists is an issue, but the projected prices for most read-only or simple read/write tags falls within the bounds of acceptability, as determined by user polls during field demonstrations. For systems incorporating more sophisticated technologies, such as "smart" cards, prices may be prohibitive for ETC applications alone. However, the wide utility of such cards may be a mitigating factor for potential buyers.

*B. Legal*

1. Violations

The favored approach to apprehending violators is to record the license number of any vehicle passing a reader with an inadequate toll account balance, or carrying a stolen tag. In such cases, the reader would send a signal to a camera, which would record an image of the vehicle's license plate. A bill for the toll plus an administrative fee, or even a fine, would then be issued to the registered owner by mail.

This can be done with a video camera, a standard still camera, or an electronic (i.e., filmless) still camera. Since all new license plates are now highly reflective,[13] with large characters, this can be done very accurately.

A camera-based enforcement subsystem would require a change in the California Vehicle Code to permit owners (i.e., persons holding the vehicle registrations) to be held liable for fines. Caltrans believes this is not a major hurdle, since it has been done almost routinely in other jurisdictions.

Camera enforcement is not foolproof, however: a thick coating of dirt or ice can prevent a reading, and scofflaws have evaded detection on the E-470 toll road in Denver by speeding through the read zones, or by driving past on the shoulder, out of the field of vision of the cameras.[14]

In actual practice, no single enforcement method is adequate. It would be prohibitively expensive to have 100 percent camera coverage of all toll-read zones; technical compliance devices probably will be scattered and random. Traditional enforcement by highway patrol officers and the threat of severe fines will deter most potential violators.

The Oklahoma Turnpike Authority uses such a combination of methods on its ETC-equipped system. A light visible to state troopers parked near a toll plaza (but not to motorists) alerts them that a violation has occurred; if an officer stops a violator, there is a minimum $87 fine for failure to pay a toll. If the video enforcement system identifies a violator (e.g., a suspended tag, or one with insufficient toll), the Authority cross-checks the make and model against the registration; if there are no discrepancies, they send a letter to the registered owner, requesting a flat $10 fee ($15 for trucks) which covers the toll and administrative costs. An average of 0.3 percent of those using the ETC lanes on the Oklahoma Turnpike are in violation.[15]

The Oklahoma Turnpike Authority reports that by using a combination of automatic enforcement and observation by the Highway Patrol in areas where the cost-benefit ratio is favorable—they apprehend at least 80 percent of violators.[16] This kind of result is being duplicated by other systems.

Since Oklahoma did not install enforcement measures system-wide, due to poor cost-benefit tradeoffs in rural areas, many violators escape detection.

The Texas Turnpike Authority claims that its random manual audits of Amtech's machine accounting found no problems.[17] The Authority batch-processes data during the night, so they are not aware of nonpayment or underpayment in real time. But the system does keep track of all discrepancies, according to a spokesperson.[18]

Of 46,400 letters mailed by the Texas Turnpike Authority, requesting remittance of unpaid tolls for the Dallas North Tollway, 67% resulted in replies, 24% did not, and 9% were undeliverable. Ultimately, 35% paid an average of $5; the maximum penalty is $100 and a lien on the vehicle. The enforcement process also required 15,069 follow-up telephone calls,[19] a significant overhead expense.

2. Undetected Thefts

The case of owners whose tags are stolen and used extensively before the thefts are detected is apparently fairly rare. Typically, the toll authorities will assume the loss if a police report has been filed, and the owner is not held responsible.

*C. Privacy*

An ETC test in Hong Kong from 1983 to 1985 was a complete technical success, but failed politically due to users' concerns over monitoring of their movements. Although a major ETC test in California showed that privacy would not be a major concern,[20] there is a significant minority who object to having their whereabouts tracked. The problem can be dealt with administratively and technically.

The California Senate Judiciary Committee, led by Chair William Lockyer, has reported out a bill that would prohibit toll operators from correlating toll accounts with license or registration information.[21]

The state of Florida has dealt with this problem in two ways. The legislature recently passed tightened restrictions on access to license and registration databases, and the Chairperson of the Transportation Committee has indicated intent to push a law denying even police agencies access to AVI databases.[22]

The system can be set up with numbered accounts *à la* Swiss banks. This is the method used for the Dallas North Tollway.[23] The number does not have to be associated with an individual's name, Social Security number, registration number, or license plate number. The account can be maintained with cash deposits, and a monthly statement—if desired—can be sent to an anonymous post office box.

Any of the ETC technologies can accommodate privacy protection. The least sophisticated passive systems need only be integrated with an accounting system that guarantees anonymity, as on the Dallas North Tollway. The most sophisticated microprocessor-based systems (e.g., AT&T's “smart” card or AT/Comm's tags) can maintain their own internal data, and incorporate high-level encryption to protect the stored data, including user identification.

Privacy, then, is a matter of “rules,” not “tools.” So far, there has been no significant objection raised against any ETC system planned or implemented in the United States.

## V. ETC Experience

Actual use or field testing of systems similar to that specified by Caltrans is underway in eight nations. As of this writing, there are approximately 400 readers installed, with 370,000 users worldwide. Some of the major installations in the United States are, shown in Table 1:

**Table 1**

| Facility | Approximate Number of Tags in Use |
|---|---|
| Oklahoma Turnpike | 125,000 |
| Dallas North Tollway | 45,000 |
| Crescent City Bridge (La.) | 26,000 |
| Lake Pontchartrain Causeway (La.) | 11,500 |

A San Diego-Coronado Bay Bridge demonstration project, for which Science Applications International Corp. (SAIC), was the integrating contractor, employed an early ETC system developed by X-Cyte.[24] Initially, there were problems due to excessive sensitivity of the readers to range, angle, etc. X-Cyte upgraded the equipment, resulting in improved performance; but even with the two readers per lane, the system never achieved the accuracy levels taken for granted today.[25] However, it was a runaway success among users, who protested vehemently when the project was concluded.[26]

## VI. SETTING STANDARDS

*A. The Need for Standards*

Standards are needed to ensure uniformity, interoperability, or minimum levels of functionality. They enable users who are not highly competent technically to make informed, rational decisions regarding which products will satisfy their needs, how they can be used, or perhaps ways that they should not be used.

Take, for example, the American Standards Association (ASA) photographic film "speed" standard. It provides camera manufacturers a framework within which ambient light levels can be related to lens settings. It provides users with a uniform system for configuring automatic cameras for the film and lens combinations they are using. And it provides guidance to film processors regarding chemical formulas, temperatures, and immersion times to be used in developing and printing exposed film.

Without such a widely-accepted standard, a chaotic situation would have evolved in which camera design, picture-taking, and film-developing would become highly inefficient hit-or-miss processes.

*B. Kinds of Standards*

Since some available ETC technologies are totally incompatible by their nature (e.g., laser and RF), some groundrules are necessary to ensure a functional system. The following paragraphs suggest various interdependent methods of setting standards.

1. Functional or Performance Standards

The most flexible specification would be a loose *performance* specification. That is, one would assign upper or lower limits to parameters such as accuracy, vehicle speed, number of transactions per hour, RF radiation levels, security measures, etc., all reasonable in terms of the actual working environment. This would give potential vendors wide latitude in designing the system architecture and components.

2. Communications and Interface Standards

One must specify how the readers and tags will communicate, or even regional compatibility is impossible. The protocols discussed earlier lend themselves to the frequency band reserved for such systems by the FCC, and they can handle the required levels of data traffic. Message content and sequence must be specified, too, as Caltrans has done with its standard.

One can adopt a protocol to define the interface between the readers and the accounting system. This might specify data format, hardware and operating software, connector type, etc., again allowing vendors maximum freedom to design an effective, efficient, reasonably priced system.

3. Complete System Specification

This is the avenue Caltrans has taken, by specifying MB technology to the exclusion of all others.

*C. How Standards Are Set*

Standard-setting is a consensus-building process, not one of government fiat. Nor can it be imposed on users: if they do not accept an approach to product design, manufacture, or operation, they will not buy, and the product will disappear from the market.

The chief executive of one ETC vendor provided what is perhaps the most succinct insight into the nature of standard-setting:

“No standards exist until there are *de facto* standards . . . defined by market penetration, not bureaucratic pronouncements or technical superiority.”

A perfect illustration of that process was the scenario played out in the video cassette recorder (VCR) industry. Two formats—Video Home System (VHS) and Beta—emerged in the early- to mid-1970s, when consumer VCRs came to market. Although Beta was first on the market, and offered superior video quality, its manufacturer's proprietary stance limited its application. The VHS format, on the other hand, was widely licensed. Within a decade, VHS VCRs had captured over 90 percent of the market, and that format became the *de facto* standard.

Had some government agency or the personal computer industry adopted a standard in 1980 that called for an Intel 8088 microprocessor, 64 kilobytes of random-access memory, and 5.25-inch 360-kilobyte floppy disk drives, we might not yet have the desk-top computer-aided design, desk-top publishing, or interactive multimedia educational systems, and the wide choice of hardware, software, and operating systems that we take for granted today.

Although *de facto* standard-setting does not always result in the technically “ideal” solution, it probably provides users with the best tradeoffs between costs and benefits, advantages and disadvantages. And the VCR experience should serve as an object lesson to some ETC vendors who are jealously guarding their technology, and engaging in political lobbying to achieve what their products—on their own merits—may not; they would be hard-pressed to find success stories among companies that have employed the same sort of nonmarket strategies.

*D. Toll Road Operators' Approaches to Standard-Setting*

If the shake-out scenario is unacceptable, would a broad functional specification and a data interface protocol be adequate to ensure compliance with S. B. 1523 while allowing maximum competition? Let us examine approaches taken elsewhere.

1. New York, New Jersey, and Pennsylvania Interagency Group

The cooperative standard-setting activity undertaken by this interstate agency favors the broad functional approach. On 31 March 1992, potential vendors submitted detailed technical information on their systems, including descriptions of operational installations in the tristate area. The winner will be the best available state-of-the-art system, and the intent is to develop a voluntary interim regional standard.[27]

Recognizing that currently available systems are only "starting points" for ETC, the requirements specified the following:

- data content;
- speed;
- mounting location;
- accuracy;
- Federal Communications Commission (FCC)-approved frequency;
- power density.

2. Florida Department of Transportation (FDOT)

Florida has adopted a similar approach to its 340-lane demonstration project, for which RFPs are to be issued in late 1993.[28] They will issue a five- to seven-year contract for vendor operation of a turnkey system, for which the FDOT will retain audit and accounting responsibilities. Their performance-based specification, which will not be finalized until December 1992, will require:

- read/write capability;
- 100-MPH read speed;
- compliance with the ANSI standard for maximum power density;
- a specific frequency.

The FDOT's view is that a permanent statewide specification will be impossible to develop before the end of the century, after extensive field experience and technology advancement.

3. Orlando-Orange County Expressway Authority (OOCEA)

OOCEA began its acquisition program before FDOT, so their schedules were not compatible. The two agencies agreed that OOCEA should proceed with its program, recognizing that in five years' time, standards will have evolved into something quite different from what works today.

Their RFP specified the following:

- read accuracy;
- vehicle speed;
- security requirements;
- ability to use the tags on vehicles with metallized windshields.

The latter constraint, their conviction that in-pavement antennas were easier to maintain than overhead readers, and their fear of lawsuits stemming from radiation levels, led OOCEA to select Vapor Canada as the ETC subcontractor, with SAIC having responsibility for system integration.[29]

4. Oklahoma Turnpike Authority

Oklahoma authorities contacted other toll highway operators regarding which systems worked. The consensus at the time favored the off-the-shelf MB system made by Amtech Corp. Oklahoma acquired its system through a negotiated RFP process, rather than soliciting open bids from vendors whose systems met a published standard.

5. Paris-Normandie Highway (France)

This is a gated system. The specifications provided with the Request for Tenders specified the following:

- frequency band;
- passive (read-only) tags;
- tag data capacity;
- read distance;
- vehicle speed;
- transaction rate;
- error rate;
- plaza computer data capacity;
- communications protocol;
- message content.

The toll authority eventually acquired SAAB PREMID hardware, which has achieved extremely high accuracy and reliability (see Figure 2).

6. Dartford River Crossing (United Kingdom)

Authorities conducted tests of several available systems, including Amtech's, before issuing their Request for Tenders (RFT). Six companies responded with proposals, and the agency ultimately selected SAAB's PREMID system.

7. Mersey Tunnels (United Kingdom)

When Merseytravel, the operator of a pair of tunnels under the Mersey River in Liverpool, needed to upgrade its toll collection equipment, it wrote a broad specification that dealt primarily with the integration of new equipment, such as ETC, into the existing infrastructure. Its immediate purpose was to select a system integrator, which would in turn make its own choices regarding subsystems and vendors. Those choices would be subject to review and acceptance by Merseytravel.[30] The agency had conducted extensive research into ETC technologies, standards, and systems, including consultation with the Port Authority of New York and New Jersey.

The authority preferred a read-only ETC subsystem, as it wanted to economize and did not anticipate shared use with any other facility in the foreseeable future. The selection of the integrator, Compagnie de Signaux et d'Equipements Electroniques (CSEE), was subject in part to the following requirements:

- microprocessors had to meet a minimum mean-time-between-failure (MTBF) level, and be capable of storing 72 hours' worth of data if the plaza computer failed;
- other electronic equipment had to meet a different MTBF;
- plaza computers had to be IBM-compatible, based on Intel 80286 or later chips, and run standard operating systems and software.[31]

CSEE has integrated the SAAB PREMID system into its existing toll collection equipment line, and in fact functions somewhat as a “value-added reseller (VAR)” of the ETC subsystem. They claim that PREMID is the only AVI equipment approved by the British Department of Trade and Industry; they feel that it is the most reliable, and—being “semiactive” (i.e., remotely programmable)—has more flexibility and growth potential than competitive systems.[32]

8. Rhône-Alps Highway (France)

AREA, the operating agency, conducted tests of a number of available products, ultimately selecting the SAAB PREMID system for its read/write capability.

*E. Broader Standard-Setting Activities*

1. IVHS America

This government-industry-academic association, formed to promote and coordinate the implementation of intelligent vehicle/highway systems, has a Standards and Protocols Committee under which there is a Subcommittee on Communications for AVI systems. The latter panel is attempting to coordinate the standard-setting activities of diverse organizations such as the Society of Automotive Engineers (SAE), the International Standards Organization (ISO), and the American Society for the Testing of Materials (ASTM). They have several concerns:

- premature standard-setting, which may discourage further development and improvement of such systems;

- the possibility of specifying technologies which actively interfere with each other;

- proper balance of standards for devices that may be used for a variety of purposes in a broad spectrum of environments (devices similar to ETC systems are being used for identification and tracking of ship cargo, railroad cars, and personnel).[33]

At their meeting in Washington on 21 November 1991, the Standards and Protocols Committee concluded that it would be ". . . impractical to adopt a common set of standards under the time constraints that each of the agencies represented were working under." The Committee will attempt to develop ". . . a common set of standards for the *next generation* [italics mine] of ETC installations. These standards would . . . address . . . tag data content, operating frequency, power density, and antenna placement."[34]

IVHS America favors a flexible approach, one that embodies the understanding that AVI/ETC is an infant technology that is changing rapidly. It may be many years before realistic standards can be set, permitting some semblance of compatibility without closing the door to innovation and improvement. Meanwhile, the interested parties—users and vendors—should work together to bring as much order out of chaos as is reasonable in a dynamic environment.

2. American Society for the Testing of Materials (ASTM)

Of all of the industry and professional organizations striving to develop an ETC standard, ASTM seems to have the strongest commitment to AVI, and is the most active.

At a recent meeting, organizations such as ASTM, IEEE, etc., were asked to present strategies for developing ETC standards. ASTM proposed a "red team" approach, using parallel groups, each of which would document its deliberations and proposals, then resolve differences.[35] None of the other societies responded, although some bridled at the suggestion of “anointing” ASTM's leadership.

ASTM ETC committee and subcommittee members have come forth with some guidelines for any entity trying to set standards:

- Ask “What do we have? What can be reasonably promulgated?”

- Carry on a continuous dialogue with the affected technical community.

- Don't try to do what shouldn't be done, but don't settle for what is easy to do.

- Remember that standard-setting is a *process*, not a *product*.

They have also suggested a reasonableness test for a standard:

(1) Does it allow technological evolution?

(2) Does it preserve proprietary rights and advantages?

(3) Does it resolve problems, bringing order out of chaos?

3. Industry Cooperative Ventures

Companies at all levels of the ETC market (i.e., component, subsystem, system, and integration) are working to achieve interoperability, if not full compatibility. For example, a toll tag could have common circuitry to manage its basic functions, and several radio circuits to communicate with different reader types. The cellular telephone industry is taking this approach to ease the transition from analog devices to higher-capacity digital devices without unduly inconveniencing users.[36]

Hughes has been very active in promoting a standard for ETC, and has submitted its own standard to Caltrans, using the Department's own format.[37] In addition, they have modified their design to be backward-compatible with the Vapor system, the HELP standard, and MB. The MITRE Corp. has proposed the Hughes standard as a starting point for the IVHS America Standards and Protocols Committee's efforts to develop a standard.

In addition to what is going on in the ETC industry, the automobile manufacturers' advanced development establishments are examining possible data management and embedded computer systems, perhaps an evolutionary capability based on the current optional on-board computers, to be built into cars of the future. As yet, there has been no attempt to develop standards, although the Society of Automotive Engineers (SAE) is the primary standard-making body for the automotive industry, and is following the evolution of ETC technology very closely. Having observed the problems brought on by overly-complicated consumer electronics gear (e.g., VCRs), they are proceeding very cautiously in this area.[38]

Manufacturers of automotive accessories are also actively pursuing markets involving intelligent highway concepts:

- Autotalk, Inc. is marketing a $127 module that connects to the vehicle radio, and uses a television sideband to receive real-time voice messages from Caltrans' Traffic Operations Centers (TOCs) and the United States Weather Service's short-wave weather alerts.[39]

- Teletrac and Lojak are on-board beacons, costing under $600, which can be activated by the police, allowing them to home in on a stolen vehicle. Autotalk and Teletrac are planning to integrate their devices functionally.

The tag might be connected to such a device (Hughes Aircraft Co.'s tag has a built-in RS-232 serial port for just this purpose), or an integral transponder could be part of the computer. Such systems could do far more than Caltrans' standard envisions: navigation,[40] two-way emergency communications, continuous readout of emission levels, “smart” card parking and drive-in business transactions, etc.

*F. Evolution of the California Compatability Standard*

1. Early Activities

The agency based its original compatibility specification on the standard adopted for the Heavy Vehicle Electronic License Plate (HELP) project. (HELP combines AVI with “weigh-in-motion” and other technologies to track loads and eliminate weight checks and other time-consuming delays for interstate trucking.[41])

When Caltrans asked potential vendors to comment, their responses typically cited unnecessarily rigorous requirements (given the basic requirement to collect tolls) and inclusion of proprietary technology based on patents held by Vapor Canada.[42,43,44,45]

Caltrans sought assistance from Lawrence Livermore National Laboratory (LLNL), a Department of Energy (DOE) facility in the San Francisco Bay area managed by the University of California (UC). The agency asked LLNL to evaluate the technical challenges and questions evoked by the initial draft specification, and then advise on the rewriting process. The LLNL team proceeded under the following Caltrans-established ground rules[46,47]:

- Because of the wide range of anticipated operating environments, readers “. . . must function from in-pavement. . . as well as above-pavement antennas.”

- The system “. . . must allow the detection and identification of nontagged vehicles.”

- “The specification should be limited to . . . `what goes on in the air'.” This meant simply defining “. . . a communication protocol and . . . record formats.”

It is interesting to note that Caltrans' standard violates its own guidelines (i.e., the last item above).

LLNL invited vendors to brief them on state-of-the-art ETC technology. (This invitation was not formally issued to all vendors, and some are unaware that any such opportunity ever existed.) One major electronics firm that visited LLNL at Caltrans' behest said that the LLNL team branded their approach—which has been demonstrated in a severe environment at the General Motors Proving Ground[48]—unworkable.

2. Current Status

The comment and revision process went through several iterations, until Caltrans released a final draft specification on 6 February 1992. This version specifies the following key characteristics:

- frequency;
- MB technology;
- reader-to-tag communication sequence.

(It should be noted that Caltrans dropped all standards not required to ensure *compatibility*.)

The Caltrans Office of Electrical and Electronics Engineering submitted its final draft to the Office of Administrative Law (OAL) on May 14th of this year. The OAL can take thirty days to pass on such a proposal, which is then submitted to the Office of the Secretary of State. Thirty days after that, the specification can become law. At the earliest, this will occur on July 13. The LLNL team has told Caltrans that they believe that the final draft specification complies with the legislative mandates.

The current version of the proposed standard has also provoked negative reactions from legislators and industry. Specific objections are:

- it specifies what technology must be used;

- the only vendor of that technology is a non-California company,[49] not a popular item in a state particularly hard-hit by the recession;

- no off-the-shelf system can meet the standard, and achieving the performance demanded with that technology will require at least eighteen months and millions of dollars of development;

- excessive reader power levels may be necessary, posing a hazard to motorists and Caltrans workers;

- it will be more expensive than other approaches, since one reader will be required for every lane.

## VII. CONCLUSIONS AND RECOMMENDATIONS

### *A. Conclusions*

California—although having more motor vehicles and more licensed drivers than any other state[50]—has relatively little experience with toll collection, compared to Oklahoma and the Northeastern states, for example.

Caltrans' chief advisor at LLNL, although highly knowledgeable with regard to MB, did not even examine SAW technology; he seemed unsure of how it worked, what frequencies were used, etc. In any event, nobody at LLNL has any experience in toll collection.

Most users (i.e., toll road authorities), systems integrators, and ETC system vendors believe that S. B. 1523 and the proposed Chapter 16 additions to the California Code of Regulations are unnecessarily restrictive, and their objections encompass technical, economic, and other factors.

It *is* probably necessary to specify frequency, communication protocol, and message format. These constraints tend to define the circuitry that can do the job, but need not restrict the field to one vendor or even one technology.

Although California represents a significant part of the estimated $20-billion worldwide ETC market, and will therefore have a major influence on the evolution of such systems, it is not in the best interests of motorists to constrain that evolution with unnecessarily rigid standards. The proposed Caltrans standard goes far beyond ensuring statewide compatibility, which itself is of questionable benefit to private motorists or even commercial vehicle operators.

Whatever Caltrans does, there is a high probability that it will be irrelevant to the future of ETC.

*B. Recommendations*

The best long-term approach seems to be to:

- set realistic performance standards that would encourage ongoing improvement of the technology while protecting motorists from RF radiation hazards, etc.;

- set data transfer protocols that ensure that initial hardware and follow-on equipment will interface with computers, networks, software, etc.;

- conduct “shoot-outs” of competing equipment and technologies to ensure that they will work on the specific project;

- let the technologies and the marketplace determine the standards in the long term.

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## GLOSSARY

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| A. B. | Assembly Bill: law passed by the California Assembly |
| ANSI | American National Standards Institute |
| ASA | American Standards Association |
| ASTM | American Society for the Testing of Materials |
| ATC | Automatic Toll Collection |
| ATM | Automatic Teller Machine |
| AVI | Automatic Vehicle Identification |
| CAFE | Corporate Average Fuel Economy |
| CSEE | Compagnie de Signaux et d'Equipements Electroniques (French electronics firm) |
| ETC | Electronic Toll Collection |
| FCC | Federal Communications Commission |
| FDOT | Florida Department of Transportation |
| HELP | Heavy-Vehicle Electronic License Program |
| IEEE | Institute of Electrical and Electronics Engineers |
| ISO | International Standards Organization |
| IVHS | Intelligent Vehicle-Highway Systems |
| LLNL | Lawrence Livermore National Laboratory |
| MB | Modulated Backscatter |
| MTBF | Mean-Time-Between-Failure |

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|---|---|
| OAL | Office of Administrative Law (California Department of Transportation) |
| OEEE | Office of Electrical and Electronics Engineering (California Department of Transportation) |
| OOCEA | Orlando-Orange County Expressway Authority |
| RF | Radio Frequency |
| RFP | Request for Proposals |
| SAAB | Svenska Aeroplan Aktiebolaget (Swedish aerospace, automotive, and electronics conglomerate) |
| SAE | Society of Automotive Engineers |
| SAIC | Science Applications International Corporation |
| SAW | Surface Acoustic Wave |
| S. B. | Senate Bill: law passed by the California Senate |
| SS | Spread Spectrum |
| TDMA | Time Division Multiplexed Access |
| TOC | Traffic Operations Center |
| UC | University of California |
| VAR | Value-Added Reseller |
| VCR | Video Cassette Recorder |
| VHS | Video Home System |

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