Electronic Toll Collection Systems

The Future Is Now

ETC system on Greater New Orleans Bridge.

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A car passes through a toll plaza without coming to a stop. The tag installed on the car communicates with a computer located at the toll booth. The roadside computer identifies the vehicle and debits the amount of the toll from the monetary balance on the tag. The long lines of patrons waiting to pay tolls have disappeared. The toll agency's revenue collection process is more efficient and more secure. The agency can now try more experimental pricing policies, such as time-of-day variable tolls.

This scenario is not a futuristic dream. The future is now, as electronic toll collection (ETC) systems are operating today in the United States and around the world. In Atlanta, Dallas, Denver, Houston, Miami, New Orleans, New York, and New Jersey, and on portions of the Illinois Turnpike and throughout the Oklahoma Turnpike system, agencies have implemented ETC systems that are reducing congestion and improving the efficiency of revenue collection. Toll agencies in California, Florida, Kansas, Maine, Massachusetts, New Hampshire, Pennsylvania, and Virginia are moving forward with the implementation of ETC systems, and many others are investigating their feasibility. These systems also operate in France, Germany, Great Britain, Italy, Japan, Norway, Sweden, and Switzerland.

Automatic vehicle identification (AVI) is the technology that makes these ETC systems possible. AVI works by means of wireless communication between a small tag or transponder mounted on a vehicle and a sensor located at the roadside or in the toll lane. Sensors can read information about the tag while the vehicle is stopped or while it is moving at high speed. The communication between the tag and sensor can be one-way (read-only) or two-way (read or write). In addition to the collection of tolls, AVI can be used for a variety of other purposes, such as identifying trucks at weigh stations or at state and national border crossings, or for fleet management of trucks, buses, or taxis.

Role of ETC in Transportation

Many of the nation's roads are congested, and mobility is being threatened. At the same time, building roads is becoming financially and environmentally more difficult. Many of the major roadways being planned and built are private, and ETC technology will be implemented on a number of them. Automation of toll collection can reduce congestion around toll plazas and, through toll incentives, can help promote ridesharing. This technology also provides the capability to implement demand management programs based on road-pricing to shift or limit travel demand. As a result, these systems have the potential to reduce congestion, improve energy efficiency and air quality, and enhance economic productivity—at a cost significantly less than additional road construction and toll plaza expansion.

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Available Technologies and Characteristics

All current AVI and ETC technologies operate by (*a*) intercepting modulated electromagnetic radiation from a vehicle transponder, (*b*) recovering the information contained in the signal, and (*c*) using a computerized data base to identify the tag. Although performed by all AVI technologies, these functions may be accomplished in different ways. For example, AVI transponders used for ETC systems have progressed from Type I transponders that can only be "read" (or reflect a unique vehicle identification when interrogated), to Type II transponders that can be "read" from and also receive information "written" back to them. This feature allows Type II transponders to store and update unique variable data, such as entry and exit locations along a toll road, account balance, and vehicle maintenance and inspection reports. Type III transponders, relatively new to the ETC industry, have the added capability to interact and communicate with the driver.

Technologies can be divided according to the frequency of the electromagnetic radiation, the method by which the signal is modulated, and whether the vehicle tag generates or simply reflects electromagnetic radiation. Three frequency ranges are in use: (*a*) very low frequencies (below 200 kHz), which are used in inductively coupled systems; (*b*) microwave frequencies (500 to 3000 MHz); and (*c*) optical or near-optical frequencies (30 GHz to 1000 GHz), which include infrared frequencies.

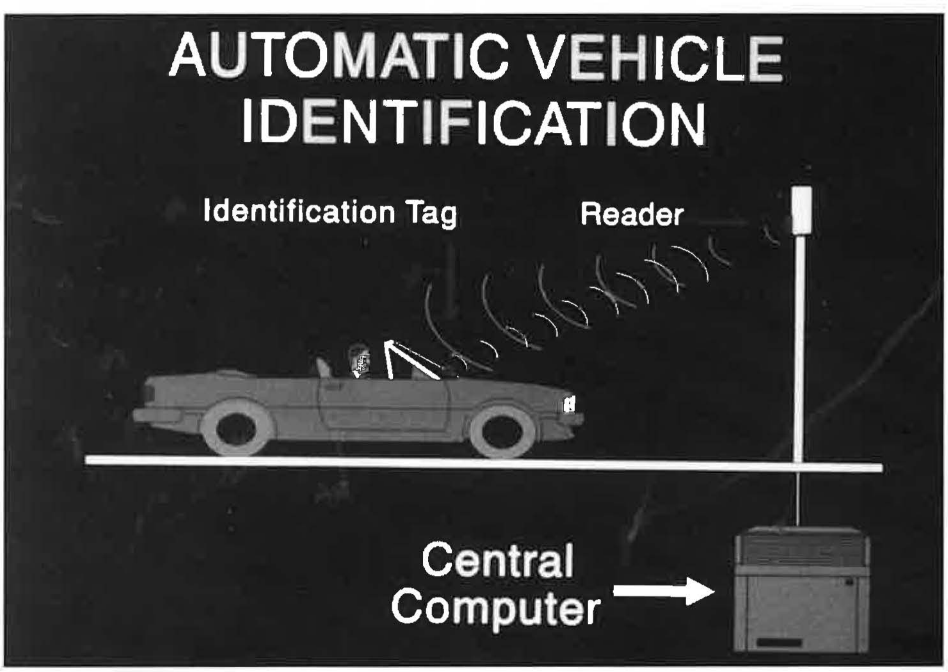
Types of transponders.

Accuracy and Reliability

The possibility of improperly reading a vehicle tag because of an unacceptable level of electrical interference must be considered when an ETC system is implemented. Electrical interference can occur in two ways. Interference can be caused by other (non-ETC) transmitters operating on the same or nearby frequencies. Possible sources are cellular telephones, pagers, police and other mobile communications, and radar. This type of interference can be minimized by obtaining a Federal Communications Commission license for a dedicated frequency. The second type of electrical interference can occur from improper design or installation. Allowing the transmitted signal from one ETC lane to overlap another lane can result in multiple recordings of the same vehicle or failure to record vehicles. The remedy for this type of interference is proper selection and placement of all antennas and specification of a well-defined antenna beam pattern.

Metal-oxide vehicle windshields can also cause disruptions and attenuation in ETC signals that must pass through the windshield. At this time, it is not certain how widespread the use of metal-oxide windshields will be by the time ETC systems are deployed throughout the United States. Currently, industry experts estimate that less than 2 percent of the nation's vehicle fleet is equipped with these windshields. The disruptions caused by metal-oxide could be minimized by mounting the transponder on the outside of the vehicle.

The actual reliability of ETC technology varies. Most vendors claim reliability in the range of 99.95 to 99.99 percent. However, recent field performance evaluations conducted by the Center for Urban Transportation Research in Florida and by the Interagency Group in New York indicated reliability for various technologies to be below this range—in the range of 89.7 to 98.4 percent. By comparison, current conventional toll collection equipment has been known to operate in the 93 to 98 percent reliability range.



AVI works by wireless communication between small tag or transponder mounted on vehicle and sensor on roadside or in toll lane.

Standards and Protocols

The communication, software, and hardware industries, all suppliers of ETC technology, play a crucial role in successful long-term product development and broad-based consumer acceptance. Establishing standards too early could stifle

ETC field performance evaluations conducted by Center for Urban Transportation Research on Sawgrass Expressway in Broward County, Florida.

innovation. On the other hand, the ETC industry cannot realistically be expected to curtail product development while waiting for nationwide standards to be defined.

California has taken the first steps toward ETC technology standardization. However, the California state standard cannot currently be achieved by many technologies. As a result, a group of local toll authorities and vendors has successfully gained an exemption from the new state standard. The exemption permits toll agencies to use ETC equipment that does not comply with the state standard for up to five years.

The national standard-setting process for ETC technologies has already begun, although no specific standards have been established. The Intelligent Transportation Society of America has established a Committee on Standards and Protocol to serve as an oversight and coordinating agency for all standards activities in the United States relating to ETC. The committee does not expect to create or promulgate standards, except as a last resort. Instead it will rely on other standard-generating bodies (e.g., American National Standards Institute, International Standards Organization, International Electrotechnical Commission, ASTM, SAE, Institute of Electrical and Electronics Engineers, and others) to establish industry standards. The objective of the committee will be to ensure appropriate attention to ETC needs, promote effective communication among parties interested in standards, and minimize duplication of effort.

Regulation

Additional analysis is needed to determine the communication-related requirements for ETC products. Designs should minimize the number of different communication technologies. It may also be important to consider the same communication frequencies for other traffic control and information systems. Although no spectrum has yet been dedicated to ETC use, most existing systems operate in the 902 to 928 MHz band, which is one of three dedicated for industrial, scientific, and medical (ISM) use. Several frequencies in this bandwidth are currently licensed to manufacturers and providers of pagers and mobile cellular phones. Occasional interference with these and similar devices has already been experienced in the testing and evaluation of ETC systems. Because of the current level of use in the 902 to 928 MHz band, the industry is moving toward the two higher ISM bands. These two bands are centered around 2450 and 5800 MHz. A decision has been made in Europe to use the 5800 MHz band; and in the United States the Florida Department of Transportation has specified 2450 MHz for its "SunPass" procurement process. Assignment of a bandwidth not currently used by ETC systems would require additional investment in research and development before other systems could become operational. In particular, using the 5800 MHz band (which has the least traffic of the three ISM bands) would require further product development in ETC transponder technology.

Traffic Operations

Implementation of ETC systems requires significant rethinking of traffic operations in the vicinity of toll plazas. In particular, current treatments and methods for vehicle classification, toll collector safety, toll lane gates, and advance signing and channelization will need to be modified.

An important decision for an agency is whether to operate dedicated ETC lanes (i.e., lanes in which only vehicles equipped with this technology can enter) or to adopt the technology in mixed-use lanes, in which it is one of several payment options. Average capacities for the basic types of toll plaza lanes are shown in Figure 1. Depending on the specific plaza lane configuration and patronage levels, the inclusion of ETC has the potential to significantly increase conventional plaza lane capacity.

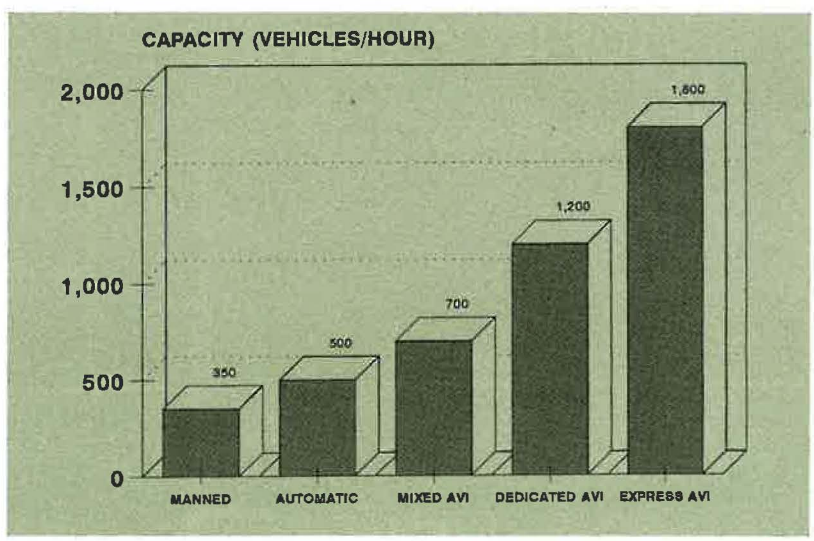


FIGURE 1 Average capacities for basic types of toll plaza lanes.

SOURCE: Average of counts obtained from Florida Turnpike, New Jersey Turnpike, and Dallas North Tollway. Express lane capacity is based on Level-of-Service D capacity for freeways.

Actual patronage levels for ETC are extremely difficult to forecast because they depend on specific market characteristics. Therefore participation levels can be forecasted only on the basis of reasonable assumptions. The highest current participation rates are on the Lake Ponchartrain Causeway in Louisiana (80 percent of patrons); Treasure Island Causeway (60 percent) and Bay Harbor Island Causeway (40 percent) in Florida; the Oklahoma Turnpike (40 percent); and the Dallas North Tollway (30 percent). These levels of ETC participation have been achieved with high-level marketing programs, such as the high-profile tag store in Dallas. In addition, ETC patrons using the Lake Ponchartrain Bridge enjoy a 50 percent discount off the cash price for tolls.

Enforcement

ETC lane violations are important to customers because of the delays and inconvenience that violators can create and to toll collection agencies because of lost revenue. A successful system will probably need to incorporate a high-speed video camera system to deter violators. It is believed that some cameras in operation now can provide legible images of the license plates of vehicles traveling at speeds up to 100 miles per hour. However, the camera triggering technique for violators and the image storage and retrieval process are still being refined.

Most states in which ETC systems are located have passed laws enabling authorities to identify and cite violators on the basis of videotape or photographic evidence. Colorado is an example of a state in which the toll authority entered into an agreement with local law enforcement agencies specifically for the prosecution of ETC violators traveling on the E-470 beltway toll highway in Denver. Illinois was the first state to win conviction of a driver using pictures generated from remote video cameras as evidence. Several years ago in Texas, ETC patrons incurring violations on the Dallas North Tollway were sent letters detailing their alleged violations. It took the violators only a short time to realize that the evidence generated from the tollway's video cameras could not be supported in the state court system. State highway patrol officers continue to issue citations to violators on site because video enforcement legislation has not yet been enacted. New York recently passed legislation detailing the need for an enforcement agent to witness the patron avoiding the payment of a toll and to issue a summons at that time. In Florida the infraction must be witnessed by an officer and the citation must be issued to the driver of the vehicle. However, legislation was recently passed in Florida that will allow photographic imagery to be used as legal evidence against an alleged toll violator.

Privacy and Equity

Appropriate safeguards and guidelines for the control and use of ETC information must be established to protect the privacy of individuals. (It should be noted that according to surveys conducted among San Francisco Bay Area motorists, only 7 percent of the respondents indicated a strong concern that electronic tags could permit tracking of their vehicle.) The Electronic Communications Privacy Act was adopted in 1986 to protect wire or electronic communications from illegal interception by unauthorized third parties. This act creates standards and procedures for court-authorized electronic surveillance, regulates the release of information by electronic communication firms, and provides legal protection of the privacy of stored electronic communications from outside intruders and unauthorized government officials.

An ETC account may be initiated through cash, check, or credit card down payment, and patrons should not have to face discrimination on the basis of payment method. For example, if the only form of payment or account replenishment is through a major credit card, as in Denver, some potential patrons may be excluded from participation. In addition, if ETC patrons are required to pay an additional transaction fee (as in Dallas) or receive a reduced toll fare (as in Oklahoma), further discrimination may result. The toll agency bond indenture must be reviewed carefully to assess the legal options, if any, that are available to toll patrons.

Store in Dallas where ETC tags are sold.

Other Legal and Institutional Issues

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

There has also been some uncertainty about the extent to which antitrust law places limitations on collaborative research. Although the United States is more concerned with industrial cooperation than are Japan or Europe, in reality there is wide latitude in the types of ETC research activities that can now be undertaken. Another issue is how toll agencies may effectively fund productive, creative research and development and whether current contracting and procurement practices support or discourage that goal.

Cost Considerations

The costs for various lane types, including mixed-use lanes, are presented in Table 1. Costs were averaged on the basis of several toll agency bids for AVI lane equipment procurement obtained during the last three years. Equipment costs for AVI on a per lane basis are typically less than 30 percent of the cost for conventional toll lane equipment. Operating and maintenance costs by lane type are based on Florida averages for conventional lanes and system averages in Dallas and Oklahoma for ETC-related operations and maintenance. The unit price of transponders to the agency ranges from $1 to $50, depending on the technology, vendor, and quantity of transponders purchased. Type III transponders will cost more.

Serviceability and Maintenance

The costs associated with the operations and maintenance of ETC systems are difficult to assess at this time, primarily because working systems have not been in operation long enough to establish life-cycle cost factors. On the basis of limited data, maintenance costs associated with ETC appear to be at least 20 percent lower than those of conventional toll lanes. Labor costs, which constitute the majority of operational costs, are greatly reduced with ETC lanes.

Patron Payment Options

In evaluating payment systems, three issues need to be addressed: prepayment versus postpayment, payment media (cash, check, or credit card), and toll fare structures. With a prepayment toll system, users establish individual accounts with a prepaid balance. Subsequently, when the patron passes through an ETC-equipped toll lane, the toll amount is debited from the user's prepaid account balance. The postpayment system operates differently: the user is charged for actual use of the toll system during the preceding month. When a postpayment plan is considered, the additional operational costs of monthly

TABLE 1 Electronic Toll Collection System Equipment, Operating and Maintenance Costs by Lane Type

LANE TYPE	EQUIPMENT COSTS PER LANE ($)	OPERATING AND MAINTENANCE COSTS PER LANE ($)
Manual	58,500	141,900
Automatic	58,000	43,300
Manual/Automatic	107,500	111,000[a]
Manual/AVI	72,700	146,100
Automatic/AVI	69,500	47,500
Manual/Automatic/AVI	121,300	115,200[a]
AVI Dedicated	15,400	4,200
Express AVI	15,400	4,200

[a]Based on 16 hours of manual and 8 hours of automatic coin operation.
SOURCE: Florida Toll Operations Office (conventional lanes), Dallas North Tollway, Oklahoma Pikepass, and related industry bid tabs (AVI lanes).

TABLE 2 Electronic Toll Collection System Characteristics

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

NOTE: ADT = average daily traffic, AVC = automatic vehicle classification, N/A = not available.
[a] Selected since survey.
SOURCE: International Bridge, Tunnel, and Turnpike Association (IBTTA), March 1992. (A more recent survey was conducted by IBTTA in June 1994.)

statement account mailings and collections on delinquent accounts need to be evaluated. The San Diego Coronado Bridge system is one of the few to have offered a postpayment option. The trial was considered a success, but the San Diego system was a demonstration project and has never been fully implemented. Surprisingly, in a 1990 survey of patron perceptions in Florida, it was found that most potential ETC customers preferred prepayment.

ETC-generated tolls can be paid by cash, check, electronic funds transfer, or credit card. Because the use of electronic funds transfer and credit cards does not require the handling of money, operational costs are reduced and implementation and maintenance of the payment program are simplified.

There are three AVI toll structure options: charging premiums in addition to existing tolls; discounting existing tolls; or keeping the toll structure the same, neither offering discounts nor charging premiums. Advocates of premium tolls believe users of ETC should pay an extra charge for these special services. Advocates of discounted tolls believe users need to be encouraged to use ETC through discounts on services. They also contend that increased patron participation resulting from modest discounts would offset any declines in revenue.

Status of ETC Projects

The characteristics of the existing (or planned) ETC systems in the United States, as compiled by the International Bridge, Tunnel, and Turnpike Association in its 1992–1993 survey, are presented in Table 2. This survey includes both existing and planned ETC systems, but is not all-inclusive because it was conducted more than two years ago.

Summary

The implementation of ETC systems will increase toll lane capacity, thereby reducing toll processing time and queue lengths at toll plazas. Most important, ETC technology can substantially reduce the need for future expansion of toll plaza lanes, and thus significant cost savings can be realized, especially in urbanized areas. Toll patrons are provided more flexibility and convenience in paying tolls, including the option of paying by cash, check, credit card, or electronic funds transfer, and the need to have cash ready for each toll plaza passage is eliminated. In addition, dependence on toll system operators to handle currency is reduced. Furthermore, commercial users of ETC are given faster and more reliable tracking information on when and where their fleet vehicles use the toll system.

ETC lanes can reduce the need for drivers to stop at toll plazas, which can reduce noise pollution, air pollution, and fuel consumption. Non-ETC patrons would benefit to some degree by less overall plaza congestion, particularly in mixed-use lanes. As other adjacent roadway facilities become congested, variable-toll pricing (reducing normal toll rates) can be used as an incentive to divert travel to the uncongested, or less congested, toll facility. ETC can also be an incentive for ridesharing because travel costs could be shared more conveniently. This technology is not a futuristic dream; ETC systems are operating in numerous locations across the United States and around the world. However, a range of implementation issues still needs to be addressed. Agencies are encouraged to address these issues as they move forward with ETC implementation.

TABLE 2 *continued*

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

NYSDOT Soil Mechanics Bureau Celebrates 50th Anniversary

The New York State Department of Transportation's Soil Mechanics Bureau, which provides a wide variety of multimodal geotechnical services to meet the department's current $1.3 billion annual Capital Program, is marking its 50th anniversary.

Near the end of World War II, NYSDOT (then called Public Works) recognized that a surge in building construction would be necessary to modernize its transportation system. Soils engineering was growing in importance as a discipline in the civil engineering field because of past experience with foundation problems, and the Soil Mechanics Bureau was created.

Much of the bureau's early experience was obtained in the construction of the New York State Thruway from 1946 to 1955. In later years the bureau implemented many innovative geotechnical technology projects, such as control of dikes at the St. Lawrence Seaway, construction of embankment and bridge foundations on the federal Interstate highway system, and emergency repair of the Almond Dam during the 1972 hurricane Agnes. Recently the bureau has also developed a pavement design manual for new and reconstructed pavements to meet infrastructure repair needs into the next century.

Profiles

Lewis *continued from page 32*

help people cope with the budgetary implications of ADA. He finds, however, that in light of local budgetary pressures, the cost of adhering to ADA may put cities at possible risk of falling short of expectations in the deadline year of 1997.

Lewis divides his consulting practice equally between public and private sector clients and his practice between the United States and Canada. It is, he says, a life not inconsistent with his training, which he received in both the United States and Britain. He has a bachelor's degree from the University of Maryland and master's and Ph.D. degrees from the London School of Economics.

Active in TRB committee work since 1978, Lewis is a member of the Group 1 Council—Transportation Systems Planning and Administration, and is a member and former Chairman of the Committee on Specialized Transportation. He is also a past member of the NCHRP Project Panel on Cost-Effectiveness of Transportation Services for Handicapped Persons.

Lewis's honors include the 1992 William G. Bell Award from the TRB Committee on Specialized Transportation for outstanding leadership in the field of specialized transportation, and Harvard University's *Journal of Policy Analysis and Management* 1984 Saltzman Prize for Economic Literature. A regular contributor to academic journals and the trade press, Lewis says that he now has a book on benefit-cost analysis in the works and that eventually he hopes to teach. "But for now," he concludes, "I am content to serve the needs of my clients."

Donnelly *continued from page 33*

various other organizations. "It is through this interaction and information exchange at the national level that we become aware of many new cost-effective technologies," he explains.

One committee activity he found particularly rewarding was serving as Secretary to the Task Force that produced TRB's *Transportation Research Circular 386: Innovative Contracting Practices.* This study was the result of a public-private sector cooperative effort looking into state, national, and international contracting technologies.

Donnelly is a current member of TRB's Group 5 Council—Intergroup Resources and Issues, and also serves on the committees on Pavement Rehabilitation, General Asphalt Problems, and Frost Action. He was formerly Chairman of the NCHRP Project Panel on Determination of Asphaltic Concrete Pavement Structural Properties by Nondestructive Testing.

He also serves as Chairman of the TRB Committee on Conduct of Research. Donnelly organized a mid-year workshop on the subject, attended by administrators, technicians, and marketing experts from various disciplines within the research community as well as others from research organizations. One of the workshop recommendations calls for the development of a publication describing proper research methodologies. Donnelly believes that the research community needs to understand correct practices so that users can be given a product that is truly state of the art.

Innovative Contracting Practices *continued from page 13*

quality has the potential to foster positive changes to traditional ways of doing business. The nation's highway users and the industry itself will be the ultimate beneficiaries of such improvements

For further details on lane-by-lane rental during construction, see "Lane Rental: An Innovative Contracting Practice," in TR News *162, September–October 1992 (pp. 7–9).*