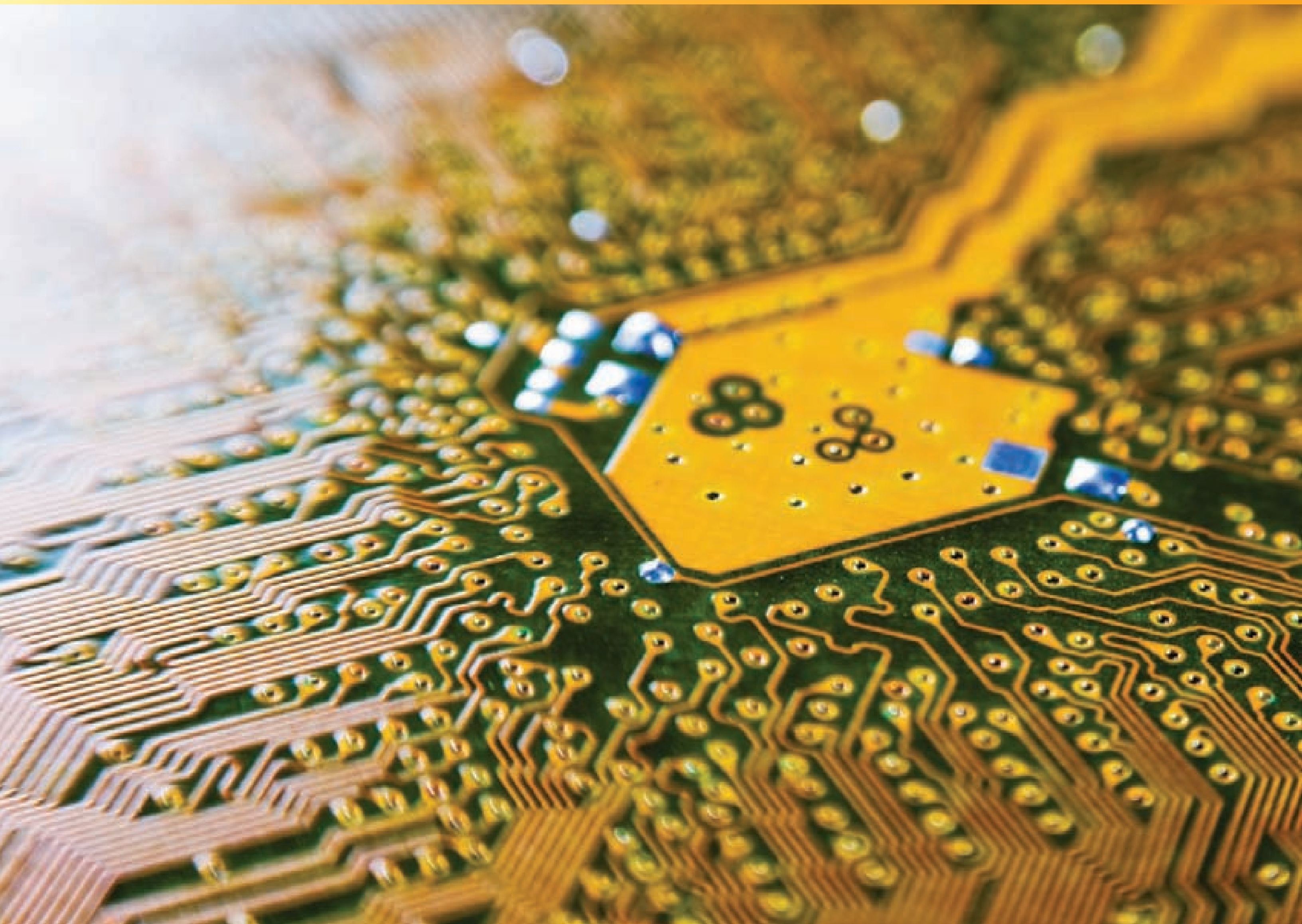
U.S. Department of Transportation
Federal Highway Administration

Technologies That Enable Congestion Pricing

A PRIMER



Quality Assurance Statement

The Federal Highway Administration (FHWA) provides high quality information to serve Government, industry, and the public in a manner that promotes public understanding. Standards and policies are used to ensure and maximize the quality, objectivity, utility, and integrity of its information. FHWA periodically reviews quality issues and adjusts its programs and processes to ensure continuous quality improvement.

Contents

The Primer Series and the Purpose of This Volume

About This Primer Series

The Congestion Pricing Primer Series is part of FHWA's outreach efforts to introduce the various aspects of congestion pricing to decision-makers and transportation professionals in the United States. The primers are intended to lay out the underlying rationale for congestion pricing and some of the technical issues associated with its implementation in a manner that is accessible to non-specialists in the field. Titles in this series include:

- Congestion Pricing Overview.
- Economics: Pricing, Demand, and Economic Efficiency.
- Non-Toll Pricing.
- Technologies That Enable Congestion Pricing.
- Technologies That Complement Congestion Pricing.
- Transit and Congestion Pricing.
- Income-Based Equity Impacts of Congestion Pricing.

Technologies That Enable Congestion Pricing

This volume explores transportation technologies that enable congestion pricing. This document considers the following:

- The functional processes for tolling and congestion pricing.
- What technologies there are to consider.
- How the technologies are applied.
- Examples of how technologies have been applied.
- What technologies may make it work better in the future.

States and local jurisdictions are increasingly discussing congestion pricing as a strategy for improving transportation system performance. In fact, many transportation experts believe that congestion pricing offers promising opportunities to cost-effectively reduce traffic congestion, improve the reliability of highway system performance, and improve the quality of life for residents, many of whom are experiencing intolerable traffic congestion in regions across the country.

Because congestion pricing is still a relatively new concept in the United States, the Federal Highway Administration (FHWA) is embarking on an outreach effort to introduce the various aspects of congestion pricing to decision-makers and transportation professionals. One element of FHWA's congestion-pricing outreach program is this Congestion-Pricing Primer Series. The aim of the primer series is not to promote congestion pricing or to provide an exhaustive discussion of the various technical and institutional issues one might encounter when implementing a particular project; rather, the intent is to provide an overview of the key elements of congestion pricing, to illustrate the multidisciplinary aspects and skill sets required to analyze and implement congestion pricing, and to provide an entry point for practitioners and others interested in engaging in the congestion-pricing dialogue.

The concept of tolling and congestion pricing is based on charging for access and use of our roadway network. It places responsibility for travel choices squarely in the hands of the individual traveler, where it can best be decided and managed. The car

is often the most convenient means of transportation; however, with a little encouragement, people may find it attractive to change their travel habits, whether through consolidation of trips, car-sharing, by using public transportation, or by simply traveling at less-congested times. The use of proven and practical demand-management pricing, which we freely use and apply to every other utility, is needed for transportation.

The application of tolling and road pricing to solve local transportation and sustainability problems provides the opportunity to solve transportation problems without federal or state funding. It could mean that further gas tax, sales tax, or motor-vehicle registration fee increases are not necessary now or in the future. The idea of congestion pricing is a conceptual first step, not a complete plan of action. It has to be coordinated with other policy measures and environmental measures for sustainability.

This toll-technology primer was produced to examine the use of technology, both primary and advanced, to support tolling and congestion pricing. It explains how current tolling and congestion-pricing technology works and what technologies may make it work better in the future.

Congestion-Pricing Options

In the United States and around the world, several strategies exist on how to implement congestion pricing. These strategies consider how best to influence traffic patterns, match the local geography, fit political boundaries, and match the policy framework of the implementing jurisdiction.

The four major types of pricing include:

- **Priced Lanes:** Fees for low-occupancy vehicles to utilize excess capacity on new or existing high-occupancy vehicle (HOV) lanes (e.g., I-15 FasTrak® between Kearny Mesa and Rancho Penasquitos, California[1], or the SR-91 Express Lanes in Orange County). Pricing can be fixed per road segment, vary by occupancy (e.g., HOV2, HOV3, or HOV4+), vary by occupancy and time of day, or vary dynamically based on the degree of congestion in the adjacent "free" lanes.

- **Variable Tolls on Entire Roadways:** Fees placed on existing and new roads, bridges, and tunnels to pay for access onto the road or facility and to pay for the cost of maintenance and construction of the road, whether the government or the private sector builds the toll facility. The toll is variable, that is, prices rise and fall depending on the measured traffic level or estimated traffic level based on time of day.

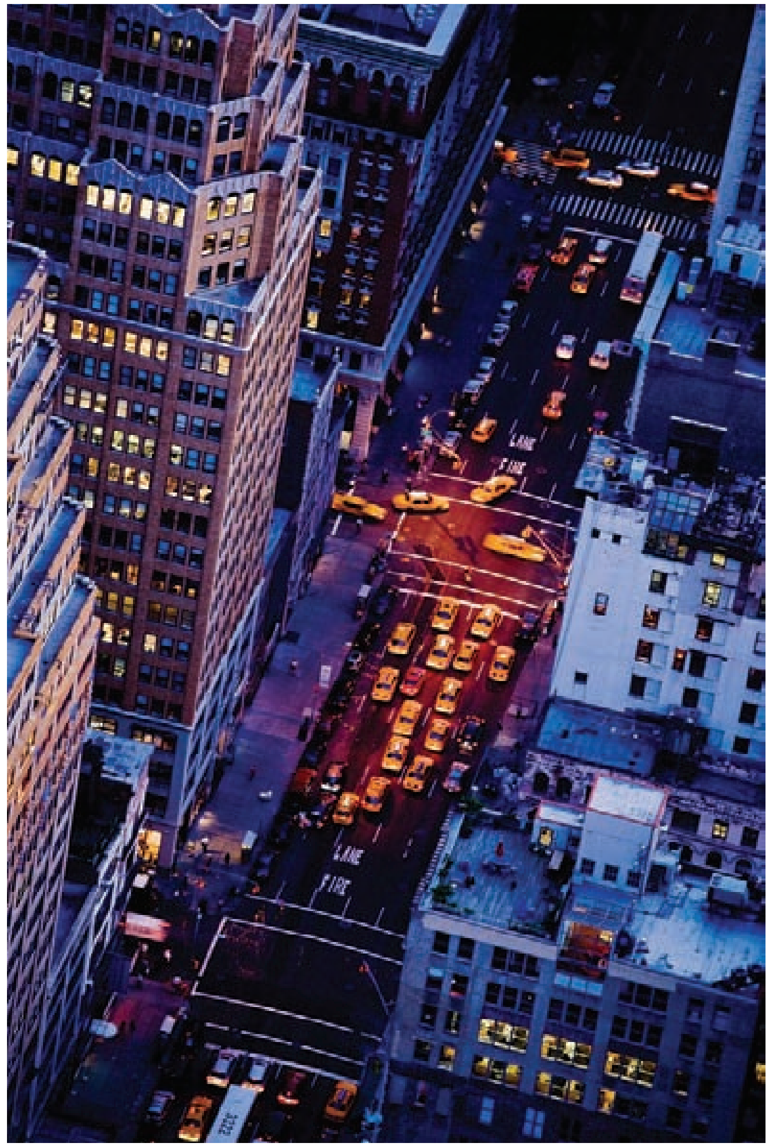
- **Zone-Based Charges:** Fees levied to charge for access or use of a designated road network in and around heavily congested areas or urban centers. There are several forms of congestion pricing, including cordon charges, area charges, and zonal charges. These variations are explained as follows:

  – *Cordon charge*—A flat or variable fee levied for crossing the designated boundary around an urban center. Cordons can be used for entrance or exit of any road designated by the cordon(s). Manchester, England, has proposed a cordon charge to enter the regional center only during the morning peak period inbound and the evening peak period outbound. It uses the natural boundary of the M-60 motorway, which circles the regional center and city of Manchester, and includes a proposed second cordon boundary closer to the city center. Stockholm is an example of a single cordon charge.

  – *Area charge*—Charge for all trips whether they originate outside the boundary and cross the designated boundary or originate inside the boundary and never cross the boundary during the charging period. The London Congestion Charging System levies a flat fee on any vehicle on public roads inside the designated charging zone or crossing into or out of the boundary. It also charges the same daily fee for all vehicles regardless of size or time spent in the charging zone.

  – *Zonal charge*—Mini-cordons within or around an urban center where fees are charged for entering each mini-cordon that can be contiguous or spatially separated with free roads in between them. Charging for each mini-cordon can be the same across all cordons or vary between them and can also vary by direction or time of day for peak-period charging or variable charging based on the degree of congestion. Mini-zones are typically drawn around known geographical or political boundaries that are easily and clearly understood by the local residents. Florence, Italy, has several mini-cordons based on centuries-old political boundaries. Residents of any specific mini-cordon are not charged for travel within their "home cordon" but are charged for entry into a neighboring mini-zone or cordon.

- **Area-Wide or System-Wide Charges:** Fees levied on a vehicle based on factors such as vehicle type, distance traveled, time of day, type of road, vehicle emissions, or type of power train (e.g., diesel engine, gasoline engine, bio-fuel engine, hybrid, electric, or hydrogen). This type of charging includes:
  - *Truck or heavy commercial vehicle pricing*—Fees levied only on trucks or heavy commercial vehicles that typically reflect charges for the weight carried (load) and distance carried on the road network. Current truck pricing examples include New Zealand's Road User Charging, Switzerland's truck tolling, and Austria's and Germany's MAUT systems.
  - *Strategic-road-network charge*—Levies imposed as spot charges on major roads or congested network links in or into city centers. Strategic-road-network charges can be a continuous series of charging points along a major access road into the urban center. These charges can vary by location and time of day, in addition to type or classification of vehicle. Strategic-road-network charges were considered in the Auckland, New Zealand, Road Pricing Evaluation Study[2] and are part of the Singapore Electronic Road Pricing (ERP) system.[3] In Singapore, these charges apply not only on the strategic road network approaching the central business district (CBD), but also to specific congested areas or streets inside the boundary of the cordon charge.[3]



These options define the major types of pricing that exist today, but the list is not all inclusive, and new concepts or combinations of the above may develop in the future. For example, Milan, Italy, has introduced an environmental charging system, and Hong Kong has explored a concept of eco-point charging or personal carbon-based trading in which users gain or lose "eco-points" based on their travel choices, time, and distance traveled.[4]

Functional Processes for Tolling and Congestion Charging

The basic function of any tolling or congestion-pricing system and supporting technologies is to collect payment from users. This can vary significantly depending on particular local conditions; policy framework; strategic, legal, and policy requirements; and the nature of the outcomes that the charging system seeks to achieve. The capabilities and/or limitations of the technologies available have often played a major role in shaping functional design: As the capabilities of technology have increased, the flexibility of tolling and road-user charging can more directly address and improve the key objectives. In the same way that some technology limitations have restricted (and still restrict) some desirable options and functions, the rapidly developing capabilities of new technologies can also offer options that may previously have not been considered.

Whatever system or technology solutions are adopted, the collection of payment from users within the framework of any tolling or road-user pricing scheme must include consideration of the following nine functional requirements:

1. **Informing:** Providing adequate information to users and potential users (often defined by legislation).
2. **Detection:** Detecting, and in some cases measuring, each individual instance of use (e.g., vehicle entering a zone).
3. **Identification:** Identifying the user, vehicle, or in some cases numbered account.
4. **Classification:** Measuring the vehicle to confirm its class, aligned with the classification framework for the scheme.
5. **Verification:** Cross-checking processes and secondary means of detection to assist in confirming transactions, reducing processing costs, and providing a backup for potential enforcement.
6. **Payment:** Pre- and post-use collecting of payment from users based on verified use.
7. **Enforcement:** Providing the means to identify and prosecute violators and/or pursue violators for payment of charges and/or fines.
8. **Exemptions:** Providing the facility with the means to manage a range of exemptions and discounts within the context of the scheme.
9. **System Reliability and Accuracy:** Providing all of the above through cost-effective systems and technologies that can meet the required levels of reliability and accuracy and minimize revenue leakage and fraud.

This base functional framework has been used through several of the following sections of this primer to consider and compare the functional capabilities and operation of candidate technologies and example systems.

Primary Tolling and Pricing-System Components

The following sections describe the primary system technologies and provide examples of locations where they are being used. Along with the more advanced technologies, this list also includes basic systems such as paper-based and manual facilities. This is partly for completeness, but it is also to assist in better illustrating and describing the basic functions for a simple system that will improve understanding through the later more complex options.

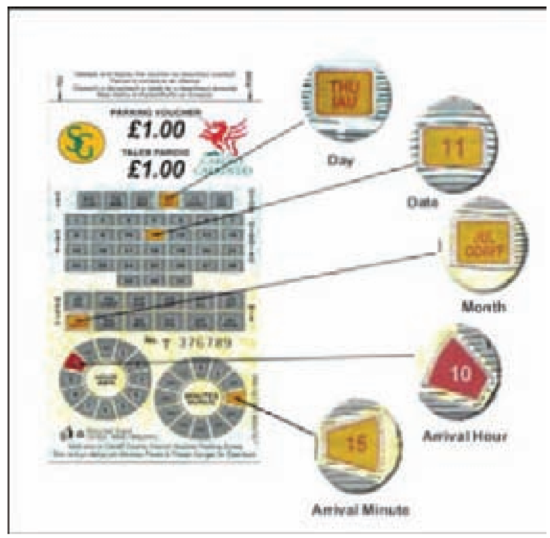
PAPER-BASED SYSTEMS

Paper-based systems require road users, who wish to use (or keep) their vehicles within a defined area during a defined time period, to purchase and display a supplementary license or permit. This usually takes the form of a paper license displayed on the vehicle's windshield or dashboard as shown by the examples provided on this page.

There are two main options for implementing paper-based schemes:

- **Entry Permit Schemes:** Vehicles display a valid license sticker to enter (or leave) a defined area (the restricted zone).
- **True Area Licensing Schemes:** Vehicles display a valid license to travel or park within a defined area.

The distribution of permits or licenses is usually managed through a combination of existing retail outlets and other system operator channels, such as vending machines, the Internet, and phone-based mail order. For tolling, coupon books have been used in a number of facilities. In the Baltimore Harbor Tunnels, a user can purchase a book of 10 coupons for paying the toll at a discounted price.



Example of paper license used in the United Kingdom.

Example of a paper license used in Singapore.

Singapore's Area Licensing Scheme, which operated from 1975 until 1998, required car drivers entering the CBD during the morning peak period to pay three Singapore dollars per day (with exemptions for vehicles that carried four or more people). This was managed by using a paper-based (sticker) system with stickers purchased for each day and placed on the inside of the windshield. Drivers were able to travel into and around the priced area several times a day without paying multiple charges. Enforcement was addressed at checkpoints where officials inspected each vehicle to ensure a valid license was displayed.

Street-based equipment is generally provided for the distribution of permits or licenses. The need for and location of permit or ticket vending machines vary by system but in most cases can be installed to suit the local environment. More advanced units can be installed with built-in mobile communications and solar power units, which require no direct connections to street services.

MANUAL-TOLL FACILITIES

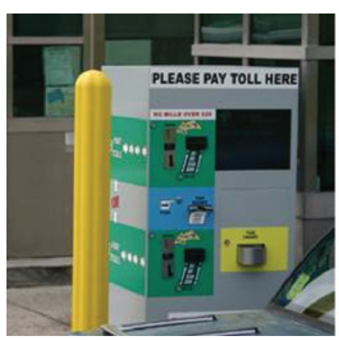
Manual-toll facilities, toll booths, or plazas have been used around the United States and the world for many years and comprise payment points at which drivers pay a charge by using cash, vouchers, charge cards, credit cards, or smart cards. Some of these manual-tolling systems are still in use today. Replacement modern versions have changed little in that a manual-toll terminal or cash register is used to collect and record the toll or charge while a traffic light and automatic boom gate hold the car present in the toll lane until payment is made. At one time, on facilities such as the Pennsylvania Turnpike, New York State Thruway, New Jersey Turnpike, Florida Turnpike, and Kansas Turnpike, a driver encountered a toll booth upon entry and exit. A paper ticket was provided on entry to record the start of the trip on the turnpike, and it was used upon exit to charge the driver for the distance driven on the road.

Because of (a) the amount of space required for conventional toll booths in dense urban road networks, (b) the congestion caused by the need to slow down or to stop to pay, and (c) the associated negative public perceptions, this method is generally not considered appropriate for urban pricing. Automated payment machines have helped reduce the costs of manual collection.

One of, if not the only, manual-based congestion charge schemes in operation is the Durham City, United Kingdom (UK), scheme implemented in 2002, which uses a system of bollard gates and manual payment machines. Drivers are required to pay the designated charge when exiting the city center zone before the bollard gate will open. These gates are manned by an official, and drivers who are unable to pay are allowed to pass but incur a fine.

The street-based equipment required for a manual system includes charging booths, additional lanes to increase throughput, gates at all entry points, sufficient space to install the required equipment, and access to power and communications.

Sticker purchase machine.



Manual toll booth.

Manual toll collection in Durham City, UK.

IMAGE-BASED TOLLING/AUTOMATIC LICENSE PLATE RECOGNITION (ALPR) TECHNOLOGY

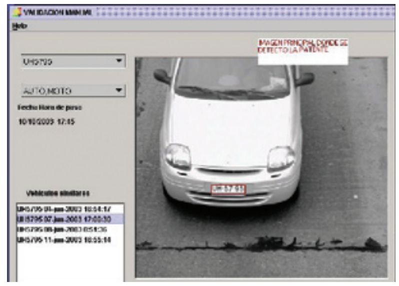
ALPR technology is commonly used on most electronic tolling facilities around the world, both in free-flow and toll-lane-based situations, although most often it is used as an enforcement backup to dedicated short-range communications (DSRC) or vehicle-positioning system (VPS) technology.

ALPR is based on images taken of vehicle license plates, which are then processed through optical character recognition software to identify the vehicle by its license plate. Some systems use front- and rear-located cameras to capture the images to improve identification rates. Once identified, the required charge or permit-checking processes are undertaken in a similar way to other systems.

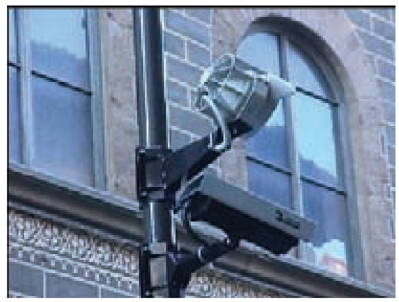
A key issue with ALPR facilities is the level of reliability of the images. The best systems are capable of read rates of around 98 percent in good conditions, but this can be reduced as a result of light reflections in the image or dirty or damaged plates. This leads to the need for manual checking of those plates and can add significantly to processing costs.

The London Congestion Charge, an area-licensing scheme, is the only scheme that currently relies entirely on ALPR on a large scale as an enforcement system. Several other toll facilities provide ALPR-only account options to users, but most require additional administration fees to compensate for the increased cost of processing these types of transactions. The London scheme also requires ALPR stations within a designated zone, at fixed locations, and on mobile enforcement units.

In the United States, most ALPR systems have been used on toll roads for payment violation enforcement, but this is changing. As toll facilities move to cashless open-road tolling, they are using ALPR systems as a tolling account rather than tags or DSRC transponders. Denver's E-470 and Tampa's Selmon Expressway are two examples where ALPR is used extensively to record the toll transaction. In Toronto's 407 toll facility, drivers can use either tags or their license plate as identification for paying the toll.



Example of ALPR image.



Typical ALPR camera and illumination device.

The roadside- or street-based equipment required for an ALPR system would include pole and/or gantry-mounted cameras and illumination devices. In some cases, these are combined into one unit. Depending on the overall system design, there may be a requirement for additional cameras (front and rear), classification devices, and independent verification. In addition to the camera mountings, some form of system controller would be required near each installation, requiring full power and communication connections via a purpose-designed base unit connected to each camera location. Communications connections may need a dedicated or leased fiber-optic network, and the power supplies may need an uninterruptible power supply.

DSRC FREE-FLOW TOLL USING TRANSPONDERS AND GANTRIES

DSRC is the most common form of primary electronic congestion-pricing technology in general use and is the standard on most free-flow toll facilities. The technology is based on on-board units (OBUs), sometimes referred to as *tags* or *transponders*, which communicate with gantry-mounted equipment at checkpoints. The roadside equipment identifies and verifies each vehicle's OBU, and depending on the type of system, either processes a charge from its designated account or confirms its rights of access. In most multi-lane free-flow systems, the DSRC system also acts to locate the vehicle within its detection zone by using an array of DSRC transceivers. Combinations of toll points can be used to facilitate distance-based charging systems, with special charging conditions for particular entry and exit points or times. The enforcement of this type of scheme is generally addressed by using roadside enforcement cameras and ALPR technology.

DSRC tolling started in the United States at the North Dallas Toll Road. It became the harbinger for electronic toll collection (ETC) that has grown rapidly around the world. These early single-lane ETC facilities can still be found in New York City at the Port Authority of New York–New Jersey bridges and tunnels and on the San Francisco Bay area bridges and tunnels. Multiple lane, free-flow, or open road tolling (ORT), removed the toll booth and single lanes and combined ETC for two or more lanes at facilities in Oklahoma, Denver's E-470, and most of the Orlando–Orange County expressway system.

There is a range of DSRC systems in use and under development. Some use infrared communications; this technology has not been deployed widely in higher speed applications and is not generally considered as an open standard. Most are based on microwave communication. The most common systems currently in use are based on a 5.8-GHz frequency, using the European CEN-278 standard. This standard is now well developed and delivers robust and secure OBU devices with an average battery life of around 5 years.

The next generation of 5.9-GHz systems, which are being developed mainly in the United States to address a wider spectrum of intelligent transportation systems (ITS) applications, will provide longer range communication and multiple channels. Although not currently in use on any operational pricing system, these OBUs are planned to become standard installations in all new vehicles within the next decade.

DSRC systems can be expanded relatively easily onto other routes or across adjacent areas through the deployment of additional toll or check points. However, expanding these types of systems to cover much wider areas is less cost-effective, because the numbers of toll points to provide effective coverage can increase significantly.

The street-based facilities required for a DSRC system include a range of equipment, such as pole- and/or gantry-mounted transceivers, ALPR cameras and illumination devices, vehicle-classification devices, independent verification devices, and roadside control cabinets.

In the urban environment, some street layouts may require modifications to improve the operation of the system (e.g., to provide localized separation of traffic from opposing direction streams and to assist in reducing the need for full gantries in street situations). The transceiver/classifier units are generally mounted separately from the cameras to allow the cameras to detect vehicles in the pricing zone, although technologies are available to combine all functions at one location. A further variation in some arrangements is the use of front and rear cameras, which may require an additional camera support structure.

Some form of system controller would also be required in the vicinity of each installation, requiring full power and communication connections via a purpose-designed base unit connected to each location.

Components of Singapore's ERP system.

Example of vehicle positioning system.

In multi-lane situations, an array of transceivers and classifiers will be required, generally mounted on purpose-built gantries or potentially mounted on existing structures. Where multi-lane facilities are to be installed in two directions, the relative location of gantries also requires consideration, because a degree of separation is required between some equipment.

Singapore operates an ETC system as its primary technology for congestion pricing. Groups (arrays) of transceivers mounted on entry-point gantries communicate with units in each vehicle to locate the vehicle and record the transaction. The OBUs are also equipped with smart card payment facilities.

In Italy, several major cities operate access control systems that use the TELEPASS toll system, which was developed and has been operating on the Italian motorway network. This system is based on the use of 5.8-GHz transceivers and OBUs and is designed for use in single-lane toll-gate situations only.

VPS TECHNOLOGIES

Internationally, road authorities have been exploring and implementing VPS (e.g., global positioning system [GPS], Galileo, Global Navigation Satellite System [GLONASS]), which do not require on-road infrastructure to assign a position to a vehicle. Instead, these systems use satellite-location systems, generally GPS, to determine the vehicle's position and to measure location and distance travelled for the purposes of charging and access control. These systems offer greater flexibility for authorities to vary charges to influence more aspects of travel and transportation choice. In Europe, the launch of the Galileo satellite system will complement the U.S. GPS system with over 30 more satellites in orbit, ensuring greater accuracy of position and location. The Russian GLONASS is currently being renovated and will add 30 more positioning satellites in orbit by 2015. In total, the fleet of positioning satellites, GPS, Galileo, and GLONASS will provide nearly 100 total satellites for positioning and navigation systems that will be accurate to less than 3-feet positioning in the next 5 to 7 years.

Although VPS technologies are an effective means of tracking vehicle position, the information they gather and store needs to be communicated to central systems on a regular basis, and as such, VPS units are generally combined with other technologies (e.g., digital maps, wide-area communications, and short-range general packet radio service [GPRS] communications) to charge and enforce the system. Additional features required include enforcement checkpoints (fixed and mobile) and depending on the focus of the system, these can be extensive. New DSRC systems such as the 5.9-GHz technology along with Wireless Fidelity (WiFi), Worldwide Interoperability for Microwave Access (WiMAX), and other third-generation communications capabilities that are being implemented in Baltimore and in other cities across the United States will make VPS more popular for navigation, tolling, and congestion pricing.

The current cost of units has been a major factor in these systems that are only being used for heavy-vehicle application to date. Once established, VPS-based systems have the advantages of wide coverage and far fewer checkpoints than do other technologies. It is expected that on-board VPS units will become standard features in new vehicles within 10 years; this migration is a specifically identified strategy for the European Union.

VPS-based systems require far less on-street equipment than do other systems, with the primary function of the street-based facilities being backup enforcement at selected checkpoints. Fixed on-street checkpoints are most likely to use DSRC and ALPR technologies that require a series of pole- or gantry-mounted devices. These fixed enforcement stations will most likely be supported by mobile units that will reduce the number of locations required.

VPS-type technology is in use on several wide-area, heavy-vehicle, road-user charging facilities, including systems in Germany and Switzerland. VPS-based systems have been introduced or considered (in the United Kingdom) as technology solutions for the introduction of distance-based charging, primarily for heavy vehicles. The German model is beginning to demonstrate that the technology is moving toward being "proven," but only for a distance-based charge.

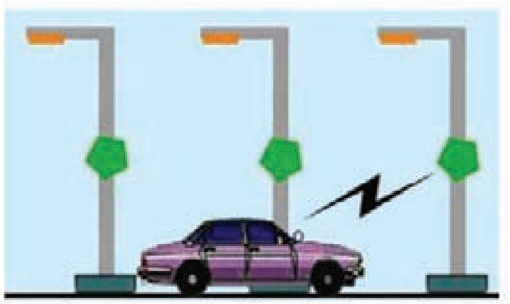
Nowhere in the world has VPS been used for a more contained urban-congestion-pricing scheme, primarily because of difficulties in receiving signals from satellites in the urban environment (with its canyon effect) and because the higher costs of in-vehicle units are prohibitive in smaller areas. In an urban area, the costs of the scheme would also likely rise dramatically because of the need for "repeater" units to overcome the canyon effects and improve boundary accuracy. Similar systems have been used in Seattle for testing driver responses to tolling. Portland, Oregon, also ran a test with such a system in which drivers could pay the distance charge rather than pay a higher excise tax for fuel at the pump. The pilot test indicated that such a concept could act as a transition approach to moving away from fuel excise taxes to distance-based charges.

CELLULAR TELEPHONE AND PICO-CELL SYSTEMS

A cellular network is basically a radio network made up of several radio cells, each served by a fixed transmitter that is known as a cell site or base station. These cells are used to provide radio coverage over a wider area. Cellular networks use a set of fixed main transceivers, each serving a cell and a set of distributed transceivers, which provide services to the network's users.

Pico-cell technology is, in simple terms, a more concentrated cell network that uses smaller transceivers and thus develops a cell network that provides a greater ability to locate mobile devices within the network. By using this type of network, it is possible to locate properly equipped vehicles with a high degree of accuracy, thus providing the potential to introduce distance-based charging by using a ground-based technology. The sensor networks being developed for this type of application consist of a large number of devices (known as motes) that are connected by using wireless technology.

Recent trials in Maryland and California have involved the cellular network to gather traffic data based on a static network of motes connected to bus stops and mobile motes placed on buses, which become transient members of the static network as they approach a bus stop. The system



Pico-cell data transmission illustration.

trials have been used to provide position information collected from the buses. Future intelligent infrastructure pico-cell systems are based on the concept of a dense network of low-cost short-range transceivers located within vehicles and on roadsides.

Trials of this type of technology have recently been undertaken in the United Kingdom (Newcastle and London) to test the feasibility of this technology for congestion pricing. These trials have indicated that this type of technology does have the potential to provide a viable alternative to other location-based systems such as VPS.

The street-based equipment required for this type of system includes an extensive network of short-range communications devices that make up an integrated web of communications. These devices would be located in vehicles and as part of roadside infrastructure and would have minimal impact in terms of space or visual intrusion.

As with VPS-based systems, this type of system would require some on-street enforcement, although far less than other systems, with the primary function of the street-based facilities being backup enforcement at selected checkpoints. Fixed on-street checkpoints are most likely to use DSRC and ALPR technologies and require a series of pole- or gantry-mounted devices. These fixed enforcement stations would most likely be supported by mobile units that would reduce the number of locations required.

COMBINATION SYSTEMS

The majority of current pricing systems, including toll roads and urban charging and access schemes, use a combination of technologies to manage the collection and enforcement process. This includes almost all U.S. toll roads from Maine to Florida and from New York City to San Francisco.

One of the most common combinations is the use of DSRC OBUs as the primary payment and identification technology and ALPR technology for enforcement and casual-user transactions. This combination allows operators to benefit from the higher accuracy and lower operating costs of DSRC, while using ALPR to overcome DSRC limitations of casual-user management and enforcement. This package also limits the use of the less accurate and more operations cost-hungry ALPR technology to a reduced number of transactions.

Other global example combinations include the deployment of VPS on the German and Swiss truck toll systems, which use VPS to address the distance- and location-based elements; DSRC to provide the necessary local roadside communication; and ALPR as a base-enforcement technology.

Sub-System Technologies

As indicated in the *Functional Processes for Tolling and Congestion Charging* section of this primer, the tolling process is a combination of sub-processes that require close integration. The overall effectiveness of tolling and congestion-pricing technologies will be the aggregate improvement in all steps of the process for reliability and accuracy and minimized revenue leakage and fraud. There are several related sub-systems for which a range of technology options exist, which include the following:

- Informing and providing standard signs and lane markings to increase driver recognition and understanding of the tolling or congestion pricing across the United States.
- Vehicle occupancy detection technologies.
- Vehicle identification and classification systems (e.g., laser, video, digital loop, axle detection treadles, etc.).
- Telecommunications: Roadside and centralized control equipment (e.g., in-unit, controller-based processing).
- Automation of operations (e.g., payment and enforcement processing, account setup and management).
- Payment systems for pre- and post-collection of tolls or congestion-charging fees.
- Verification and secondary enforcement systems (e.g., scene image capture, mobile and portable enforcement).
- System reliability and accuracy of DSRC systems.
- OBU distribution facilities.
- ITS integration.

INFORMING AND PROVIDING STANDARDIZED SIGNS AND LANE MARKINGS

As tolling systems have grown across the United States, toll facilities have been very individual and unique enterprises. With the introduction of each facility and the advent of ETC, each of these facilities has developed its own branding of its ETC package. Today, a plethora of arcane and distinct brand names for ETC exist in the United States, including E-ZPass, FasTOLL, SunPass, MnPass, and a host of other names. In an age of standardization and interoperability, these names may confuse drivers who travel across the country.

A similar situation existed in Sydney, Australia. Each toll road had its own brand name for its ETC. To solve the driver-recognition problem, a standard symbol of a green square with a yellow "E" was added to each toll lane and free-flow sign to indicate an interoperable ETC facility where any and all ETC transponders or OBUs could be read and accepted.

With the advent of potential interoperable standards such as the vehicle infrastructure integration (VII) or 5.9-GHz technologies, a similar approach should be taken to mark all interoperable facilities across the United States. This would allow each toll facility to retain its branding for local recognition, but as it adopts a national interoperable standard, a common designation is necessary, as in Australia.

Legally, each toll facility must be marked as a toll road to advise the user of the requirement for tolling. This is a common requirement across all toll facilities in the United States. Although this is a legal requirement, there are no standard road signs or lane markings for toll roads, priced lanes, or congestion-pricing areas in the Manual on Uniform Traffic Control Devices (MUTCD) to integrate the efforts and provide a common set of signs, colors, and markings as toll roads, priced lanes, and congestion pricing grow in size and numbers across the United States. In the United Kingdom, for example, the red circle with a white "C" was originally developed for the London congestion charge. It appeared on all signs and lane markings to indicate to drivers the boundary of the congestion-charging zone in London and to provide information concerning the London congestion charge.

In addition, color or road designation of these facilities—toll roads, priced lanes, and congestion-pricing areas—should be designated for ease of map making and recognition. Just as we have standardized icons, colors, and signs for Interstates and highways, we need to develop these designations for tolling and congestion pricing.

VEHICLE-OCCUPANCY DETECTION TECHNOLOGIES

A promising technological advancement that could improve congestion-pricing operations for priced-lane operations is the development of a more accurate vehicle-occupancy system. At present, some imaging software is able to read closed-captioned television (CCTV) images and discern the number of occupants. In addition, infrared sensors can detect human-heat signatures. Although more advanced algorithms and other advances in available technologies have made significant improvements in the software's ability to identify human occupants, several inherent limitations prevent complete implementation of automated "outside the vehicle" occupancy monitoring. For example, sensors often have difficulty rendering data from all seats within a vehicle, particularly in the dark or when one of the passengers is a small child. Further complications arise in non-barrier-separated roads where movement between lanes has minimal physical restrictions. For automated enforcement to be implemented, sensors must achieve near perfect accuracy, which thus far has not been possible to attain.

One potential solution is to instead focus on occupancy monitoring from inside the vehicle. Seatbelt and air-bag sensors are already standard equipment on today's vehicles, monitoring front-seat occupancy via mechanical seatbelt closure sensors and weight/pressure sensors installed within seats. In the future, additional sensors could be installed in the rear seat, allowing the vehicle to have a complete analysis of the number of occupants in the vehicle. Additional advanced sensors, including light-emitting diode (LED) and infrared imaging, could be added to ensure a more accurate measurement. The in-vehicle system could communicate occupancy information with sensors imbedded in the infrastructure via a radio transponder/receiver system, GPS, or cellular signal to allow single-occupancy and high-occupancy vehicles using HOT lanes to be assessed the appropriate charges.

VEHICLE-IDENTIFICATION AND CLASSIFICATION SYSTEMS

The task of vehicle classification for congestion pricing varies with the type of scheme and primary technology used. For manual or semi-automated toll lanes, in which vehicles are confined to a single lane at reduced speed, classification can be measured by size, weight, or number of axles. In these situations, devices such as weigh-in-motion (WIM) detectors, treadles, or lasers can be used with relative accuracy.

Once a free-flow environment is introduced and vehicles are required to be classified at full speed and in a multi-lane environment, the ability to classify with the use of technology is reduced, along with the range of technologies available. Current axle treadles and WIM technology do not provide sufficient accuracy to classify vehicles in this type of environment, and a size-based classification system is therefore required.

There are currently two sufficiently reliable methods available to classify vehicles by size in a multilane free-flow environment: scanning-laser technology and stereoscopic-video technology. Digital loops also provide an option but are affected by lane-change movements and do not provide the range of classification available with laser and video systems.

The technologies for classification are another area in which standardization is needed across all toll facilities in the United States. A common reference system would assist drivers in knowing the charges they will incur. Current classification systems and their application create confusion and uncertainty in the minds of drivers. Only from a national perspective can this effort be directed and then implemented by states and toll agencies.

TELECOMMUNICATIONS: ROADSIDE AND CENTRALIZED CONTROL EQUIPMENT

All congestion-pricing systems require the continuous processing of large volumes of transactions. Depending on the charging scheme and primary charging technology used, the complexities and volumes of these transactions can be managed in different ways to achieve a suitable balance between system reliability and operational cost.

One major area of consideration is the balance between roadside and centralized processing and the communications architecture developed to support these processes. Decisions should be based on several factors:

- The volumes of data that need to be moved around the system.
- The availability, reliability, and cost of communications.
- The number, security, and accessibility of roadside installations.

Congestion charging schemes rely on large volumes of transaction data passing between a network of roadside facilities and the back-office systems. Depending on the type and structure of the system, this data may be relatively low-volume, character-based files, or much larger (for ALPR) digital-image files. These system requirements will have a significant influence on the architecture of the system and, in particular, the communications networks. For example, conducting ALPR processing at the roadside may significantly reduce communications and storage costs if the system provides for this type of operation; however, this requires a greater level of functionality within roadside equipment that may prove too costly to provide at a large number of locations.

These decisions and the resulting system architecture can have a major influence on the cost effectiveness of the entire system. For example, the London congestion charge is based on a high level of centralized processing with large volumes of data being transferred daily from many roadside facilities. This leads to higher costs, with recent technology reviews and trials highlighting the potential savings that could be made through a more efficient architecture. ALPR-based systems have the most to gain from improved architecture design, having the highest potential data requirements. DSRC systems

Roadside processing equipment.

Centralized processing equipment.

that use an ALPR enforcement component would be the next highest user, with VPS and cell systems most likely to have the lowest demand.

Recent trends in the development of the primary DSRC and ALPR equipment have led to the consolidation of some processing within these units, thus reducing the functions of roadside control units and further improving cost efficiency.

AUTOMATION OF OPERATIONS

The major operational costs of congestion-pricing systems result from the continuous processing of large volumes of transactions. Depending on the charging scheme and primary charging technology used, these transactions and processes can be automated to reduce cost and improve the overall efficiency of the system. A key objective is to minimize manual processing, particularly where there is no direct customer contact.

The use of OBUs is a major contributor to reducing operational cost across most free-flow facilities. As the most reliable means of automating vehicle (or account holder) identification, this technology reduces the level of manual processing required and thus minimizes cost.

Other areas of automation include account setup and management processes through interactive voice response (IVR) and the Internet, ordering of statements, and account top-up facilities.

The selection of appropriate systems to automate back-office functions is critical to developing a cost-effective road-charging system. Congestion pricing is based on high-transaction volumes and relatively low-transaction values that lead to a focus on small costs to ensure a cost-efficient system.

Back-office operations.

PAYMENT SYSTEMS FOR PRE- AND POST-PAYMENT OF TOLLS AND CHARGES

There is a wide range of payment options available, and the selection of an appropriate package of options needs to address the specific needs of each scheme. A key issue is the balance between providing security of payments at a reasonable cost and providing user convenience.

Where manual or machine-based payment options are available, the use of cash and standard card-payment options is feasible, and although the management of cash payments involves some cost to the operator, the convenience and anonymity of cash addresses a key concern of some users.

For most electronic tolling and congestion-pricing systems, the primary and preferred payment mechanism is through customer accounts. These provide greater security of payment for the operator (as users are generally required to prepay and provide bank account or credit card details) and reduce the cost of operation. Accounts are also more convenient for most users, because they are not required to make individual payments for each transaction. Account-based payments can be used with any OBU or ALPR-based system and are the most common form of payment for free-flow toll facilities.

A further option is the use of smartcards, as used in the Singapore ERP system. These cards are used with the vehicle's OBU, and payment is debited from the card balance. This provides a further level of convenience that is preferred by some customers, and as the balance on the card is prepaid, there is a degree of security for the operator. The main disadvantages are the increased complexity and cost of the OBU and the need to provide real-time roadside processing of payments.

One advanced electronic-payment technology with potential application in congestion-pricing programs involves the use of contactless bank cards. Contactless smart bank cards, such as the Visa Wave or the MasterCard PayPass, are being distributed by several U.S. banks already, and more plan to follow. These cards allow payment by radio frequency identification (RFID) transaction—just tapping the card on the reader—instead of requiring the magnetic stripe of the card to be run trough the reader (a slow and fraud-prone process). EMV is a protocol, developed by Europay, MasterCard, and Visa (EMV), for authenticating credit and debit card payments at point-of-service (POS) terminals and automated teller machines (ATMs) through the use of interoperable chips.

Although it has failed to gain traction in the United States, this standard is used throughout most of the world, including Europe and Asia. The version of EMV used on the contactless bank cards, called contactless EMV, uses an encryption algorithm that makes them essentially fraud proof. In congestion-pricing programs, the contactless EMV cards could be used in OBUs that act as the toll-tag transponder. OBUs with contact smartcard card readers are in use in Singapore, and the Norwegian company Q-Free built OBUs with contactless card readers that were used at the 2006 Winter Olympics in Turin, Italy. By using such transponders and cards, congestion-pricing programs could avoid having individual user accounts to administer—users would pay directly by bank card.

SECONDARY ENFORCEMENT

ALPR is effectively the foundation of all electronic free-flow charging, because it is the only common point of reference for all vehicles passing through a toll checkpoint or zone boundary.

In most free-flow tolling applications, ALPR is used only as an enforcement tool, with the majority of users charged and verified through an OBU. Even in this situation, secondary enforcement systems, such as color-scene images, are recorded for evidence and to back up the basic ALPR records.

ALPR enforcement.

However, in situations in which either ALPR is the primary technology or there is a need for further enforcement backup, other backup systems and technologies can be used, such as front and rear ALPR systems or digital video recording of traffic that can be accessed later to assist in identifying offending vehicles. These systems can provide an alternative view of traffic from the primary ALPR systems and can overcome adverse environmental conditions such as sunlight or shadow effects.

SYSTEM RELIABILITY AND ACCURACY OF DSRC SYSTEMS

Pricing systems using vehicle-based OBUs are used widely across the world for a range of tolling and road-charging applications. These systems generally use a microwave signal at or around 5.8 GHz to provide the critical vehicle-to-roadside communication function. The most widely used standard for this frequency range is the European CEN-278 standard.

As the planned role for vehicle-to-roadside and vehicle-to-vehicle communications becomes more widespread (i.e., moving into dedicated safety systems, traveler information, and other ITS applications), the 5.8-GHz standard is being superseded by a standard in the range of 5.850–5.925 GHz. This developing standard, known as WAVE, has greater range and greater multi-channel capability. Although there are no current road-charging applications in operation, it is likely that this standard will replace and enhance current systems over the next 10 years or so.

In the United States, the implementation of DSRC-enabled devices serves as part of the VII initiative, which brings together vehicle manufacturers, government agencies, and professional organizations in the design of architecture, standards, policies, and potential business models of a system that will enable vehicles to communicate with each other and roadside equipment. It is envisioned that VII transponders will be installed soon in all vehicles and that roadside equipment will be deployed at major intersections and along roadways throughout the nation to form a nationwide network. Applications for VII include public safety, traveler information, and demand management. The vision for VII is to deploy roadside units throughout the country, thus creating a uniform, nationwide data network. Combined with GPS, all connected vehicles will know their location and have the ability to communicate location, traffic conditions, and other information to the system. The ability to exchange such information could be useful in congestion pricing.

OBU DISTRIBUTION FACILITIES

The distribution and management of OBUs for DSRC and VPS-based systems incorporate a range of technologies and systems designed to address the specific requirements of particular schemes. The majority of OBUs would be distributed from a central facility by mail, by customer collection, or through agent networks. However, the use of vending machines has helped improve distribution and availability, as is the case with the Austrian Motorway toll system.

Banks and financial institutions also distribute tags, OBUs, and transponders. For example, in Spain and southern France, the VIA-T project proved that drivers could sign up for toll accounts through banks and financial institutions. These institutions provide the OBUs and the account mechanism for drivers by linking payments to (a) the bank-issued credit card, (b) a person's checking account (direct payment), or (c) a savings account/debit account. Just like the issuance of a credit card, the OBU was dispatched from a central depository to the individual by express and registered mail.

As toll roads, priced lanes, and congestion pricing become more common, the business model for standardized OBUs should change, as well as the business model that people use to secure them.

ITS INTEGRATION

The level and type of ITS integration will depend on the type of pricing system adopted and the payment structures and technologies used, but opportunities exist to integrate at many levels. Another major area of ITS integration is the use of pricing-system data to provide travel time and congestion information. One of the best-developed systems is the Italian TELEPASS system that has been in operation on the motorway network for many years. The large numbers of OBUs continually moving across the motorway network are tracked by purpose-designed stations to provide real-time travel-time information, linked into traveler information systems.

Acronym List/Glossary

ALPR—Automatic License Plate Recognition. Software that enables authorities to match the vehicle license plate with identity information in registration data.

ALS—Area Licensing Scheme. Singapore's ALS, operated from 1975 until 1998, required car drivers entering the CBD during the morning peak to pay three Singapore dollars per day (with exemptions for vehicles carrying four or more people).

ATM—Automated Teller Machine. A computerized telecommunications device that provides the customers of a financial institution with access to financial transactions without the need for a human clerk or bank teller.

CCTV—Closed-Circuit Television. The use of video cameras to transmit a signal to a specific place, such as a limited set of monitors.

CBD—Central Business District. The commercial and often geographic heart of a city.

CEN—European Committee for Standardization. The CEN was founded in 1961 by the national standards bodies in the European Economic Community and European Free Trade Association countries. CEN contributes to the objectives of the European Union and European Economic Area with voluntary technical standards, which promote free trade, the safety of workers and consumers, interoperability of networks, environmental protection, exploitation of research and development programs, and public procurement.

DSRC—Dedicated Short-Range Communications. A short- to medium-range communications service that supports both public safety and private operations in roadside-to-vehicle and vehicle-to-vehicle communication environments.

EMV—Europay, MasterCard, and Visa.

ERP—Electronic Road Pricing. Electronic toll-collection system that prices roads based on usage.

ETC—Electronic Toll Collection. The collection of tolls based on the automatic identification and classification of vehicles by using electronic systems that do not require drivers to stop or slow down.

GHz—Gigahertz. A unit of alternating current (AC) or electromagnetic (EM) wave frequency equal to one thousand million Hertz (1,000,000,000 Hz). The gigahertz is used as an indicator of the frequency of ultra-high-frequency and microwave EM signals.

GLONASS—Global Navigation Satellite System. Based on a constellation of active satellites that continuously transmit coded signals in two frequency bands, which can be received by users anywhere on the earth's surface to identify their position and velocity in real time based on ranging measurements. The system is a counterpart to the United States' global positioning system (GPS), and both systems share the same principles in the data transmission and positioning methods. GLONASS is managed for the Russian Federation Government by the Russian Space Forces, and the system is operated by the Coordination Scientific Information Center (KNITs) of the Ministry of Defense of the Russian Federation.

GPS—Global Positioning System. A U.S. space-based radio-navigation system that provides reliable positioning, navigation, and timing services to civilian users on a continuous worldwide basis—freely available to all. For anyone with a GPS receiver, the system will provide location and time.

GPRS—General Packet Radio Service. A packet-oriented mobile data service available to users of Global System for Mobile Communications.

HCV—Heavy Commercial Vehicles. Includes all heavy motor vehicles used for the transportation of passengers for hire, or constructed or used for transportation of goods, wares, or merchandise.

HOT—High-Occupancy Toll. On HOT lanes, low-occupancy vehicles are charged a toll, whereas high-occupancy vehicles are allowed to use the lanes free or at a discounted toll rate.

HOV—High-Occupancy Vehicle. Highway lanes are typically reserved for these vehicles with two or more occupants.

ITS—Intelligent Transportation Systems. An electronic toll-collection system without toll plazas, where all drivers are charged the toll without stopping, slowing down, or being in a specific lane.

IVR—Interactive Voice Response. A phone technology that allows a computer to detect voice and touch tones using a normal phone call.

LED—Light-Emitting Diode. A semiconducter diode that emits light when an electric current is applied.

MUTCD—Manual on Uniform Traffic Control Devices. Defines the standards used by road managers nationwide to install and maintain traffic control devices on all streets and highways. The MUTCD is published by the Federal Highway Administration.

OBU—On-Board Unit. Also called an on-board transponder. The in-vehicle device component of an ETC system. A receiver or transceiver permitting the Operator's Roadside Unit to communicate with, identify, and conduct an electronic-toll transaction.

ORT—Open Road Tolling. An electronic toll-collection system without toll plazas, where all drivers are charged the toll without stopping, slowing down, or being in a specific lane.

POS—Point of Service (or Sale). A retail shop, a checkout counter, or the location where a transaction occurs.

RF—Radio Frequency.

RFID—Radio Frequency Identification. A technology similar to bar-code technology. With RFID, the electromagnetic or electrostatic coupling in the RF portion of the electromagnetic spectrum is used to transmit signals. An RFID system consists of an antenna and a transceiver, which read the radio frequency and transfer the information to a processing device and a transponder, or tag, which is an integrated circuit containing the RF circuitry and information to be transmitted.

RUC—Road-User Charging. A mechanism through which motorists pay to use a defined area of road, usually through payment of a toll.

U.K.—United Kingdom. The United Kingdom is a state consisting of four countries: England, Northern Ireland, Scotland, and Wales.

UPS—Uninterruptible Power Supply. A device that maintains a continuous supply of electric power to connected equipment by supplying power from a separate source.

U.S.—United States. A constitutional republic consisting of 50 states and 1 federal district.

VII—Vehicle Infrastructure Integration. VII will work toward the deployment of advanced vehicle–vehicle and vehicle–infrastructure communications that could keep vehicles from leaving the road and enhance their safe movement through intersections.

VPS—Vehicle Positioning System. Satellite-based system for vehicle tracking and positioning.

WAVE—Wireless Access in Vehicular Environments. Wireless communications that will let motor vehicles interact with roadside systems to access safety information and travel-related services, even at high speeds.

WiFi—Wireless Fidelity. A term for certain types of wireless local area networks that use specifications in the 802.11 family.

WIM—Weigh in Motion. Devices designed to capture and record truck axle weights and gross vehicle weights as the trucks drive over a sensor.

WiMAX—Worldwide Interoperability for Microwave Access. A telecommunications technology that provides for the wireless transmission of data by using a variety of transmission modes, from point-to-point links to full mobile-cellular-type access.

References

1. San Diego Association of Governments. (2008). *FasTrak®*. Retrieved on November 10, 2008, from http://fastrak.511sd.com/

2. New Zealand Ministry of Transportation. (2005). *Auckland Road Pricing Evaluation Study, Final Report*. Retrieved on November 10, 2008, from http://www.transport.govt.nz/arpes-index/

3. Singapore Land Transportation Authority. (2008). Retrieved November 10, 2008, from http://www.lta.gov.sg/

4. Hong Kong Transportation Department. (2001). *Feasibility Study on Electronic Road Pricing: Final Report*. Retrieved November 10, 2008, from http://www.td.gov.hk/publications_and_press_releases/publications/free_publications/feasibility_study_on_electronic_road_pricing_final/index.htm

For more information, contact:
Jimmy Chu
Office of Transportation Management, HOTM
Federal Highway Administration
U.S. Department of Transportation
1200 New Jersey Avenue, S.E.
Washington, DC 20590
Tel: 202-366-3379
E-mail: jimmy.chu@dot.gov

U.S. Department of Transportation
Federal Highway Administration

Office of Transportation Management
Federal Highway Administration
U.S. Department of Transportation
1200 New Jersey Avenue, S.E.
Washington, DC 20590
Tel: 202-366-6726
www.ops.fhwa.dot.gov/siteindex.htm

October 2008
FHWA-HOP-08-042