U.S. Department of Transportation
Federal Highway Administration

Technologies That Complement Congestion Pricing

A PRIMER

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The Primer Series and the Purpose of This Volume

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 the consolidation of trips, car-sharing, by using public transportation, or by simply

This volume explores transportation technologies that complement congestion pricing. This document considers:

- How technology complements congestion pricing.
- What technologies there are to consider.
- How the technologies are applied.
- Examples of how technologies were applied to retrofit congestion pricing on an existing facility.

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.

traveling at less-congested times. The use of proven and practical demand-management pricing that 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 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.

The purpose of this volume is to consider the technology options that are available to complement congestion-pricing approaches. This primer explores how technology broadens the success for congestion pricing by supporting the traveler's decision to change travel time, travel mode, and travel route. Complementary technologies (a) extend the benefits of congestion-pricing strategies to those directly and indirectly affected, (b) improve public acceptance of congestion-pricing strategies, and (c) improve the value of existing travel options available to individuals.

How Technology Complements Congestion Pricing

Applications of complementary technologies, such as integrated corridor management (ICM) and active traffic management, implement a wide array of technologies that have been proven throughout the Nation and in international markets to improve travel reliability across multiple travel modes. The coupling of these approaches and technologies to congestion pricing serves to inform travelers both pre-trip and en route and guides them through the facilities that apply congestion pricing. In addition, these technologies establish continual communication with travelers; thus, they become more acclimated to the congestion-pricing approach that is implemented.

Congestion pricing requires a number of enabling technologies to inform travelers of incurred costs, to collect charges, and to manage charges. Complementary technologies further extend the impact of congestion pricing by informing travelers of their travel options, by enhancing the performance of the roadway network, and by improving the reliability of travel of those who are directly and indirectly charged. This primer explores the technologies that enable the retrofit of different transportation facilities to operate in concert with each other to further extend the benefits of congestion pricing.

At present, it is well known that demand-management strategies, including congestion pricing, have the potential to influence mode choices, choices regarding departure times, and in some cases, choices to eliminate a trip altogether, which result in better use of the available capacity of the highway network. Some studies suggest that there is an increase in speeds and vehicle and person throughput as a result of applying these strategies in concert.

One of the intents of congestion pricing is to enable individual travelers to make decisions that are system-optimal rather than user-optimal. A *system-optimal decision* is one in which the system as a whole benefits. A *user-optimal decision* is one in which only the individual traveler benefits. An individual acting solely for personal interests may produce unfavorable outcomes for the system as a whole and ultimately produce an even less-favorable personal outcome.

Influencing a traveler's behavior involves conveying guiding messages, controlling movement, and imposing regulatory restrictions. Complementary technologies apply these guiding, controlling, and regulatory aspects with the aim of achieving an equilibrium that results in streamlined and reliable travel. This sensibility is reflected in the United Kingdom's Commission for Integrated Transport:

> It appears common sense to conclude that if new technology is to be widely accepted by users its introduction must not be seen to bring with it onerous and intrusive responsibilities that monopolise additional time and concentration of the driver. Instead it must have an enabling effect, allowing the driver a seamless and convenient journey.(1)

Coordinated approaches that use complementary technologies further promote trip reliability. The ability to dynamically manage recurrent and non-recurrent congestion based on prevailing traffic conditions yields benefits to individual travelers and to the effectiveness and efficiency of the facility. Coordinated technology approaches, such as active traffic management and ICM, help establish a positive cycle in which travelers derive personal benefit, accept congestion pricing, and observe system improvements in terms of performance reliability and improved alternative travel options.

A Menu of Technology Options

There is a range of technologies that comprise an intelligent infrastructure that actively monitors and manages transportation assets. Such technologies are applied by transportation agencies to anticipate, manage, and intervene in the operation of the transportation system to sustain the safe and efficient movement of people and goods. What follows are the types of technologies that are most commonly used for managing freeways and arterial highways, transit systems, and commercial vehicles. These are technologies that can vastly extend the benefit derived from a congestion-pricing approach.

INFLUENCING TRAVELERS EN ROUTE

Travelers already on the transportation network can be influenced towards other routes and modes to avoid higher tolls at peak times, congestion, or traffic-impeding crashes. En route information has the potential for redistributing demand and maximizing available capacities across all available facilities.

Dynamic Message Signs

A widely applied technology for en-route–traveler information is through dynamic message signs (DMS). DMS also can be applied to describe the congestion pricing for using a particular facility. For example, DMS can show the dynamic price for vehicles that do not meet the occupancy requirement in order to use the high-occupancy toll (HOT) lanes along I-95.[2] Understanding this cost can motivate a traveler to explore or continue to use other travel options, such as rapid transit.

Perhaps most visibly, over 40 metropolitan areas in the United States already use DMS for providing travel time information along highway segments. The effective application of DMS can prepare a traveler to decide on taking a diversion route if there is some incident or construction activity downstream.

Full-Matrix Signs

Full-matrix signs spanning the roadway can be effective in emulating a guidance sign, but with the added benefit of changing into various guidance signs to promote positive progression as vehicles continue to their destinations. This is beneficial for dynamic routing to divert motorists toward unfamiliar routes to circumvent congestion. Several assessment studies have indicated that under normal conditions, between 8 and 10 percent of motorists adhered to the route information, and network performance improved by 5 percent. Germany applies full-matrix signage to perform dynamic routing based on measured traffic conditions and incidents.

INFLUENCING TRAVELERS PRE-TRIP

Engaging travelers before they begin their trip offers the best chance of influencing their overall travel. Providing real-time status of all available travel options, plus tools for planning the travel, can motivate travelers toward fewer congestion-inducing choices and provide the information needed by travelers who wish to avoid paying higher toll rates that may be charged during peak times.

Web-Based Traveler Information

Web-based traveler information provides an on-demand service for travelers who seek information on toll rates, alternative modes, and traffic and travel conditions. This type of approach is most common for pre-trip traveler information, in which a traveler may plan a route and compare monetary costs and travel times for various travel options. Travelers can access a complete range of real-time multimodal transportation information at home, work, and other major sites where trips originate. Based on this information, the traveler can select the most cost-effective departure time, route, and modes of travel, or perhaps decide not to make the trip at all. Many traveler information Web sites in the United States and abroad enable this convenience, most notably in San Francisco (e.g., www.511.org) and the United Kingdom (e.g., www.transportdirect.info).

511 Telephone-Based Traveler Information

The Federal Communications Commission (FCC) established the 511 dialing assignment specifically for the purpose of providing telephone-based traffic and travel conditions information. Since 2000, over 40 systems have been established across the United States, with some systems covering entire States and others covering only specific urban areas. A 511 Deployment Coalition of States was established to provide guidelines to promote consistency of the service and its interface. Although 511 is aimed toward delivering pre-trip traveler information, studies indicate that travelers use 511 for en-route information when they experience unusual congestion from a crash or some other lane-blocking event.

Transit Traveler Information

Transit traveler information is critical for encouraging passenger-car commuters onto transit vehicles. To accomplish this, transit information needs to provide not only transit schedule and fare information, but also compelling transit reliability. Now that the Web is being used increasingly at transit locations, transit providers can offer real-time information about arrival times at transit-vehicle stops. This encourages ridership, because travelers can directly integrate the transit schedule with their personal schedule. An example of this approach exists in the New York City area's Trips 123 tool (www.trips123.com), which offers trip-planning tools that consider real-time transit status.

INFLUENCING PERSONAL BEHAVIOR

Advances in telecommunications and information technology make it possible to highly influence individuals. Directly targeted information gives individuals the widest perspective for making their trip choices, or not traveling at all.

In-Vehicle Traveler Information

In-vehicle traveler information is widely available through much of Europe, several nations in Asia, and in America's largest markets. A component of Germany's real-time traffic and traveler information program is the Radio Data System–Traffic Message Channel (RDS-TMC), which is broadcast on commercial and public FM stations. These RDS-TMC signals are received on in-vehicle global positioning satellite (GPS) and navigation units and relay route conditions and routing information that may not be displayed through DMSs. Many automotive manufacturers now install these receivers in their vehicles. In the United States, providers such as Tom Tom, XM NavTraffic, and Sirius Traffic broadcast similar location-based traffic conditions in the largest urban markets.

Targeted Traveler Information

Personalized traveler information that is conveyed directly to the traveler is common in many regions. Examples include alerts via text messaging to mobile phones and email alerts that describe impediments to travel, the price schedule for the congestion pricing scheme, and the anticipated travel times. Often a traveler can define filters that enable tailored information to be delivered at specific times or when an anomalous event occurs. The sophistication of technology that pushes information to individuals is growing rapidly, particularly with location-aware mobile phones that can accept information specific to the traveler's location.

Telework

Telework, or telecommuting, enables one to choose no transportation mode at all. In essence, some trips to work can be avoided by moving the work to the worker. Not all activities can be satisfied through telecommuting; however, pollution reductions have been demonstrated through aggressive marketing of telecommuting to employers.

INFLUENCING VEHICLE FLOW

Managing the supply of roadway capacity helps to delay the onset and magnitude of congestion. Regulating the flow of vehicles onto a freeway has been demonstrated to improve the travel performance for all travelers. With congestion pricing of a freeway, price signals are used to reduce demand during peak times and to prevent a breakdown of traffic flow. However, demand tends to vary from day to day, and it is difficult to set toll rates to perfectly match the variations in demand. Complementary strategies, such as ramp metering and variable speed limits, can help moderate flows on days when toll rates are not perfectly matched to demand.

Variable Speed Limits

Variable speed limit (VSL) signs are both regulatory and dynamic and establish a new speed limit that suits the prevailing flow conditions. VSLs can be applied to provide speed progression in which a sequence of VSL signs display incrementally reduced speed limits along a highway section. This has the effect of gradually slowing the progression speed of vehicles over a longer distance. The effect of applying VSL in this manner is reducing sharp variances in speed in a short length of roadway, thus reducing a causal factor in rear-end collisions that impede overall flow.

Speed variance reduction was observed in the implementation of VSL in several European cities.[3] Germany observed a 30-percent reduction in personal injury crashes. The Netherlands applied VSL to help reduce carbon emissions in sensitive areas and observed a 16-percent crash reduction while increasing throughput by 5 percent.

Photo credit: Florida DOT

Variable speed limit sign deployed on I-4 in Orlando, Florida.

Ramp Metering

Ramp metering has been demonstrated in numerous metropolitan areas throughout the United States, and it has been proven effective for reducing travel time and improving travel speed. The implementation of ramp metering for a variably priced-lane facility rests with stabilizing the entry of vehicles to the non-managed lanes and preserving free flow for as long as the capacity permits. The residual benefit is smoother operation for the variably priced lanes, which may become sensitive to capacity breakdown conditions in the non-managed lanes.

An evaluation of ramp metering in Minnesota revealed dramatic results.[(4)] When the meters were shut down, traffic volumes on the freeway mainline were observed to decrease by 9 percent, there was no appreciable change in the volumes on the parallel arterials observed, and freeway speeds were reduced by 14 percent (i.e., 11.9 km/h; 7.4 mi/h), resulting in greater travel times that more than offset the elimination of ramp queue delays. Moreover, when the meters were shut down, there was no appreciable change in the travel times on the parallel arterials, travel times were nearly twice as unpredictable, and crashes on freeways and ramp segments increased by 26 percent.

Special-Use Ramp Management

Special-use ramp management treatments include strategies that give "special" consideration to a vehicle class or classes to improve safety, improve traffic conditions, and/or encourage specific types of driving behavior. The most popular special-use ramp management application is the designation of high-occupancy vehicle (HOV) bypass lanes or ramps. Designation of HOV bypass lanes and ramps limit use of these facilities to only those vehicles with multiple occupants in an effort to reduce overall freeway delay.

Special-use ramp management.

Adaptive Signal Control

Adaptive signal control continuously monitors arterial traffic conditions and the queuing at intersections and dynamically adjusts the signal phasing to accommodate the broadest free flow for all approaches. The adjustments to the signal timing could be influenced by counting those vehicles that are equipped for the variably priced roadway and by extending the green phase; thus, these vehicles could enter the limited access facility more quickly. As an alternative, the adaptive signal control can detect high-capacity vehicles, such as those in Bus Rapid Transit, and adjust the signal timing for those vehicles as well.

Lane Controls

Lane controls establish restrictions on speed and use for specific lanes, such as dynamic shoulder travel lanes. They may also be used on regular lanes to ensure safety when dynamic shoulder lanes are in use for travel. By using lane controls with dynamic shoulder travel lanes, the structural width of the roadway can be fully utilized for periods of the day when there is a capacity demand. Enabling this temporary travel lane is valuable for older facilities in which there is a limit on available space for a permanent travel lane. If a single lane on an existing facility is under consideration for conversion to a variable-priced lane, the remaining general-use lanes can be augmented for specific periods of the day using lane controls. This would enable the opportunity to maintain a level of service for the flow of the general-use lanes and to minimize the impedances for congested flow on those general-use lanes upon the variably priced lane. Alternatively, all lanes could be used as priced lanes during peak periods. Lane controls could be used to harmonize speeds on all lanes. In case an incident causes blockage of any particular lane, lane controls could be used to direct motorists away from the blocked lane(s) upstream of the incident location. In case of incidents, lane controls may also be used to reserve at least one "open" lane for use by high-occupancy vehicles and for those other vehicles willing to pay a premium toll.

Automated Vehicle Location for Transit

Automatic vehicle location (AVL) systems calculate the real-time location of any vehicle equipped with a GPS receiver. Data are then transmitted to the transit center through radio or cellular communications and are used immediately to correct scheduling and other operational deviations. Data can also be archived and used for schedule and route planning, reporting, and performance analysis. Successful AVL and computer-aided design implementation can reduce fleet sizes by 2–5 percent. The Maryland Transit Administration reduced its fleet size in Baltimore to meet the same level of service, resulting in savings of $2–$3 million per year.

Approach for Bundling Technology

Technology can enable the smoother performance of roadway facilities in which there is at least one managed lane. The variable pricing imposed on a managed lane may apply to vehicles that carry less than an established threshold of occupants; however, variably priced lanes without barrier separation from non-managed lanes are not operated on a distinct facility that may become operationally sensitive to the flow of the non-managed lane. Variably priced lanes that have some separation from the other non-managed lane may also be influenced. The challenge is to apply a set of layered technologies that work to sustain the available flow for both the variably priced and non-managed lanes.

One example of coordinated technology exists on the I-15 corridor in San Diego. User fees are charged for single-occupant vehicles to access the HOV lane. Tolls vary dynamically with the level of traffic demand and are adjusted periodically in 25-cent increments. DMS, 511 traveler information, and Web sites communicate the adjusted charge to travelers along with information about travel time to select locations. Ramp metering is coupled with these technologies to further extend free flow and to delay the onset of congested conditions on the general-use lanes.

GETTING STARTED

Bundling technology involves planning to make the technology application suitable to the agency's business practices and to deliver desired outcomes. Many agencies have established transportation management centers to help better manage assets and to deliver a range of services to customers.

Planning the Technology Deployment

Successful intelligent transportation system (ITS) integration and interoperability involve two different yet fundamental issues: technical and institutional integration. To address this, the National ITS Architecture was developed to provide a common structure for the design of ITSs. The National ITS Architecture provides a common framework for planning, defining, and integrating ITSs. It is a mature product that reflects the contributions of a broad cross-section of the ITS community—transportation practitioners, systems engineers, system developers, technology specialists, consultants, and others.

The architecture defines the functions (e.g., gather traffic information or request a route) that are required for ITS, the physical entities or subsystems where these functions reside (e.g., the field or the vehicle), and the information flows and data flows that connect these functions and physical subsystems together into an integrated system. Establishing the National ITS Architecture enables agencies and other entities to coordinate their technology deployments to maximize operational efficiency and to minimize operation costs. Nearly every part of the United States has established regional ITS architectures to assist in their planning, design, implementation, and operation efforts.

Establishing Transportation Management Centers

Traffic management centers (TMCs) located throughout the Nation monitor and control traffic and the road network. These facilities manage a broad range of transportation facilities, including freeway systems, rural and suburban highway systems, and urban and suburban traffic control systems.

The TMC purpose is to monitor and manage traffic flow and to monitor the condition of the roadway, surrounding environmental conditions, and field-equipment status. TMC operators coordinate with maintenance and construction managers to maintain the road network. They coordinate and adapt to maintenance activities, closures, and detours. Incidents are detected, verified, and incident information is provided to coordinate public safety response. Information is also provided to drivers and local media outlets. TMC operators are engaged in responding to a range of incidents, from minor traffic incidents to major disasters. When required, special traffic management strategies are implemented to support evacuation and reentry.

The TMC supports HOV-lane management and coordination, road pricing, and other demand management policies that can alleviate congestion and influence mode selection. It also manages reversible-lane facilities and barrier and safeguard systems that control access to them. TMC operators in complex jurisdictional areas coordinate traffic information and control strategies in neighboring jurisdictions to promote the smooth flow of transportation operations across the available travel modes.

Implementing Coordinated Technologies

Integration of various technologies can lead to substantial gains in transportation system performance and agency effectiveness. One can consider integration of the disparate technologies as the opportunity to make the whole system greater than the sum of its parts.

Active Traffic Management

Active traffic management is a concept that relates to the ability to dynamically manage recurrent and non-recurrent congestion based on prevailing traffic conditions. By focusing on trip reliability, it maximizes the effectiveness and efficiency of the facility. Active traffic management techniques aim to increase throughput and safety through the use of integrated systems with new technology, including the automation of dynamic deployment to optimize performance quickly and without delay.

Active traffic management strategies include the following:

- **Speed Harmonization:** An application of VSLs that limits variation in travel speed along a highway section. Variation in travel speed is known to correlate directly with vehicle crashes.
- **Temporary Shoulder Use:** An application of lane-control signs and DMSs that temporarily increases roadway capacity during peak travel periods.
- **Queue Warning:** An application of DMSs at regular intervals that warn of the presence of downstream queues that may pose a crash risk.
- **Dynamic Merge Control:** An application of ramp metering and specialized ramp metering to dynamically manage or close specific upstream lanes. This approach offers the potential of delaying the onset of mainline congestion.
- **Construction-Site Management:** An application of traveler information and variable speed limits in which work zones are actively monitored to reduce the disruption to the remaining travel lanes.
- **Dynamic Truck Restrictions:** An application of DMSs, traveler information, and specialized ramp metering, this approach attempts to segregate large trucks from other travel lanes. The effect is a reduced risk of truck–car crashes.
- **Dynamic Rerouting and Traveler Information:** An application that coordinates traveler information and DMSs to provide positive guidance away from congested locations.
- **Dynamic Lane Markings:** An application that relies on lane-control signs and DMSs to clearly instruct freeway drivers about the use of a temporary travel lane along a shoulder.
- **Automated Speed Enforcement:** An application that has the potential to ensure compliance with active traffic management strategies and to

reduce congestion, the impact of incidents, and the impact of transportation on the environment.

Lane-management applications, such as temporary shoulder use, speed harmonization, and lane control, are particularly favorable to supporting congestion pricing. These approaches enable an agency to reserve capacity specifically for HOVs and those vehicles subject to fee for use. This is achieved without penalty for travelers who use regular lanes, and it can be implemented rapidly for a much lower cost than building the additional capacity that would otherwise be needed. Temporary shoulder use has been observed in Europe to delay the onset of congestion and breakdown, increasing the overall throughput of the facility. In the Netherlands, for instance, temporary shoulder use increased capacity up to 22 percent and traffic volume by 7 percent.

An illustration of this is the demonstration in Minneapolis under the U.S. Department of Transportation's (DOT's) Urban Partnerships program. To create and manage priced dynamic shoulder lanes, the Minnesota Department of Transportation will use many advanced technologies. To ensure proper and safe-lane usage, dynamic lane-assignment technology— including light-emitting diode arrows, in-pavement markings, and the like—will direct motorists precisely to the appropriate sections of the roadway. DMS will inform travelers about the availability of the lanes for non-bus use, toll rates when the lanes are available, travel speeds on the priced lanes versus on the general-purpose lanes, and also transit alternatives (i.e., park and ride) to driving on the priced lanes. Electronic signage will also provide substantial information about arterial travel alternatives to freeways for drivers trying to avoid priced freeways and to bypass incidents.[5]

Speed harmonization has been shown to reduce the mean travel speed and the crash rate in various locations in the United States and Europe. This approach minimizes the speed variance among vehicles along the roadway, allowing for safer and smoother access to freeways. This approach is being applied more frequently, with new deployments in Orlando, FL, and Washington, DC, where there is localized congestion that can pose a crash threat for upstream vehicles.

Reversible lanes can provide additional capacity for specific categories of vehicles (e.g., HOVs) or for priced vehicles by making use of unused capacity in the opposing direction travel lanes. This offers the opportunity to support bus rapid transit and other high-occupancy approaches while providing capacity on variably priced lanes.

Integrated Corridor Management (ICM)

Transportation corridors often contain unused capacity in the form of parallel routes, the non-peak direction on freeways and arterials, single-occupant vehicles, and transit services. These could be leveraged to help reduce congestion. Traffic information today is often fragmented, outdated, or not completely useful. Networks are often independently operated, and efforts to date to "reduce congestion" have focused on optimization of individual networks. The combined application of technologies

Photo credit: Minnesota DOT

Minnesota dynamic pricing DMS for HOT lanes.

and a commitment of network partners to work together have the potential to transform the way corridors are operated and managed.

ICM optimizes the use of existing infrastructure and leverages underutilized capacity in urban corridors. ICM institutional partners manage the transportation corridor as a system rather than using the more traditional approach of managing roadways as individual assets. The integration of operations programs, such as traffic-incident management, work-zone management, traffic-signal timing, managed lanes, real-time traveler information, and active-traffic management, helps maximize the capacity of all facilities and modes across the corridors and allows for greater mobility.

In an ICM corridor, because of proactive multimodal management of infrastructure assets by institutional partners, travelers could receive information that encompasses the entire transportation network. They could dynamically shift to alternative transportation options—even during a trip—in response to changing traffic conditions. For example, while driving in a future ICM corridor, a traveler could be informed in advance of congestion ahead on that route and be informed of alternative transportation options, such as a nearby transit facility's location, timing, and parking availability.

DMS are assets to ICM corridors and congestion pricing alike. Adequate display of travel times and the current charges can inform travelers who are considering use of a tolled facility. DMS applications on arterials can have a profound effect on traveler behavior.[6] Frequent traveler interaction with DMS and the traveler's perception of the DMS messages enable the traveler to make a more informed decision to remain on the arterial or to enter the tolled facility. Because nearly all travelers use an arterial prior to entering a limited access facility, the decision-making process can be heavily influenced. A study on this arterial–DMS interaction in Wisconsin demonstrates that 66 percent of travelers diverted their route at least once per month.

ICM relies heavily on the interaction of the freeway and arterial systems. Most critical in this interaction is the presence of real-time signal control. Real-time signal control for arterials that are intersecting the tolled facility can be combined with the application of DMS messaging to further improve the performance of congestion pricing. The perfor-

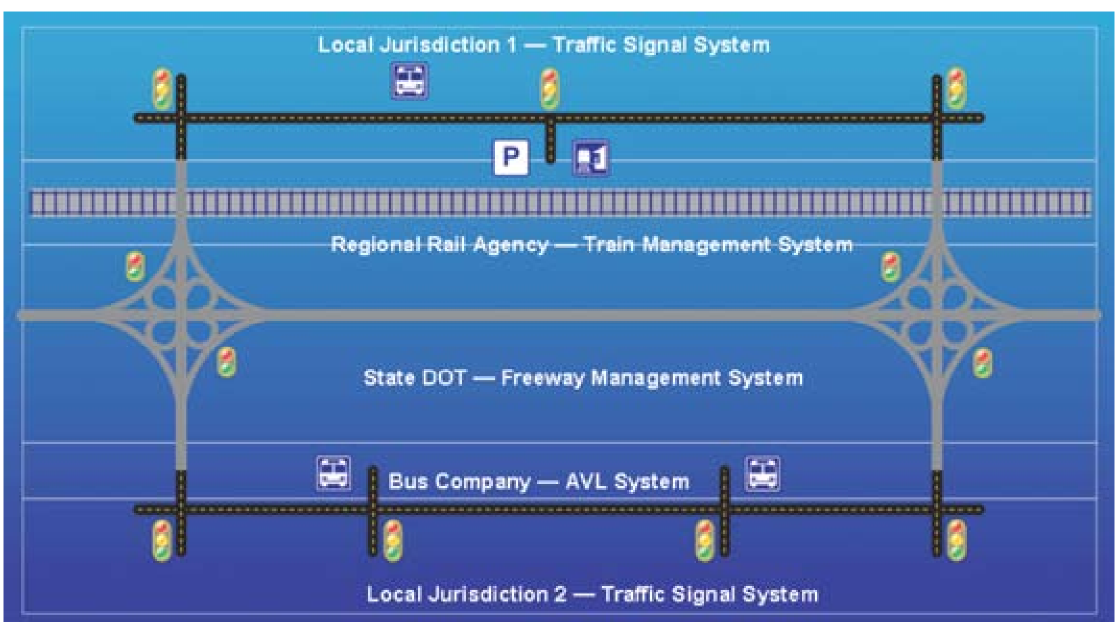

Photo credit: USDOT

Integrated corridor management concept. AVL = Automatic vehicle location.

mance of the limited access highway is often directly influenced by the performance of the arterial network with which it intersects.

Adaptive traffic signal control is a progression beyond real-time signal control in which automated adjustments to the signal performance are made based on measured traffic patterns. This can effectively couple an arterial system to a freeway based on the dynamic traffic conditions on the freeway, allowing for a greater free flow of vehicles to and from the freeway.

An example of this arterial management capability is demonstrated in Oakland County, MI, where the Road Commission of Oakland County implemented the Sydney Coordinated Adaptive Traffic System (SCATS). The SCATS provides the Road Commission with the capability to detect real-time demand and to adjust signal coordination to meet the demands. This helps to reduce congestion along freeway corridors and the arterial network by limiting unnecessary stops and by extending the green phases where demand is greatest.

Central Business District Considerations

The road space limitations for a central business district can be severe. The high density of commerce and livable space is known to generate a high number of trips, spreading the potential for congestion. Therefore, the challenge is to coordinate all the travel options to ensure that the use of road space is optimized.

The congestion charging in the central zone of London demonstrates the benefits of addressing the challenge. The congestion charge, together with improvements in public transit financed with revenues from the charging system, led to a 15-percent reduction in traffic in central London, and a 30-percent reduction in travel delays. There was no significant diversion of traffic to local roads outside the congestion-charged area. An effort to conduct cordon or area charging needs to consider the demands for reliable transit and the safety of pedestrians and bicyclists.

Travelers who enter the central business district or area in which pricing is implemented need to comprehend the charges they are incurring in order to motivate a modal change or other desired behavior. DMSs can be a tool to aid the traveler in comprehending the variable charges. In Singapore, variable prices are updated periodically and posed on DMSs for the different vehicle classifications. Commercial vehicles, motorcycles, and passenger cars are distinguished on these DMSs that are located throughout the central business district.

Parking management systems may have information dissemination capabilities. They are most commonly deployed in urban centers or at modal transfer points, such as airports. They monitor the availability of parking and disseminate the information to drivers, thus reducing traveler frustration and congestion associated with searching for parking. Information on parking options needs to be provided to travelers who may elect to change modes to a lower cost alternative, such as bus rapid transit. This information is useful in providing positive guidance to motorists seeking a parking location by helping them determine the availability of parking space and the parking charges.

A challenge in the central business district is the interaction of vehicles with pedestrians and bicyclists. Promoting the safety of pedestrians and bicyclists is critical in order to provide a sense of safety to those travelers who elect to change modes to transit, walking, and cycling, or a combination of the three.

Pedestrian and bicyclist detection has been applied in locations throughout the United States in order to extend the crossing time on streets and arterials. Pedestrian-activated lighted crosswalks; specialized pedestrian signals, such as countdown timers; and bicycle-actuated signals can further improve the safety of all road users at signalized intersections and unsignalized crossings. These safety applications have proven effective in reducing the number of vehicle–pedestrian or vehicle–cyclist collisions that would impede the flow of vehicles in the charged area.

PERFORMANCE MONITORING

All the congestion-pricing strategies are data-driven programs that require effective data warehousing and performance measurement. Many transportation management centers ingest vast quantities of real-time data from various sources on the operational status of the transportation system. These real-time data are used to effect operational decisions that span from incident management to facility control. Agencies increasingly realize that the real-time information of today becomes the archived data that influence agency performance tomorrow. For example, archived data can be used to assess the need to adjust variable toll rates and to determine the magnitude of the adjustment that might be needed.

Data Collection

Real-time data collection is essential for any agency that seeks to manage transportation assets. The value of a real-time information program to travelers is experienced at a personal level. Toll, transit fare, traffic, and travel conditions information is decision-quality information that allows travelers to choose the most cost-efficient mode, time of departure, and route to their final destination. This information should be easily accessed at a low cost in order to be useful to the average traveler. Timely and detailed information about transit vehicle arrival times, transit delays, traffic incidents, weather conditions, construction activities, and special events aid in improving travel time predictability, better choices, and reduced congestion.

The value of a real-time information program to transportation agencies is greater control of system-wide transportation assets. Information collection and dissemination are critical for enabling public agencies to provide for efficient Interstate movement of goods and to reduce the level of congestion commonly experienced in metropolitan areas.

Data Archiving and Performance Measurement

Archiving these data is critical to assess the performance of the transportation system based on decisions made at the transportation management center. Interpreting such archived data to determine the functional performance of the transportation network over time, to apply such performance-based assessments to prioritize capital and operating expenditures, and to set variable toll rates on congestion-priced facilities to maintain a consistent level of service is equally valuable.

Continuous evaluation of the congestion-pricing strategy is critical toward maintaining the public confidence in the congestion plan. Any region that is implementing a congestion-pricing strategy should (a) consider the performance measures that are most meaningful for assessing the effective performance of the system and (b) provide information to the public on a regular basis. There are vast performance measurement opportunities from archived data. Eleven of the 12 performance measures defined by the National Transportation Operations Coalition are based on direct measurement of the transportation network.[7]

An additional potential benefit enabled through performance measurement and data warehousing is the depiction of benefits. Aside from time savings that the congestion-pricing schemes yield, travelers may be able to calculate their personal contributions toward carbon emissions. Through cordon pricing in its central business district, London reduced emissions of particulate matter and nitrogen oxides by 12 percent and carbon dioxide emissions by 20 percent. In a similar vein, both Singapore and Stockholm experienced measurable decreases in carbon dioxide emissions. These societal benefits can be expressed in personal terms; thus, individual travelers gain an appreciation for the personal contributions toward improving environmental conditions.

Another benefit may be the ability of enhanced route planning to predict overall costs in advance of travel, thus establishing a basis for pre-paid travel for a predictable cost. This may enable goods movement delivery services to more fully predict the total cost of the congestion charges they may face and can allow them to transfer those costs to shippers or receivers.

Approach to Facilitate Retrofitting

Congested facilities can support the retrofitted through the practical application of technology. The challenge for an agency is to develop a concept of operations to prepare travelers for the transition. In 1964, Reuben Smeed led the development of a study for the British government to consider viable approaches toward establishing congestion pricing. The "Smeed Report" identified the following as operational requirements:[8]

- Pricing should be related to the amount of use made of the roads.
- Costs should vary according to location, time, and type of vehicle.
- Costs should be stable and known in advance.
- Payment in advance of travel should be possible.

Complementary technologies aid the traveler in comprehending and becoming acclimated to the cost for travel on a facility or into an area. The fact that the charges vary according to the volume of travel establishes a unique challenge, that is, correctly conveying the cost for a particular trip and conveying it so that a decision can be made to delay travel, modify the time of travel, or adopt a different mode of travel. This needs to be coupled with information regarding the reliability of the travel, including identification of any impedance that may present an unexpected delay.

I-95 EXPRESS EXPERIENCE

As part of the Urban Partnership Agreement between U.S. DOT and Florida DOT, the leftmost travel lanes of I-95 in South Florida will be converted to HOT lanes. In preparation for establishing this capability on the existing infrastructure, Florida DOT is applying a suite of complementary technologies to provide positive guidance for their customers. Florida DOT, itself, expresses confidence that with the improved driver information and with increasing familiarity of the public, the HOT lanes will operate smoothly.

The goal of the I-95 Express effort will be to maintain a high travel speed during peak travel periods by encouraging carpooling of three or more passengers and establishing a direct I-95 bus rapid transit service between Miami-Dade and Broward counties. Passenger cars with less than three occupants will be charged variable tolls throughout the day for use of the express lanes. In addition, trucks will be prohibited from the express lanes at all times.

The implementation of I-95 Express draws on traveler information, ramp metering, and DMSs to attain success. DMSs will be positioned at regular intervals to indicate the variable toll from the entry point on the express lanes to key downstream express lane exits.

I-35W EXPERIENCE

As part of the Urban Partnership Agreement between U.S. DOT and Minnesota DOT, the existing HOV lanes along I-35 will be converted to HOT lanes, and priced dynamic shoulder lanes will be established on one segment, offering a temporary travel lane during peak periods.

Minnesota's goals for increasing transit ridership on express transit routes, increased use of park and ride facilities, and overall improved transit and traffic mobility depend on DMSs and various traveler information outlets. Minnesota seeks to provide active information about the status of bus arrivals and parking space availability in order to encourage travelers to switch to the lower cost-transit alternatives. Minnesota will be monitoring the demand of the I-35W HOT lanes and priced dynamic shoulder lanes, along with the capacity of the park and ride lots, to determine appropriate congestion charges.

To increase user satisfaction, Minnesota will provide customers with comparative travel times for car and bus. This combined congestion and travel-time information will allow travelers to make informed decisions about the mode choice that they select. Along the arterials that run parallel to or intersect with I-35W, Minnesota will be providing transit signal priority to improve transit reliability, improve transit travel times, and improve transit user satisfaction.

Summary

Congestion pricing requires complementary technologies to promote and sustain a positive public perception. There are many different technologies available for consideration, and careful consideration of the technology is needed to define a technology solution that is tailored to suit the particular congestion-pricing approach that is under consideration. The complementary technologies have proven successful in several implementations throughout the United States and internationally. These technologies enable individual travelers to become more informed about their travel options and to begin to make travel choices that benefit the performance of the transportation system as well as satisfy their own personal needs.

Coordinated approaches that use complementary technologies reinforce the most economical personal choice for travel. Examples include pretrip and en-route traveler information products, active traffic management, and ICM. Traveler information is a critical technology for both enabling congestion pricing and sustaining the value of congestion pricing. Travelers require reinforcing information at regular intervals so they can be guided through the priced facility. DMSs and messages via 511 telephone-based traveler information have garnered high attention from transportation agencies, and travelers have grown to expect high-quality travel condition information.

Among the many criticisms of congestion pricing is that the cost of everything that is transported will increase and ultimately be passed on to consumers. Complementary technologies can be used to demonstrate that personal benefits can be realized through congestion pricing. One approach is to describe how congestion pricing yields a net reduction in the total cost of transport because of reduced travel time. Commuters can experience more reliable travel in a congestion-pricing scheme because the overall reliability of travel, including transfer across modes, will be vastly improved. Travelers will be able to interpret and develop an accurate expectation of their congestion-pricing costs, because they encounter consistent pricing approaches and remain informed about pricing strategies in advance.

Through the application of technology, an agency can enable greater public acceptance of congestion pricing because the public can better comprehend how the congestion-pricing scheme works as they use the transportation network. Paramount to this is comprehension of the congestion-pricing strategies for the facilities or areas that they enter. Travelers need to understand that there is a personal benefit from the congestion-pricing strategy, that is, that their surrender of a personally preferred travel choice in favor of a system-optimal travel choice ultimately yields a personal benefit. Complementary technologies can reinforce the motivation of the traveler to gravitate toward a lower cost, more reliable travel option by changing the time of travel or the mode of travel.

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