INNOVATIONS IN ROAD FINANCE
Examining the Growth in Electronic Tolling

Paul A. Sorensen, PhD, is an associate operations researcher at the RAND Corporation in Santa Monica, California. His research interests include highway and transit finance, transit systems performance, global supply chain policy, and alternative fuel infrastructure logistics.

Brian D. Taylor is associate professor and vice-chair of urban planning and director of the Institute of Transportation Studies at UCLA. His research examines the politics of transportation planning and finance and the demographics of travel behavior.

PAUL A. SORENSEN
The RAND Corporation
BRIAN D. TAYLOR
University of California, Los Angeles

This research examines the policy objectives, technical approaches, and political reactions associated with the current upsurge in electronic road pricing (ERP). The authors recently examined more than 90 implemented or proposed ERP projects around the globe, falling into four general categories: (a) facility congestion tolls, (b) cordon congestion tolls, (c) automated weight-distance truck tolls, and (d) distance-based user fees spanning entire road networks. Findings suggest that political and structural liabilities associated with traditional finance mechanisms—most notably motor fuel taxes—have motivated jurisdictions to explore alternatives such as local option sales taxes, public-private partnerships, and ERP. A compelling advantage of ERP is that it provides decision makers with what appears to be an effective tool for combating traffic congestion and automotive emissions. Meanwhile, many of the underlying technologies to support ERP have matured in recent years, enabling the rapid proliferation of experimentation and implementation in this arena.

Keywords: *transportation finance; road pricing; congestion tolls; cordon tolls; truck tolls; mileage tax; electronic tolling; intelligent transportation systems*

To pay for the development and maintenance of road systems, governments in the United States have traditionally relied on property taxes for local streets and fuel taxes for highways. At the time they were adopted, each of these tax instruments was viewed as a means of charging private beneficiaries for public investments in roads. Both, however, are burdened with political liabilities that have in recent years retarded their ability to raise sufficient revenues for addressing either street repair needs or increasing demand for highway use. In response, state and local government agencies responsible for streets and highways have scrambled to tap a variety of revenue instruments—such as the sales tax or general obligation bonds—that are not linked to the benefits of street system access or highway system use. Such trends raise important, and troubling, questions about the future of road finance.

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Against this backdrop in the United States of a gradual drift away from transportation finance mechanisms that link charges paid to benefits received is a nascent, but rapidly growing, countertrend around the developed world toward electronic tolling, also referred to as electronic road pricing (ERP). Although the promise and prospects for ERP—to manage congestion, reduce road damage, minimize emissions, and so on—have been examined extensively over the years, the recent burst in electronic tolling (including both field tests and fully operational systems) warrants collective examination and reflection. To date, many individual projects—in Singapore, in Southern California, in central London, on German highways, and so on—have been reported in great detail. In this article, we adopt a more synoptic perspective, examining a wide variety of significant ERP projects around the world to identify broad themes and trends in the transition from road pricing theory to tolling practice.

Against this backdrop of a gradual drift away from user fee-based transportation finance is a nascent, but rapidly growing, countertrend toward electronic tolling.

Our aim is to consider the implications of an international trend toward electronic tolling in the context of a general move away from transportation user fees in the United States. Accordingly, this article begins with a brief overview of the evolution of highway finance in the United States. Next, it explores the manner in which the recent introduction of a suite of new transportation and information technologies—ranging from global positioning systems (GPSs) and digital road networks to electronic transponders and satellite-based cellular communications—has fueled a renaissance in the development of innovative applications for road finance and travel demand management. These include congestion tolls for facilities and cordon areas, automated weight-distance tolls for trucks, and general-purpose, distance-based user charges spanning entire road networks. The research is based on careful review of recently implemented projects and innovative new proposals and draws not only on information presented in research papers, in press accounts, and on the Web sites of agencies responsible for the changes but also from background interviews with individuals involved with the planning and implementation of these systems.

Our synthetic analysis begins with a more detailed introduction to each of the distinct road pricing strategies listed above and then reviews the manner in which various innovative technologies are being used to implement these programs. Next, we evaluate the relative success or failure, both in terms of technical feasibility and the achievement of policy goals, of these new finance mechanisms. Where possible, we cite specific examples to illustrate typical outcomes; in certain cases, however, most notably for those projects still in the planning stages, it is only possible to speculate on their potential effects. In the concluding section, we consider the motivations behind the flurry of recent high-tech highway finance proposals, discussing how these motivations may point to the future structure of U.S. highway finance.

Recent Trends in Highway Finance

Tolls and levies on transportation facilities, ranging from roads to bridges to ferry crossings, are an ancient and well-established tradition. Ever since societies first began to develop formal transportation networks, either to facilitate friendly trade and cultural exchange or to pave the path for hostile incursion, it has been necessary to raise revenue to pay for the construction and repair of the facilities. With the advent and rapid growth of automobile usage in the 20th century, road networks have grown denser and more heavily utilized, and the need for transportation revenue has likewise intensified. In response, governments have developed often elaborate frameworks for collecting revenues for transportation.

In the United States, these include direct user fees, such as facility tolls, indirect user fees, such as fuel taxes, and other general revenue sources, such as property and sales taxes. For most of the 20th century, property taxes were the principal source of revenue for local streets, whereas fuel taxes have generated the vast majority of highway revenues (Brown et al., 1999). At the time they were adopted, these two principal road finance instruments were viewed as appropriate means of charging private beneficiaries for public investments in roads: In the case of property taxes, the value of private property increases with improved local street access; in the case of fuels taxes, the benefits of travel accrue to highway users in rough proportion to fuel consumed.

Such principled links between the costs and benefits of transportation systems have long been endorsed by most economists, who argue that transportation finance programs should, as much as possible, charge users the marginal social cost of travel (Murphy & Delucchi, 1998; Saleh, in press; Small, Winston, & Evans, 1989; Vickrey, 1963). However, a large body of research shows that the current transportation finance programs do not make users pay the marginal social cost of vehicle use (California Department of Transportation, 1997; Deakin & Harvey, 1995; Forkenbrock & Schweitzer, 1997; National Cooperative Highway Research Program, 1994; Pozdena, 1995; Puget Sound Regional Council, 1997), and the gap appears to be widening. For instance, to pay for highway maintenance and improvements in recent years, county, regional, and state agencies have increasingly relied on sales taxes and other forms of finance largely unrelated to highway use. As a result, highway finance in the United States is moving further away from marginal social cost pricing of transportation (Goldman & Wachs, 2003).

Why the move away from user fee pricing? Despite its many merits, the motor fuels tax is also burdened with political liabilities. Fuel taxes are typically levied on the volume of fuel sold, not the price. As a result, inflation and increasing vehicle fuel efficiency combine to erode the buying power of the fuel tax over time. This means that unless the per-gallon levy is regularly increased, fuel taxes gradually "sunset." Fuel-tax increases were commonplace during the first two decades after the World War II but have since grown increasingly rare and politically contentious; as an outcome of this political reluctance, fuel-tax revenues per mile of vehicle travel in inflation-adjusted terms are now less than half of the corresponding rates in the late 1960s (Brown, 2001; Rufolo & Bertini, 2003; Taylor, 1995; Wachs, 2003). Alarmingly, recent estimates suggest that the national Highway Trust Fund—the repository for federal fuel-tax revenues dedicated to federal highway and transit project—will reach a negative balance within the next few years (GAO, 2006), and many state-level transportation programs are facing similar crises.

Based on these factors, highway finance in the United States appears to be at a crossroads. One clear trend is toward a more ad hoc approach to funding, increasingly reliant on general revenue sources largely unrelated to use of the transportation system. But we also see evidence of a move toward more direct pricing of road use—one that is guided by marginal cost pricing principles, enabled by technological advances, and motivated by chronic transportation funding crises. The remainder of this article will focus on the evidence for and implications of a shift toward more direct road use pricing.

Recent Developments in Road Pricing

Despite the conceptual merits of marginal social cost pricing of roads, a variety of technical limitations have until recent years rendered such ideas impractical. For example, the motor fuels tax was originally adopted during the first third of the 20th century as an indirect distance-based user charge in place of a vehicle mileage tax because it was much easier and less expensive to administer than direct tolling (Brown et al., 1999). Similarly, because the primary method of collecting tolls—the manned toll booth—was slow and cumbersome, often leading to significant traffic delays, using tolls as a means of improving traffic flow was likewise impractical (to be sure, tolls were in fact applied to a limited set of facilities such as bridges, tunnels, and turnpikes, but in these cases, the primary motivation was invariably to retire debt for a specific facility rather than to manage traffic flow).

With the recent introduction of a wide variety of enabling technologies, however, such limitations on direct tolling are evaporating. In particular, research in intelligent transportation systems (ITS) has led to the development of new techniques that make it both possible and efficient to impose congestion fees or to charge vehicles directly based on the number of miles and the types of roads traveled. For example, both in the United States and abroad, planners

Table 1: Explanations for the Rapid Adoption of Electronic Tolling Applications

Motive	*Explanation*
Desperation	Eroding purchase power of existing road finance mechanisms
Efficiency	More efficient collection of tolls possible with electronic toll technology
Equity	Possible to charge users according to benefits received or costs imposed
Feasibility	Allows finance mechanisms that would not be possible to implement manually

and governments have already implemented a number of successful facility-based congestion tolls, area (or cordon) congestion tolls, and electronic weight-distance tolls for trucking. Several jurisdictions around the developed world are also currently expending considerable resources to investigate direct distance-based vehicle fees as a long-term replacement for the fuels tax.

Why the recent upsurge in new technology-driven transportation finance mechanisms? There are several possible explanations, the most obvious of which is a desperate shortage of available transportation funds. Given the eroding buying power of fuel taxes, any new program that promises to raise revenue (and possibly reduce the need for new capacity by influencing demand) is likely to generate interest. Another potential motivation is the desire to improve the efficiency of revenue collection mechanisms (by, for example, collecting tolls electronically rather than manually). In addition, some of the interest may be motivated by increasing recognition of the conceptual benefits of new finance mechanisms, such as the ability to charge users more accurately for the costs they impose on the system. Finally, it may simply be the case that the suite of new technologies now available allows planners to implement programs that they have always favored (for any or all of the above reasons) but never before been able to achieve. These motivations are summarized in Table 1.

The Approach Taken in This Study

It is likely, of course, that each of the factors above has played some role in the rapid adoption of new road finance mechanisms in cities and regions around the world. In the remainder of this report, however, we focus on the last of these: Specifically, to what extent has the introduction of new technologies fueled the increasing interest in and application of innovative road pricing schemes?

To answer this question, we conducted an international scan of electronic road charging programs—recently implemented, currently under development, or in advanced planning stages. To identify potential cases for study, we reviewed the research literature, conducted keyword searches on the Web, and contacted scholars and public officials working on electronic tolling to ask them about programs or projects that we might have missed. After identifying and reviewing almost 90 electronic tolling programs, projects, and proposals, we ultimately selected—based on the degree of technical and policy-related innovation—a smaller subset of approximately 20 cases for more detailed examination. For each of these, we performed detailed Web searches for relevant online documentation and press accounts in addition to reviewing the standard research literature. For many of the cases, we also conducted background interviews with key personnel involved with the programs. We now turn to the results of this investigation.

New Technologies and Their Applications

APPROACHES TO CHARGING FOR TRANSPORTATION FACILITIES

Among the tolling applications that we reviewed, transportation charges for road use can be categorized along two primary axes: first, the type of facility usage for which the fee is levied and, second, the manner in which the fee is calculated. In terms of the facility type, four common options have been proposed or implemented in recent years:

- Tolls on an individual facility, such as a highway segment, bridge, or tunnel
- Tolls on an enclosed cordon area, such as a congested central business district (CBD)
- Tolls on a set of linked facilities, such as a network of interregional highways
- Tolls on all road types throughout an entire road network

Regardless of the type of facility, the fee can be computed according to a variety of criteria, depending both on the characteristics of the vehicle and the nature of the travel. In terms of vehicle characteristics, the following options are possible:

- A flat fee
- A fee adjustment for the type of vehicle (e.g., truck vs. auto)
- A fee adjustment for the number of axles and/or weight of vehicle
- A fee adjustment for the emissions class of the vehicle (e.g., the European Union has specified several distinct emissions categories for trucks that correspond to different amounts of pollution emitted per unit of distance traveled)

A fee adjustment for the use of ancillary equipment that exacerbates road wear, such as chains or studded snow tires

- For travel characteristics, in turn, the following choices are available:
- A flat fee
- A fee based on distance traveled
- A fee adjustment for the types of roads traveled
- A fee adjustment for the prevailing level of congestion (by time of day, direction, etc.)

FOUR INNOVATIVE ROAD USER CHARGING SCHEMES

Although there are many possible permutations of the road pricing characteristics described above, our scan identified four novel, distinct, and relatively well-defined forms of road user charges that have been implemented or proposed in recent years.[1] These are:

1. Congestion charges on individual facilities
2. Congestion charges for cordon areas
3. Electronically calculated weight-distance charges for trucks
4. General purpose, distance-based user fees applied to an entire road network

Tolls on individual facilities have been around for years. Varying the amount of the toll based on the prevailing level of congestion, however, is a relatively recent innovation, one that has proven quite useful for managing the demand for scarce road resources in addition to raising revenue. Variable congestion tolls are typically applied to access-controlled facilities such as bridges, tunnels, and highways, and they can be implemented as HOT (high occupancy toll) lanes, as FAIR (fast and intertwined regular) lanes, or as managed lanes. With HOT lanes, single-occupancy vehicles can opt into free-flowing carpool lanes for a price that depends on the prevailing level of congestion (Fielding & Klein, 1997). With FAIR lanes, highways are divided into fast lanes and regular lanes, and any car traveling in the fast lanes (regardless of occupancy) must pay the congestion toll (DeCorla-Souza & Turnbull, 2001). Finally, with managed lanes, all vehicles on all lanes are charged—there are no free rides. Regardless of the specifics, however, all facility congestion tolling schemes involve the identification of the prevailing congestion levels, the calculation of the appropriate market-clearing price given these congestion levels, the communication of the price to drivers considering whether or not to use the facility, and the (usually) automated collection of the fees.

Congested cordon tolls, in which vehicles are assessed a fee for driving in a congested urban area such as the CBD, are also a relatively new development. And much like facility congestion tolls, the main purpose of cordon tolls is to manage the demand for scarce street and highway capacity, although they, too, can raise considerable revenues in the process. Depending on the scheme, cordon tolls can vary by time of day, but in their simplest form, they are structured as a flat rate that applies only during congested hours—typically, the morning and afternoon weekday peak periods. One of the biggest challenges to implementing cordon tolls is that there are many entry and exit points for a given area, which makes it more difficult to identify and charge vehicles.

Unlike congestion tolls, weight-distance charges for trucks have been around for many years. Although they have been popular with many highway officials, they have been bitterly opposed by the trucking industry as burdensome and costly. Over time, the number of U.S. states with some form of weight-distance fees has declined to just one: Oregon (Brown et al., 1999). This is primarily because of the fact that in the past their implementation has been rather cumbersome, relying on time-consuming and labor-intensive roadside weight checks and inspections of bills of lading and self-reported itinerary logs. Recently, however, there have been many efforts to automate this process. The primary goals of such efforts have been to increase efficiency, to prevent toll evasion, and to more fully capture the costs imposed by trucking activity. The latter is particularly relevant in Europe, where charges applied to trucks in one country, such as through fuel taxes, may not be shared with other countries through which the trucks may travel. Though existing and proposed truck tolling programs vary in detail, they tend to share several common technical tasks, such as noting when a vehicle enters or leaves a jurisdiction, determining the distance traveled by the vehicle within the jurisdiction, identifying the weight and/or class of the vehicle, collecting fees in a seamless manner, and identifying and flagging potential toll evaders. In addition, truck tolling systems may attempt to account for the types of roads traveled (heavy-duty highways vs. more fragile surface streets) and the time of travel (to encourage travel during noncongested periods), but to date these more sophisticated provisions have not yet been implemented.

Much like congestion tolls, proposals for the implementation of general-purpose, distance-based user fee systems encompassing entire road networks represent a relatively new development. Though this form of pricing could offer many benefits, the primary motivation behind such proposals is to develop a long-term replacement for the ailing system of motor fuel taxes. With respect to the stability of highway funds, the main advantage of a per-mile charging scheme is that the resulting revenue stream would be unaffected by changes in fuel economy or even fuel type.[2] Per-mile charges would still need to be adjusted periodically to offset the effects of inflation, but it is assumed that this could be achieved through some sort of automated indexing scheme. In addition to providing a more stable source of highway revenues, the idea of distance-based tolling is intriguing to many transportation analysts because the required support technology would also enable jurisdictions to implement additional forms of road pricing with relative ease. For instance, per-mile charges could be increased on urban roads during peak travel hours to reduce congestion, or they could be decreased for more fuel-efficient and less polluting vehicles to encourage reductions in the emissions of greenhouse gases and local air pollutants.

Of the four novel approaches to road pricing reviewed for this research, full network pricing is by far the most technically sophisticated. Necessary elements include identification of the geographical district in which a vehicle is traveling (such that fees may be apportioned to different jurisdictions) and calculation of distance traveled. Optional features may include identification of the specific roads on which a vehicle is traveling (such that charges can be differentiated by road type, if desired), identification of the time and region of travel (such that congestion charges can be applied, if desired), and determination of various vehicle characteristics (such that adjustments can be applied based on vehicle weight, number of axles, level of emissions, etc., if desired). To date, no such systems have been implemented. In recent years, however, several jurisdictions have developed detailed proposals for such a scheme.

Viewing these four different road pricing schemes in aggregate, a set of distinct technical tasks emerge: (a) detecting the entry or exit from facilities, (b) detecting vehicle presence within an area or jurisdiction, (c) detecting position on the road network or the specific

Table 2: Technical Tasks for Various Road Pricing Schemes

Road Pricing Scheme	*Entering/ Exiting Facilities*	*Presence in Area*	*Position on Road Network*	*Distance Traveled*	*Time/ Congestion Level*	*Vehicle Class/ Weight*	*Charges Owed*	*Data Communication*	*Data Storage*	*Payment/ Billing*	*Enforcement*
Facility congestion tolls	●				●	○	●	●	●	●	●
Cordon congestion tolls		●			●	○	●	●	●	●	●
Weight-distance truck tolls	○	○	○	●	○	●	●	●	●	●	●
General distance tolls		●	○	●	○	○	●	●	●	●	●

type of road traveled, (d) calculating distance traveled, (e) determining current congestion levels, (f) identifying vehicle weight and/or other characteristics, (g) calculating charges owed, (h) communicating with billing infrastructure, (i) storing data, (j) collecting payment, and (k) enforcing compliance. Table 2 relates the applicability of each of these tasks to the four different road user charging schemes discussed above. A solid circle indicates that a particular task in required for the charging scheme, whereas a hollow circle indicates that it is optional but not necessary.

ENABLING TECHNOLOGIES

In recent years, there has been a proliferation of new technologies that have helped to make various road pricing strategies, and their associated tasks, possible. Many of these have been developed as a result of the recent research focus on ITS (Shladover, 2002). As indicated in Table 3, the relevant technologies (not including more ubiquitous tools such as online banking and database systems) can be loosely grouped into three broad categories: sensing technologies, processing technologies, and communications technologies.

Table 4 provides an overview of the potential applications of each of these technologies with respect to the technical tasks identified earlier in Table 2.

Evaluating Existing Projects and Proposals

Generally speaking, the types of road pricing strategies discussed in this article, where implemented, have proven successful (and here we define successful in a functional rather than a normative sense, which we further define below). In this section, we briefly review where each strategy has been proposed and/or implemented and discuss in some detail relative successes and potential shortcomings.

DEFINING SUCCESS

To achieve widespread adoption, any pricing scheme must be both technically and politically feasible and in addition offer compelling advantages over current highway finance mechanisms.

Given that most of the projects and programs reviewed here have only recently begun operation or are still in development, we need to be very precise about how we define success. We begin by drawing a distinction between feasibility and desirability. For a strategy to be feasible, it must be possible to implement the necessary elements with existing technologies. Furthermore, the scheme must have some level of politically acceptance to ever see the light of day. Any real-world deployment of a road user charge that reaches operational status, then, demonstrates (by definition) technical feasibility and at least offers limited evidence of political feasibility. To achieve widespread adoption, however, the pricing scheme must not be merely technically and politically feasible but must also offer compelling advantages that make it more desirable than current highway finance mechanisms.

Table 3: Summary of Enabling Technologies by Category

Sensing Technologies	*Processing and Analysis Technologies*	*Communications Technologies*
Global positioning system (GPS): A system of earth-orbiting satellites that can be referenced to triangulate relatively accurate latitude, longitude, and altitude coordinates.	On-board units (OBUs): Vehicle-mounted computers that can read GPS coordinates, determine position on a road network, track distance traveled, and compute user fees.	Electronic transponders: Vehicle-mounted devices that transmit data to sensors on overhead gantries or road-side fixtures, frequently used for electronic tolling.
Digital cameras: Devices that can capture still shots or video of traffic streams.	Geographic information systems (GIS): Systems capable of determining position on the road network, given GPS coordinates and an accurate digital road map.	Smart cards: Small, transportable data storage devices that can be used to transfer information to and from an OBU.
Vehicle detectors: Devices such as repeater loops, often embedded in the roads, that can be used to sense passing traffic and congestion levels.	Automated number plate recognition systems (ANPR): Software that analyzes images of automobiles captured by digital cameras to detect the license plate numbers of vehicles that have passed by a particular location.	Dedicated short-range communications (DSRC): A microwave frequency used for broadcasting and receiving data over short distances and in real time between vehicles and road-side communication devices.
Weight sensors: Devices to measure the weight of a vehicle for the purpose of assessing a vehicle weight charge.		Global system for mobile communications (GSM): Long-range cellular communications facilitated by a system of low-orbit satellites.
Tachographs: Units commonly mounted in trucks that can be configured to sense and track a variety of data, including speed, time, distance traveled, etc.		

Table 4: Application of Technologies to Road Pricing Tasks

Technologies	*Entering/ Exiting Facilities*	*Presence in Area*	*Position on Road Network*	*Distance Traveled*	*Time/ Congestion Level*	*Vehicle Class/ Weight*	*Charges Owed*	*Data Communication*	*Data Storage*	*Payment/ Billing*	*Enforcement*
GPS	●	●	●	●							
Digital cameras	●	●									●
Vehicle detectors					●						
Weight sensors						●					
Tachographs				●		●					
OBUs						●	●		●		●
GIS	●	●	●	●							
ANPR	●	●									●
Electronic transponders	●							●			●
Smart cards								●	●	●	
DSRC	●							●		●	●
GSM								●		●	

NOTE: GPS = global positioning system; OBU = on-board unit; GIS = geographic information system; ANPR = automated number plate recognition; DSRC = dedicated short-range communications; GSM = global system for mobile communications.

And what are the elements of an effective road pricing scheme? Based on our review of the literature and discussions with key personnel involved with specific projects, we conclude that the road pricing schemes discussed here aim to achieve one or more of the following goals: (a) raising or preserving revenue, (b) charging users for the marginal social cost of use, (c) charging external (e.g., foreign) users, (d) streamlining the toll collection process, (e) reducing road wear (e.g., by pricing truck tolls to encourage lighter loads and more axles), (f) improving

Table 5: Relevant Goals for Road Pricing Strategies

Road Pricing Scheme	*Preserve/ Raise Revenue*	*Charge Full Costs*	*Charge External Users*	*Efficient Toll Collection*	*Reduce Road Wear*	*Improve Safety*	*Optimize Capacity*	*Reduce Demand*	*Improve Environment*
Facility congestion tolls	●			○			●	○	
Cordon congestion tolls	●			○		○	○	●	○
Weight-distance truck tolls		●	●	●	○	○		○	○
General distance tolls	●	○	○	○		○	○	○	○

safety (e.g., by reducing the number of vehicles traveling in a crowded urban area), (g) optimizing road capacity, (h) reducing demand for scarce road resources, and (i) improving the environment (e.g., by reducing congestion and/or offering price breaks for less polluting vehicles).

Table 5 provides an overview of the relevant goals, or motivating factors, most commonly associated with each of the four road user pricing strategies discussed here. A solid dot indicates that the goal is a primary objective for most of the relevant cases studies, whereas a hollow dot indicates that the goal is relevant for at least a few of the cases.

With these considerations in mind, then, we can evaluate the relative success, or at least promise, of these various road pricing schemes, based on evidence accumulated to date. First, if there are at least a few examples of operational deployments, then a scheme must be judged feasible. If the deployments have in practice met the relevant goals, then the scheme can be considered desirable as well (and, hence, successful). Usually, if a scheme is both feasible and desirable, then there will be not just a few but many operational deployments (or at least many in the planning stages).

FACILITY CONGESTION TOLLS: TECHNICAL AND POLITICAL SUCCESS

In terms of technical feasibility, political support, and practical effects, congestion tolls on individual facilities appear to be a resounding success.

There are many facility congestion tolls already in existence and numerous others in the pipeline, so such an approach is, by our definition, both technically and politically successful. To date, facilities for which congestion tolling schemes have been implemented include: SR-73 (USDOT, 2004), SR-91 (Sullivan, 2002), and I-15 (Brownstone, Ghosh, Golob, Kazimi, & Van Amelsfort, 2003) in Southern California; I-394 in Minnesota (Samuel, 2005b); the New Jersey Turnpike (USDOT, 2004); the Hudson River bridges and tunnels between New York and New Jersey (USDOT, 2004); the Katy Freeway/I-10 (Shin & Hickman, 1999) and US-290 (USDOT, 2004) in Houston; the 407 ETR in Toronto (McCallum & Parmar, 1999); the Namsan Tunnel in Seoul (Son & Hwang, 2002); and several toll roads in France (Lecoffre, 2003). Additional facility congestion toll projects that have recently been planned or evaluated include: the highways around Phoenix (USDOT, 2004); I-580 (USDOT, 2004) and I-680 (Bourgart, 2003) in Alameda County; the San Francisco Bay Bridge (Nakamura & Kockelman, 2002); I-25, US-36, and C-470 in Denver (USDOT, 2004); the Sawgrass Expressway in Broward County (USDOT, 2004); the Florida Turnpike and I-95 in Miami-Dade County (USDOT, 2004); GA 400 in Atlanta (USDOT, 2004); I-90 in Chicago (USDOT, 2004); 10 separate highway links in Maryland (Hoffman & Turnbull, 2001); I-40 in the Raleigh/Piedmont region (USDOT, 2004); Highway 217 in Portland (USDOT, 2004); the Pennsylvania Turnpike (USDOT, 2004); the LBJ Freeway (I-635) in Dallas (USDOT, 2004); I-35 in San Antonio (USDOT, 2004); I-495 in Virginia (Groat, 2004); SR-167 in Washington (WSDOT, 2005); and the highway electronic toll road network in Korea (Chang, Kang, Oh, & Jung, 2002). Furthermore, extensions are currently being developed for both the I-15 HOT lanes in San Diego and the Katy HOT lanes in Houston (USDOT, 2004). In most cases, the technical solutions rely on in-vehicle transponders communicating with overhead gantries, though in certain applications automated number plate recognition (ANPR) systems may be used instead.

Studies on the performance of several of these projects collectively suggest that they are indeed providing the anticipated benefits, particularly with respect to raising revenue and optimizing capacity. The I-15 HOT lanes in San Diego, for example, generate close to $2 million annually. Of this, about $1 million goes to covering operational costs, whereas the remainder is channeled to help subsidize express bus service along the same corridor. Varying toll prices are updated every 6 minutes, based on the current congestion level, to ensure free-flowing traffic in the lanes. As a result, drivers have an option to avoid congestion as long as they are willing to pay the price (Regan, 2004).

Despite initial fears that the I-15 HOT program would be perceived as "Lexus lanes," benefiting only the wealthy, in practice they have proven to be popular with both users and nonusers alike, a fact that does much to bolster the long-term potential for facility congestion tolls. In a survey conducted of 800 regular drivers along the I-15 corridor, including those who used the HOT lanes on a regular basis and those who did not, more than 90% of the respondents thought that it was valuable to have a time-saving alternative available, and more than 75% perceived the arrangement as being fair (Supernak et al., 2002). In terms, then, of technical feasibility, political support, and practical effects, the idea of congestion tolls for individual facilities appears to be a resounding success.

CORDON CONGESTION TOLLS: PROMISING BUT POLITICALLY CHALLENGING

As with facility congestion tolls, several cities throughout the world have successfully employed cordon tolls, including Ft. Myers (Burris & Swenson, 2002), Oslo and Trondheim (Odeck & Brathn, 2002), Singapore (Fabian, 2003), Durham (Goodwin, 2004), and London (Transport for London, 2003). Meanwhile, similar projects are being evaluated or planned in San Francisco (Samuel, 2006), New York (USDOT, 2004), Hong Kong (Clark, 2000), Jakarta (McBrayer, 1998), Dublin (Gibbons & O'Mahony, 2000), Genoa (PRoGRESS, 2003), Rome (Di Carlo, 2004), Stockholm (Dickinson, 2004), Bristol (Raje, 2003), and Leicester (Tyrer & Burton, 1998). From an implementation perspective, then, cordon congestion tolls are clearly feasible, though to date no consensus has emerged as to the best technical approach. Singapore, for example, has relied on on-board units (OBUs) with electronic transponders and overhead gantries at entry points, whereas London has pursued a strategy based on self-reporting (e.g., via the Internet) relying on ANPR for enforcement.

Two of the primary policy goals for cordon congestion tolls are raising revenue and managing demand, and current evidence suggests that these projects are indeed meeting these aims. During the first 6 months following the inauguration of London's program, for example, the number of daily auto trips into the charging zone decreased by around 60,000, leading to a 14% reduction in journey times to and from the zone, a 30% reduction in traffic delays within the zone, and a 30% improvement in journey time reliability. Public transit delays also dropped by about one third, and transit ridership increased dramatically. In terms of revenues, the charge program was projected to net £68 million in its first year of operation and £80 million to £100 million in subsequent years. All proceeds are channeled into public transportation improvement projects (Transport for London, 2003).

Both in terms of feasibility and desirability, then, initial experiments with cordon congestion tolls appear to be a success. There are, however, at least two obstacles that may limit the political acceptability of this type of charging program in many cities. First, unlike most current facility congestion tolls in which only a few of the lanes are priced, cordon congestion tolls are not optional; drivers must pay the toll each and every day that they enter the charging zone regardless of the route used. If high-quality transit alternatives do not exist, such a tolling structure may be viewed as a regressive tax on the poor and middle classes who have no option but to drive to work (Santos & Shaffer, 2004).

Second, if cordon congestion tolls reduce the overall number of visitors to an area, retail businesses within the charging zone may suffer. Indeed, within the first 6 months of London's operation, retail traffic at establishments within the zone fell by around 7%, but whether this pattern can be attributed to the congestion toll is unclear. Several other circumstances, such as a significant reduction in London's underground transit patronage because of system maintenance and construction activities, may also have played a strong role (Transport for London, 2003). Even so, it is clear that the perception of potential adverse effects to the local economy may be sufficient to generate significant political opposition. For example, in February of 2005 voters in Edinburgh, Scotland, rejected by nearly a 3 to 1 margin a proposal to institute a cordon congestion toll within the city similar to that of London; potential harm to the retail community along with the absence of high-quality transit options were both cited as primary reasons for the rejection (Dalton, 2005).

WEIGHT-DISTANCE TRUCK TOLLS: MIXED TECHNICAL RESULTS

To date, automated weight-distance truck tolls have been introduced in Switzerland (Balmer, 2004; Werder, 2004), Austria (Schwarz-Herda, 2004), and Germany (Rothengatter, 2004; RPPI, 2004; Ruidisch, 2004; Samuel, 2005a). Other countries considering or actively planning such programs include Australia (Koniditsiotis, 2003), Hungary (Timar, 2004), and the United Kingdom (Worsley, 2004).

The technical sophistication of the various operations and plans varies considerably. The Austrian GO program, for example, relies on a simple OBU that communicates, via dedicated short-range communications (DSRC), with overhead gantries spread throughout the highway network. For each gantry passed, an additional distance charge is levied, adjusted for vehicle category (size and number of axles) as a surrogate for weight. The Swiss HVF system, somewhat more complex, incorporates an on-board GPS unit that determines whether or not the vehicle is within Swiss borders. Whenever the vehicle is within Switzerland, the OBU records travel distance information from the tachograph, which is used in combination with the vehicle class to compute a fee. The OBU also communicates via DSRC with overhead gantries but mainly to verify correct OBU functioning and prevent toll evasion. The recently launched German Toll Collect system is even more sophisticated, with a user fee schedule that depends on both the number of axles (as a surrogate for weight) and the emissions class of the vehicle.[3] Toll Collect relies on GPS to determine both position and distance traveled on the Autobahn system and uses global system for mobile communications (GSM) to communicate billing data with the Toll Collect computer center. In theory, Toll Collect provides the greatest level of flexibility, allowing the potential to record and charge for the use of other road types as well. Such sophistication came with a steep price tag, though. Technical integration of the various system components proved more complex than originally anticipated, resulting in significant deployment delays of more than a year and a cost overrun of $875 million (RPPI, 2004). Although late, however, the program is now up and running smoothly, collecting around 450,000 tolls per day and metering around 22 billion vehicle-kilometers per year (Samuel, 2005a).

All of these programs share the goals of increasing system efficiency and recapturing external costs, and evidence to date suggests that they have been successful in these aims. From the viewpoint of political acceptability, the latter of these two issues has proven to be particularly important for European nations eager to ensure that foreign trucks passing through their borders pay their fair share of road maintenance costs and do not enjoy an unfair cost advantage over domestic trucks (Worsley, 2004). In addition to these goals, the Swiss program has been designed to raise the overall costs of trucking so as to encourage greater goods transport via rail (in fact, surplus revenues from the program are explicitly earmarked for the expansion and improvement of Swiss rail lines). To forestall opposition among the trucking industry, the Swiss program also allowed for an increase in the size of trucks allowed to cross through the Alps, thereby enabling trucking firms to achieve higher degrees of efficiency (Balmer, 2004). In summary, the concept of automated weight-distance tolls for trucking has achieved initial successes with Switzerland, Austria, and Germany, and other countries appear to be following their lead. The German experience, however, highlights the potential difficulties in achieving on-time and within-budget delivery when developing customized and highly sophisticated ERP applications.

GENERAL DISTANCE-BASED USER FEES: TOO EARLY TO TELL

Despite a recent flurry of field tests, to date there have been no implementations of general-purpose, distance-based road pricing schemes spanning entire road networks.

To date, there have been no attempted implementations of general-purpose, distance-based road pricing schemes spanning entire road networks. Conceptually, however, the idea is quite popular, as indicated by the recent flurry of research activity in this area. Examples include a study performed for the U.S. Department of Transportation by researchers at the University of Iowa (Forkenbrock & Kuhl, 2002), a technical feasibility research effort at the University of Minnesota (Nelson, 2003), a proposal developed for the Oregon Department of Transportation (Whitty, 2003), a trial program for the Puget Sound region (Puget Sound Regional Council, 2002), a conceptual design proposed by Malick (1998) that has received consideration in Australia and New Zealand, a trial program in Copenhagen (PRoGRESS, 2003), a modeling evaluation in Helsinki (PRoGRESS, 2003), a Dutch proposal termed Mobilmiles (Crawford, 2002; Dalbert, 2002), a feasibility analysis in Gothenburg, Sweden (PRoGRESS, 2003), a research study in Newcastle on Tyne in the United Kingdom (Thorpe & Hills, 2003), and a feasibility study for a pan-European road tolling project being conducted by the European Space Agency ("Satellites Will Soon," 2003). Of these, the study and demonstration projects in Iowa, Oregon, and the Puget Sound region are among the most sophisticated and advanced. For the Iowa and Oregon projects, the goals are to develop the technology to support distance-based pricing and demonstrate its effectiveness through real-world pilot tests; in Puget Sound region, the aim is to use similar technology to perform trials of networkwide distance-based congestion tolling. In all three cases, the adopted technology solutions have been successfully demonstrated, and the pilot tests are either underway or soon to start.

One of the clear motivations for these investigations is concern over the waning buying power of the fuels tax (especially in the United States) because of inflation, increasing vehicle fuel efficiency, and the anticipated shift to alternate fuel vehicles in the coming years (Forkenbrock & Kuhl, 2002; Whitty, 2003). Another motivation is to increase the equity of charges levied to ensure that all drivers pay in proportion to the costs they impose. Finally, as suggested by the Puget Sound study, the infrastructure required to support distance-based charging opens up the possibility of layering in other sophisticated pricing mechanisms such as distance- and time-based congestion tolls across entire urban road networks (facility congestion tolls can vary by distance, but they do not cover all road segments; cordon congestion tolls, in turn, include all road segments within the charge area, but do not vary by distance). Despite these potential advantages, however, the political feasibility of such pricing schemes is unproven. In the Netherlands, for example, the well-developed and extensively vetted Mobimiles proposal was killed in 2002 when a new (and in this case more conservative) government came to power (Crawford, 2002).

Within the United States, the primary political objections relate to concerns over privacy and the environment. With respect to privacy, some commentators have voiced concerns that the use of GPS receivers within vehicles could theoretically allow the government to monitor the travel behavior for all drivers on the road, resulting in a disturbing "big brother is watching" scenario. In terms of the environment, other critics worry that the replacement of the fuels tax (which results in higher charges for less fuel-efficient vehicles) with a flat, per-mile charge regardless of fuel use would decrease the incentive for purchasing fuel-efficient vehicles. Careful analysis by researchers involved with the Iowa (Forkenbrock & Kuhl, 2002) and Oregon (Whitty, 2003) studies, however, shows that both of these problems can be prevented through appropriate technical design and pricing policies. For example, the OBU can be configured to report aggregated rather than detailed data, and the pricing structure can be set up so that more fuel-efficient vehicles are assessed a lower per-mile charge than are less fuel-efficient vehicles (Sorensen & Taylor, 2005). Even so, many skeptics are not convinced, and overcoming these concerns represents an important challenge to the implementation of distance-based user charges.

Political considerations aside, a distance-based user fee applied across entire road networks is quite difficult to implement from a technical standpoint as well. Generally speaking, all of the proposals to date involve the use of GPS (either in stand-alone fashion or in combination with the odometer or tachograph) to determine position on the road network and distance traveled by road category, but beyond that there is little similarity. Some proposals call for GSM-based cellular communications (Malick, 1998), whereas others advocate radio frequency broadcasts (Whitty, 2003). Still others forego wireless communications altogether in favor of manual transmission of data via smart cards (Forkenbrock & Kuhl, 2002). A number of open questions related to policy and institutional structure remain as well, many of which influence the choice of technology. These include the level of user privacy protection, the structure of billing and payments, the nature of private vendor involvement, and the level and organization of public sector oversight. Many transportation economists and analysts have long argued the merits of comprehensive marginal cost road pricing (Murphy & Delucchi, 1998; Saleh, in press; Small et al., 1989; Vickrey, 1963); although still on the horizon, the many developments in electronic tolling reviewed here suggest that such an approach to road management and finance is now technically feasible if still politically in doubt.

Conclusion: The Road Ahead

Based on the trajectory of recent technical and policy-oriented developments reviewed here, the future of road pricing remains uncertain.

At one end of the spectrum, the new technologies allow us to simply replicate existing highway finance mechanisms, though often in a more efficient manner. For example, electronic tolling on bridges and toll roads (not involving congestion charges) can allow drivers to bypass queues at toll booths. Similarly, automated weight-distance trucking toll collection (even if revenue neutral) can allow trucks to avoid weigh stations and pay tolls in a seamless manner. Such innovations are largely nonthreatening to existing stakeholder interests because the relative contributions to highway finance remain more or less unchanged.

At the other end of the spectrum, these new technologies open the doors to many pricing options long advocated by economists and analysts but never before deemed feasible. Several of the schemes discussed in this article, including facility congestion tolls, cordon congestion tolls, and distance-based user fees across the entire network, fall into this category. Further in the future, we may see weight-distance truck tolls that sense current weight loads and account for different road types, time- and distance-based congestion tolls that apply across entire road networks, and variable emissions fees that depend not only on the vehicle type but also on the ambient air quality in the region through which the vehicle is currently traveling. Such changes have the potential to optimize highway systems by using prices to link highway users with the highly variable costs they impose on the system. Such changes, however desirable, are likely to redistribute the burden of highway finance costs among existing stakeholders. Experience suggests that losers in such redistributions are likely to object strenuously, whereas potential winners are far less likely to organize in favor of potential future gains (Fielding & Klein, 1997; Kahneman, Knetsch, & Thaler, 1991; King, Manville, & Shoup, 2005).

So to which end of the spectrum is the future of road finance likely to head? In part, the answer depends on the price tag for the technology involved, and this can vary enormously. Equipping vehicles with electric transponders and toll facilities with overhead gantries, for example, is relatively cheap, whereas equipping all vehicles with GPS antennas can be extremely expensive (on the order of $100 per vehicle or more). As such, it may be fair to assume that new technology will only be applied to existing pricing mechanisms (assuming revenue neutrality) if the savings gained by moving to a new technology outweigh the cost. On the other hand, expensive-to-implement solutions are likely to be deployed only if the costs are offset by increased revenue collections. This would likely the case, for instance, with distance-based congestion pricing schemes.

Another potential wildcard is the nascent development of public private partnerships for transportation infrastructure (Giglio, 2005). Although elected officials may lack the political willpower to increase transportation fees, private corporations are expected to earn a return on their investments, and innovative electronic tolling strategies such as congestion charges offer one of the most efficient ways to collect revenue and ensure high-quality service (in the form of free-flowing traffic) to customers. To underscore this point, two of the earliest facility congestion toll examples—the SR-91 express lanes in Southern California (Sullivan, 2002) and the 407 ETR in Toronto (McCallum & Parmar, 1999)—were developed by private firms.[4] More recently, the city of Chicago and the state of Indiana have sold, for billions of dollars, long-term leases on existing toll facilities to private firms, and it is expected that these corporations will implement various forms of electronic tolling to recoup their investments and generate an acceptable profit stream.

Regardless of this trend, however, much of the road network is likely to remain in public hands for many years to come. Accordingly, the future scope of innovative electronic tolling applications in the United States depends largely on whether the stakeholders in the current highway finance system—both winners and losers—allow increased fuel levies to breathe new life into usage-based pricing schemes or whether the new wave of general tax measures for transportation (such as the sales tax) continue to be popular with voters. If partisan stands against tax increases of any sort continue to harden, then revenue shortfalls may well accelerate the turn toward new transportation user fee schemes, implemented through electronic tolling technologies, sooner rather than later. What is clear from this review is that the technical obstacles to direct user fee charges have all but disappeared. The challenge to ERP, then, is no longer technical but political.

If partisan stands against tax increases of any sort continue to harden, then revenue shortfalls may well force a turn toward new transportation user fee schemes, sooner rather than later.

Notes

1. Within our study, we have not included applications of electronic tolling technology to standard time-invariant tolls on individual facilities such as highways, bridges, or tunnels. Although such applications are also on the rise, they do not represent an innovative form of road pricing but rather a more efficient method of implementing long-established pricing strategies.

2. Although most motor vehicles currently run on gasoline or diesel, it is anticipated that alternate-fuel vehicles running on electricity, natural gas, biofuels, or hydrogen will gain an increasing market share in the coming years. The current structure of the motor fuel tax does not provide a way to charge such vehicles for their use of the road system.

3. As an interesting side note, the initial instantiation of the German toll applies only to vehicles greater than 12 tons, which has spawned a new market for 11.9 ton trucks within the country.

4. The SR-91 Express Lanes were subsequently purchased by the Orange Country Transportation Authority, but the congestion pricing program has continued under the new public management.

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