Paper No: 09-0222

Paying for Roads in the 21st Century With TDP Pricing

November 13th, 2008

Paper word count: 6715
Abstract word count: 235
1 Table
2 Figures

Prepared for the 88th Annual Meeting of the Transportation Research Board

by

Bern Grush
Chief Scientist
Skymeter Corporation
101 College Street, Suite 227
Toronto, Ontario, MSG 1L7
Phones: [desk] +1 416 673 8406 [cell] +1 647 218 8600
E-mail: bgrush@skymetercorp.com

and

Gabriel Roth (Corresponding author)
Civil Engineer and Transport Economist
4815 Falstone Avenue
Chevy Chase MD 20815
Phone: (301) 656 6094
E-mail: roths@earthlink.net

Skymeter Corporation is involved in the development of TDP pricing systems and has a financial interest in the subject of this paper.

PAYING FOR ROADS IN THE 21ST CENTURY WITH TDP PRICING

by

Bern Grush and Gabriel Roth

ABSTRACT

On the basis of arrangements currently used in telecommunications systems, this paper describes a TDP (Time-Distance-Place) low-cost system for identifying road charges on all sections of a road network; billing road users appropriately; collecting payments at the designated rates; and crediting the providers of the roads on which the travel takes place; all without identifying the travellers.

The data used by the system are generated within secure in-vehicle metering units, in response to location information received from the Global Positioning System (GPS). Charge calculations are based on time of journeys ("T"); distance travelled ("D") and places in which the journeys are made ("P").

The amounts owed are collected by competing "Network Tolling Operators" (NTOs), which have no access to journey description data. The NTOs, in their turn, pay the appropriate road providers, in the manner of E-ZPass and similar systems today, revealing to them only the total volumes of traffic for which payment is made at the relevant rates.

The system described could be introduced on a voluntary basis, to co-exist with existing road payment systems. It could finance either a publicly- or a privately-provided road system, or one containing elements of both. It could also be used to bill road users for other services, such as street parking and "Pay-as-you-drive" (PAYD) vehicle insurance.

Recent tests indicate that the costs of such pricing systems need not exceed ten per cent of revenues collected.

INTRODUCTION

Electronic road pricing is often regarded as a way of reducing traffic volumes in congested areas and raising money for hard-pressed local authorities (*1*). It can achieve these tasks, but a reliable TDP GPS-based road pricing can do much more: Using technologies already developed for the telecommunications sector, it can provide a mechanism to charge for the use of all roads and, simultaneously, provide pricing signals and funding for road improvement. A TDP road pricing system can enable road users everywhere to obtain the road services they are prepared to pay for, and thus to include roads in market economies, in the manner of food, water, telecommunications and other necessities. It can also be used in non-market economies, to charge whatever prices are deemed appropriate by governments.

This modern method of comprehensively charging for the use of all roads requires the interaction of the following elements:

- A clear and identifiable road owner, or road service provider designated by the owner;
- A reliable and robust road-use metering system, secure in the protection of road users' privacy;
- A secure billing and collection system;
- A method of allowing road users to audit their charges
- A method of making correct payments to road providers;
- A method of admitting paying visitors to the network;
- An enforcement mechanism to minimize evasion;
- A convenient and reliable method of changing from the existing charging system to the new one; and
- A regulator to protect road users against fraud and monopolistic abuse.

Each of these elements is described below.

The comprehensive nature of the system is important, and essential to it. Road systems — and indeed transportation systems — are networks, often consisting of elements in competition with one another. Systems of pricing and investment that apply to some elements and not to others are likely to lead to evasion and distortion. To paraphrase Abraham Lincoln: Transportation networks "cannot endure permanently" half priced and half free.

The road charge system described in this paper is similar in many respects to, and builds on, that presented by Prof. David Forkenbrock at the 83rd Annual Meeting of the Transportation Research Board in 2005 (*2*). Recent developments in technology enable the Forkenbrock proposals to be implemented in greater detail and at lower cost.

Road Ownership

Each road segment should have an owner who is entitled to receive payments from road users in accordance with applicable laws. Road owners are generally state or local governments, but they can be private entities. They are responsible for maintaining and operating their roads in a safe manner, and for paying applicable rents and taxes. They have the power to delegate their responsibilities to others. For example, a state can designate a concessionaire to operate a road for an agreed period.

Vehicle Use Metering System

Recent work on different kinds of electronic metering systems has been summarized in the 2007 ITS-UK white paper "Technology Options for Road User Charging in the UK" (*3*). The authors concluded "the key technologies for charging and enforcement that could contribute to National Road Pricing are already commercially available."

Each vehicle participating in a TDP payments system requires an on-board unit (OBU) that can continuously, accurately and reliably record road-use by time and position. This must be done in a way to ensure that no vehicle is overcharged or undercharged as a result of timing or positioning errors. Global Navigation Satellite Systems (GNSS) such as GPS provide the only practical and affordable means to do this on an any-road, any-where basis.

There are a number of ways to construct such systems. The ITS-UK white paper distinguishes between ***"thin"*** systems, which means that location data are forwarded from the car to a data center where charges are calculated and billed using those data, and ***"thick"*** ones which means everything is handled inside the vehicle including payment, using, as in Singapore, smart cards. With *thin* models come a perception of privacy loss and high telecommunications cost, and with *thick* models come higher OBU and map-management costs (*4*). In this paper we present an ***"intermediate"*** design that alleviates these issues.

In all cases, a GNSS-based TDP system collects frequent, usually second-by-second, estimates of the vehicle position, which, when appropriately filtered, permit calculation of at least time of travel, distance, and road segment used. Depending on the specific implementation, such telematics systems may also meter speed, acceleration, emissions, idling, and parking, and can detect various forms of tampering activities.

To ensure the privacy of the vehicle owner and its operator, the OBU cannot be in any way connected to, or referenced by, any system that holds both vehicle identifying information and location information. In other words, the OBU must either calculate charges and settle payment within the vehicle (*thick*), or send out payment information that can *only* be used for billing and collection, without any reference to location information (*intermediate*). Thus, it must be possible to meter road-use without vehicles being tracked by an entity external to the vehicle.

There now exist technologies that record road-use and accept payment within the vehicle so that no location information is available outside the vehicle if payment is properly made. These operate in the same manner as the familiar navigation devices that display location information only to the vehicle driver, but they handle payment information rather than navigation advice. Currently, these devices cost $300 to $400, plus operating expenses, to keep internal mapping data up to date as roads and prices change. It is these attendant operating expenses, required to ensure that payment is always correct in a flexible and changing market, that inhibit the deployment of GPS-TDP payment systems. While device costs are likely to drop, experience with distributed databases teaches us that data-driven operating expenses are more likely to rise.

However, TDP pricing systems can avoid this problem and can also be made more flexible by having the pricing calculations made outside the vehicle in special facilities placed between the vehicle and the billing office. In the International Organization for Standardization (ISO) draft standard 17575 (*5*), the term "Proxy" describes such a facility. This permits an *intermediate* ("OBU-plus-proxy") system design that has the lower cost and flexibility of the *thin* model but the computational performance of the *thick* model. This is because the *intermediate* architecture permits an extreme form of compression so that journey data are dramatically fewer than in the thin model (saves telco and compute costs) and there is no need to move map data to the OBU as is expected in the thick model (saves telco and storage costs).

It is also possible to configure this system for full privacy. An analogous technology, which operates at a similarly high level of security and privacy, is already in use for billing anonymous cell phone calls (*6*). This billing information can then be passed to a Network Tolling Operator (NTO) *without vehicle ID and without location information.* The NTO will have the account holder ID matched to OBU serial number for credit accounts, but this account can be anonymous if the OBU has been pre-paid.

This approach, which can reduce OBU and operating costs by well over half, has major operational advantages. It makes it possible to avoid the high costs of distributing map and business rules databases, and to easily add services and make service changes, such as applying selective discounts to a subset of OBUs, adding individualized services, and providing richer online customer services. Such capabilities, which would require a highly complex management system for a fully on-board (*thick*) system, become far more manageable in this *intermediate* configuration. Consider the trouble that would be incurred to manage a vehicle population whose owners move an average of once every three years, and who may be entitled to discounts in the region in which they live if the requisite charge-management information is on-board only? Such personalized business rules are far easier to change, secure and audit at a billing office that knows the customer rather than within an anonymous, on-board metering service that knows only journey information.

Figure 1 illustrates a privacy-oriented, GPS-based tolling system with four critical parts: (1) inside the vehicle is an OBU that accurately meters road use; (2) these data are forwarded to a facility ("tolling proxy") that turns journey data (time, distance, place) into an anonymous billing feed that does not reveal the identity of the vehicle ("privacy shield"); and (3) the billing data are forwarded to a payment operator who matches the billing feed to either a pre-paid or credit account, then (4) collects on behalf of and distributes revenue to road providers.

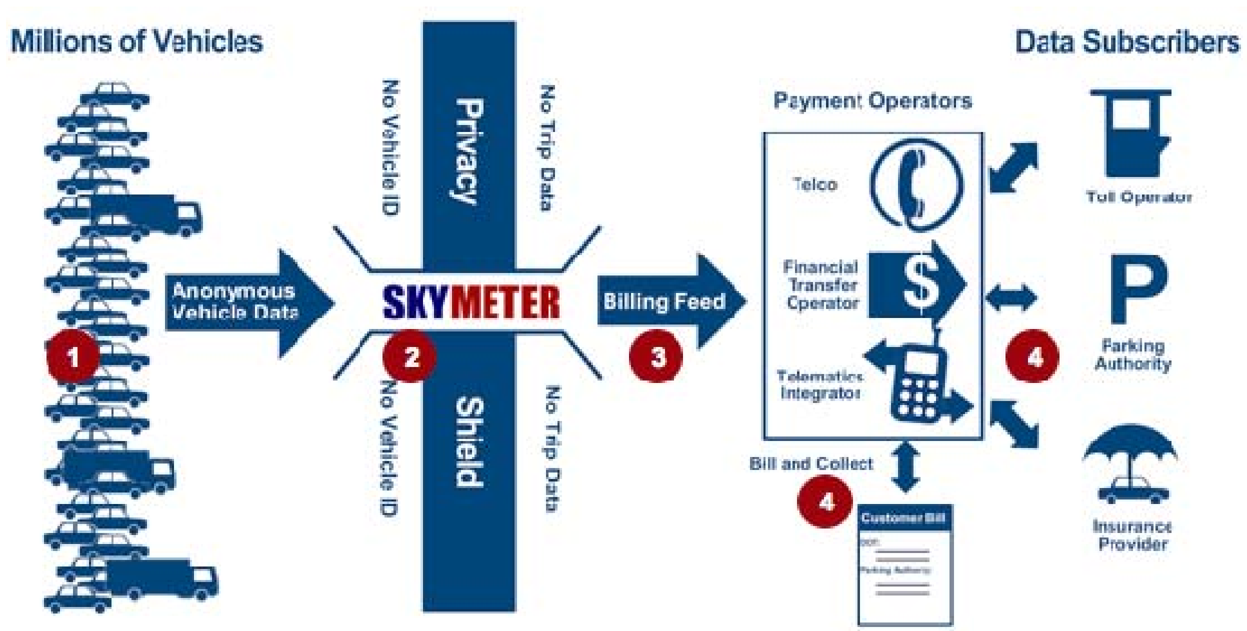

FIGURE 1: A privacy-oriented GPS-based tolling system design (*7*)

A fully in-vehicle system ("*thick*") is very expensive to provide, secure and maintain, and lacks the required flexibility. The "*intermediate*" TDP pricing system we describe (Figure 1), with travel information held securely in OBUs and an anonymous proxy, provides superior travel-privacy, while being much less expensive, more secure, and more flexible. And its mapping database and pricing rules can be edited at little cost relative to frequent updates to a fully-onboard system. Furthermore, its service programs can be extended as necessary with simple upgrades in processing and memory to the shared proxy – something that is impractical with the fully in-vehicle system.

This approach conforms to the Road Charging Interoperability (RCI) European Electronic Toll Collection Service (EETS) reference architecture (*8*) that "is the result of consensus among 26 European partners including the tolling operators, toll service providers, truck manufacturer and suppliers. The RCI architecture builds upon the roles and responsibilities as defined by the European operator community (ASECAP) and Member states (Stockholm Group) in the CESARE III project. It extends this role model with technical functional blocks and interfaces that have been derived from CEN/ISO work (such as 17575 and 15509)." (*9*)

OBU and Proxy Costs

Based on our engineering designs and best cost-estimates from our suppliers, the OBU described above currently costs from $120 to $150 in volumes of 100,000 to one million. Small manufacturing volumes currently cost twice this. Prices can be expected to fall after two years of feature enrichment and should settle at about $50 by 2013 or 2014. Installation costs, by vehicle owners, are nearly zero. Professional installation would be optional and the vehicle owner's responsibility.

The wireless telecommunication costs to move trip data from OBU to proxy for this particular system architecture is a couple of dollars per vehicle per month. The required average volume of asynchronous data moving from the OBU to proxies for 250,000,000 vehicles in the United States is well under 80MB – the equivalent of 20 iTunes songs – per second. Given a reasonable peak-to-trough ratio of 10:1, this is still a far smaller number than is commonly handled by telecommunications operators.

Processing costs to convert trip data to billing data would be under a dollar per vehicle per month. The wireline telecommunication costs to move billing data from proxy to the NTOs are negligible. There is however a one-time set up cost to arrange the "pricemap" — the database of Time, Distance and Place prices used to calculate road-use charges. Dynamic pricing can be set to update the price map as price changes occur. The on-board unit requires no change.

Since the same OBU and proxy combination can be used for several other applications, including charging for parking and "Pay-As-You-Drive" insurance, the monthly operational cost of TDP road-use metering is likely to be under five dollars including the monthly charge for renting the OBU.

Hence, depending on the scale of deployment, the applications used, and the level of charges, the costs of such a system will generally be expected to fall below ten percent of the revenues collected. One way to reduce costs to road providers is to use the same metering and payment system(s) for parking, PAYD insurance and other mobility payment programs, thereby distributing the metering costs among multiple sectors. In addition, there would be savings to cities from better management of parking (*10*) and to insurers from better management of insurance risks and reduced accidents. (*11*)

Other Costs

Clearly, the OBU and privacy-shielding Proxy, however cost-optimized, represent a cost higher than current radio frequency ID (RFID) transponders. For tolling large networks this cost is more than offset by the removal of the requirement for gantries to mount RFID readers or dedicated short range communication (DSRC) beacons. Hence, as a region or nation migrates from gas-tax dependence to TDP pricing, and as the lane-miles of roads tolled rises, this new generation of tolling technology will enjoy a lower total cost of ownership (TCO) than will current RFID-based systems.

For completeness, there are 3 others cost elements outside the scope of this metering sub-system: billing and collection, enforcement and guest management.

Billing and collection can be handled in the same manner as with current electronic toll collection (ETC) or open road tolling (ORT) systems, but they can also be handled very effectively by any billing operator. In fact, the business model for distributing, servicing, billing and collection for a personal (in-car) mobility meter is identical to that for a cell phone, as discussed below. Hence, billing and collection for this new technology will be at least as cost effective as it is for the current generation of tolling technology, and will achieve improved economies of scale.

Enforcement can be handled by mobile (vehicle-mounted), moveable (temporary, road-side) or handheld license recognition with integrated RFID/DSRC readers. Enforcement systems and policies should be designed to be self-funding from the fines generated. Hence, enforcement should be a profit center, rather than a cost.

Guests to any road network or parking facility – i.e., occasional users who do not have a meter, will have to acquire a temporary (day, week, quarter) pass to use those facilities (this is integrated with enforcement via "white-list" management). Guest-pass systems can also be designed to be self-funding based on a small, premium charge per-pass. Hence, guest-pass management should also be a profit center, rather than a cost.

Billing Systems

Billing for road use can be as simple as the methods already in use for the payment of cell-phone bills, despite the fact that a vehicle might use roads belonging to different jurisdictions or owners, having different charging rates, or to the same jurisdiction or owner but having different charging rates at, say, different times of the day.

This problem is relatively easy to solve with the *intermediate*, location-anonymous metering systems described above, as this approach uses well-known, proven, data-management and account management techniques common to mobile telecommunication operators already in place to handle "roaming".

An additional advantage of using the *intermediate*, OBU-plus-proxy, architecture is that the OBU can behave analogously to an anonymous handset in a cellular service while a system of payment settlement among the NTOs is analogous to payment redistribution among cellular service providers. The same architecture can be used to identify and route payments from road users to road owners, as well as to parking and Pay-As-You-Drive (PAYD) insurance providers. Such transaction systems are already robust, scalable to serve any population size, trusted and auditable. Because existing cellular operators operate them, these billing operators are positioned to be the NTOs that manage payment for road-use in the 21st century.

Allowing Vehicle owners Full Control Over Their Data

Billing systems require transparency, hence a road-use metering system must allow a vehicle-owner to audit charges and, in the case of commercial vehicle use, prepare expenses. This may be needed several days or weeks after a bill is received. For fleet managers, an ability to rapidly aggregate data from large numbers of vehicles is crucial.

Figure 2 illustrates just some of the trip and administrative data that are held anonymously at the OBU. These data are releasable to the proxy on demand or on a fixed schedule for use in creating a billing feed, for other pre-agreed applications, or for private user access. These data may or may not be visible to the driver at the OBU. Real-time visibility of a current price or the charge for an earlier trip requires extra hardware and telecommunication expense, adding about one or two dollars per vehicle per month, and is an option. However, visibility of a month's audit would be impractical at the OBU, and every additional information appliance in the vehicle potentially adds further distractions for the driver.

The limitations of on-board auditing and the expense of providing even a limited solution means that either deployment of online access or the processing and mailing of monthly billing statements — possibly both — will be required. Monthly billing statements would include only charges and road categories, such "May 2011, $31.40, City Cordon TDP fee, 104.67 miles" or "June 2011, $46.28, highway distance fee, 841.45 miles". Daily or hourly breakdowns are clearly possible, but an increase in billing granularity increases expense and diminishes privacy.

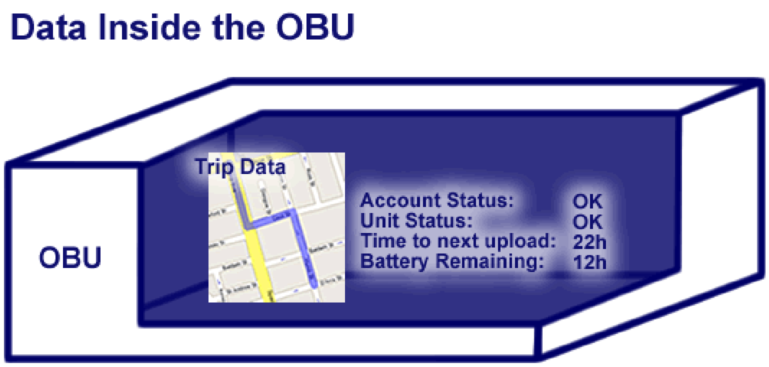

FIGURE 2: The on-board unit in a GPS-based-TDP system stores journey information, releasing it (encrypted) to the proxy on schedule or on demand. Batteries are replenished from the vehicle battery

In the OBU-plus-proxy system anonymous travel data can be securely stored in arbitrary volumes and for an arbitrary length of time at the proxy. These anonymous data are associated with an OBU serial number and could be accessed via the Internet, phone or kiosk, but only with that serial number and a private password that is set by the vehicle owner. Specifically, the only practical way any 3rd party can read data associated with a particular vehicle is to subpoena the vehicle owner's serial number and password. The proxy operator knows neither, and the billing operator can only know the serial number – or nothing if the OBU is anonymous and pre-paid.

Auditable Data

In the event that vehicle owners wish to appeal a charge, they may view any trip data still retained, secure and untampered, by the proxy. They can be viewed online in a geographic, temporal or combined frame: "Show me all journey data from May 6th between 11:00 and 19:00". Breakdowns of distance, and speeds are available but, most valuably, at each charge point there is a measure of certainty of the charge determination. This is used as evidence when distinguishing between parallel roads that may be only a few meters apart. In all cases, vehicle owners can examine the evidence used to calculate a charge, and use that evidence in refutation. Vehicle owners would be able to purge trip data after payment has been made.

A related concern here is that lane-specific use, e.g., in the case of HOT lanes, would require very exacting geo-coordinate tracking and could be subject to dispute. This concern can be mitigated in four ways:

- The on-line OBU can process location data to the correct lane in the case of open-sky (no buildings, etc) meaning that many stretches of roadway can be priced without error (the portion of lane miles where this is true will increase when Galileo comes on-stream);
- In those areas with buildings, tunnels, rock cuts, etc, where multipath errors may be generated, tests in Seoul have shown that Skymeter systems can precisely assess charges to properly debit the right vehicle and credit the right road provider;
- Alternatively, virtual gantries may be used, by creating short unambiguous segments that cannot be missed or confused with another;
- It is also possible to add roadside beacons, but this is not recommended for reasons of cost and aesthetics.

Dealing with Those Without Working Meters

It is doubtful that any form of on-board meter will be made mandatory — certainly not everywhere. Even if it were, we can expect visitors and others without working meters. For example, a meter may malfunction and the vehicle operator may wish to continue using her vehicle while waiting for its replacement. It will also be necessary to collect the legal payment from vehicles that do not have working on-board meters.

We identify three types of road users without working meters: compliant guests; non-compliant guests; and those with malfunctioning meters.

Compliant guests may acquire a "pass" for a fixed region and a fixed period, such as a day or week. This could be done by phone, web, travel kiosk, or convenience store wherein the driver would register payment against a registered plate number. This plate number is retained on a time-marked "white-list" of numbers indicating correct payment for road use. As vehicles use the roads, we can employ mobile cameras (handheld license plate readers equipped with short-range communication) to pick up plate numbers from non-meter users (the health signal from a correctly operating meter causes the license plate readers to ignore it). These numbers are recognized as being on the visitor white list or not (non-compliant guests, failed meters, tampered meters).

Non-compliant guests could be invited to pay the fees owed, as is currently done on Ontario's Highway 407 Express Toll Road. Legal action would be pursued against those who fail to pay.

Those with non-working meters could be either the victims of failed meters or carriers of tampered meters. All such cases would need to be pursued, and fines levied against those who tamper with their OBU.

The cost for such enforcement would be similar to that of current speed-trap systems, red-light cameras and the like. Of course there would be an incremental cost of linking and managing vehicle "white lists" (paid guests and meter users) and blacklists (scofflaws, meter tamperers) as well as processing of claims. The OBU we are describing is self-enforcing unless removed or tampered and because of the design of its memory and health signal subsystem which can be checked while parked and at speed.

The licence-recognition cameras would be installed and maintained by the road operators, who decide on their numbers and locations. Camera locations help to determine the distribution of visitor fees and citation revenues. The number of cameras would be determined by the road operators to ensure the desired intensity of enforcement. The level of fines could be determined by the need to achieve acceptable levels of compliance and cover all enforcement costs.

Paying Road Providers

The owner of each road segment determines the price to be paid for its use by different kinds of vehicles. The prices for road use can vary by time of day, by day of the week, and (to prevent excessive congestion) by the degree of congestion. Prices should be known in advance, and not be changed without notice, as required by law. Where prices are determined by actual congestion (as currently on Interstate route I-15 north of San Diego, and the Minnesota I-394 MnPASS toll lanes) the rules governing the changes have to be known, and the actual prices charged displayed at the entrances to the tolled roads, or optionally available on-board as described earlier.

Payments are made to the NTOs who in turn aggregate the amounts payable for the use of different road segments and, periodically credit the road owners with the amounts due to them. Payments can be made daily, weekly or monthly, as agreed among the parties concerned. To show the calculations on which the payments are made, the NTOs should generate tables showing, for each road segment, traffic totals, broken down to relevant categories such as vehicle classes and time of day.

An example of what such a report could contain is shown in Table 1, which is a mock-up of a payment statement regarding a single road segment that accompanies transfer payments from an NTO to a road owner. This type of statement can be enriched with high-resolution, aggregated travel information for use by road owners or governments. Even origin-destination reports can be developed while protecting driver anonymity by obscuring end-point information in order remove the ability to use data-mining to infer an individual driver's behavior.

TABLE 1: A portion of a payment statement accompanying a transfer payment

Date	Time	Charge/mi	Volume (Total veh)	Flow (veh/hr)	VMT	Revenue
May 16	24:00-06:00	$0.20	660	110	410	$82
	06:00-09:00	$0.50	4260	1420	2680	$1340
	09:00-16:00	$0.30	7350	1050	4510	$1353
	16:00-19:00	$0.50	4530	1510	2850	$1425
	19:00-24:00	$0.25	2550	510	1530	$765
	Totals		14200	592	9900	$4985
May 17	24:00-06:00	$0.20	780	130	465	$93

Determining the Prices To Be Charged for Road Use

It can be helpful to distinguish between three ways of paying for road use:

By mileage charges. The majority of through roads in the US are in competition with other roads. Their owners, whether private or public entities, might be left to determine the prices to be charged for their use, subject to regulation, as in the case of water or electric utilities. Another way of determining the prices would be to invite private providers to bid for concessions to provide clearly specified services, e.g. maintenance, traffic control, etc. The bidding could then be on the basis of the vehicle-mile rate to be charged to the road users, and paid to the concessionaires. The TDP systems described earlier could then debit users the agreed charges, and credit the revenues to the appropriate road owners.

By taxes on property. As the main function of local roads is to provide access to properties, their financing by property owners, by means of property taxes, could be appropriate. This is how street lighting is financed, also elevators in buildings, which provide vertical transportation. The levels of property taxes, and the amounts to be spent from their revenues on local roads, should be determined by the property owners concerned acting through local government authorities or through private associations, as in Sweden (*12*). It also seems reasonable that the same property owners should determine the charges to be imposed on other vehicles. For this to be done, a road pricing method is required that can distinguish between vehicles belonging to local property owners and vehicles owned by others. The TDP system described in this paper has this capability. In the absence of such discrimination, local communities can be devastated, as in many parts of Manila, by through traffic seeking to avoid priced or congested arterial roads.

By congestion charges. Excessive traffic congestion is associated with under-charging for the use of scarce road space, and TDP systems can help to relieve the congestion, debiting road users the charges considered appropriate by the road owners, or by governments. The economic literature suggests (*13*), (*14*) that the price to charge for the use of a congested road is the price that maximizes the benefits obtainable from that road. This price is the amount equaling the costs imposed by a vehicle on other road users, under the conditions prevailing after the imposition of that price. A lower price would result in too much congestion, in the sense that vehicles were imposing costs in excess of what their owners were willing to pay; a higher price would result in too little congestion, in the sense that vehicles were excluded even if their owners were willing to pay the costs their use imposed on others. There is a substantial literature on how to calculate the prices that optimize the use of congested roads (*15*), but little on how prices for road use are determined in practice. Operators of the priced segments of Routes SR-91 and I-15 in Southern California charge prices designed to offer uncongested travel corresponding to a Level of Service "C" (*16*). In Minnesota, Program Manager Ken Buckeye of the Minnesota Department of Transportation reported (unpublished data), that Minnesota aims to achieve on its I-394 MnPASS toll lanes traffic speeds in the range 50-55 mph, which are also consistent with Level of Service C.

Private road owners subject to competition would also be likely to attempt to charge prices that maximize the benefits from their roads (*17*), (*18*), because (in the absence of conspiracies to keep prices high on road networks) such prices tend to maximize revenues. This is because a private road owner would wish to allow on her road only vehicles whose drivers are willing to pay the costs they impose on others, which is the theoretical optimum price.

Congestion charges are controversial. They are mentioned here not to enter this controversy but to point out that, should they be introduced, the GPS-based TDP systems described in this paper can debit users the appropriate charges, and credit the revenues to the appropriate road owners.

Changing from Existing Road Charging Systems to TDP Systems.

Reforms in pricing and financing roads cannot be made at once, if only because the 250 million OBUs required for nationwide-coverage in the United States would take 24 to 48 months to produce and distribute. But it is not necessary to have complete coverage before the introduction of TDP charging. For a time, the old and new systems can be run simultaneously. This is an important element of the Oregon pilot program for replacing the present state road use charging system there by one based on miles travelled (*19*). The Oregon system is designed to give road users a choice: To continue paying the existing fuel taxes or to pay the new mileage charges instead.

Furthermore, when a new charging system is introduced, it would be desirable that, for an initial transition period, the decisions to change to the new system be made voluntarily by the individual road users concerned. If given the choice, road users may be expected to choose the system that is most economical for them, so the new system would have to be made attractive. Governments wishing to encourage the change could offer road users “stick and carrot” incentives to opt into new systems. The “sticks” could be increases in fuel taxes, not payable by those who switch to the new system; the “carrots” could be the elimination of annual license fees (The OBU, costing nothing to road users, could replace the license sticker) and the distribution of cash per-mile rebates equivalent to current fuel taxes dedicated to road improvement, say two cents per vehicle-mile for cars.

Consider the three types of payments discussed earlier.

Roads subject to mileage charges. Where it is desired to charge for the use of through roads (i.e. roads which are neither local nor congested) by mileage charges instead of by fuel taxes, the change could be offered as a voluntary one, as in Oregon’s pilot program. Inducements to switch could be given by offering the road users concerned remission of annual license fees and cash rebates equivalent at least to taxes dedicated to road improvement. The TDP systems record mileage driven and could easily process such credits.

Roads financed by taxes on property. These arrangements would not need to be changed. TDP systems could, as mentioned earlier, be programmed so that those who pay property taxes would pay no mileage charges while using the roads financed by their own taxes.

Roads subject to congestion charges. Congestion pricing would speed up traffic and thus benefit some road users, particularly those who place a high value on their time. But those “priced off”, particularly for journeys that cannot be effectively made by transit, could become worse off. Their objections could be mitigated by using TDP pricing methods to credit the accounts of road users in the area with additional payments, over and above those required to compensate for the switch from fuel taxes to mileage charges. Kara Kockelman and her colleagues have discussed these inducements as Credit-Based Congestion Pricing (*20*). The Puget Sound Regional Council is also investigating the potential of cash inducements to encourage the acceptance of congestion pricing. (*21*)

To encourage early change to the new system, the inducements could be made bigger for those who choose to switch earlier. At the end of the transition period, which could last for, say, five to ten years, the new system could be made mandatory and some of the inducement payments could cease.

Funding for the cash elements of the “carrots” could come from various sources, depending on the particular circumstances. In the case of the US and UK, the central (e.g. federal) governments are offering substantial grants to urban areas willing to introduce congestion pricing. For example, the US federal government offered New York City $354 million from the Urban Partnership program to introduce congestion pricing, and the UK central government offered the city of Manchester £1.5 billion for this purpose.

Regulation to Protect Road Users Against Monopolistic and Other Abuses

Users of the new system could be concerned about two of its aspects:

(1) That the prices charged by road owners for road use accord with relevant regulations and with posted notifications, and

(2) That the revenues collected by the NTOs are properly paid to the correct road owners.

Public utilities in the US are subject to regulation, and regulation of the road charging system could give road users confidence that TDP systems are properly run. A regulator could be appointed to ensure that road users are not victimized by monopolistic collusion or by fraud. The regulator, who should have access to all the necessary technical information, could be a federal official with offices in all the states in which TDP systems are operated. A federal official would be in the best position to apply lessons learnt in one state to problems arising in others, and so would be preferable to separate state regulators. But some may prefer state regulation.

The regulator's staff and offices could be financed by a small percentage of the revenues generated by the TDP systems.

Transit subsidies

Many (including the governments of Greater London and New York City) consider congestion pricing an appropriate source of funding for transit. While TDP pricing can be made consistent with the workings of the market economy, it can also enable governments to direct revenues for any purpose considered desirable, including transit subsidies.

Furthermore, even if roads were provided as part of the market economy, road owners would pay rent for their use of land, and appropriate taxes, thus transforming roads from public liabilities to commercial assets. In that situation, the revenues from rents and taxes would be available to subsidize transit.

Tests, Trials and Tenders

Tests of GPS road-use metering systems have been carried out in Abu Dhabi, Australia, the Czech Republic, Denmark, Dubai, France, Germany, Hong Kong, Hungary, Korea, The Netherlands, New Zealand, Singapore, Slovakia, Slovenia, Sweden, Switzerland, United Kingdom, and the United States over the past decade.

Test results reported by Transport for London in 2006 (*22*), which did not include Skymeter systems, "showed a significant improvement on previous trials in 2004/2005". While overall mean distance and charging errors still hovered in the 5% to 15% range, "the best-performing [TDP] system at the overall charging level had an average billing error of 0.86% and a magnitude of journey length error of 0.82%." Cisco-Skymeter test results in Seoul showed similar improvements between a navigation-grade GPS meter and a 'liability-critical" TDP meter in 2008. (*23*)

Such tests have shown the growing viability of using GNSS data such as GPS for the purpose of metering road use; a GPS-based system has been operational in Germany since 2005, another prototype system is currently being tried out in the Czech Republic. Slovakia is already in negotiations with a winning consortium for 100,000 units for Heavy Goods Vehicles for 2009. A number of the above-mentioned countries including France, The Netherlands, Slovenia, and Sweden are now planning or preparing requests for proposals for tolling or congestion pricing systems based on GPS technology.

The main points of concern through these many tests has been charging accuracy in built-up cities, system costs and privacy management. The solutions to these three issues developed by the Skymeter Corporation are:

- Accuracy is improved via patented systems within the OBUs positioning capabilities even in "urban canyons";

- System costs have been reduced by the application of numerous techniques taken from geographic information systems. They are also reduced by the use of an intermediate, "OBU-plus-proxy" architecture which also permits the deployment of billing and roaming systems of the telecommunications industry as well as sharing of the data management systems with other applications;
- Privacy and even anonymity are assured by the use of a proxy" in a way that completely separates journey data from vehicle ownership data.

CONCLUSIONS

On the basis of the considerations described above, and of tests carried out in Britain, the Czech Republic, South Korea**,** The Netherlands, Singapore, Slovenia, the U.S. and others, it seems likely that reliable, GPS-based TDP systems to price the use of roads could be applied on a substantial scale within one to three years**.** Such systems could be introduced gradually, on a voluntary basis, and enable road use to be priced as easily as current methods of charging for the use of cellular phone service.

GPS-based road metering systems could also bring substantial benefits by enabling insurers to better manage accident risks and local authorities to better manage street parking space.

By enabling road users to be charged at mileage rates designated by different road providers, and the payments thus made to be routed and credited to the relevant suppliers, TDP pricing could facilitate the integration of road use into market economies. Governments preferring "command" to market economies could also apply TDP pricing to roads under their control, as a convenient way of charging for road use at prices of their choice and crediting the revenues to whomever they deem appropriate.

The cost of GPS-based TPD systems could be less than ten percent of revenues raised, depending on the uses made the data and on the levels of road-use charges.

ACKNOWLEDGEMENTS

Thanks are due to Ian Catling, Ian Catling Consultancy (Intelligent Transportation Systems), www.catling.com; to Todd Litman, Victoria Transport Policy Institute, www.vtpi.org, for advice freely given in the past and for comments on an earlier draft of this paper; and to Lee Haber, Skymeter Corporation, for help in preparing the drawings and tables.

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