

A Mileage-Based Road User Charge Concept

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Abstract

This article presents a new approach for charging vehicles that travel on public roadways. The new approach applies intelligent transportation system (ITS) technology to the problem of assessing road user charges, enabling these charges to be fairer, more stable, and more flexible. This approach will be amenable to alternative forms of vehicle propulsion systems. Though very simple in concept, the new approach has required that a number of institutional and technological issues be resolved. Key to the new approach is a simple on-board computer that stores a record of actual road use charges. Periodically, this record is uploaded and transmitted to a data processing center; we refer to it as the collection center. The center bills a vehicle owner and reimburses the states, counties, and cities operating the roads on which the vehicle has traveled. The on-board system is simple, secure, and capable of protecting the user's privacy. Importantly, the on-board system enables a variety of user charge conventions. In its simplest form, this approach can be used to assess a vehicle-miles-traveled (VMT) user charge. With a VMT user charge, the computer would calculate road mileage actually traversed; it compares this mileage with that obtained through an odometer feed. It then applies appropriate user charge rates to the mileage traveled within each jurisdiction.

INTRODUCTION

At both the state and federal level in the United States, the primary method for charging road users is the motor fuel tax. In many ways this tax has served quite well. Road users are charged roughly on the basis of the amount of travel on the public road system. As such, motor fuel taxes have the desirable attribute of being a “pay-as-you-go” form of user charge. There are, however, several major shortcomings with motor fuel taxes including:

- an inability to generate the necessary revenue to provide quality transportation services in future years as hydrogen fuel cell vehicles and those with other new propulsion systems become more commonplace;
- high evasion, in the range of 10 to 15 percent for diesel fuel;
- increased fuel efficiency meaning lower receipts per mile traveled;
- no relationship to the type or cost of the facility being used or the level of service provided; and
- a weak relationship to the relative costs of particular trips such that some vehicle operators pay user charges that exceed the costs they impose, while others pay substantially less than their costs.

From the standpoint of efficiency, motor fuel taxes are not entirely satisfactory. Vehicle operators are not given signals to make them aware of the costs a particular trip may impose on society. With motor fuel taxes, it is not possible for government agencies to provide incentives to vehicle operators to change the nature of their road use, such as traveling on higher-standard roads or during off-peak hours.

The move away from state and federal motor fuel taxes must be accomplished with great care. When combined, fuel tax receipts at both levels of government account for almost two-thirds of all road user charges. In short, a very large amount of road financing capability is at stake. Placing greater emphasis of vehicle registration fees is not a good alternative. These fees have no relationship to the amount of road use and thus the cost of serving the traveler. Property taxes, which are a major source of revenue to finance local streets and roads, also have no relationship to road use. Visitors to a jurisdiction, especially through travelers, pay no property taxes directly, and indirect payments through patronizing local businesses are very limited indeed. Quite clearly, a new means for assessing road user charges is needed.

The purpose of this article is to present a system for charging road users that embodies as many attributes of an ideal system as possible. The key attributes of such a system include:

- a low cost of collection for both agency and user,
- a stable revenue stream,
- an ability to assess higher charges for users who impose higher costs,
- a low evasion rate,
- the ability to offer incentives for users to travel on appropriate roads and to spread their trips across time periods, and
- a procedure that is unaffected by the method of vehicle propulsion.

The approach to charging road users must not be burdensome, and it must be tamperproof, absolutely reliable, and a useful tool for achieving a variety of policy objectives. Perhaps of greatest importance, it certainly must not diminish the privacy of road users.

Fortunately, newly emerging technology makes it possible to design an approach to charging road users that avoids the problems and shortcomings of current mechanisms and that embodies the desirable attributes listed above. A wide variety of new positioning and computing equipment is collectively referred to as intelligent transportation system (ITS) technology.

To begin moving toward an ideal system of road user charges, we have developed a new approach that is intended to be practical and cost-effective. The new approach will enable a real-time assessment of road user charges that are based on mileage accrual and, in the case of heavy vehicles, the option exists to take into account actual vehicle operating weights and configuration, as well as on the type of road being traveled.

The simplest way to assess a per-mile road user charge would be to periodically record the readings of certified odometers. Virtually no additional equipment would be required, and because only the total mileage traveled over a given period of time would be recorded, user privacy would be protected. Such a system, however, has a fatal flaw—there is no reasonable way to apportion the road user charges that are collected among the jurisdictions (primarily states) where the road usage actually occurred. Quite likely, the jurisdiction where the vehicle is based would retain all user charges collected; as a result, jurisdictions that attract numerous trips from other jurisdictions (e.g., those with major tourist attractions or those that serve substantial through traffic originating elsewhere) would fare poorly.

Thus, a key requirement of a mileage-based approach to assessing road user charges is the capability to return the revenue collected to the jurisdictions in a manner consistent with where the travel actually has occurred. A related point is that each jurisdiction should be able to establish per-mile road user charges that are in accord with its needs and public policy choices. This said, the approach must respect the privacy of the traveling public, and it should incorporate the other attributes of an ideal user charge system as outlined above.

SKETCH OF THE NEW APPROACH

A simple graphical overview of the new approach appears in Figure 1. Key to the new approach is a simple on-board computer. The computer stores a record of actual road use charges. Periodically, this record is uploaded and transmitted to a data processing center; we refer to it as the collection center. The center bills a vehicle owner and reimburses the states, counties, and cities operating the roads on which the vehicle has traveled. The on-board system is simple, secure, and capable of protecting the user's privacy. Importantly, the on-board system enables a variety of user charge conventions. In its simplest form, this approach can be used to assess a vehicle-miles-traveled (VMT) user charge. With a VMT user charge, the computer calculates the number of miles actually traversed; then it compares this mileage with that obtained through an odometer feed. It then applies appropriate user charge rates to the mileage traveled within each jurisdiction. In a more sophisticated form, the new approach would enable a lower per-mile user charge for energy-efficient vehicles or others that help advance other societal objectives.

Charging autos

Inputs to the computer can be quite simple for autos, involving only a global positioning system (GPS) receiver, a fairly basic geographic information systems (GIS) data file, and the vehicle's odometer (for back-up data on distance traveled). The GIS file contains data that define boundaries of the respective jurisdictions, typically states. A receiver on board the auto uses GPS signals to determine the vehicle's

position.¹ The computer reconciles this position with the stored data polygons (a series of coordinates that define the boundaries of the respective states) to determine the state where travel has occurred; the miles traveled within that data polygon are used to compute user charges, which in turn are stored. When a vehicle crosses into another state, it enters a different data polygon; and travel within that polygon is used to compute user charges. Of course, substate polygons, such as those defining a metropolitan area, also are feasible.

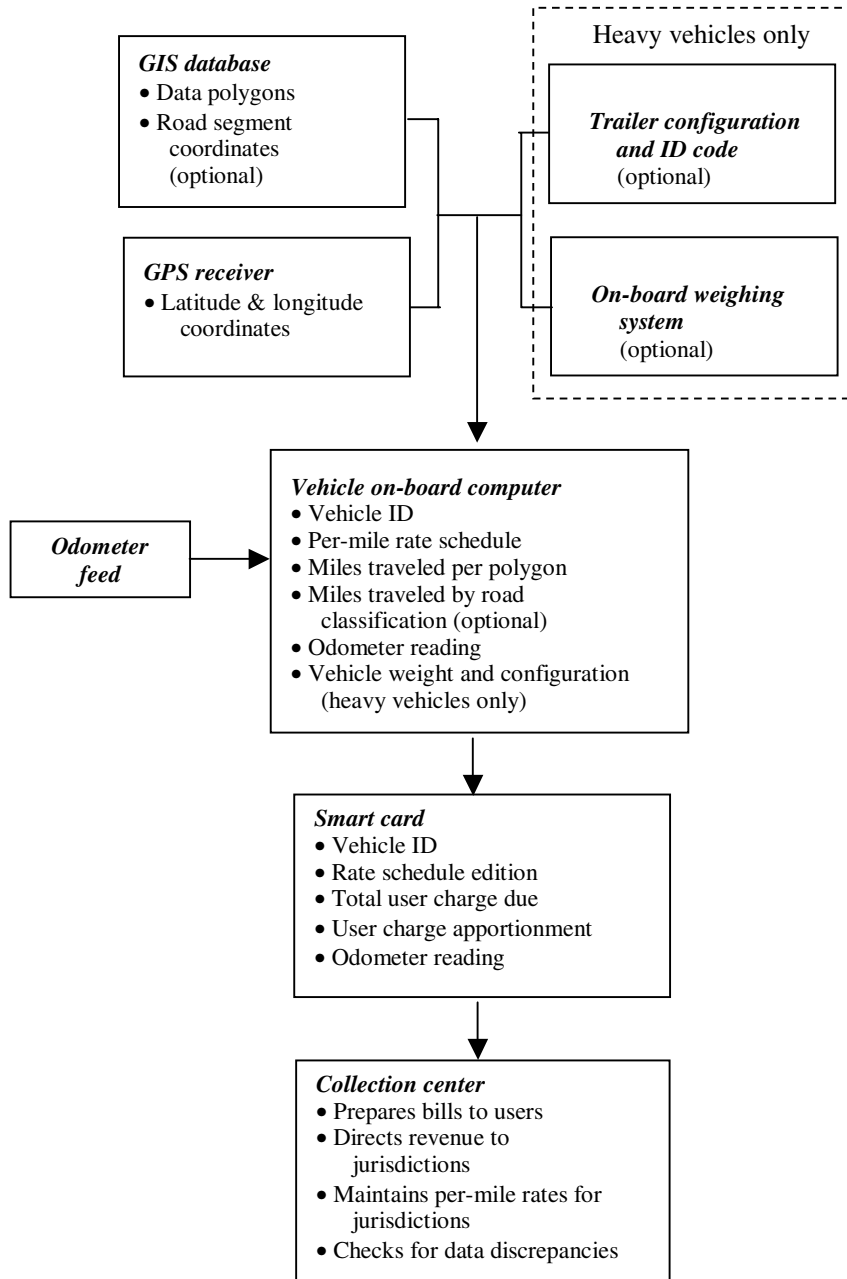


Figure 1. Overview of the new approach to assessing road user charges

¹ Good discussions of GPS principles and performance appear in Abbott and Powell (1), Earth Observation Magazine (2), Shaw et al. (3), and Fontana et al. (4).

The GIS file that defines polygons is stored in the on-board computer and is readily updateable. Periodically, the collection center transmits updates of the GIS file to the vehicle using a smart card as a “messenger.” A smart card is a small credit card-sized plastic device that contains an embedded computer chip in the form of a microprocessor and/or a memory module (see (5)). This technology was developed in France more than 20 years ago. Smart cards are very durable and should serve a typical user for the life of the vehicle. If the smart card is lost or destroyed, it can easily be replaced at a small cost to the user (a typical smart card costs less than \$5). Communication via a smart card is done using a reader that closely resembles the credit card readers found in nearly all businesses. Normally, the smart card occupies a slot in the vehicle’s dash panel. The on-board computer continuously updates the smart card regarding total user charges owed to each state or other jurisdiction defined by a polygon. Data transferred to the smart card, then, are in units of dollars. Before storing the data, the on-board computer will have (1) measured the distance traveled within each polygon, (2) applied the appropriate per-mile user charge as established by the applicable jurisdiction, and (3) calculated the user charges owed to each jurisdiction. Thus, the vehicle operator can remove the smart card at any time and insert into a reader to transmit the charges due to the collection center.

Why would a vehicle owner want to upload billing data promptly? A simple display on the instrument panel during vehicle start up displays the current user charges stored in the on-board computer. Each jurisdiction can choose to levy an interest charge for road use that occurred more than, say, 30 or 45 days in the past. The instrument panel display can show both current user charges and interest accrued. As the interest charges mount, the display will serve to encourage the vehicle owner to upload the billing data. Failing to upload data at all may result in a requirement to pay all user charges in arrears before receiving the next year’s vehicle registration.

During the data uploading process, the smart card authenticates the user and then anonymously uploads the road use information. When the collection center identifies the user, it checks for fraudulent behavior or malfunctions. If there is a problem, the smart card is notified to prompt the user to go to a service center; and the system flags that particular vehicle. During this communication, the collection center updates the vehicle’s rate schedule through the smart card, if the stored schedule is not current. The center also provides a one-time encryption key to the smart card to facilitate anonymous uploading of the user charges arising from travel in each jurisdiction. Once the collection center receives the information on how much mileage occurred in each jurisdiction, the center apportions the funds to the appropriate jurisdictions.

We stress that the transfer of apportionment data will be anonymous. It is not necessary to know which vehicle generated a particular sum of user charges for each jurisdiction; what is necessary is the amount to be apportioned to them. In every case, the total amount for all jurisdictions taken together equals the single value uploaded in the initial contact made by the vehicle via the smart card. Thus, the only figure that can be tied to a particular vehicle is a single dollar amount for total user charges and interest due, if applicable. This approach maximizes user privacy and ensures a fair distribution of revenue.

User acceptance of the new approach to assessing user charges could be increased if other benefits result. For example, navigation displays, now a costly option on luxury autos, could become standard equipment or a low-cost option. Nearly all of the components needed for such displays will be on board the auto; mass-producing them for all vehicles will be simple. Note, too, that looking a few years into the future, regardless of how user charges are assessed, traveler information displays are likely to become commonplace (their costs already are beginning to fall). In that case, adding the capacity to store road use information will be easy and inexpensive.

Another user benefit of the GPS/GIS system will be emergency location notification. The Advanced Collision Notification System, which is beginning to receive national attention, uses cellular transmissions to relay a vehicle's exact location to the appropriate service provider in the event of a crash, health problem, or mechanical breakdown. The protection this sort of system offers motorists is likely to be valuable to many people, but it will be especially beneficial to elderly drivers and those who travel in remote areas or unsafe parts of cities. It should be stressed, however, that the GPS system itself does not transmit any form of location data. GPS satellites only send radio waves that the vehicle's GPS receiver uses to calculate its location. GPS satellites are unable to receive any form of information from a vehicle.

Charging heavy vehicles

In the case of large trucks and other heavy vehicles, simple per-mile user charges could be instituted in a manner similar to that for autos. Optionally, these charges could be somewhat more tailored to take into account vehicle and roadway attributes. Like autos, heavy vehicles will have a GPS receiver and stored GIS information in the form of data polygons. Because privacy is much less of an issue with commercial vehicles, the polygon data could be supplemented with several levels of road classes. In this way, user charges for road use by heavy vehicles could be varied according to the standard of road traveled. For example, a state may choose to levy a lower per-mile charge for travel by heavy vehicles on interstate highways and other facilities that are capable of withstanding high axle loads without being damaged. The road user charges uploaded to the collection center can easily be made to reflect several different per-mile rates that vary with the standard of road used.

Especially in the case of heavy trucks, societal costs of travel vary substantially with the standard of road. Data from the 1997 Federal Highway Cost Allocation Study (6) indicate that the per-mile costs imposed by a heavy truck can vary by a factor of five, depending on the standard of the particular road being traveled. These costs also vary greatly with a truck's gross weight and configuration (i.e., number of axles). Small, et al. (7) contend that an 80,000-pound combination truck imposes pavement costs 34 times as great as one weighing 33,000 pounds. The same authors estimate that an 80,000-pound combination truck with six axles damages pavement about 41 percent less than a comparable truck with five axles.

A rather basic weight indicator would be activated each time the cargo doors are closed (in the case of a freight semi-trailer truck). The weight indicator, which is a simple strain gauge attached to the trailer's suspension, would transmit information to the on-board computer, indicating the current weight. A code would inform the computer about the configuration of the trailer, especially the number of axles. The computer then would take into account vehicle weight and configuration, along with type of road being traveled, in calculating the road use charges that are due.

It is noteworthy that the new approach eliminates the pitfalls of generally unsatisfactory methods such as weight-distance taxation: The uniform per-mile rate (regardless of current weight) of that approach is replaced with a much more flexible approach, and evasion will cease to be a problem. Of course, individual states can determine the extent to which they assess user charges based on the type of road being traveled or on vehicle weight and configuration.

It is noteworthy that with the new approach, motor carriers will benefit by the elimination of tollbooths; and interstate permitting can be automated. Also, opportunities that do not exist today become available; for example, by adding axles and traveling on higher-standard roads, operators can minimize their user charges. Both motor carriers and jurisdictions providing roads can benefit.

In summary, much less detailed data on road use could be collected from autos traveling on public roadways than from heavy trucks (e.g., those over 26,000 pounds). A standard per-mile user charge for autos will suffice quite nicely. Because of the considerable disparity in the costs imposed on society by trucks of different weights and configurations operating on roads of different standards, it is advisable to vary per-mile assessments for heavy trucks. Such variation in user charge structures would mean that more detailed data will need to be collected for trucks than for autos. As privacy requirements are very different for the two general types of vehicles, collecting the different levels of data should not pose much of a problem.

A STATE-LEVEL DATA POLYGON SYSTEM

To allay privacy concerns during the initial implementation phase, we suggest that no road-specific data be included in the road use file stored on board autos. Instead, only the boundaries of the 48 contiguous states (and possibly Alaska and Hawaii) should be stored (requiring only a very small GIS file). The on-board GPS receiver will position the vehicle within a given polygon (state). In this way, road use within each state could be recorded for uploading to the collection center. No data need to be stored regarding the specific roads traveled or the time of travel.

A graphical depiction of a data polygon system defining state boundaries is presented in Figure 2. The arrows depict both intrastate trips and those that begin in one state and end in another. For each trip, the on-board computer will store the appropriate data for road use within a given state before the vehicle crosses the boundary into a neighboring state.

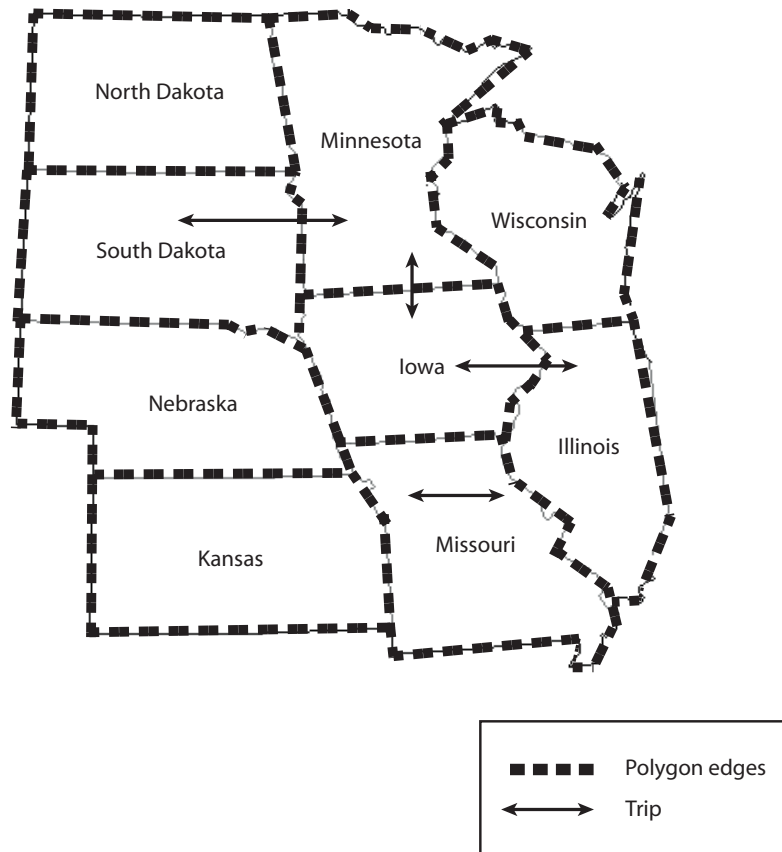


Figure 2. Example of state data polygons

Two options for data storage

Applying the smart-card technology, two different data storage options are workable: vehicle miles traveled (VMT) or total road user charges. If VMT data were stored, the number of miles actually traveled within each state polygon would be uploaded to the collection center. The center would apply the correct per-mile user charge for each state in which travel occurred, and the vehicle's owner would be charged for the total amount owed to the respective states.

Smart-card technology, however, also can enable the collection center to download to the vehicle the current per-mile user charge rate for all states when the vehicle operator uploads data on road use. It would thus be feasible for the on-board computer to multiply the number of miles traveled within each state by the applicable per-mile charge. If this were done, only one number would be uploaded for road use within each state—the total user charge due.

There are several advantages to the latter approach. It absolutely maximizes privacy and comfort on the part of the public that no data on miles traveled on particular roads or even in specific areas of the state will be stored. A second advantage is that it will be possible to display on a vehicle's instrument panel the current total user charge owed. For user charges that are delinquent beyond a certain period of time, perhaps 30 or 45 days, an interest charge could be applied to encourage prompt payment. This interest charge also could be displayed.

It is perhaps ironic that with this approach, if different functional classes of roads within a state had varying per-mile user charge rates, privacy would be further enhanced. Looking at someone's total user charge for a state, it would be impossible to determine exactly how many miles were traveled within the state; there could have been more miles traveled on lower cost, high standard roads or fewer miles driven on lower standard roads for which user charges may be higher.

Upon review of the pros and cons of each data storage option, we recommend the one in which user charges will be computed on board the vehicle, stored, and uploaded as a dollar amount to the collection center. Being able to inform users of their exact current total charge owed constitutes a major advantage. The slight improvement in perceived privacy also is an advantage worth pursuing.

Substate user charges

In time, once society becomes accustomed to the state-level mileage-based user charge, it very well may be the case that substate user charges will become attractive replacements for other less equitable means of financing roads. For example, local governments (e.g., municipalities and counties) could choose to replace property taxes with mileage-based user charges. In many locales, up to three-quarters of the revenue used to construct, maintain, and repair roadways is derived from property taxes. Out-of-town visitors generally do not contribute property taxes, but they impose costs comparable to those of local residents. By the same token, local property tax payers who make little use of the local road system pay property taxes regardless.

At some point in the future, it would not be difficult to update polygons to define substate areas, if the public supported doing so. Such polygons could coincide with the limits of a multi-government metropolitan area, a several-county area, or even a single community. Miles traveled within each polygon could easily be measured by the on-board computer and appropriate per-mile user charges applied to them for subsequent transfer to the collection center for inclusion in billings.

Eventually it may even be acceptable to record road use by type of road standard. Should that materialize, moving from a polygon data system to one based on coded road segments would not be difficult. The GIS files stored aboard vehicles would be replaced with updated, more detailed versions.

Beginning with a polygon data system and progressing to coded road segments would mean that more time will be available to geocode the many lower-standard roads across the country that do not appear in currently available GIS road files.

SYSTEM SECURITY AND PROTECTION

The new approach to assessing road user charges must be designed to cope with a wide range of security threats, ranging from individual attempts to subvert the system to avoid payment of charges to large-scale, coordinated attacks intended to disrupt operations of the system overall. These security threats can be effectively dealt with by incorporating the following features into the design of the system:

- Using an independent, reliable, and secure odometer signal as a validation mechanism. This odometer information will allow both the on-board computer system and the collection center to detect disablement or subversion of the GPS system as well as general system malfunctions. Digital odometer data are available on the vehicle data bus of all currently manufactured vehicles and commercial trucks.
- Providing an additional, completely separate and independent verification of the actual vehicle odometer reading to the collection center at periodic intervals such as at the time of license renewal or vehicle sale. This will allow the collection center to detect disablement of the on-board system or disablement/subversion of the data communications subsystem.
- Employing digital signatures to authenticate and validate all data uploaded from the vehicle to the collection center. This requires that each manufactured on-board computer be assigned an embedded private encryption key at the factory with an associated public encryption key that can be registered with the collection center (see Stinson et al. (8) and Stallings (9)).² With digital signatures, the collection center can authenticate the source of all reported data and can ensure that the reported data have not been altered or otherwise compromised. User privacy will not be sacrificed when the data are uploaded.
- Checking at the collection center for lack of reporting activity by vehicles for extended time periods to identify potential cases of in-vehicle system disablement or failure.
- Employing standard best practices in the design and operation of the collection center to minimize exposure to hacking and denial-of-service attacks.

Almost any modern information system poses at least some threat to personal privacy. In the case of the telephone system, detailed records are kept of calls placed to and from a given phone. For cellular phones, additional information is recorded regarding the cells from which calls originate; and, in fact, the movement of a powered-on cellular phone can be traced through cells even when no calls are being made. Even everyday activities such as paying for purchases by credit card generate recorded time and location information. While the new approach to assessing road user charges cannot guarantee absolute protection of personal privacy, there is no need for such a system to compromise personal privacy to a greater extent than is routinely accepted in today's society. Specific steps that can be taken in the design and operation of such a system to minimize its intrusion on personal privacy include the following:

- Limiting the amount of specific time and location data that are stored and reported by a vehicle's on-board system.

² Once data are encrypted with a public key, only the corresponding private key can decrypt it. A public key cannot decrypt a message once it has been encrypted. At that point, only the private key can be used for the decryption. A cryptographic system that uses both public and private keys is referred to as asymmetric encryption. Note that public keys are used only with asymmetric encryption.

- Encrypting any potentially sensitive data that are stored in the on-board system using a local, embedded encryption key that cannot be revealed by the system to any external entity.
- Encrypting all data communicated to the collection center using asymmetric encryption. In this case, the encryption should be done using the collection center's public key so that the data can be decrypted only via the collection center's closely held private key. The collection center should change its private key frequently to minimize the potential of discovery by an outside entity.
- Reporting data anonymously where possible.
- Employing standard best practices in the design and operation of the collection center to prevent unauthorized access to any potentially sensitive information stored there.
- Enacting appropriate regulatory and statutory controls on the collection center to minimize the potential for misuse of collected data.

System security and protection are critical aspects of the new approach to assessing road user charges. Each of these aspects brings its own complexities and trade-offs, but there is nothing in the concept of the new approach that should preclude achieving these important qualities.

GPS/GIS reliability and accuracy

The use of GPS data and an associated GIS database to accurately determine a vehicle's location on a given road segment is clearly of central importance to the automated road usage charge concept. The two major robustness issues for the GPS/GIS subsystem are accuracy (not generally a problem) and the ability to deal with a transient loss of GPS signal. Any GPS system will be subject to temporary loss of GPS signal due to physical obstructions, atmospheric conditions, or other periodic conditions. It is therefore necessary that the new approach include mechanisms to compensate for this loss.

To provide back-up information, various types of software-based schemes, such as dead reckoning and motion prediction algorithms could be used. Dead reckoning algorithms typically extrapolate an expected vehicle motion path from past motion history (IEEE (10), Caldwell (11), and Wood and Mace (12)). If necessary, they can also employ a predictive vehicle motion model that utilizes control signals derived from on-vehicle sensors (e.g., accelerations, velocity, and steering angles), although this would be quite difficult to implement for the new approach because the predictive model must be vehicle-specific. Various dead reckoning algorithms have been developed and used extensively in various applications ranging from the U.S. Department of Defense's Distributed Interactive Simulation (DIS) program (10) to video games (11). However, even sophisticated prediction algorithms can only accurately track vehicle trajectory for short periods of time without recalibration to a known location.

For short losses of GPS signal, relatively simple interpolation and extrapolation schemes will probably suffice because the cost (in terms of assessed road use charge) of inaccurately placing the vehicle for a brief time interval would be negligible in most cases. Only if the vehicle were operating near the edge of a data polygon would there even be an issue. For longer losses of GPS signal (e.g., a vehicle operating in an "urban canyon" environment, or in the event of GPS system failure) some alternative form of approximating vehicle movement will be needed. The simplest alternative is an independent odometer that is sampled and maintained by the on-board system. Coupled with the knowledge of the vehicle location at the onset and end of GPS signal loss, data generated by the odometer may permit a sufficiently accurate approximation of the vehicle's location during the signal loss period to permit appropriate user charge allocation. To provide more accurate directional tracking, a relatively basic inertial chip or simple rate gyro may prove valuable although slightly more costly. Extensive

prototyping and experimentation will be needed to determine the best solutions for the new approach to assessing road user charges.

Extended GPS subsystem malfunctions (i.e., on the order of weeks or months) could be detected from uploaded vehicle data (e.g., discrepancies between the GPS-based road user charges and the odometer reading), and vehicle owners would be notified to undertake needed repairs. Escalating charge schedules could be used to motivate owners to effect these repairs in a timely manner. This would also be an effective means of dealing with deliberate disablement of the GPS receiver as discussed below under the security heading.

DATA UPLOADING

A critical element of the new approach to assessing road user charges is the communication and management of road-use data. This includes acquiring data on the vehicle miles traveled (VMT), maintaining current rate schedules for user charge calculations, computing applicable road user charges, storing the charges, uploading this information to the collection center, and error checking. For data communication and management to be carried out well, the key attributes of privacy, reliability (including robustness and redundancy), security, and user convenience must be emphasized.

The “messenger” between the vehicle and the collection center is a smart card, a small credit card-sized plastic device that contains an internal embedded computer chip in the form of a microprocessor and/or a memory module. The technology was developed in France more than 20 years ago. Smart cards are very durable and should serve a typical user for the life of the vehicle. If the smart card is lost or destroyed, it can be easily replaced at a small cost to the user (a typical smart card costs less than \$5). Communication via a smart card is either done through a short-distance wireless communication link or through direct physical contact with gold contact plates on the surface of the card. In the new approach to assessing road user charges, a direct-contact smart card is most appropriate; it contains a microprocessor with internal memory.

Several smart-card frameworks are in widespread commercial use. These include Sun Microsystems’ Java Card technology and Microsoft’s SmartCard for Windows. These frameworks support mechanisms for customizing smart cards for various applications while providing protection of data and programs stored on the card and secure communication of data to and from the card. An example of this type of smart card is depicted to the right. Smart cards can have built-in encryption modules that allow them to be used for applications requiring high security. Currently, smart cards are being used to store electronic money, PIN numbers, and cryptographic keys. Some applications even use smart cards for personal identification, which depends on biometric technology such as fingerprints and retina scans.



In the new approach to assessing road user charges, a smart card can be used as an intelligent and flexible interface between a vehicle’s on-board computer and the collection center. This technology does not require specialized infrastructure at refueling stations. The importance of this becomes clear when one considers advances such as electric vehicles, which do not require conventional refueling stations, they constitute an appropriate application of this technology. In the initial phase of implementation of the new approach, vehicles could also take advantage of the smart-card approach until the refueling infrastructure adapts to support a more user-friendly, direct connection to the vehicle through its refueling point.

A rate schedule downloaded from the collection center and stored in the on-board computer enables a road user charge to be computed for each jurisdiction using the incoming VMT information. While the vehicle is in use, a smart card is connected to the vehicle's on-board computer and is constantly updated with road user charge information. When a user wishes to upload his or her road use information, the person removes the card from the vehicle's dash panel and inserts it into an upload station. These stations will resemble a credit card reading device and will be located in numerous convenience stores and other businesses or even in a person's home. In time, refueling facilities may be equipped to allow a direct data transfer between a vehicle and the refueling apparatus.

During the uploading process, the smart card authenticates the user, uploads the total charges accrued during the reporting interval, and then anonymously uploads the road use information needed for the apportionment of these charges among jurisdictions. When the collection center identifies the user, it checks for fraudulent behavior or malfunctions. If there is a problem, the smart card is notified to prompt the user to go to a service center, and the system flags that particular vehicle. During this communication, the collection center updates the vehicle's rate schedule through the smart card if the stored schedule is not the current edition. Once the collection center anonymously receives the information on how much of the mileage occurred in which jurisdictions, the center correctly apportions the funds to the appropriate jurisdictions in which travel has occurred.

CONCLUSIONS

This article has summarized the results of our research to design a new approach to assessing road user charges. A new approach is needed because there is little doubt that in the foreseeable future, new vehicle propulsion systems will enter the marketplace. As new propulsion systems, such as hydrogen fuel cells and electric hybrid systems, become more common, the traditional motor fuel tax will become less productive. Thus, our research objective was to design an approach to assessing road user charges that (1) is capable of ensuring a stable stream of revenue to provide adequate funding of the U.S. road and highway system and (2) has a series of other desirable qualities. These other qualities include a low evasion rate, efficiency in terms of cost of collection for both the agency and user, convenience and ease of use, and above all, assurance that the privacy of road users will be protected. Another important quality is the flexibility to enable the respective states (and substate areas) to pursue various public policy objectives such as creating incentives to travel on appropriate roads and to spread demand across time periods.

The best approach to assessing road user charges, we have concluded, is one that is based on the actual mileage traveled. It is essential that there be a means for crediting the state (or substate jurisdiction) for the miles of travel occurring within it. With a vehicle-miles-traveled (VMT) user charge, an individual state can tailor the per-mile rates to pursue equity and efficiency objectives as well as to encourage environmentally friendly vehicles and travel on appropriate roads (e.g., for heavy vehicles to use roads capable of supporting their axle loads).

While the new approach definitely is technologically feasible, a series of important public policy issues need to be considered prior to implementation. First and foremost, each state must decide whether to supplement the primary objective of revenue collection with one or more other purposes. As a general rule, we recommend not complicating the new approach with other features and instead focusing on revenue collection. As designed, the new approach to assessing road user charges will not compromise user privacy when merely used to collect user charges. If, in time, the traveling public wishes, several other features can be added to the new approach, including:

Implementing a voluntary (opt-in or opt-out) sampling procedure that would allow anonymous data to be gathered on trip patterns within a metropolitan area. These data have the potential to revolutionize the travel demand analysis process and to dramatically improve cities' transportation

planning capacities. Likewise, pavement management practices could be substantially upgraded if data on traffic volumes and composition were to become available. In much the same way that the apportionment information will be transmitted from the vehicle to the collection center anonymously using encryption, data on vehicle travel patterns also could be provided to the collection center. The center would aggregate the data, further protecting the privacy of individual road users, before providing them to governmental agencies for transportation planning purposes.

Varying the per-mile user charges assessed for different classifications of roads. For example, a state may wish to allow local governments within it to charge higher per-mile rates for travel within residential areas to discourage through traffic from taking shortcuts using residential streets. In the same vein, heavy vehicles may be charged more per mile for travel on lower-standard roads than on arterial highways that were designed to accommodate higher axle loads.

Encouraging the operation of energy-efficient vehicles by charging a lower per-mile rate for travel by these vehicles within the state.

Enabling privately owned highways, such as freight truck-only routes. With the new approach, the traditional barriers to privately constructed and operated highways are mostly eliminated. Currently, the motor fuel tax corresponding to miles traveled on private facilities cannot easily be apportioned to the operating entity, making toll booths necessary at all points of entry and exit. The new approach will enable private operators to determine an appropriate per-mile user charge, and travel on these highways can be credited to these operators. Tollbooths would be unnecessary.

Varying per-mile charges with traffic volume on major highways. With communication between the highway and the vehicle, it would be technologically possible to increase these charges as a facility approaches its functional capacity. User charges thus become a form of rationing mechanism to encourage higher vehicle occupancy rates and deferral of trips to off-peak periods.

We stress that it is our recommendation to focus on applying the new approach to ensure a stable revenue stream regardless of how vehicles are propelled in future years. When the motoring public becomes comfortable with the new approach, it may be possible to explore other public policy considerations; but we think that should wait. Our purpose in summarizing these other objectives has been to (1) highlight the substantial inherent flexibility afforded by the new approach to assessing road user charges and (2) suggest that in time several policy actions that address lingering problems may become practicable. We have designed the new approach to be a flexible tool for policy makers to use in making transportation systems function well.

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