TECHNOLOGY CONSIDERATIONS FOR THE IMPLEMENTATION OF A STATEWIDE ROAD USER FEE SYSTEM

Robert L. Bertini
Department of Civil and Environmental Engineering
Portland State University
P.O. Box 751
Portland, OR 97207-0751
Phone: 503-725-4249
Fax: 503-725-5950
Email: bertini@pdx.edu

Anthony M. Rufolo
School of Urban Studies and Planning
Portland State University
P.O. Box 751
Portland, OR 97207-0751
Phone: 503-725-4049
Fax: 503-725-8770
Email: rufoloa@pdx.edu

March 2003

INTRODUCTION

The fuel tax system used for financing the U.S. highway transportation infrastructure is becoming less effective and less equitable over time. While many people prefer the relatively less fuel-efficient sport utility vehicles, the general trend over time is toward more fuel efficiency. While the popularity of light trucks and SUVs has slowed the increase in average fuel economy for new vehicles, the continuing replacement of older, less fuel efficient vehicles with newer, more fuel efficient ones tends to lead to continuing increases in fuel efficiency for the light vehicle fleet as a whole. Further, the introduction of hybrid and fuel cell vehicles will also affect average fleet fuel economy over time. The increasing use of more fuel-efficient vehicles and alternative fuel vehicles means that tax revenue does not keep pace with road usage and that there is greater variance in payment among drivers of different vehicles. In response to the potential for declining revenue even as vehicle miles traveled (VMT—see Table 1 for a list of all abbreviations used in this paper) increase, some agencies have begun testing innovative forms of road finance in order to meet their infrastructure needs. For example, agencies have constructed new toll roads on new rights-of-way (TCA, 2002; ASCE, 1998; Samuel, 2000) added toll lanes to existing freeways (Reinhardt, 1993; CPTC, 2002; Sullivan, 2000) and converted a high occupancy vehicle lane facility to a high occupancy toll lane facility (SANDAG, 2002a; SANDAG, 2002b; Supernak, *et al*., 2000; Hultgren and Kawada, 1999). Some of these have been made possible by the emergence of new, low cost, reliable toll collection technology.

In response to these changes, the state of Oregon has created a Road User Fee Task Force to consider new road finance strategies and develop a series of pilot demonstrations of several alternatives. The objectives of this paper are to assess available revenue-collection technology, develop a technological framework for collecting an alternative fee or tax in lieu of or to supplement a statewide gasoline tax and introduce some of the issues that must be addressed with these technologies. While specifically developed for Oregon, the issues would be generally applicable to most jurisdictions considering alternative finance strategies.

BACKGROUND

In 1995, National Highway Cooperative Research Program (NCHRP) Report 377, *Alternatives to Motor Fuel Taxes for Financing Surface Transportation Improvements*, set out to evaluate "alternatives to motor fuel taxation and recommend an innovative approach to financing surface transportation" (Reno and Stowers, 1995). At that time, increased fuel efficiency and the use of alternative fuels were seen as potential threats to future road finance due to the heavy reliance on fuel taxes. Among the major conclusions were:

1. Motor fuel taxes will remain important components of state and federal surface transportation revenues for at least the next three decades.
2. Fees or taxes based on VMT, including congestion pricing, have desirable attributes, but their implementation depends on political and technological development.
3. Rather than replace motor fuel taxes abruptly, agencies should phase in promising new sources as elements of revenue programs.
4. Research programs should develop revenue collection technologies for VMT fees, emissions-based fees or congestion pricing. (Reno and Stowers, 1995)

However, technology limitations constrained further demonstration or detailed design of improved pricing systems. Since 1995, there have been technology advancements in the areas of telecommunications, toll collection systems, data processing, storage and security systems, automotive safety and security, as well as some important advancements in automobile propulsion systems. The propulsion system improvements increase the concerns related to revenue from the gas tax while the other changes make alternative revenue systems more feasible.

Wireless communications have become nearly ubiquitous in terms of numbers of users and geographical coverage. As presented in CTIA (2000), there were approximately 110 million cellular phone users in the U.S. in 2000 and more than 180 million projected U.S. users by 2004 (growing from 42% to 70% of the population). The wireless industry has developed basic coverage of nearly all of the populated areas of the U.S. by analog technology. Advancements are being made using higher bandwidth digital systems, but at present, analog cellular provides the basic backbone of the cellular system, particularly in rural areas.

Using cellular technology, the automobile industry has developed telematics systems, that combine embedded cellular communications, location capability using global positioning systems (GPS) and in-vehicle computing to enable services such as airbag deployment notification systems; emergency call and roadside assistance; stolen vehicle tracking; remote door unlock; door-to-door navigation systems; access to consumer information such as news, weather, sports, stocks and traffic conditions; and remote vehicle diagnostics. For example, if a vehicle is involved in a crash and the airbag deploys, the telematics system will automatically call a service center via the embedded cellular phone, and provide the vehicle's identification and location. An operator will attempt to make voice contact with the occupants. At the same time, the operator will dispatch the appropriate emergency services to the vehicle's exact location. General Motors has developed its own service entity called OnStar, while other automakers use a service provider called ATX Technologies.

Drivers are also adopting automatic vehicle identification technologies ("toll tags") for bridge, tunnel, and highway toll payment at a rapid rate, despite privacy concerns (New York State Thruway Authority, 2000; BATA, 2000). Automatic toll collection systems such as FasTrack and E-ZPass are expanding rapidly due to user demands, and in Southern California, a fast food company experimented with accepting these devices for payment (Dove Consulting, 2001; Baukney, 2001). These tags are being miniaturized so that they are hardly noticeable and their cost is almost negligible.

At the same time, computer-processing capabilities are becoming faster and less expensive, and the use of large databases is becoming commonplace. This development substantially increases the feasibility of tracking charges to large numbers of vehicles and to differentiate the prices based on a variety of factors.

Changes in the vehicle fleet since 1995 are spurring interest in the use of these new technologies for collecting road fund revenue. Gasoline-electric hybrid vehicles have entered the market (Honda's Insight and Civic and Toyota's Prius), and sales have been above expectations despite their small sizes and higher prices. These vehicles are two- to three-times more fuel-efficient than an average vehicle. Most major automakers have announced plans to release hybrid vehicles in the next model year (e.g., Ford Escape will be released in 2003 as will a Dodge sport utility vehicle hybrid). Partially in response to California's zero-emission-vehicle mandate, the auto industry has developed a fuel cell partnership, a demonstration project for testing fuel cell cars, trucks and buses. Some of the fuel cell vehicles are based on hydrogen as a primary fuel source, while other vehicles use more traditional fuels, including gasoline. There are also a small number of pure electric vehicles (mainly in fleet applications) and a small number of small, low speed neighborhood electric vehicles present in tourist areas. Clearly the trend toward increased fuel efficiency represents a corresponding drop in fuel tax revenue for these vehicles, and some alternative fuels may be difficult to tax for transportation purposes.

PERSPECTIVES

It is important to consider the cost of a new system for collecting road use fees as compared to the existing system. The existing system is very simple; the fuel tax is paid at the gasoline distributor level, so that there are approximately 200 "taxpayers" in the state of Oregon. With a road use fee system there would be approximately 2.9 million "taxpayers," using the number of registered passenger vehicles in the state of Oregon (ODOT, 2000). The number would be even greater if the system applied to out-of-state vehicles when they traveled in the state. The total estimated VMT in Oregon in 1998 was about 32.8 billion miles (ODOT, 2000) and the total annual fuel tax revenue is about $390 million. Thus, the average vehicle contributes about $134 per year with the current $0.24 state fuel tax (this corresponds to an average vehicle traveling about 11,310 miles per year, consuming approximately 560 gallons of fuel per year). If the fuel tax were to be replaced completely by a VMT fee, the required rate for revenue neutrality would be about 1.2 cents/mile.

The average Oregon driver would likely be surprised to learn that he/she is currently paying only $134 per year in state fuel tax (less than $12/month), since there is no summary document, analogous to a property tax bill, that provides such a figure to drivers. This $134 figure must be considered when establishing the per-vehicle cost of the technology used to collect a road user fee. Commercial vehicles tend to pay larger amounts through fuel and registration fees, so the cost of administration would be a smaller percentage for them, but there is much less concern about increasing fuel economy with the truck fleet.

A variety of pricing systems for road use are in use or have been proposed. These range from simple replacements of the fuel tax with a per-mile VMT charge to more complex systems that monitor vehicle usage by location and time of day to determine charges. A pure VMT pricing system would charge drivers the same amount for each mile driven, regardless of the individual vehicle's fuel efficiency. This may create a perception that drivers of the least fuel-efficient vehicles would be the "winners," and drivers of more fuel-efficient vehicles would be the "losers." A VMT pricing system could be structured to prevent revenue loss or to encourage people to purchase hybrid, fuel cell and electric vehicles as a means of reducing air pollution and energy consumption. The latter benefits are quantifiable but would not be seen as actual revenue for road improvements by the state. There is one international example of creating an incentive for drivers to use alternative–fuel vehicles. In London, a congestion-charging system (using license plate recognition video cameras) now levies a daily charge of £5 for all vehicles entering the central city, with a 100% discount for drivers of electric and alternative-fueled vehicles (Crawford, 2000; Millar, 2001).

ASSUMPTIONS

This technology discussion considers a continuum of possible road pricing systems. At one end are relatively simple systems targeting only the highly efficient gasoline powered vehicles and alternative-fuel vehicles. At the other end are systems in which the current fuel tax system would be completely replaced. Capabilities for any sort of variable pricing (such as by location and/or time of day) and distinction between in-state and out-of-state driving are also included in the discussion. The discussion remains "vendor-neutral," and rather focuses on general categories of technology. A slight preference is given to systems that are based on reliable infrastructure. For example, the GPS satellite network is maintained by the U.S. Department of Defense and is perceived to be very reliable. Also, because a partial or full fuel tax replacement system must be available statewide, in both urban and rural settings, only relatively mature technologies are considered. However, it is probable that all technologies considered will undergo continuing improvements and component/system cost reductions. Some technologies that are in a development phase are mentioned briefly for completeness.

BASIC TECHNOLOGIES CONSIDERED

Figure 1 shows a taxonomy of possible technologies for collection of road user fees and describes the categories of basic technologies considered for this analysis. In the basic VMT reporting/inspection systems, only three pieces of data are critical: vehicle identification number, date/time, and cumulative distance traveled.

Odometer

An odometer included as original equipment on every vehicle (referred to on the taxonomy as an original equipment manufacturer (OEM) device) could be used as the basis for a simple road user fee determination. An odometer registers the cumulative distance a vehicle travels and can be mechanical or computerized in nature depending on the age of the vehicle. The computerized odometers are sealed and are designed to be more difficult to tamper with than the older mechanical type. They use a toothed wheel mounted to the output of the transmission and a magnetic sensor that counts the pulses as each tooth of the wheel goes by. Knowing the distance the car travels with each pulse, the odometer reading is stored and updated via an electrical/communication bus between the engine control unit (the vehicle's computer) and the dashboard. These readings only provide the distance traveled in the forward direction. The odometer value is displayed in the vehicle and also can be read using a diagnostic computer, generally available at all auto service facilities.

As shown in Figure 1, a self-reporting VMT system could be augmented by an audit system where odometers would be checked for data, thereby also checking if any tampering has occurred. Odometer fraud (a federal crime) is most often detected when titling a vehicle in a new state; however, a revenue system based on odometer readings would increase the incentive for tampering. The National Highway Traffic Safety Administration estimates that the illegal practice of rolling back odometers is an important problem, estimated to cost American consumers between $2 billion and $4 billion annually (U.S. Department of Justice, 2002). While computerized odometers may lead to reductions in this loss over time, security would be a concern for any system based on simple vehicle odometer readings.

Hubodometer

A hubodometer is a relatively simple after-market device that records mileage with every turn of the wheel, forward and backward, needing no wiring or complicated programming. A hubodometer would be a standardized, more secure device for recording VMT as part of a statewide road user fee system. Hubodometers are factory sealed and are often used on fleet vehicles (e.g. buses) to facilitate scheduling and monitoring of regularly scheduled maintenance and safety inspections. Some manufacturers state that their hubodometers are secure, but it is likely that a small potential exists for evasion. There are tamper-evident systems that attempt to overcome evasion tactics.

Hubodometers can be mechanical or electronic. Mechanical hubodometers are mounted on the axle hub, and show the actual mileage the vehicle traveled. Electronic hubodometers record distance using electronic sensors. Electronic hubodometers can be enhanced with a simple radio frequency (RF) data transmission system that facilitates reporting of mileage to a central system. RF data transmission would be suitable for a drive-in type inspection, where distances are short and little interference is present. Cellular communications would be appropriate and necessary for long-range communications and for a system without a drive-in component. Hubodometers used in vehicles serve as a simple gauge to verify important distance-related warranties for tires and brakes. As shown in Figure 1, reporting systems for hubodometers could be similar to those for an odometer based system. For future applications in hybrid, electric or fuel cell vehicles, electronic hubodometers could be used to record VMT as a requirement for vehicle registration. The primary benefit from specifying a hubodometer to record VMT would be that the state could standardize the equipment and have greater confidence that the system's security is not violated. The approximate price of a simple mechanical hubodometer is in the $25-50 range, while an electronic hubodometer may cost approximately $300 for the hubodometer only. Adding an RF data receiver for an electronic hubodometer would reflect an additional cost ranging between $1,500-2,000.

ADVANCED TECHNOLOGIES CONSIDERED

With more advanced technologies come more capabilities, data requirements, flexibility and higher costs. For the systems described below there are four key variables needed in order to monitor when and where a vehicle is traveling: vehicle identification, *x*-coordinate, *y*-coordinate (longitude and latitude) and time. Using the changes in *x*- and *y*-coordinates, distance can also be calculated.

Global Positioning Systems

GPS is based on a satellite network developed by the U.S. Department of Defense that can be used by consumers equipped with a small receiver to estimate location (*x*- and *y*-coordinates or latitude and longitude) over time. GPS technology is mature and very accurate, particularly since May 2000 when intentional scrambling (known as selective availability or SA) was turned off. This made higher-accuracy signals available to the general public. Figure 2 (National Geodetic Survey, 1997) shows how 300 point-estimates represent the location of a fixed point both with and without selective availability. As the National Geodetic Survey is a U.S. government entity, this test was conducted in 1997 using non-SA GPS signals. With selective availability the rule of thumb was that GPS could locate a point within an area the size of a football field (100 meters) with a 95% confidence interval. Without selective availability, GPS can locate something within an area the size of a tennis court (30 meters) with a 95% confidence interval. In areas with minimal ionospheric interference, GPS can provide accurate readings within a few meters. (National Geodetic Survey, 1997) GPS has some limitations in urban areas where tall buildings interfere with satellite signals. GPS is used for navigation systems, fleet management, emergency location and many other location-based services. If a vehicle's GPS location is reported on some frequent basis (e.g., every 30 seconds), the distance traveled can be calculated. If the location is matched to a digital map, then the facility type and jurisdiction can be matched with time of day to determine whether a variable price (toll) was applicable. The U.S. Coast Guard has established land-based auxiliary differential GPS (DGPS) stations near coastal waters that provide improved location capabilities. There is a movement to expand DGPS throughout the nation. The use of GPS location data for vehicle tracking raises substantial privacy concerns. However, for a distance-based road user fee, systems can be designed that calculate distance on-board the vehicle and simply report total distance traveled without revealing actual locations and times associated with a particular vehicle.

Wireless Communications

Wireless communications are expanding rapidly, both in the areas of voice and data communications. Analog cellular provides the best geographic coverage of the state of Oregon, while digital cellular is available in many urban areas. Figure 3 (TeleAdapt Group, 2002) shows dark zones corresponding with analog system coverage and light zones corresponding with digital coverage. Cellular providers are also increasing the bandwidth of their systems to enable Internet-style browsing and transmission of large quantities of data using broadband systems (ITE, 2000). New short-range wireless systems are also being developed using Bluetooth technology (Klein, 2001).

Currently, the precise locations of cellular emergency 911 (E911) calls cannot be determined. Some 911 systems can identify the nearest cellular tower. But the Federal Communications Commission has mandated that all cellular E-911 calls provide location data to a specified degree of accuracy in the next several years. Some have proposed that cellular location data can be used to provide traffic information, and a demonstration of this is currently underway in Maryland and Virginia (Lovell, 2001; Smith *et al.*, 2001; Klein, 2001).

Automatic Vehicle Identification (AVI)

Automatic Vehicle Identification (AVI) allows the identification of a vehicle at a particular point in space. Typically, a roadside "reader" is placed at a fixed location and is able to read "tags" on passing vehicles. AVI is the main component of an electronic toll collection system, determining ownership of a passing vehicle for charging a toll to the proper customer account. AVI technology is point based, i.e., identifiers are fixed at locations for identifying the vehicle, which carries an identification tag/sticker that transmits the information. Application of AVI may be made at cordon lines or state border crossing points where vehicles entering or leaving an area or the state could be identified and recorded.

AVI technology is mature and may be classified under four main categories: Laser, Radio Frequency, Infrared and Video:

- **Laser** systems use a bar coded sticker attached to the vehicle. A laser scanner can read it as the vehicle passes through the lane or the cordon.
- **Radio Frequency** systems use a transponder mounted either on the vehicle bumper, inside the windshield or on the roof, that is read by a radio frequency reader/antenna.
- **Infrared** systems are very similar to radio frequency systems in that they use an in-vehicle tag that is read by a reader/transmitter installed in the lane.
- **Video** systems employ stationary video cameras with license plate reading systems that identify vehicles using the license plate image.

Laser technology has several drawbacks that limit its use in the toll collection environment, including ease of forgery and sensitivity to weather and dirt. In addition, the laser scanner is limited in the distance it can be placed from the vehicle. Radio frequency technology overcomes these limitations and is the most popular AVI technology for electronic toll collection systems. Infrared systems also overcome many of the same limitations over laser scanner systems. Video systems have some limitations in terms of the ability of cameras to detect license plate images during inclement weather.

For the purpose of auditing or enforcing cordon entry or exit violations, video cameras are typically incorporated at toll facilities in addition to the primary AVI device. The three main types of video recording systems are:

- **Image capture** of violation vehicle license plate image for disk storage transmission.
- **Videotape** recording of all activity in time-lapse mode, with violations in real-time mode.
- **Line-scan** camera with compressed storage on disk for telephone-line transmission (most notably for visual identification of untagged vehicles).

In addition to toll collection, some types of radio frequency tags are being used solely for traffic management functions, where a vehicle's travel time is measured between two vehicle identification locations (ITE, 2000). There are three main radio frequency technologies that are either in use today or undergoing extensive trials: radio frequency tags, radio frequency smart tags and smart cards with radio frequency transponders

- **Radio frequency/Infrared** tags are located in or on the vehicle, and are used with an in-lane antenna/reader to communicate vehicle identity to the toll system. The information stored on the tag is fixed (read-only), cannot be changed and the tag does not have any processing capabilities. The read-only type is also called a type-I transponder.

- **Radio Frequency Smart** tags are radio frequency devices located on the vehicle, used with an in-lane antenna/reader to identify the vehicle, customer, and account balance information to the toll system. Some portions of the tag information are fixed (such as vehicle and customer data) while others are updateable (such as balance information). The smart tag contains a small microprocessor that maintains account balance information, and is updated each time the smart tag is used. Radio frequency smart tags operate in full duplex mode, meaning that they are able to send and receive data at the same time. They actively generate the signal used to communicate with the antenna/reader via a transmitter. They are also referred to as type-II transponders.

- **Smart Cards** require two components: the smart card itself, and a separate radio frequency/infrared transponder. Smart cards (such as those being tested for single transit fare payment systems) contain an integrated circuit device, with a microprocessor and memory to store account balance information. The transponder is located in or on the vehicle, interfaces with the smart card and allows the smart card to communicate with the in-lane antenna/reader. In addition, the transponder contains information about the vehicle that it transmits to the antenna/reader along with the smart card information. Smart cards with radio frequency transponders are currently undergoing extensive trials in Europe (ITE, 2000).

The functioning of an AVI system involves the deployment of AVI tags, installation of multiple AVI reader systems, and a data processing system to collect and process payment information. AVI systems in place today must meet stringent security and accuracy specifications. For example, the California Department of Transportation (Caltrans) and the San Diego Association of Governments require vendors to maintain 99.9% vehicle identification accuracy for their FasTrak systems (SANDAG, 1997). In addition, customer service standards and strict public scrutiny dictate that all billing be conducted accurately and maintain privacy in accordance with accepted credit card industry standards (drivers use their credit cards to pay for bridge and highway toll transactions).

An AVI tag reader costs on the order of $1,000 per installation per lane plus power and communications costs, while a tag costs no more than about $20 for the most advanced type. However, since an AVI system can only record the passage of a vehicle at a particular point, it cannot record the total mileage traveled by all vehicles. Therefore, as shown in Figure 1, AVI would not satisfy the requirements for a VMT road user tax system; it would have be used in combination with other technologies as described below.

Automatic Vehicle Location (AVL)

AVL uses GPS to locally or remotely record the location of a vehicle (*x*- and *y*-coordinates or latitude and longitude) over time, at some specified interval. The location data can be stored in the vehicle for later processing, or transmitted in real time or periodically via cellular communications to a central data processing unit. The combination of GPS with wireless communications is used to locate and communicate with almost any moving object.[1] For commercial fleet operators, such systems, using an Internet-based user interface, provide an efficient way to locate and monitor their vehicles. The mobile units transmit GPS location data at some frequency over wireless communications networks to a base station that uses the GPS data to display vehicles' real-time location on a digital map. By providing dispatchers with accurate real-time fleet location, a mobile positioning system can increase the efficiency of commercial businesses such as taxi services and tow truck operations.

AVL systems include vehicles equipped with a GPS receiver, a simple processor, a cellular modem, and a cellular antenna, connected to a base station consisting of a computer station as well as a GPS receiver and interface. AVL also enables companies to structure delivery routes more efficiently by compiling a database of vehicle information, including location of customers in relation to established delivery routes. In Oregon, Tri-Met (the transit provider in the Portland metropolitan area) has all of its buses equipped with AVL for dispatching purposes, and the Oregon Department of Transportation (ODOT) has its incident response (COMET) trucks equipped with AVL for maintenance and management purposes (ODOT, 1998; ODOT, 2001).

AVL is used to increase the accountability of field personnel and improve the efficiency of a company's dispatching procedure. Dispatchers can obtain a real-time snapshot of driver adherence to a route, provide customers with an estimated time of arrival, and communicate directly with drivers. AVL systems operate without expensive receivers or other equipment. The GPS unit installed in the vehicle makes use of a minimal amount of power and transmits GPS location data, either on a regularly timed basis or in response to a command.

As shown in Figure 1, AVL may be used as a dynamic, accurate, time stamped means of collecting user charges. Auto companies, their telematics service providers or other contractors could be engaged for collecting location information from vehicles equipped with AVL, either via cellular communications, short-range radio-frequency communications or a physical data download at particular drive-in locations such as fuel stations or auto service centers. Vehicles' locations can be matched to a digital map in real time or via post-processing to determine distances traveled out of state, within variably priced cordons or on variably priced corridors.

The initial cost of an AVL system would exceed the current annual fee paid by an average Oregon driver. Navigation systems are available on many new vehicles, and they are also available as an after-market device. A navigation system includes a GPS receiver, a computer interface and a map database (typically a CD-ROM or DVD). To operate the system, the driver types in a destination address and the computer displays the shortest path route on a screen and provides turn-by-turn directions using computer-generated speech and graphical displays.

[1] It would be possible to use other means of communication, such as a radio frequency transmitter, to transmit data from an AVL system. However, due to its short-range communications limitations, such a communications system would require vehicles to drive by a receiver or drive into a facility with radio frequency receiving capabilities. This becomes an AVI system where vehicles are identified at specific points rather than over a large area. A true AVL system would benefit from the existing private cellular infrastructure while a radio frequency based AVI system would require installation of a completely new statewide array of receiving stations.

Navigation systems currently cost about $2,000. Auto manufacturers offer telematics/mayday systems as standard equipment on many models, with a small service fee required after the first one or two years. There would be an opportunity to leverage from GPS-based systems already being installed in many models on the market today. Fleet users may already be pursuing the purchase of hybrid or other alternative-fueled vehicles, due to the availability of state and federal tax incentives. Therefore, it would be possible to leverage the installation of a fleet management system that could be integrated with a road user fee system.

Hubodometer + AVI

AVI alone could not effectively meet the needs of a road user pricing system. As shown in Figure 1, when combined with an odometer or hubodometer for charging for basic VMT, AVI can detect vehicles at points where transponders or tags or video detection are present such as at state boundaries, cordon lines, toll corridor payment points and at intersections. This can help in detecting the vehicles moving out of Oregon's borders or entering any areas (cordons or corridors) where variable pricing may be applied. AVI receivers could be placed on public rights of way or within private establishments such as gas stations or auto repair facilities. As vehicles pass an AVI receiver, its cumulative mileage could be transmitted and recorded along with the vehicle's identification. These data could be used to calculate a mileage-based charge and the vehicle owner could then be billed by a public or private entity.

Hubodometer + AVL

A vehicle equipped with AVL would not need an odometer or hubodometer in order to assess basic VMT pricing. However, for transition purposes, it may be desirable to consider using the hubodometer for basic pricing and AVL for variable pricing. This combination also facilitates detecting when and where the vehicle leaves and re-enters the state, by using AVL as an "on-off switch" at state boundaries and cordon areas.

AVL + AVI

It may not be necessary for vehicles to be equipped with both AVL and AVI. However, as shown in Figure 1, it may be desirable for a system to use AVL to calculate a basic VMT based fee while using AVI for the variable component of cordon or corridor based pricing systems. The benefit of using AVI for this purpose is that the driver can receive feedback in the form of a transponder's "beep" when charged a particular price, such as for entering a highway during a peak period.

ADMINISTRATION

All administration systems for future road user fee collection would be more costly than the current system for collecting state fuel tax revenue. Some possible scenarios include:

- **VMT Reporting (low cost)**: Using an honor system with selective enforcement, vehicle owners would report their VMT on a periodic basis, using paper forms or electronic filing. As an analogy, many transit systems have shifted to a barrier-free fare payment system using an honor system with fare inspectors. Enforcement would be a critical component of a low cost VMT reporting system, particularly since there is currently no requirement that a vehicle have an operating odometer. Federal Motor Vehicle Safety Standard (FMVSS) No. 580 and Oregon state law require that a seller complete a written disclosure of the odometer reading when selling a motor vehicle. In the future, Oregon could require functional odometers as a condition for registration within the state. A VMT reporting system could be accomplished in partnership with a multitude of possible entities, including:

- **Department of Revenue**: taxpayers could report VMT on state tax returns.
- **Department of Transportation, Driver and Motor Vehicle Services**: vehicle owners could report VMT at DMV facilities upon biennial vehicle registration.
- **Department of Environmental Quality**: for vehicle owners residing within DEQ boundaries, VMT reporting could be conducted at DEQ facilities.
- **Service stations or auto dealerships**: private entities such as gas stations or auto dealers could provide VMT reporting facilities.
- **Auto manufacturers**: auto manufacturers maintain current information on their customers for recall and other customer service and brand loyalty purposes. The manufacturers could also collect VMT data from vehicle owners as part of their continuing customer contacts.
- **Insurance companies**: vehicle owners could report VMT to their insurance companies for reporting to the state.
- **Private contractors**: the state could contract with a private organization to establish a statewide VMT reporting system, perhaps giving the public confidence in privacy and security.

- **VMT Inspection (medium cost)**: Similar to above, many entities could provide an inspection-based means of accurately reporting VMT.

  - **DMV/DEQ**: vehicle owners could have VMT inspected at DMV/DEQ facilities.
  - **Service stations/auto dealerships/insurance companies/private contractors**: VMT inspection facilities could be provided for reporting to the state.

- **AVI/AVL Solution (higher cost)**: A system based on more advanced technology for collecting VMT information with capability to apply variable pricing according to time and location could be administered by a variety of entities:

  - **State**: a state department (DMV, DEQ, etc.).
  - **Insurance company**: the state could partner with insurance companies providing location-based insurance services; a company in Texas demonstrated such a system using GPS technology (Paul, 2002; EPA, 2000; Wenzel, 1995).
  - **Auto security company**: LoJack is a familiar theft prevention system based on GPS technology. The state could partner with such a company.
  - **Private contractors/service stations**: A private partner could be responsible for setting up a technology-based system. Oil companies are currently investigating technology improvements for their service stations so that large data streams can be transmitted to/from vehicles while in a service station (Sun Microsystems, 2000).

Such a short-range communication system could be used to transfer road use information to the state. Service stations could manage the administrative aspects of a VMT pricing system, and the state could arrange appropriate incentives to cover the costs to the stations.

- **Auto companies/service providers**: Telematics service providers, including OnStar and ATX Technologies could provide VMT and location information to the state. Telematics systems are capable of directly reading the odometer and transmitting the information via cellular communications to the service center. The service provider could record a vehicle's location periodically or record to specify when a vehicle crosses a state boundary or enters an urban area with a cordon pricing system. Auto companies would be ideal partners for testing a field demonstration of an advanced road pricing strategy. In recognition of the viability of such a system, a pooled-fund study led by the state of Minnesota has begun a demonstration project to evaluate the feasibility of monitoring automobile usage using GPS systems (Forkenbrock and Hanley, 2001).

A technology-based system would likely be more financially feasible and publicly acceptable if it were phased-in. At this stage it is difficult to estimate administrative costs for a stand-alone statewide technology-based system. It is important to consider the possibility of leveraging benefits from administrative structures already established, such as in the area of telematics. In terms of cost and administrative magnitude, one could compare a statewide VMT pricing system that monitored actual vehicle use on particular facilities with a telephone system. From publicly available records, it appears in 2001 that Qwest, the local telephone provider for Portland, had about $19,695 million in revenue, and reported administrative costs of about $5,231 million, or about 26% of the revenue (Qwest, 2001). Despite the fact that telephone systems are not necessarily statewide, it does follow that the complexity of a telephone system might be similar to a statewide highway user fee system. For example, many households have more than one phone, are billed monthly and require establishment of a credit relationship and extensive record keeping. Merely as an illustration we can consider Oregon's current fuel tax revenue of approximately $390 million per year. If the state could match the administrative costs of the telephone system, a centralized, stand-alone billing system would consume almost half of the revenue generated. This is a substantial concern when compared to the existing motor fuel tax system with very low administrative costs.

COMPARISON OF TECHNOLOGY OPTIONS FOR PRICING ROAD USE

Table 2 shows a matrix used for comparing five technology options in eight evaluation categories, using a subjective scale between 1 and 10 (where 10 represents the most desirable and 1 represents the least desirable option in a given category). These ratings were developed in conjunction with a technical advisory committee comprised of key ODOT staff representing economics, policy and technology aspects of the department. Some example weights have been applied to each category. In this analysis, perspectives of both users and the agencies have been explored, and thus, in Table 2, evaluation categories are related to specific groups. For example, costs to owners, ease and convenience, and public acceptance all relate to user acceptance; while start up costs, life cycle costs, and partial implementation relate to agency acceptance.

The first category is reliability of the hardware and/or software needed to implement each system. The Hubodometer Only system would have the highest reliability, while the systems relying on GPS (the AVL and AVL+AVI) would likely have the lowest reliability. In terms of evasion potential, the Odometer Only would have the highest evasion potential, while the other systems would have uniformly lower evasion potential due to the likelihood of a drive-in or other communications-based reporting system. The Odometer Only would provide the lowest cost solution while the AVL systems would be the most expensive. Once deployed, all systems would be relatively easy to use and convenient to vehicle owners, although all would require more effort and cost than the current gasoline tax system.

The Odometer Only system would be the lowest cost system for the State to deploy, while the AVL systems would be most costly. The relative costs of the system depend on the level of technology, with the AVL based systems being the most costly to operate. Similarly, the public would likely accept the simpler, less costly systems, while they may object to the more expensive systems and the recording of vehicle location information. None of the potential systems would require a full deployment involving all vehicles in the state. Any of the systems could be partially deployed and/or phased in. However, there would likely be economies of scale, for example, in purchasing in-vehicle or roadside equipment. In addition to a lower cost per unit as more units are purchased, the fixed costs of roadside equipment would in effect be spread over a larger number of vehicles if the system were used extensively. As shown in Table 2, the simpler systems would be easier to phase in for this reason.

PHASING IN A NEW ROAD PRICING SYSTEM

There are many ways that a new road pricing system could be phased in. Here are some issues to be considered:

- As a data collection and research tool, a paper or web-based reporting system could be adopted immediately for all vehicle owners while maintaining the fuel tax. Vehicle owner could report their VMT annually as part of a vehicle registration, county property tax or state income tax payment. For example, an electronic form could be designed to collect vehicle make, model, and total mileage, along with other demographic information. Such a database would fill in many of the gaps described in this report and inform policy makers about whether and where alternative-fueled vehicles are proliferating. The data collected could also help establish VMT fees as well as providing information about urban/rural equity concerns.

- One of the first major administrative issues to be resolved would be the mechanism by which a driver would pay the VMT fee while a gasoline tax was still in place for other drivers. For example, a gas station could handle the administration and add a VMT fee to the total gasoline bill based on an odometer/hubodometer/transponder reading. Alternatively, a VMT vehicle could be exempt from paying gasoline taxes at the gas station and could submit the VMT fees directly to the state or to a service provider. Alternatively, a vehicle owner could submit evidence of gasoline tax paid as an offset to their VMT fee, and receive a refund or pay the difference directly to the state or service provider. Tests of these possibilities could be conducted and feasibility and user reaction could be measured.

- Based on the information gained from one year of VMT reporting, a voluntary pilot program could be established for payment of a VMT fee for certain types of vehicles or for vehicles in certain regions. One method would be to partner with a manufacturer of hybrid vehicles and begin an experiment using secure odometers or hubodometers installed in such vehicles registered in Oregon. A reporting system could be instigated in the near term, while requiring these manufacturers to include a technology-based reporting system in future model years for vehicles registered in Oregon.

- Parallel pilot programs could be tested with a rental car company, an auto insurance company, and/or with an auto manufacturer that offers navigation and telematics/mayday systems (e.g., DaimlerChrysler, General Motors, BMW) for testing AVL-based systems. Via these partnerships, various reporting mechanisms could be tested, with an eventual requirement that VMT reporting capabilities be included as standard equipment for vehicles registered in Oregon. Most auto manufacturers are developing automatic diagnostic systems that can be accessed remotely—this could very easily include reporting of an odometer reading that could be transmitted to the state for billing purposes.

FUTURE RESEARCH

Additional research steps are necessary to focus this analysis on selected road use pricing scenarios, in order to demonstrate the capabilities of the various systems and estimate actual deployment costs and benefits. The next steps should identify a small menu of alternatives, timeframes and penetration rates for desired deployment. At that time, it will be possible to provide actual cost estimates and further details relating to possible private partners, administrative and communications costs, evasion rates based on actual experience and further analysis of user acceptance and privacy concerns.

TECHNOLOGY ISSUES SUMMARY

Reno and Stowers (1995) concluded that VMT charges should be tested and that some form of mileage charges would be the best alternative to fuel taxes. This conclusion still seems valid, and the improvements in technology make more sophisticated VMT systems less expensive and more reliable than those existing when NCHRP 377 was written. Over the past five years, there have been many important technology advancements in the areas of telecommunications, toll collection systems, data processing and storage systems, automotive safety and security, as well as important advancements in automobile propulsion systems. Drivers have adopted automatic vehicle identification (AVI) toll tag technology at a surprisingly rapid rate as toll authorities have replaced or augmented traditional tollbooths with automatic toll collection for bridges, tunnels and toll roads. AVI technology has also been used for several value pricing facilities (CPTC, 2002; Sullivan, 2000; SANDAG 2000; Supernak, *et al*., 2000). The rapid technology adoption has been surprising, particularly in view of privacy concerns.

While there are no perfect off-the-shelf solutions, the components necessary for a new road pricing system are largely proven and exist in various forms. In Texas, the Progressive Insurance Company demonstrated a distance-based insurance program that showed that it is technically possible to monitor vehicle use by location and time of day for the purpose of imposing charges

(Paul, 2002; EPA, 2000; Wenzel, 1995). Despite its temporary implementation, the program's apparent acceptance by voluntary users indicates that the privacy issues may not be as great a barrier as previously thought. In addition, the presence of approximately 2 million vehicles with telematics systems indicates that there may be opportunities for states to collaborate with auto manufacturers in planning new road pricing strategies.

Pricing systems could be administered in partnership with a multitude of possible public agencies and private entities. Systems could be voluntary or mandatory, cover part of the fleet or all of it, and include the entire state or merely a region. Administration could be in the form of simple reporting, inspection, or a technology-based solution requiring varying degrees of vehicle monitoring. For example, gas stations could collect VMT information and tax vehicles accordingly as part of the fuel purchase transaction. VMT taxes could be paid as part of a vehicle insurance payment. The state of Oregon could partner with auto manufacturers and/or mayday service providers (OnStar or ATX Technologies) to charge vehicle owners for VMT fees as part of another service.

The evidence from existing experiments is that some form of pricing is both feasible and politically acceptable under certain conditions. Pricing has been used to pay for new options in a growing number of places. The key elements to its acceptance appear to be that new options are offered, that existing users are no worse off, and that participation is voluntary. Alternatively, it appears that people may voluntarily choose alternative systems if they provide benefits to the user. Thus, raising existing taxes or fees and offering a lower-cost alternative to those using the new technology may provide an acceptable transition mechanism. Given these conditions, several options exist for implementing the technology. While it has yet to be used in the U.S., a number of countries have also successfully implemented some form of cordon or access pricing on a broader scale, without offering options for those who wish to avoid the payments (Crawford, 2000; Downs, 1992; May and Milne, 2000).

To move forward, it would not be necessary to evaluate all of the trade-offs that exist among the technological, economic, and political issues that are raised by alternative methods to raise revenue for the road system. However, it is necessary to identify some broad categories of promising alternatives and develop more definitive information on the likely cost to users, administrative costs, evasion rates, and privacy issues. The technological improvements and reduced cost of the new technology have substantially improved the prospects for these alternatives relative to what was available at the time of NCHRP Report 377, but the assertion that more testing is needed is still valid.

ACKNOWLEDGEMENTS

The authors are grateful to the Oregon Department of Transportation for funding this research, and would like to acknowledge Alan Kirk, James Whitty, Jack Svadlenak, Mark Joerger, Barnie Jones and Galen McGill for their support. Thomas Kimpel assisted with the literature review. The authors particularly appreciate the helpful comments and suggestions provided by two anonymous reviewers.

REFERENCES

American Society of Civil Engineers, ASCE (1998). California refines design/build transportation scheme. *Civil Engineering*, **68(8),** 22.

Baukney, H. (2001) Did somebody say convenient? *CIO Magazine*, February 15, 2001.

Bay Area Toll Authority, BATA (2002). *Toll bridge report to the California legislature, FY 2001-2002*. Metropolitan Transportation Commission, Oakland, CA.

California Private Transportation Company, CPTC (2002). *91 express lanes project history*. Available at: http://www.91expresslanes.com.

Cellular Telecommunications and Internet Association, CTIA (2000). *Semi-Annual Wireless Industry Survey*, Washington, D.C.

Crawford, I. (2000). *The distributional effects of the proposed London congestion charging scheme*. Institute for Fiscal Studies, London.

Dove Consulting (2001). *The new way to pay: industry report*. Available at: http://www.consultdove.com/article_download/transponders.pdf.

Downs, A. (1992). *Stuck in traffic*. Brookings Institution/Lincoln Institute of Land Policy, Washington, D.C./Boston.

Environmental Protection Agency, EPA (2000). Final XL project agreement for Progressive Auto Insurance Company, Available at: http://www.epa.gov/projectxl/progressive/fpa2draft.pdf

Forkenbrock, D. and Hanley, P. (2001). *GPS accuracy issues related to the new approach to assessing road user charges*. Pooled Funding Study on a New Approach to Road User Charges, Technical Paper 4, Public Policy Center, University of Iowa.

Hultgren, L. and Kawada, K. (1999). San Diego's Interstate 15 high occupancy/toll lane facility using value pricing. *ITE Journal*, **69(6),** 22-27.

Institute of Transportation Engineers, ITE (2000). *Intelligent transportation primer*. ITE, Washington, D.C.

Klein, L. (2001). *Sensor technologies and data requirements for ITS*. Artech House, Boston.

Lovell, D. (2001). Accuracy of speed measurements from cellular phone vehicle location systems. *ITS Journal*, **6(4),** 303-323.

May, A. and Milne, D. (2000). Effects of alternative road pricing systems on network performance. *Transportation Research A*, **34(6),** 407-436.

Millar, S. (2001). London leads—will rest follow? *Guardian Unlimited*, London.

National Geodetic Survey (1997). Removal of GPS selective availability, Federal Geographic Data Committee. Available at: http://www.ngs.noaa.gov/FGCS/info/sans_SA/compare/DSRC.htm.

New York State Thruway Authority (2000). *E-ZPass evaluation report*. Albany, NY.

Oregon Department of Transportation, ODOT (1998). *Oregon ITS strategic plan 1997-2017*. ODOT Transportation and Policy Division, Salem, OR.

Oregon Department of Transportation, ODOT (2000). *Key Facts*, ODOT Director's Office, Salem, OR.

Oregon Department of Transportation, ODOT (2001). *TransPort transportation Portland: a new way of thinking*. ODOT Region 1 Traffic Section, Portland, OR.

Paul, K. (2002). Advocating mileage-based auto insurance. *Conservation Matters: Journal of the Conservation Law Foundation*, VIII(3).

Qwest (2001). Qwest Annual Report 2001. Available at: http://qwest.com/about/investor/financial/reports/2001.

Reinhardt, W.G. (1993). Kiewit moves SR91 financing to closure launching a new era in U.S. toll roads. *Public Works Financing*, **65**, 1-7.

Reno, A. T., & Stowers, J. R. (1995). Alternatives to motor vehicle fuel taxes for financing surface transportation improvements. *NCHRP Report 377*, Washington, D.C.

Samuel, P. (2000). Variable toll rates catching. *Public Works Financing*, **141**, 26.

San Diego Association of Governments, SANDAG (1997). *Request for proposals for electronic toll collection system*. I-15 Congestion Pricing Project, San Diego, CA.

San Diego Association of Governments, SANDAG (2002a). *I-15 Fastrak Toll Schedule and Information*. Available at: http://www.sandag.org/fastrak.

San Diego Association of Governments, SANDAG (2002b). *I-15 managed lanes value pricing project planning study*. San Diego, CA.

Smith, B., Pack, M., Lovell, D., Sermons, M. (2001). Transportation management applications of anonymous mobile call sampling. In: *Proceedings of the 11th Annual Meeting of ITS America*, Miami, FL.

Sullivan, E. (2000). *Continuation study to evaluate the impacts of the SR91 value-priced express lanes: final report*. California Department of Transportation, Sacramento, CA.

Sun Microsystems (2000). *Sun Microsystems hits the road with Java technology solutions for the automotive industry*. Available at: http://www.java.sun.com.

Supernak, J., Golob, J., Golob, T., Kaschade, C., Kazimi, C., Schreffler, E. and Steffey, D. (2001). *I-15 congestion pricing project phase II year three overall report*. San Diego Association of Governments (SANDAG), San Diego, CA.

TeleAdapt Group (2002). Ositech CellFlex overview. Available at: http://www.teleadaptusa.com/nme/ositech_overview.htm.

Transportation Corridor Agencies, TCA (2002). *The toll roads: San Joaquin, Foothill and Eastern*. Available at: http://www.tcagencies.com.

U.S. Department of Justice (2002). *The federal odometer tampering statutes*, Monograph, Office of Consumer Litigation. Available at: http://www.usdoj.gov/civil/ocl/monograph/odom.htm.

Wenzel, T. (1995). *Analysis of national pay-as-you-drive insurance systems and other variable driving charges*. Energy & Environment Division, Lawrence Berkeley Laboratory, Berkeley, CA.

FIGURE 1: Taxonomy of Possible Technologies for Collection of Road User Fees

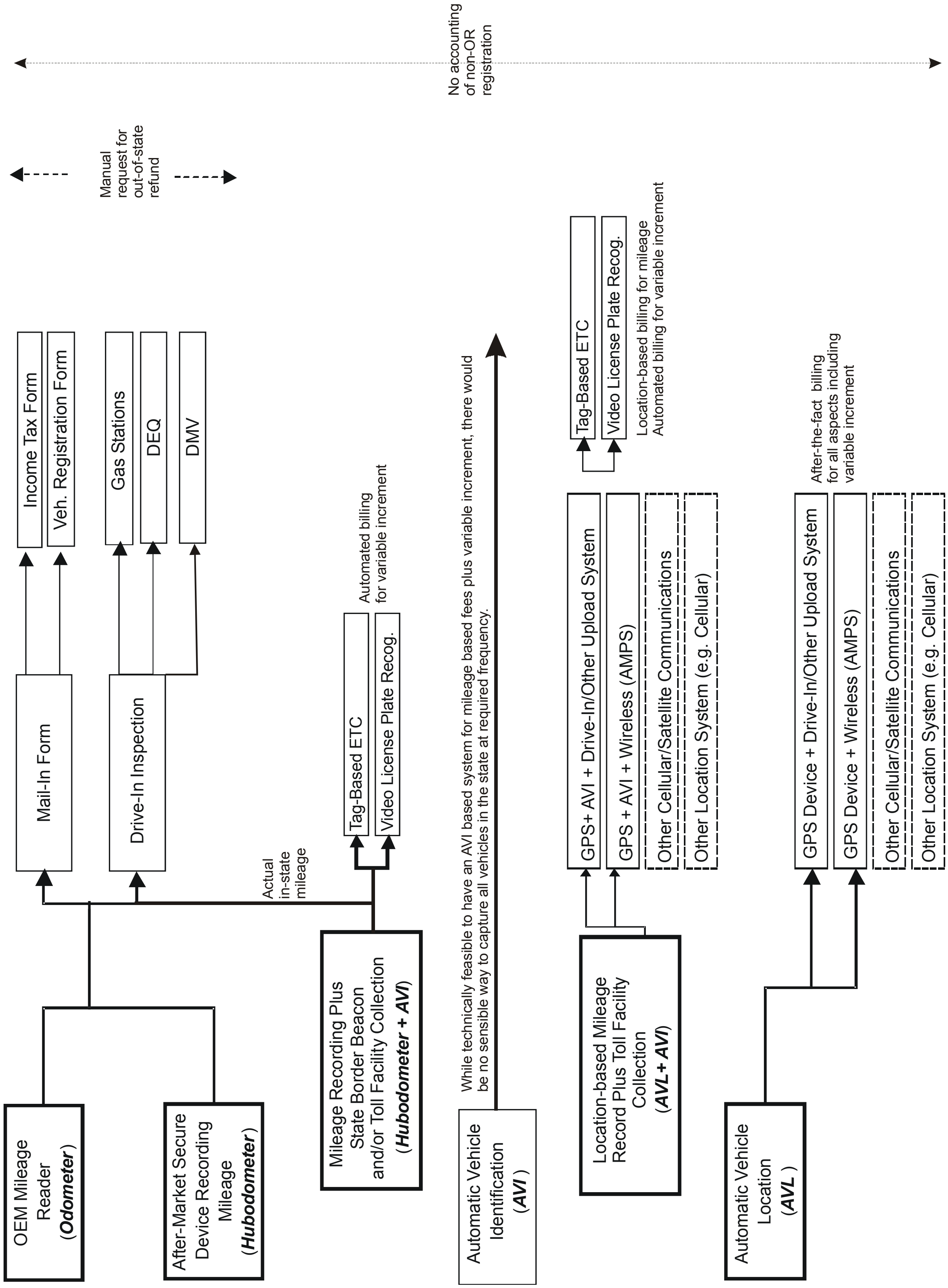

Figure 2 GPS ACCURACY

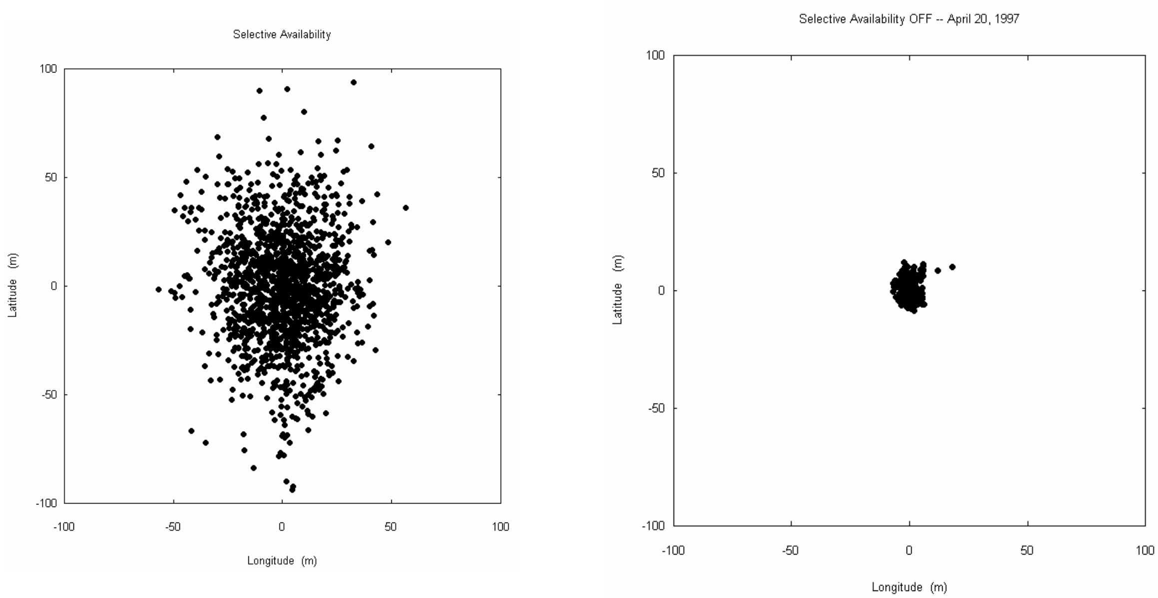

Figure 3 CELLULAR COVERAGE, 2001

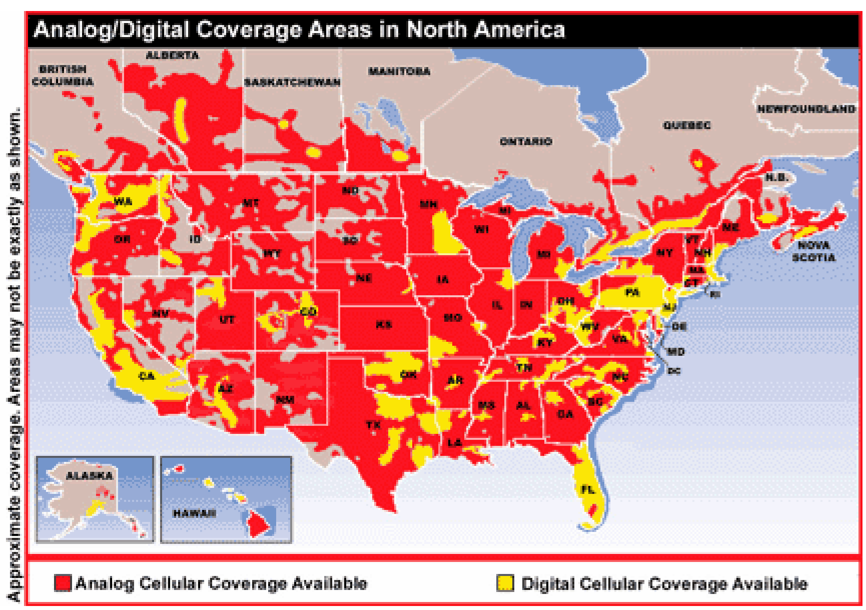

Table 1 ABBREVIATIONS

Abbreviation	Definition
AVI	Automatic vehicle identification
AVL	Automatic vehicle location
Caltrans	California Department of Transportation
CD-ROM	Compact disc, read-only-memory
DEQ	Department of Environmental Quality
DGPS	Differential global positioning system
DMV	Department of Motor Vehicles
DVD	Digital versatile disk
E911	Enhanced 911
FMVSS	Federal motor vehicle safety standard
GPS	Global positioning system
NCHRP	National Cooperative Highway Research Program
ODOT	Oregon Department of Transportation
OEM	Original equipment manufacturer
RF	Radio frequency
VMT	Vehicle miles traveled

Table 2 QUALITATIVE COMPARISON OF FUEL TAX TECHNOLOGY OPTIONS

Possible Technologies for Collection of Road User Fees	**Weight**	**Odometer**	**Hubodometer**	**Hubodometer+AVI**	**AVL**	**AVL+AVI**
Hardware/Software Reliability *[1=Unreliable, 10=Reliable]*	20%	8	9	8	6	6
Evasion Potential *[1=High evasion, 10=Little evasion]*	5%	8	5	5	5	5
Costs to Vehicle Owners *[1=Highest cost, 10=Lowest cost]*	10%	10	7	6	1	1
Ease and Convenience to Vehicle Owners *[1=Least convenient, 10-Most convenient]*	15%	9	8	8	8	8
Start-up Costs to Agencies *[1=Highest cost, 10=Lowest cost]*	10%	8	6	3	2	1
Life Cycle Costs to Agencies *[1=Highest cost, 10=Lowest cost]*	10%	8	7	5	2	1
Public Acceptance *[1=Least acceptable, 10=Most acceptable]*	20%	9	9	6	3	4
Partial Implementation/Phasing *[1=Difficult to phase, 10=Easiest to phase]*	10%	8	8	6	6	6
TOTAL	100%	8.55	7.85	6.25	4.35	4.35

NOTE: These subjective ratings have been scaled so that a rating of 10 is the most desirable and a rating of 1 is the least desirable.